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EDITORIAL

We have much pleasure in presenting this Centenary Number of the Journal of the Madras University, B (Science Series). In another few weeks this university will be celebrating its first centenary along with the sister universities of Calcutta and Bombay. Our minds naturally go back to those men of vision who launched these three universities in 1857, in the year of the Great Indian Mutiny. We salute them for their sagacity. In the comparative political quiet of 1957 we consider ourselves fortunate in being able to celebrate this occasion in Free India with this special Science number with invited articles from eminent scientists in India and abroad. When our invitations went out hardly five months ago, I had some misgivings about the response we were likely to have. Many distinguished alumni and well wishers of India and Indian science have responded generously to our invitation. It is my pleasant duty to offer on behalf of this university my most sincere thanks to all those whose articles are now before you. Many of our distinguished invitees have written articles in their own names, others have sent joint articles with their associates. In the latter cases, the names of the invitees in each case are indicated by an asterisk.

I shall be failing in my duty if I do not thank my colleagues on the editorial board and my own colleagues in this laboratory for the readiness with which they gave their time in many editorial matters. The Press deserves my special thanks for cordiality and co-operation and I offer it with pleasure.

University Botany Laboratory,
December 1956.

EDITOR

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J. Madras Univ., B, 27, No. 1. Centenary Number, 1957.

The Optical Behaviour of Polycrystalline Solids

BY

Sir C. V. Raman

(Memoir No. 89 from the Raman Research Institute, Bangalore 6)

ABSTRACT

The paper discusses the influence of the factors which determine the penetration of light into a polycrystalline solid, viz. the birefringence of the crystallites, their size and shape and their relative orientations. The results of the theoretical discussions are compared with the facts of observation. Five X-ray diagrams are also reproduced which exhibit the relation between the structure and optical behaviour of polycrystalline media in particular cases of interest.

1. *Introduction.*

As examples of polycrystalline solids which by reason of the desirable properties they possess have been extensively used for the fashioning of works of art may be mentioned especially the following minerals: marble, alabaster, chalcedony and jade. Visual observations supplemented, where necessary, by examination of thin slices under the polarisation microscope and the use of X-ray diffraction techniques reveal that individual specimens of these minerals may be widely different in regard to the size and shape of the crystallites of which they are composed and the manner in which these crystallites are disposed within the solid. Alongside of these differences and obviously related to them are noticed some striking differences in the optical characters of the specimens. As the external appearance of a finished work of art is influenced a good deal by such differences, it is not without interest to discuss in some detail the nature of the relationship between the structure and the optical behaviour of polycrystalline solids in general.

In all the cases mentioned, the basic substance is a transparent crystalline solid and accordingly the aggregate could also have been expected to be free from colour. Though this is so in some instances, it is not always the case. Indeed, the presence of some favoured colours often enhances the value of the material very greatly. The nature of the intrusive material responsible for such colour and the manner in which it is diffused through the substance and influences its optical behaviour are questions of considerable interest, but we shall not enter into them here.

It should be mentioned that the structure of polycrystalline solids and its relation to their optical behaviour has been the subject of both theoretical and experimental investigations by the present writer and his collaborators and the results have been reported in detail in some earlier memoirs of this Institute. In the present publication it is proposed to summarise broadly the results which have emerged from these studies and in addition to present some fresh observational material.

The five illustrations accompanying the present paper are X-ray-diffraction photographs of some interesting specimens recorded by Mr. A. Jayaraman at this Institute. In each case, the structure revealed by the X-ray diagram is found to be very clearly related to the optical characters exhibited by the specimen. We shall return to these diagrams and their significance later in the paper.

2. *Theoretical Considerations.*

If no extraneous material be present in a polycrystalline solid and its optical heterogeneity arises solely by reason of the varying orientations of the crystallites, the birefringences of the latter would give rise to a diffusion of the light in its passage through the material. At each incidence of the light on an intercrystalline boundary, it would be reflected and refracted and hence all trace of the original direction of propagation of the light would quickly disappear. After the passage of the light through a sufficient number of crystallites, a state of affairs would establish itself in which we have a diffusion in all directions, forwards and backwards as well as laterally. The greater the birefringence of the material, the fewer would be the number of intercrystalline boundaries needed for such a situation to establish itself. We may visualize the resulting phenomena by imagining a pencil of light to fall normally on a restricted area in the plane face of a block of the material. The observable results would then depend upon the various factors involved, namely the thickness of the block, the size of the crystallites and the magnitude of their birefringence.

In the absence of any absorbing material and if the thickness of the block be sufficiently great, all of the incident light must necessarily be turned back towards the original source of light and would re-emerge from the same face spread out from a much larger area than that on which it is originally incident. On the other hand, if the thickness of the block be not too great, part of the incident radiation would also emerge from the rear face of the block spread out over a large area. In each case, the observable effects would be profoundly influenced by the size of the crystallites. The smaller the crystallites are, the more quickly would the incident light be turned back towards the source and the less, therefore, would be the depth of the penetration of the light into the medium. The presence of any absorbing material in the solid would necessarily modify the observable results to a very great extent.

3. *Diffraction Phenomena.*

While the arguments set forth above based on geometrical optics may be adequate when the crystallites are of sufficiently large dimensions and the birefringence of the material is also fairly large, they would cease to be adequate and would fail to describe what is actually observed when the reverse is the case, i.e., when the crystallites are of small dimensions and the birefringence which they exhibit is also small. In the latter circumstances, the matter has necessarily to be considered from the standpoint of the wave theory of light, and the results indicated by such theory are very different indeed from those indicated by geometrical optics.

We may here broadly indicate the lines on which the problem can be handled on the basis of the wave theory. If the birefringence of the material be sufficiently small, the diffusion of light in its passage through it may be considered as arising from the varying retardations in phase of the light waves in traversing the differently oriented crystallites. Provided that the product of the linear dimension of each crystallite and of its birefringence is sufficiently small, we can regard the waves as moving undisturbed through the medium except for the changes of phase occurring over different areas of the wave-front; such changes may be regarded as being additive in depth and hence capable of being summed up over the whole of the path through a slab of the material, provided that the thickness of the latter is not too great. The wave-front emerging at the rear surface of the block would thus exhibit fluctuations in phase over its area. The final observable effect may then be determined by the usual methods of diffraction theory.

The foregoing brief exposition ignores certain difficulties, namely, that inside each crystallite there would be two possible directions of vibration for which the refractive indices are different and these two directions would vary from crystallite to crystallite owing to their random orientations. This difficulty, however, may be circumvented by assuming that the light incident on the block is plane-polarised and that all the crystallites are so orientated that this original direction of vibration in the wave-front is preserved in its passage through the block, the operative refractive index for any one crystallite being one of its three principal values chosen at random. Such an assumption has the great advantage that it greatly simplifies the formulation and solution of the problem while retaining its essential features. Further, by assuming the probabilities of the three different orientations to be different, we can also determine the optical behaviour of polycrystalline solids in which the crystallites are not orientated at random but prefer certain directions. What the solution of the problem gives us is the intensity of the light regularly transmitted through the polycrystalline plate. This appears as an exponential function in which the argument has a negative sign and is directly proportional to the thickness of the plate and to the size of the crystallites and also to a quantity depending on the differences between the three refractive indices which is a measure of the birefringence; it is also inversely proportional to the square of the wave-length of the light. From the theory it follows that the light emerging from the block would be polarised in the same fashion as the light incident on the first face. The theory also shows that if the crystallites have no preferred orientation, the transmission coefficient is independent of the direction of vibration in the incident light. If, however, the crystallites are preferentially orientated, the intensity of the light emerging from the plate would vary with the circumstances, viz., with the relative probabilities of the three permitted orientations. In particular cases of this kind, e.g., when all the crystallites are orientated along a fibre axis which is also the optical vibration direction, the transmission may be actually complete.

We may summarise the foregoing by stating that on the basis of the assumptions made, the light incident on a plate of polycrystalline material would emerge from it greatly enfeebled in

intensity but retaining its primitive state of polarisation. The fraction of the light regularly transmitted for a given thickness of the material would increase with diminishing size of the crystallites and would reach the limiting value of unity if they are sufficiently small. This result is precisely the opposite of that indicated by the geometrical theory according to which diminishing particle size would result in greater opacity. These two contrasting results may be regarded as valid respectively in the limiting cases of a very weak and of a very strong birefringence.

The energy that disappears from the regularly transmitted light would appear as diffracted radiation. Its distribution of intensity in different directions would be determined by the factors entering into the problem, namely, the size of the crystallites, the thickness of the plate, the birefringence of the material and finally the wave-length of the light. It is a consequence of the special assumptions made regarding the orientation of the crystallites that the diffracted radiation would be polarised in the same manner as the incident and emerging pencils. It is not, however, to be expected that this particular result would represent the actual facts of the case. As a consequence of the unrestricted randomness of the orientation of the crystallites, the diffused or diffracted radiation would necessarily be depolarised to a greater or less extent. The greater the birefringence of the material or the thickness of the plate traversed, the more complete would be such depolarisation.

It is a particular consequence of the theory that if unpolarised light be incident on a plate of material having a fibrous structure and of sufficient thickness, the regularly transmitted beam would be completely polarised on emergence, while the rest of the light would appear as a fan of diffracted rays in the plane perpendicular to the fibre axis and polarised predominantly in the perpendicular direction. It has also to be remarked that a fibrous structure of the medium is favourable to the appearance of a regularly transmitted pencil. The same material with crystallites randomly orientated might not exhibit any transmission at all, but only a diffusion of light in various directions surrounding that of the incident pencil. Finally, we may remark that since these phenomena arise by reason of wave-optical considerations depending on the wave-length of the light, the transmitted light whenever it is observable should exhibit a reddening which increases progressively with the thickness of the material traversed.

4. *Some Illustrations of the Theory.*

Marble which in its purest forms consists of calcite furnishes excellent illustrations of the optical behaviour of a polycrystalline medium consisting of strongly birefringent crystallites. The influence of the grain size on the penetration of light into the material indicated by the theory is readily confirmed by observations with different specimens. A very interesting fact is that the light diffused by marble both backwards and forwards exhibits a surprisingly rich redness even when the marble itself is only of a faintly pinkish colour.

Alabaster which consists of randomly orientated crystallites of gypsum affords good illustrations of the behaviour of a polycrystalline medium in which the crystallites have only a feeble birefringence. The size of the crystallites can of course be readily determined by cutting a thin section and viewing it under a polarising microscope. The relationship between the size of the crystallites and the optical behaviour of the material can be readily confirmed by viewing a bright source of light through a slice of alabaster mounted between microscope cover-slips with a little Canada balsam. Only with the thinnest sections is a true optical transmission observable. This appears surrounded by a diffusion halo exhibiting streaky colours in white light. The depolarisation of the halo and the polarisation of the regularly transmitted light when the incident light is polarised are also readily confirmed by observation.

The X-ray diffraction diagram of alabaster depends very much on the size of the crystallites which it contains. Unless the alabaster is very fine-grained, a collection of spots only vaguely indicative of a ring pattern is obtained. Very different is the picture shown in Fig. 3 in Plate I which shows a readily recognizable ring system, though spotty in character. This was obtained with a very fine museum piece exhibiting a remarkably high degree of translucency.

Fig. 2 in Plate I is an X-ray diagram recorded with a dish of Chinese origin stated to be of jade, but not really so. The material was colourless and exhibited a high degree of translucency. The extremely small size of the crystallites of which it is composed is evident from the X-ray diagram.

Fig. 1 in the same Plate is the X-ray diagram obtained by passing a beam of X-rays through a plate of a white porcelain-like

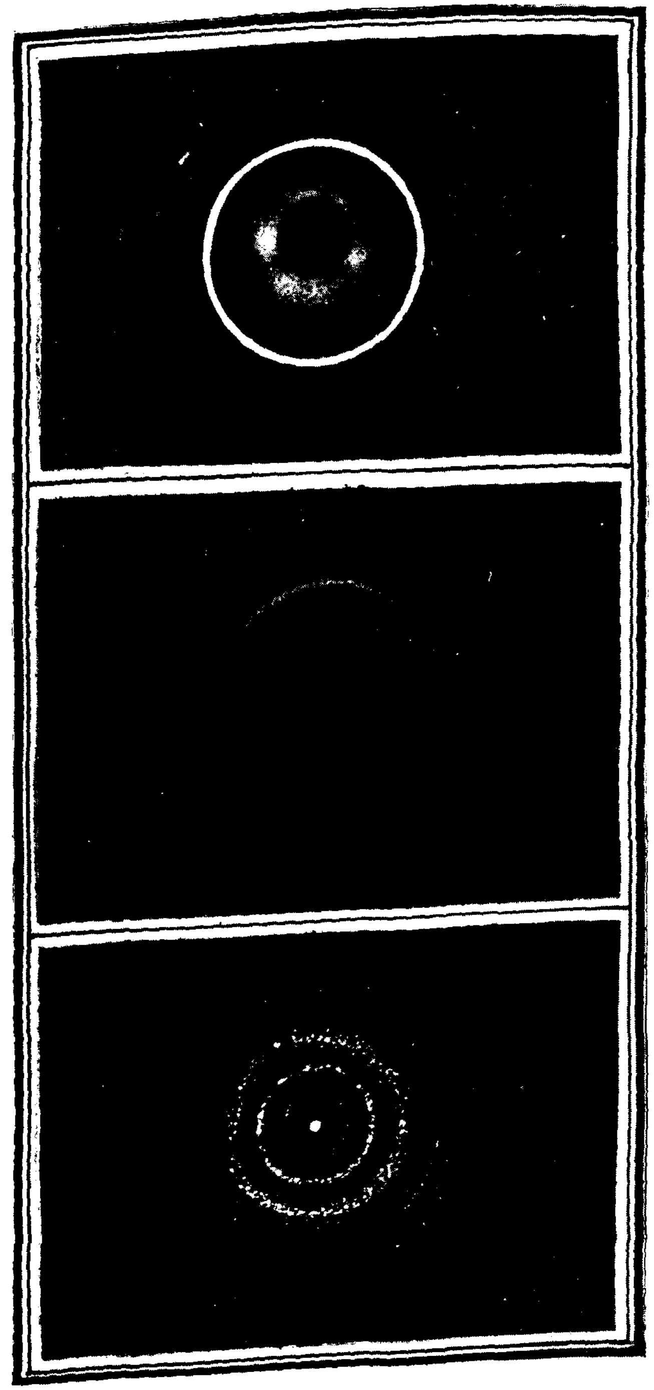
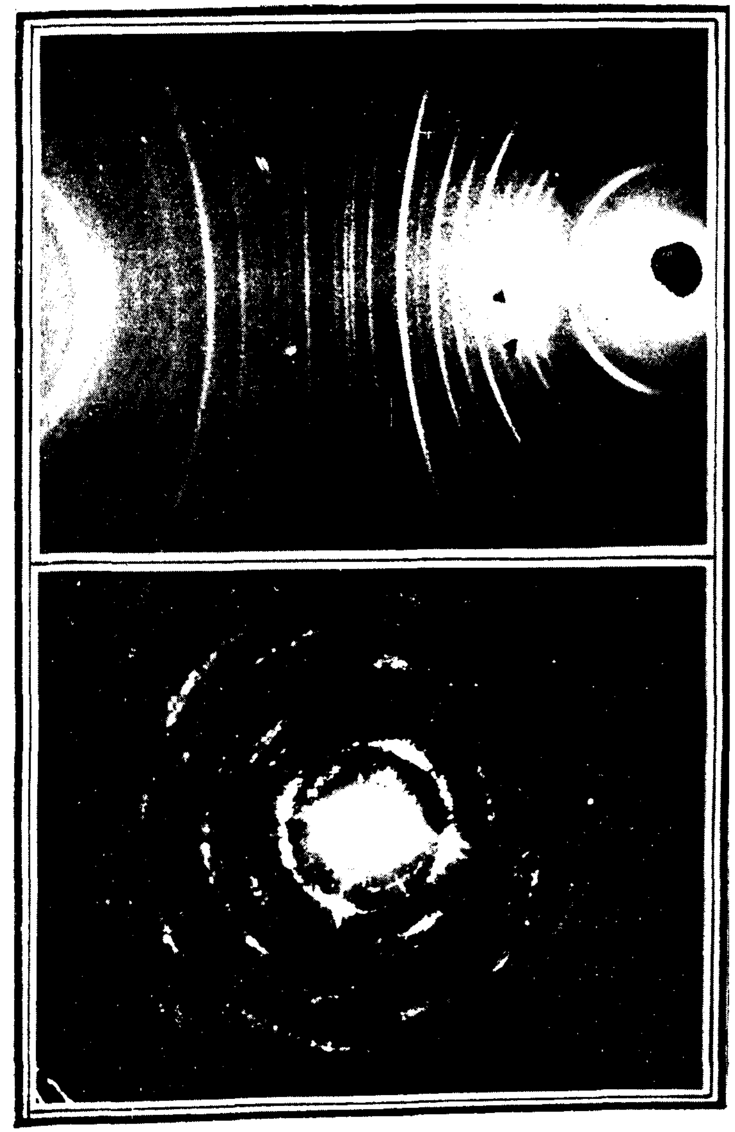


Fig. 1

Fig. 2

Fig. 3

C. V. RAMAN



material which was cut out from a block of agate and which was identified as α-cristobalite by its X-ray pattern. The extreme fineness of the particles of the material is evident from the X-ray diagram. A source of white light seen through the plate is visible, but appears of a deep red colour. The material thus furnishes an excellent example of a polycrystalline medium consisting of a birefringent material which nevertheless exhibits a true optical transmission by reason of the small size of the crystallites.

The phenomena arising from the propagation of light through a medium with a fibrous structure are beautifully illustrated by observing a source of light through a polished plate of chalcedony. They exhibit in a very conspicuous manner the various features indicated by the theory. It should be emphasized that chalcedony exhibits large variations in its structure and these correspond to striking differences in optical behaviour. Two extreme cases are illustrated respectively by Figs. 4 and 5 in Plate II. The first is an X-ray diagram recorded with a specimen of agate which exhibited only translucency but no real transmission of light. It will be seen from the X-ray diagram that this material consisted of extremely fine particles. Fig. 5, on the other hand, is an X-ray diagram of a specimen of chalcedony showing a coarsely fibrous structure. A source of light could easily be seen in perfect focus through the plate though much dimmed in intensity and reddened in colour. The transmitted light was found to be completely polarised, and this was evidently a consequence of the fibrous structure revealed by the X-ray pattern and also evidenced by the streams of diffracted light seen surrounding the image of the source.

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Some Experiments Aiming at an Isolation of Biochemical Mutations in *Pisum sativum* L.

BY

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ABSTRACT

The possibility of isolating biochemical mutations of the pea plant (*Pisum sativum* L.) after X-ray irradiation of the seeds was investigated with the aid of a root culture test method. Roots from seedlings representing the segregating X_2 generation were cultivated aseptically and their nutritional requirements tested. In 3 cases out of 75 the root clone required some additional factor present in the complete medium. After some time, however, all three clones changed back to wild type. In one of these cases it could be established that the necessary factor was a component of hydrolysed casein.

Introduction

During the last fifteen years the study of so-called biochemical mutations in lower heterotrophic plants have produced results of great interest to plant physiology, biochemistry and genetics. Efforts to isolate similar types of mutations in green plants, have, so far, been less successful. In seed plants, where such mutations, if present, would provide an extremely interesting material for various sorts of studies, only one clear-cut case has been reported, *viz.*, a thiamin-less mutant of *Arabis thaliana* (Langridge, 1955). In the present paper some experiments with the pea plant are reported which, although essentially negative, may be of some interest to other workers intending to follow the same track.

Material

The seeds for the experiments were obtained from Sveriges Utsädesförening, the Ultuna branch near Uppsala, and represented the "Torsdag III" strain of the ordinary pea plant, *Pisum sativum* L. They have been produced by X_1 plants derived from seeds treated with 6000 r and then sown in the field. Thus, the seedlings, plants and excised roots of the experiments to be described represented the X_2 generation, in which homozygous mutant individuals, if they existed, ought to be found.

Methods

The procedure applied was based upon the following reasoning:

If a biochemical mutation has been induced in one of the X-ray irradiated seeds a certain number (at the most 25 per cent) of the X_2 plants should represent homozygous mutants. Each one of these plants should, therefore, be incapable of growing, unless supplied with a particular organic compound, a metabolite, the biosynthesis of which the mutant is unable to carry out. For obvious reasons this metabolite must be supplied under aseptic conditions. However, since the cultivation of whole pea plants aseptically presents great technical difficulties, the testing could be performed by means of root cultures. This seems justified if the metabolite in question is indispensable for every cell of the plant.

The rest of the plant could be planted in soil under ordinary green-house or field conditions, where it should be able to grow by means of adventitious roots and the remaining part of the root system. If it was a biochemical mutant its fate would probably depend on the cotyledons: the organic material stored there might be sufficient for a development of the plant to maturity, if the necessary metabolite was contained in this material, or it might not. In the former case homozygous mutant seeds would be obtained.

One seed from each X_1 plant was tested according to the principles outlined above. The seeds were chemically sterilized with ethyl alcohol (70 per cent) for 10 minutes, with mercury chloride (0·1 per cent water solution) for 15 minutes, and, finally, with calcium hypochlorite (saturated solution) for 30 minutes. They were washed with distilled water before and after the treatment with hypochlorite. After sterilization the seeds were soaked in distilled water for 18 hours and then placed for germination on plain water agar plates at +20°C in darkness.

As soon as a 30 mm long root had been developed its end half was excised and aseptically transferred to a small cork float (Fig. 1) in a 100 ml Erlenmeyer flask with 20 ml of Robbins' (1946) nutrient solution for root cultures, modified according to Fries (1954) and supplemented with the following additions per flask: 1 mg yeast extract (Difco), 2 mg hydrolyzed casein (NZ-case, Sheffield Farms Co., New York), and 2·5 mg lyophilized pea root exudate. Preliminary experiments had shown that these additions did not affect the growth of normal pea roots appreciably in any direction. The cultures were kept at +25°C in darkness.

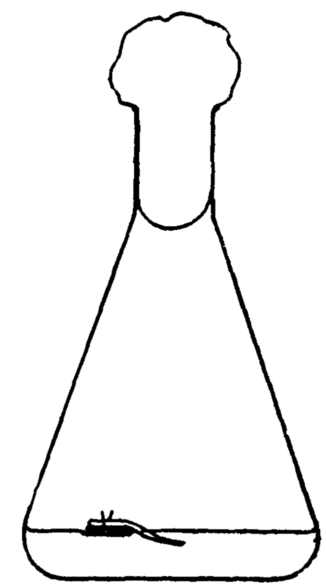

Fig. 1. The excised root placed on a float, consisting of a small cork disc covered with a thin layer of paraffin wax. Two thin chromenickel needles keep the root in position. The float is swimming on the surface of the nutrient solution.

The rest of the seedling was planted in a pot with garden soil and placed in a green-house.

After a few weeks the excised roots had increased in length and developed a number of lateral roots. Ten lateral roots, each attached to a small piece of the main axis, were cut out and transferred to new flasks with Robbins' solution: five without and five with the additions mentioned above. The former solution was called "minimal medium", the latter "complete medium". Only c. 10 mm long laterals were used, and one lateral was placed in each flask.

This treatment was performed with each of 75 seedlings obtained from just as many X_1 plants. The procedure is schematically outlined in Fig. 2.

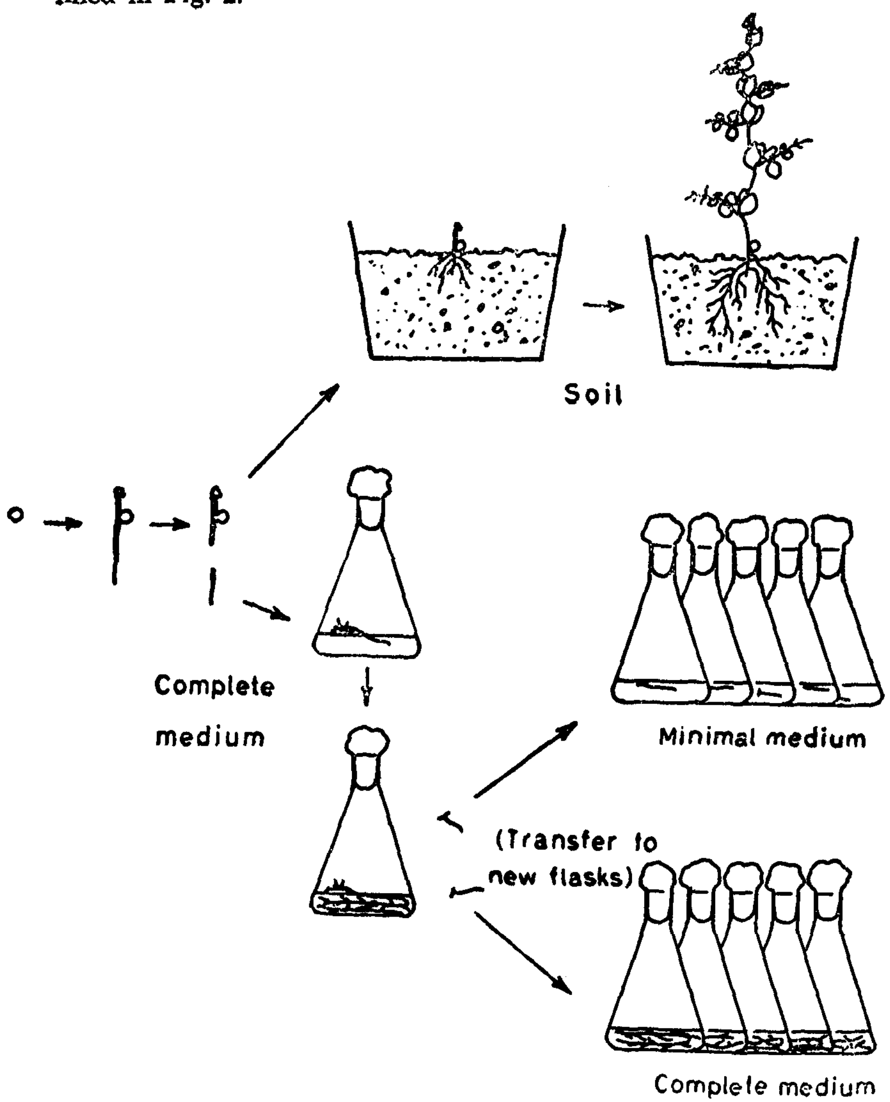

FIG. 2. Schematic illustration of the procedure used for testing the physiological properties of X_2 seedlings of *Pisum sativum*. The tested seed is assumed to be a biochemical mutant requiring a factor contained in the complete medium. The growth of the green part of the plant is limited by the amount of this factor present in the cotyledons, which in the illustrated case is assumed to enable a certain development of the plant. For further particulars see the text.

Results

Out of 75 tested root systems only three reacted in a way that differed from the normal (Table I). The laterals from these three root systems, *viz.*, Nos. 3, 6 and 33, grew only in the medium to which amino acids and other organic metabolites had been added. Since this behaviour could indicate a loss in the biosynthetic capacities of the roots in question, these root systems were further investigated.

TABLE I

Growth of root and shoot	Number of X_2 plants
Root growth in complete medium only; no shoot growth	.. 2 (=Nos. 6 and 33)
Root growth in complete medium only; normal shoot growth	.. 1 (=No. 3)
Root growth also in minimal medium; no shoot growth	.. 1
Root growth also in minimal medium; normal shoot growth	.. 71

From the five cultures on complete medium, laterals were transferred to four series of flasks, (a), (b), (c) and (d), each series comprising five flasks:

(a) Minimal medium;

(b) same as (a), plus NZ-case (2 mg per flask), to which certain L-amino acids had been added (serine, cysteine, alanine, tryptophane, γ—amino butyric acid, aspartic acid, asparagine, and proline);

(c) same as (a), plus a mixture of seven vitamins (riboflavine, pantothenic acid, *p*-aminobenzoic acid, biotin, inositol, ascorbic acid, and folic acid);

(d) complete medium.

In this experiment the growth of Nos. 6 and 33 was quite satisfactory in the minimal medium and not appreciably inferior to that in the complete medium. The physiological properties of these two root clones had obviously changed and seemed to agree with those of the normal, wild type, as far as the nutritional requirements were concerned. No. 3 also produced a rather good growth in the control series (a), contrary to the result of the very first testing experiment, but the growth in series (d) was much better than in (a), especially in terms of lateral root production and dry weight values. The best growth, however, was obtained in series (b) (Table II).

TABLE II

The growth of roots from seedling No. 3 in liquid minimal medium with various additions

Time of incubation 3 weeks. The figures in the table represent average values from 5 or 6 root cultures.

Medium	Length of main root *mm*	Total length of lateral roots per root system *mm*	Dry weight *mg*
(a) Minimal (= control) ..	123	244	7·0
(b) *Minimal + NZ-case + amino* acids ..	147	520	15·2
(c) Minimal + vitamins ..	111	275	9·2
(d) Complete ..	135	404	11·9

Further experiments were performed only with the root clone of No. 3. Amino acids were tested in groups of four, added to the minimal medium, and the effect was compared with that of NZ-case. In no case, however, did the combination of amino acids improve growth, while the effect of NZ-case was considerable.

When NZ-case was compared with Difco hydrolyzed casein this latter preparation proved to be the more active of the two (Table III). Indole acetic acid produced a weak, not quite significant effect. The growth rate in this experiment was generally lower than earlier.

TABLE III

The growth of roots from seedling No. 3 in liquid minimal medium with additions of hydrolyzed caseins and indole acetic acid.

Time of incubation 3 weeks. The figures of the table represent average values from 10 root cultures.

Added substances µg per culture	Length of main root *mm*	Total length of lateral roots per root system *mm*	Dry weight *mg*
No additions ..	39	40	1·7
NZ-case hydrolysate, 200 ..	64	155	3·7
" " , 2000 ..	77	134	4·9
Difco hydrolysate, 200 ..	52	116	4·1
" " , 2000 ..	128	432	13·9
Indole acetic acid, 0·002 ..	45	51	2·4
" " " , 0·02 ..	37	68	2·7

However, the investigation had then to be discontinued, since the next experiment (with graded dosages of Difco casein hydrolysate) showed that root clone No. 3 finally had reverted to wild type, like earlier Nos. 6 and 33. The growth in the control cultures was quite normal and not improved by casein hydrolysate, nor by yeast extract and pea root exudate.

The shoot belonging to root system No. 3 produced a few seeds in the soil culture, but it did not seem to be worth while to examine their nutritional requirements in aseptic culture. The green parts of Nos. 6 and 33 died at an early stage of development and did not produce any flowers.

Conclusions

Root systems developed from seeds of X_1 plants showed, as a rule, a quite normal behaviour in liquid culture. In a few cases only, the roots showed particular nutritional requirements during the first transfer or transfers. They needed, at least for good growth, *some organic factor or factors* included in the complete medium. In the case of root No. 3 the factor in question was a constituent of casein hydrolysate. A definitive identification of the nutritional requirements could not be carried out, since the roots after some time changed back to wild type.

The material is, of course, too small to permit the conclusion that mutations of a physiological type had been produced through the X-ray irradiation. By testing a larger number of X_2 seedlings and a corresponding number of seedlings derived from untreated ancestors it should, however, be possible to decide about this question.

It is probable that the three root clones, Nos. 3, 6 and 33, which originally proved unable to grow in the minimal medium, differed genotypically from the wild type. The great variation generally found in ordinary seed assortments of various plant species as regards the response to nutrient media is usually interpreted in this way. As a matter of fact, a successful cultivation of a species as a root clone very often starts with a sorting out and removal of those roots which show no or poor growth (Naylor and Rappaport, 1950). From this point of view, the material of the above experiments responded in a surprisingly uniform way despite the preceding X-ray treatment. This may be due to the fact that the "Torsdag III" strain used is a rather recently produced pure line.

If the three deviating root clones should be looked upon as mutants—spontaneous or induced—the sudden and deplorable reversions to wild type ought to be called back-mutations. However, in view of the well-known, as yet unexplained, variability of root cultures in the course of time (White, 1943) caution in interpreting these phenomena is warranted.

ACKNOWLEDGEMENTS

The author wishes to express his thanks to Professor E. Åkerberg, Svalöf, for the material of X-ray treated peas as well as to Mrs. Brita Nyman, Fil.kand., and Mrs. Karin Norell for valuable technical assistance.

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Problematics of the Phenomenon of Phenocopy

BY

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An individual with an aberrant, non-hereditary type, identical phenotypically with that of a known mutant, is called a phenocopy. It has become a habit recently to call any non-hereditary modification, abnormality, morphose, monstrosity a phenocopy. This is wrong, as the original definition (and literal meaning) of the term restricts it to "copies" of a mutant. It is an old genetical experience that quantitative mutant characters may overlap with non-hereditary modifications of the same phenotype e.g., in Johannsen's classic experiments with pure lines of beans a plus individual of a small line may be as large or larger than a minus individual of a hereditary large line. A systematic study of this latter phenomenon was first made by Zeleny in a series of classical papers on the facet numbers of the series of Bar eye mutants of *Drosophila*. He showed that there is a temperature sensitive period during which different temperatures affect the number of facets in a Bar eye and that this number may be pushed by temperature action to the low level shown by the higher mutant ultrabar. Zeleny (1923) called this, a demonstration "of the fact that the gene ultrabar has the same type of reaction as a temperature difference. It is possible to state the effectiveness of particular germinal factors in terms of corresponding effects of temperature." This statement implies that mutant actions attack the same developmental processes in a quantitative way as temperature actions do. Actually I had drawn this conclusion already from different kinds of experiments (Goldschmidt, 1920), namely, the old temperature experiments with butterflies of Fisher (1895). Here a temperature action (a shock), applied during a definite sensitive period, could produce a wing pattern identical with that of a known geographic variety. Nowadays one could call this effect a phenocopy. I had drawn conclusions upon the identical actions in modification and mutation which were identical with those of Zeleny, and I had gone a step further in concluding that the reason of the identical effects is to be sought in the nature of genic action, namely by the control of rates of some determining process. In a later summary of his work Zeleny (1933) joined me in these conclusions.

There is some other early work which went in the same direction. Kosminsky (1909) had shown that male pupae of Lymantria treated with heat shocks developed a double uncus (the hook in the genital armature) which is single normally, though concresced from a double anlage. Later when genetic intersexuality was discovered, I could show (1922) that this effect was identical with that of genetic intersexuality of a definite grade. Though this is not simply a mutant condition, it is genetically controlled and may be compared therefore with mutant action in the present context. It should not be difficult to find other comparable cases in which the same phenotype is known as a chance variation (though not experimentally induced), which is identical with that of a mutant. Such a parallel effect is expected, where a mutant acts embryologically by stopping prematurely a normal developmental process. Harelip, the lack of concrescence of the upper jaw anlagen, is one example, hypospadia penis is another one.

To a certain extent embryological work with vertebrates may be quoted in this connection, following the important work of Stockard (1910 ff). By treatment of embryos of different age with chemicals or abnormal temperatures, or X-rays (Little and Bagg, 1924) all kinds of monstrosities could be produced in a more or less regular way (full review by Ancel, 1950). In this work there was no emphasis on similarity with known mutants. But as many monstrosities in vertebrates are known to be hereditary, by necessity these induced monstrosities included also what are now called phenocopies.

All of this early work was of importance for problems of growth and embryonic determination and was discussed as such. But only the above quoted work of Zeleny (1923) and Goldschmidt (1920, 1922) attacked already the genetical problem, the latter (1920) already using Stockard's experiments for his analysis. This changed when the discovery was made that one and the same environmental action (heat shocks) could lead to the production of non-hereditary imitations of practically all known morphological mutants of Drosophila (Goldschmidt, 1929). A repetition on a larger scale and going into all the important phases of the problem (1935) showed beyond doubt the great importance of the phenomenon for many basic problems of genetics. The name "phenocopy" was proposed for the non-hereditary copies of the phenotype of a mutant. Since that time considerable literature has accumulated and new discoveries were made which not only enhanced the importance of the facts but also put new questions, which have not yet been answered. The most important of these findings is Rapoport's (1947) demonstration of the production of specific phenocopies in Drosophila by chemical treatment of the larvae during a sensitive period. The most elaborate repetition of the Drosophila work using heat shocks was done by Henke and students (1941) with essentially the same results as ours but adding many details and refinements.

The most important groups of facts which have to be taken into account when searching for a general explanation may be recounted, without quoting the individual contributions.

1. Almost all treatments of eggs and larvae of Drosophila which have been tried produce phenocopies e.g., temperature shocks, X-rays, neutrons, ultra-violet rays, many chemicals like ether, tryptophane, mustards, metal salts and many others. In chicken insulin (a protein) and a number of chemicals, including metal salts were effective and in mammals many types of lesions of the same type were successful. A much discussed phenocopy in man is the appearance of certain monstrosities in babies born from mothers who had German measles during pregnancy. At the other end of the phylogenetic tree are chemical phenocopies produced in Neurospora and bacteria.

2. In Drosophila all known types of morphological mutants of all organs have been copied in such experiments; but no reliable case of copying of biochemical mutants is known, though this has been produced in Neurospora. But quantity changes of pigments (darker or lighter) can be produced, which is theoretically significant.

3. Chemical treatment acts more specifically than radiations and temperature shocks do. In a few cases it seems that one specific mutant is copied after one specific treatment; but in view of recent work (see 8 and 9) this is not as simple as it appeared at first.

4. All treatments are most successful near the limit of lethal action and they may produce up to 100% phenocopies under proper conditions. Correlation of percentage of phenocopies with degree of lethality is observed, but does not occur in all cases.

5. All treatments act to some extent proportionally to intensity (dose, concentration, etc.).

6. All treatments are effective only during one or more than one sensitive periods of development. This is in most cases identical with the time of labile determination of the affected organ in development, as determined by effectiveness or failure in producing shifts of the phenotype of a wild type or a mutant in embryological experimentation.

7. In Drosophila the effect may be independent in either half of the body (no right-left correlation) and the same organ may form different phenocopies on the right and left side. One and the same imaginal disc may react as a whole or its parts may react separately. Thus an antenna may be duplicated (a phenocopy) and the two aristae may be different, one normal, and one a phenocopy. The effects always appear in different grades of expression which form a series like a multiple allelic mutant series, usually correlated to the intensity of the treatment. It might repeat a known multiple allelic series or contain more extreme members, which may be supposed to be lethal as mutants.

8. The quantity (penetrance and expressivity) of the phenocopic effect is dependent upon the genetic constitution of the treated line. In Drosophila wild type lines of greatly different sensitivity exist. The genetic basis is found in one or a few major loci and many modifiers and in mixed lines selection is successful. Comparable facts have been found also in chicken on a smaller scale.

9. The quality of the effect is also dependent upon the genetic constitution of the material. Each line has a specific pattern of phenocopies produced by the same treatment and some lines produce typically one definite phenocopy not found in others. Also the relative frequencies of the different phenocopies characterize each genetic line. Points 8 and 9 are best demonstrable for chemically induced phenocopies, and the most extensive data are derived from recent Drosophila work.

10. In chicken a correlation was found between the propensity of different stocks for production of spontaneous non-hereditary abnormalities of the same type as the mutants and induced phenocopies, and the sensitivity to phenocopic treatment of the line. But the experience in Drosophila is that the apparent non-hereditary variants of rare occurrence are not modifications but low penetrant mutants (see below).

11. It is frequently found that the phenocopic agents, when applied to mutants, either enhance their expression and also their penetrance, if not completely penetrant, or they decrease their expression towards greater normality.

12. Cases have been found in which mutants which had lost their visible effect (by accumulation of minus modifiers) produced their typical effect after phenocopic treatment.

13. Phenocopic treatment of heterozygotes +/mutant brings out (if successful) the recessive character, or, more correctly, increases the effect of the treatment in regard to the phenocopy resembling the mutant type.

(The bibliography of the enumerated results is found in Goldschmidt (1938, 1955), Goldschmidt and Piternick (in press), Landauer (in press) and for vertebrate monstrosities in general without much attention to phenocopy in Ancel (1950)).

It is obvious that such facts pose many problems the solution of which may have far-reaching consequences. The first of these is to explain why in these experiments the mutant phenotype appears and not some irregular monstrosity. From the very beginning of this kind of work it was clear (Goldschmidt, 1920; Zeleny, 1923) that the simplest assumption would be that both the mutant locus and the shock (using this word for all phenocopic agents) affect normally occuring developmental reactions in a quantitative way by speeding or retarding them relative to the other not affected processes. The facts which have become known since require some such rather simple and generalized basic explanation. It would be hardly possible that such different agents used in producing phenocopies could have identical effects if they acted by producing specific substances or interfering with the quality of specific reactions or steps. But within this generalized rate shifting action many possibilities are given, actually demanded, if we want to account for the most disconcerting facts, the genetic control of quantity, quality and specificity of the effect (thus far studied only in chemically induced phenocopies). One could appeal in a general way to a modifier system for the details of processes of development which is different in different lines. Taking a single developmental process e.g., the differentiation of a part of the antennal disc into an arista (in Drosophila) all the processes of growth and differentiation must be properly integrated to produce a normal arista. The integration is under genic control and therefore liable to shifts if the combination of controlling loci varies in the usual way. In normal conditions the collaboration of this "modifier system" varies only within the limits for normal development, though there might be variations which make one or the other part of the system come near to the point where normal development is not possible any more. Within such a system it is imaginable that such "weak points" are present for one or more definite developmental steps, differently in diverse genetic lines. A shock treatment will push the calibrated system out of gear at such points and abnormal development results for a specific process of differentiation. It is a different problem why, at least in Drosophila and also the fowl, this abnormality is identical with a mutant. One might say that integrated aberrant development is possible only in definite directions. We may use the simile of notches into which developmental processes must snap in order to succeed in the production of something orderly. These notches are the same whether the cause of the aberration is a shock or the activity of a mutant locus.

Landauer has tried to support an idea of this general type (though expressed in different language) by pointing out that in his experiments lines in which the phenocopy (e.g. rumplessness) appeared "spontaneously" reacted better to the phenocopic treatment with insulin or boric acid; and in addition in proportion to the incidence of the spontaneous variant. This could mean that these lines have already in their developmental system what I called above a "weak point," based upon a definite genetic constitution. But how can it be proved that the genetic basis of the "spontaneous phenocopies" is a definite constellation of modifiers and not rather the presence of a mutant of very low penetrance? We have studied in the course of time many mutants of low penetrance with monogenic or polygenic basis. Some of them can be selected for high penetrance, others cannot be shifted beyond a certain level which might be as low as less than one per cent. Without special inquiry they would be described as non-hereditary rare variations. As an example I might mention the concrescence of the first legs of Drosophila into a ventral, unpaired organ resembling an orthopteran labium. Some types of this variant were described long ago by Morgan *et al.* as a non-hereditary abnormality; but I found it later as a mutant of low penetrance, probably on a polygenic basis. Another example was found in *Lymantria dispar*, a case of prothetely, namely a pupal antenna in caterpillars, a rare anomaly, but once encountered as a low penetrant mutant. Thus I am inclined to consider all similar cases as mutants with low penetrance. If now, as in Landauer's case, a line producing such anomalies "spontaneously" is more liable to

produce also the phenocopy of the same phenotype; and if further a correlation exists between the percentage incidence of the "variant" and the sensitivity for producing it as a phenocopy, the suspicion arises that the phenocopy, in this case, is an enhancement of a low penetrant mutant.

We studied a number of cases in which a mutant of low penetrance can be enhanced by a phenocopic agent and such a case was also studied by Plaine and Glass (1955). In addition it is known that low penetrance may be so low that it amounts practically to absence. Further we found that a mutant which had lost completely its penetrance, probably by selection of minus modifiers may be restored to visibility by treatment with a shock which produces the same phenotype as a phenocopy (of course, this recovery is not hereditary). Taking all this together the hypothesis can hardly be avoided that all phenocopies are due to a bringing into light of already present non-penetrant, subthreshold or isoallelic mutants.

But a proof for such a hypothesis is very difficult. We have tried many ways (Goldschmidt and Piternick, in press); but in spite of a number of encouraging results thus far no fact has been established which could be considered a cogent proof. Actually such a proof would require the demonstration of a monogenic, subthreshold mutant for each successful and specific phenocopic action. But if the genetic basis were a polygenic condition the genetic element in the reaction to phenocopic treatment either would be called a set of subthreshold mutants, or, just as well, a condition of the modifier system controlling the set of different developmental conditions which permit a shift away from normal, as discussed above. Thus far we have not yet succeeded to overcome these experimental and logical difficulties.

It is obvious that a solution of such problems would greatly influence our ideas about genic action and the nature of mutation. Already at this point it becomes visible that the genic control of morphological development cannot be exercised by means of specific enzymatic actions but must require a system in which rates and timings of events play the preponderant role. This does not exclude the participation of enzymes in the setting of the proper order in the interwoven and interlocking developmental reactions e.g., by substrate affinities and competitions for substrates. Thus far I know only of one hint towards chemical identification of the actual processes involved, both in phenocopic and mutant action. Plaine and Glass found that L-tryptophane increased the penetrance of the mutant erupt-suppressor and that previous oxygen treatment increases the penetrance still further. Now Hinton *et al.* (1951) found that L-tryptophane produces many kinds of phenocopies. If we add to these two groups of facts the well known influence of oxygen upon the production of mutants we are led to visualize an interrelation of these different genetic approaches which may lead one day to satisfactory solutions of the problems which have been touched upon.

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Three New Ascomycetes on *Spartium junceum* L.

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Spartium junceum L. is a shrubby Leguminosa of the *Genisteae* sub-family in the Mediterranean region. According to Hegi (1923) it also occurs adventively in south and east Asia and in south America. The plant is the host of some peculiar Ascomycetes such as *Cainia incarcerata* (Desm.) Müller et v. Arx, *Arnaudiella coronae* (Pass.) Petr. and *Didymosphaeria spartii* (Cast.) Fabre. *Guignardia cytisi* (Fuck.) v. Arx et Müller with their imperfect stages and the *Mycosphaerella* described as *Sphaerella scopulorum* Sacc. et Cav. are always found on decayed branches. Besides these there occur a number of similar fungi imperfecti which resemble one another. They certainly belong for the greater part as conidial stages to the class Ascomycetes. We are, however, not as yet in a position definitely to determine their perfect stages. Research into Ascomycetes should in all these cases be based not only on finds but also on cultures so as to render inferences concerning the conidial stages possible.

In the last few years we have found on excursions in the Mediterranean region three apparently new Ascomycetes on *Spartium junceum* L. All three have also been isolated and cultivated on malt agar. After these experiments with cultures it is now possible to attribute to each of them a fungus imperfectus occurring on the substratum of the host. As these fungi belong to genera or subgenera which are not very well known they shall be described here in some detail.

1. *Plectosphaera spartii* nov. spec.

In several places in the south of France we have found a sphaerial Ascomycete with monocellular hyaline ascospores which cannot easily be referred to any described genera. Morphologically it almost fits into some species of the genus *Phyllachora* Nitschke, it differs, however, very distinctly in the formation of the conidial stage and in the saprophytic growth from typical species of that genus. Another genus, which comprises quite a number of saprophytic species closely related to *Phyllachora* Nitschke is *Plectosphaera* Theiss. The fungus had best be classified with this genus, the natural connection being *Plectosphaera rosae* v. Arx and *Plectosphaera salicis* (Sacc.) v. Arx et Müller (v. Arx and Müller, 1954).

We could find the fungus in the following places:

France, Alpes maritimes, Fontan, July 31, 1955.

France, Vaucluse, Mt. Ventoux, southern side, 700 metres above sea level, June 18, 1956.

France, Vaucluse, Vaison-la-Romaine, June 18, 1956.

Of the first specimen we had a pure culture at our disposal. In this culture the fungus fairly soon formed a compact pink-coloured mycelium on malt agar, covered with a but slightly developed aerial mycelium. In this aerial mycelium there arise after about two weeks fairly large pycnidia in which spindle-like monocellular conidia are produced severally from filiform conidiophores 20 to 30 μ in length. This fungus also occurs on the natural substratum and can best be referred to the imperfect genus *Myxormia* Berk. et Broome.

We have compared the perfect and imperfect stages with fungi already described. According to original material of *Laestadia spartii* Pass. which agrees fairly exactly with our fungus in the mass of asci and spores, this fungus is nothing else than *Guignardia cytisi* (Fuck.) v. Arx et Müller. So there is no need to go into this further. There is, however, a possibility of our fungus, which is by no means rare, having been found before and determined as *Laestadia spartii* or *Physalospora euganea* Sacc. (= *Guignardia cytisi*).

The conidial stages could not be identified with any form already known. The fungus classified by v. Höhnel (1910) with *Phlyctaena* and before that time as *Sacidium juncea* Mont. has been carefully described by Petrak (1924) as the type of his new genus *Selenophomopsis*. Our own material of *Selenophomopsis* shows a fungus conforming to that description but differing sharply from the fungus in question. Also identical with *Selenophomopsis juncea* (Mont.) Petr. are *Phlyctaena spartii* Bub. (Jaap, 1916), *Rhabdospora Cocconii* Sacc. and *Cryptosporium lunulatum* Bäumler. As has only recently been proved (Müller, 1956) on

culture experiments, this fungus belongs to *Guignardia cytisi* (Fuck.) v. Arx et Müller.

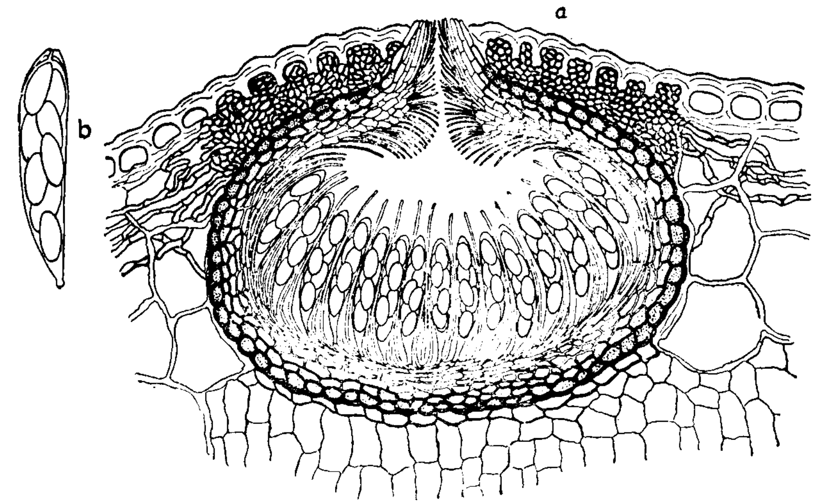

FIG. 1. *Plectosphaera spartii* (perfect stage).
(a) section of a fruit body (×250). (b) Ascus with spores (×1000)

Our fungus is, therefore, a new species which can be described as follows:

Plectosphaera spartii nov. spec.

Status conidiophorus: *Myxormia* Berk. et Broome.
Matrix: *Spartium junceum* L.
Loc.: Gallia part. Mediterr.

Status ascophorus: Perithecia subepidermalia, in substrato immersa, plerumque depressa vel globosa, 200-250 μ latitudinis, 180-220 μ altitudinis, clypeo stromatico tecta. Clypeus fuscis cellulis crasse tunicatis, 2-5 μ diam., epidermidem penetrantibus eamque complentibus. Perithecium apertum papilliforme ostiolo cellulis claris, applanatis, oblongis; centro ostioli periphyses numerosae, filiformes, hyalines. Membrana circiter 20 μ latitudinis, exteriore cellulis 8-12 μ diam., paulo applanatis, crasse tunicatis, nigris, interiore clarioribus et applanatioribus, quibusque ultimo paries fibrata oritur. Cellulae exteriores in cellulas hospitales penetrantes eiscum concrescunt. Asci numerosi, claviformes, octospori, unitunicati, 55-65 μ longitudinis, 10-12 μ latitudinis, breviter pedunculati ad marginem dispositi sunt. Sporae 12-17×5-5·5μ unicellulatae, hyalines, ellipsoides vel nonnumquam claviformes.

Status conidiophorus: Sori nigri et tecti, 350-550 μ latitudinis, curvata cuticula scissa circumdati, iuxta perithecia crescunt. Clypeus paulo formatus. Sori supra poro rotundo aperti. Membrana baso 15-20 μ latitudinis et nonnullis stratis cellularum applanatarum, exteriore crassissime tunicatarum, vertice ad 40 μ latitudinis. Conidiophori baso sori, filiformes, hyalines, 20-30 μ longitudinis. Conidia unicellulata, fusiformia vel recta vel paulo curvata, 17-21 × 4-6 μ magnitudinis, singulo hyalinia in multitudine rosae videntur.

Perfect stage: The perithecia growing under the epidermis immersed in the substratum, globose or frequently depressed, 200-250 μ in width and 180-220 μ in height, are covered with a stromatic clypeus. The clypeus is composed of rotund or very irregular, thick walled, fuscous cells, 2-5μ in diameter, which penetrate into the cells of the epidermis and often fill them completely. On the side the clypeus is looser and peters out in a network of brown entangled hyphae. The fruit body possesses a papillary ostiole rupturing the cuticle. It is composed of light-coloured, not very thick-walled, elongated and distinctly oblate cells which unravel inside at the centre into the numerous filiform, hyaline periphyses. The perithecial wall is c. 20μ in thickness and consists on the outside of opaque blackish-brown, thick-walled, but only slightly oblate cells, 8-12 μ. Inside, the colour grows lighter, the oblateness becomes more distinct and at last the cells form a fibrous fur or tunic of the perithecium. Outside, the perthecia grow together with the destroyed cells of the substratum and are sometimes intertwined or interspersed with them. The numerous claviform asci 55-65 × 10-12 μ in size with delicate simple perithecia sit on short stalks all along the perithecium. They have a distinct apical apparatus and are surrounded by not very numerous, filiform and muciferous paraphyses. The eight ascospores arranged in one or two rows are 12-17×5-5·5μ in size, unicellular, hyaline, ellipsoidal or sometimes slightly claviform in shape.

Imperfect stage: The covered black fruit bodies of the pycnidform appear mingled with the casings of the perfect stage. They are 350-550 μ in width, i.e., on an average twice as large as the perfect stage, and surrounded by the ruptured and concoidal cuticle. It is connected with the cuticle by a but faintly developed clypeus which penetrates into the epiderm. At the top the fruitbodies open in a rotund porus, sometimes they are rent wide open. The pycnidial wall is 15-20 μ at the base and consists of some layers of oblate cells, opaque, brown-black and thick-walled

on the outside, growing gradually lighter and thin-walled inside. Laterally they are just as thick, on the outside, however, they coalesce with the epiderm. In the apical area they reach a thickness up to 40 μ. The conidiphores are confined to the base. They are filiform, hyaline, 20-30 μ in length. At the base they pass into the hyaline interior cells of the fruit body, at the top they severally produce conidia, which are oblong, fusiform, straight or slightly curved, distinctly tapering at both ends, large, monocellular, 17-21 × 4-6 μ. These conidia fill the whole inside space. Alone they appear hyaline, in mass they are pink-coloured.

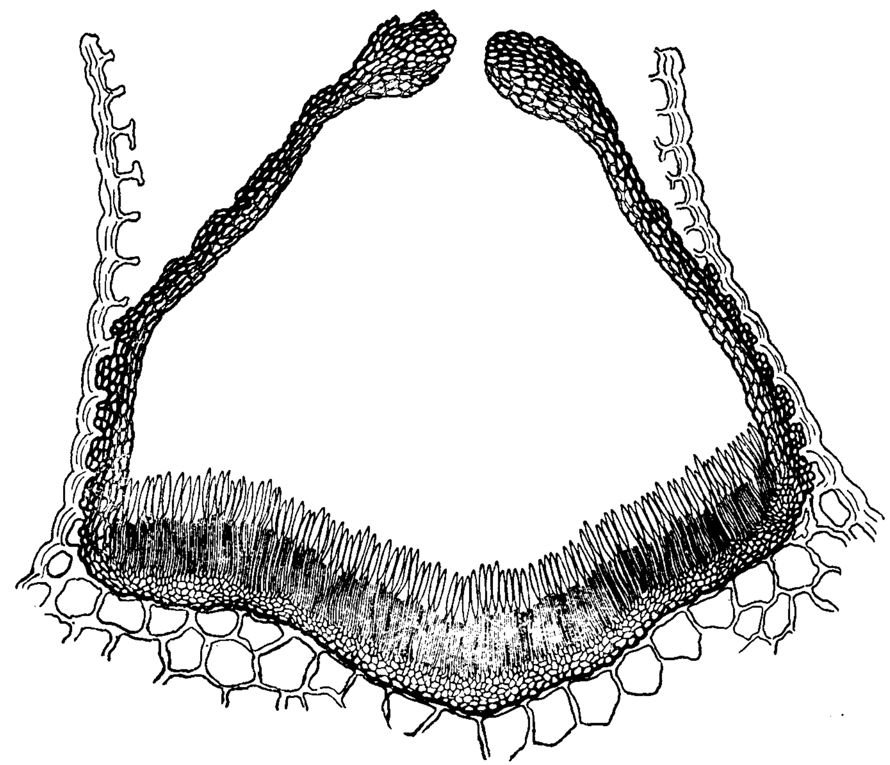

FIG. 2. *Plectosphaera spartii, Myxormia* conidial stage. Section of a fruit body, enlarged (×250).

2. *Trichometasphaeria gallica* nov. spec.

Another fungus found on *Spartium junceum* L. in several places of the Alpes maritimes has similar fruit bodies to *Plectosphaera spartii.* They, too, are covered by an epidermal clypeus. The ostiole, however, is shaped differently: it is flat or slightly papillary and protruding. In the ostiolar canal there are dark bristles. The ascospores are multi-cellular, hyaline and enveloped in a thin mucous membrane. With all its characteristics the fungus belongs to the genus *Trichometasphaeria* as described by Munk (1953).

The fungus was found in the following places:

France, Alpes maritimes, Fontan, July 31, 1955.

France, Alpes maritimes, Gréolières, Le Foulon, June 22, 1956.

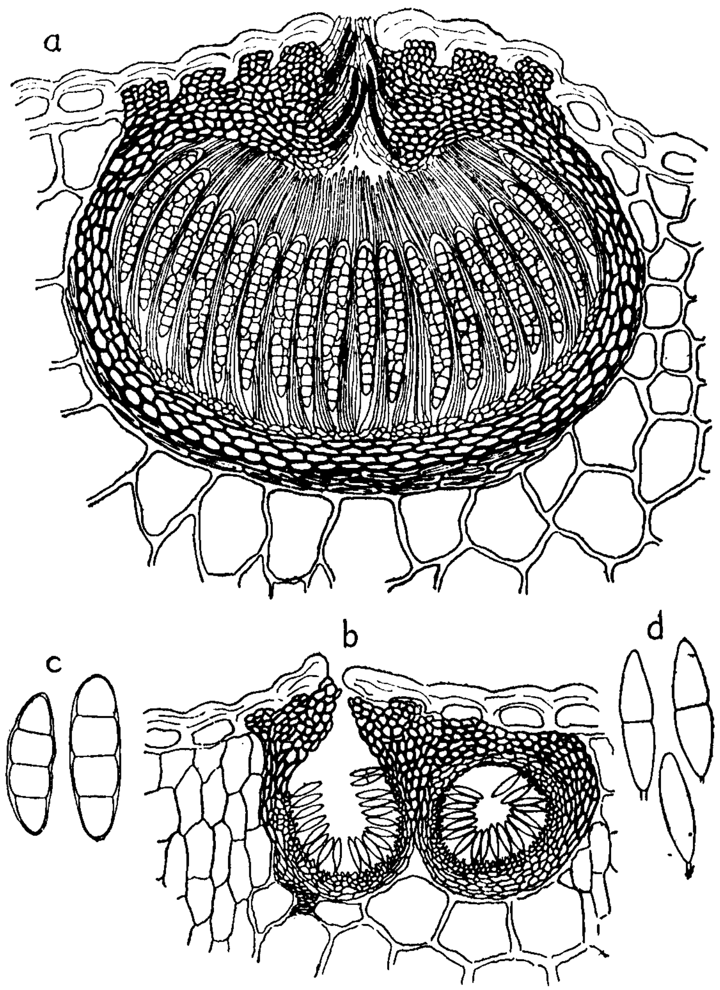

FIG. 3. *Trichometasphaeria gallica.*
(a) Section of a fruit body of the perfect stage. (b) Section of two pycnidia, (×250) each. (c) Ascospores. (d) Conidia, (× 1000) each

In both cases it has been isolated and examined in pure culture. The cultures are alike except for a few slight differences in colour.

In pure culture on malt agar the fungus forms a light grey, compact mycelium which only grows on the substratum. In this mycelium there arise pycnidia singly or mostly gathering in smaller or larger stromatic complexes. In the pycnidia fusiform ellipsoidal, monocellular or bicellular hyaline conidia are produced. We have also found this fungus imperfectus on thin branches of the host. The pycnidia growing on the natural substratum hardly differ from those growing on the agar, only the conidia are for the most part bicellular. This form of conidia fits best with the genus *Ascochyta* Lib. Presumably our fungus has already been described as *Aposphaeria mollis* (Lév.) Sacc.

Trichometasphaeria gallica nov. spec.

Status conidiophorus: *Ascochyta*

Matrix: *Spartium junceum* L.

Loc.: Gallia, part. Mediterr.

Status ascophorus: Perithecia in substrato immersa, 250-350 μ latitudinis, 180-250 μ altitudinus, globosa vel depressa, fusco clypeo cellulis 5-7 μ diam. rotundatis, crasse tunicatis, stromaticis, cellulas epidermales absolute complentibus tecta. Ostiolum planum vel cono depresso simile, perithecium per cuticulam aperiens, canale angusto perforatum, cornato fuscis saetis crasse tunicatis, hebetatis, 3-5 μ diam. Membrana circiter 15 μ latitudinis et nonnullis stratis depressarum cellularum crasse tunicatarum, fuscarum, centro clariorum, 8-10 μ diam. Numerosi asci claviformes, octospori 80-100 μ longitudinis 10-12 μ latitudinis, bitunicati crasseque, paralleli, ad marginem perithecii dispositi sunt. Asci nomerosis paraphysoidibus hyalinibus filiformibus circumdati sunt. Sporae fusiformes vel cylindricae quatercellulatae, hyalines, 16-22 × 5-6 μ, circumdatae strato mucoso.

Status conidiophorus: Parasitus caulibus hornotinis crescere videtur eosque interficiens. Pycnidia congregata, diversa forma et varia magnitudine, saepe secum coniuncta, in superiore parte clypeo simile augescens. Papiliforme ostiolum canale angusto perforatum. Membrana pycnidiarum superiore parte cellulis polyedricis, fuscis, 5-7 μ diam., crasse tunicatis; inferiore et latere clarioribus cellulis tenuius tunicatis et exteriore parte depressis. Conidiospori hyalines, 15-18 × 4-4·5 μ, fusiformes, uni vel bicellulati.

Perfect stage: The perithecia, 250-350 μ in width and 180-250 μ in height, depressed, are completely immersed in the substratum. They are covered by a fuscous clypeus consisting of rotund, rather thick-walled cells which are 5-7 μ in diameter. The clypeus fills the cells of the epiderm completely and dissolves into short, dark hyphae. The ostiole is flat or only scarcely conical and ruptures the epiderm from inside. It is pierced by a narrow canal which on the inside is spiked with dark, thick-walled, stout, blunt bristles and lined with highly flattened, hyaline, thin-walled cells. The perithecium is about 15 μ thick and consists of several layers of more or less distinctly flattened, rather thick-walled, fuscous cells which grow lighter in colour towards the centre, 8-10 μ in diameter. In the ostiolar area it grows up to 30 μ in thickness; it forms a light cavity and passes into the clypeus without a distinct borderline. The numerous claviform asci are 80-100 × 10-12 μ, thick-walled or even bi-tunicated. They are parallel all along the inside of the wall and enveloped in numerous filiform, hyaline paraphysoids. Each of them contains eight fusiform or almost cylindrical quadricellular, hyaline spores, 16-22 × 5-6 μ. The second cell is in most cases slightly thickened and all septa show a distinct constriction. They are enveloped in a thin transparent mucous membrane.

Imperfect stage: The conidium grows parasitically on the living twigs and kills them. The pycnidia are mostly immersed in the substratum in groups and very often stromatically grown together. They vary in size and shape, globose, upright, ellipsoidal or depressed, often very irregular owing to mutual pressure, 80-220 μ in diameter. At the top they are like the perfect stage thickened like the clypeus. A papillary ostiole pierced by a narrow canal breaks through to the outside. Here it consists of brown coloured rather thick-walled cells, 5-7 μ in size. On the sides and at the base these cells gradually grow lighter in colour, the wall is thinner and the cells are distinctly flatter. On the inside fusiform, hyaline, monocellular or bicellular conidia, 15-18×4-4·5 μ in size are produced by the conidiphores which stand up like short thorns.

3. *Pleospora spartium-juncei* nov. spec.

On *Spartium junceum* L. a species of *Pleospora* is often found which has been determined as *Pleospora spartii* (Sacc.) Berl. et Sacc. or as *Pleospora cytisi* Fuck. fa. *spartii* Sacc., but differs in nothing from the typical *Pleospora cytisi* Fuck. The fungus belongs

to the group of *Pleospora herbarum* (Pers.) Rabenh. It has depressed fruit bodies which vary in diameter from 8-300 μ at the beginning entirely closed, later opening in a rotund porus. The asci are broadly claviform or ellipsoidal, thick-walled or bitunicated, 100-140 × 20-25 μ, arranged in parallel order and enveloped in a cellular paraphysoid tissue. Each of them contains eight oblong ellipsoidal or slightly oval ascospores with a distinct hyaline mucous membrane clearly constricted in the middle, partitioned by 6-8 septa and 1-2 incomplete longitudinal septa, finely golden-brown coloured, 25-45 × 10-16 μ. A detailed description is to be found in Petrak (1921), who refers it to *Pyrenophora* Fr.

We have found *Pleospora cytisi* several times on *Spartium* and could isolate it in the following places:

France, Alpes maritimes, Fontan, July 31, 1955.
France, Alpes maritimes, Le Foulon Gréolières, June 22, 1956.

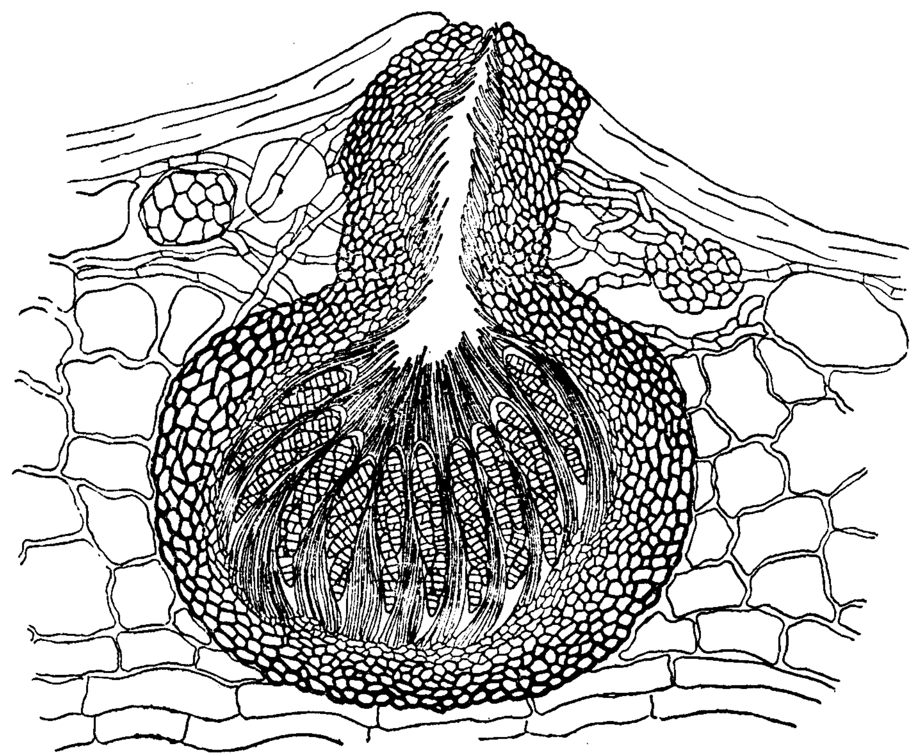

Fig. 4. *Pleospora spartium-juncei*. Section of a fruit body (× 250).

In pure culture the two specimens behave somewhat differently. In the Fontan culture there arise, especially under intensive exposure to light, numerous pycnidia, in which byciform, monocellular, hyaline conidia 4-6 × 2 μ, are produced in filiform, hyaline conidiphores up to 10μ in length. The conidiophores dissolve soon so that they can no longer be recognized in the ripe stage. This fungus is certainly identical with *Phoma sagittalis* Jaap. Jaap (1904) expressly mentions that he found it on *Cytisus sagittalis* L. besides *Pleospora cytisi* Fuck.

But this conidial fungus is not a typical *Phoma* Fr. Morphologically it belongs to the neighbourhood of *Phoma acuta* Fr., which is the type of the genus *Leptophoma* v. Höhn and belongs as an imperfect stage to *Leptosphaeria acuta* (Moug. et Nestl.) Karst.

The Le Foulon specimen produced in pure culture only few pycnidia. On the other hand the development on malt agar is always closed by the formation of the perfect stage.

The fungus can be presented as follows:

Pleospora cytisi Fuck.—Symb. Myc. 132 (1869).

Synonyms:

Pyrenophora cytisi Petr.—Ann. Myc. **19**, 99 (1921).
Pleospora cytisi fa. spartii Sacc.—Michelia **2**, 251 (1882).
Pleospora spartii Sacc. et Berl.—Nuov. Giorn. It. **20**, 86 (1883).
Imperfect Stage: *Leptophoma* described as *Phoma sagittalis* Jaap—Allg. Bot. Ztschr. **12**, 124 (1904).

Matrix: shrubby Leguminosae such as *Cytisus*, *Spartium*, *Genista*, *Sarothamnus*, *Callicothome*.

Besides this striking and frequent species of the genus *Pleospora* we have found a second one which could not be identified with any other already described. It differs from *Pleospora cytisi* not only by the claviform, rather narrow spores which are pointed at the nether end and have a mucous appendix, but the fruit bodies point morphologically to the fungus classified by Müller (1951) with sub-genus *Ciliopleа* Munk.

In pure culture from material collected in the vicinity of Vaison-La-Romaine (Vaucluse, France) the fungus is an imperfect form of the form genus *Coniothyrium* Corda and thus differs in its asexual phase distinctly from *Pleospora cytisi*. We could find this imperfect form also on material of *Spartium junceum* L. The fungus can be described as follows:

Pleospora spartium-juncei nov. spec.

Status conidiophorus: *Coniothyrium.*

Matrix: *Spartium junceum* L.

Loc.: Gallia part. Mediterr.

Status ascophorus: Perithecia dispersa, sub-epidermide nidulatia, globosa vel depressa, 200-300 μ diam. Ostiolo plus minusve conico, canale hyalini periphysibus ornato. Pariete perithecii 20-40μ crasso, e stratis pluribus cellulis angulato-rotundatis, 10-15 μ diam. composito. Asci numerosi, clavati, bitunicati, 95-110 × 10-13 μ. Sporae clavatae media constrictae, base subacuminatae et appendiculis hyalinibus, mucosis ornatae, 5-septatae (rar. 4- vel 6- sept.), in loculis mediis praeterea longitudinaliter septatis.

Status conidiophorus: Pycnidia 100-250 μ diam. epidermide tecta, globosa; ostiolo conico erumpenti. Paries pycnidiorum fuscus, cellulis 4-7 μ diam. subcrassis compositus. Pycnidia prima interna composita cellulis hyalins, demum conidis ellipsoidibus, hyalinibus vel subfuscus 2-4 × 1-3 μ diam. formata.

Perfect stage: The fungus forms dark fruit bodies completely immersed in the substratum, each standing apart, globose or mostly depressed, 200-300 μ which break through in a conic ostiole up to 120 μ in height. The ostiole is perforated by a canal straightening at the upper end, with hyaline, filiform, paraphysoid hyphae projecting into it. The perithecium is 20-40 μ and consists of numerous layers of cells, thick walled, almost opaque, fuscous, regularly polygonal, 10-15 μ on the outside; on the inside, however, they are more thin-walled, slightly depressed and lighter, and at the centre smaller and thin-walled. The numerous asci are claviform, straightening into a stalk at the base, thick-walled and bitunicate, 95-110 × 10-13 μ. They are enveloped in numerous filiform paraphysoids and contain each of them eight claviform spores, constricted in the middle and distinctly tapering, with a hyaline mucous point, brownish-yellow, 20-25 × 7-8 μ, with 4-6, mostly 5 septa and often with a longitudinal septum in one of the middle parts.

Imperfect stage: The pycnidia are immersed in the substratum, upright ellipsoidal or depressed, 100-250 μ, but break through in a slightly conically projecting ostiole. The wall is brownish and consists of not very thick-walled brown cells, 4-7μ. Inside they are almost completely filled with thin-walled, regularly polygonal hyaline cells. Later they sub-divide at the centre or in other part with monocellular, hyaline or faintly fawn coloured, ellipsoidal spores gradually arising from the part-cells. The spore-producing cells dissolve and the conidium formation proceeds from the inner to the outer cell layers. Later sterigmata are to be seen through which spores penetrate from the mother cells into the inside of the pycnidia and from there to the outside.

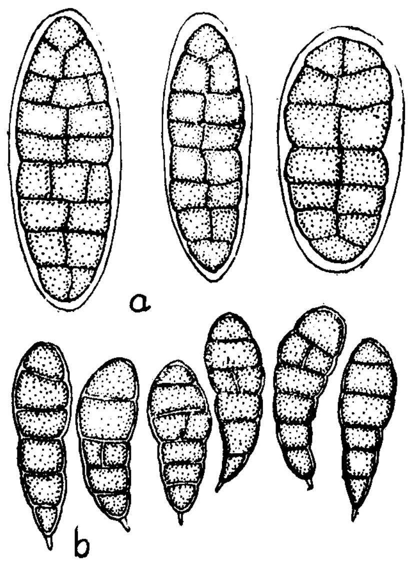

FIG. 5. Ascospores of (a) *Pleospora cytisi*, (b) *Pleospora spartium-juncei* (×1000).

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Temperature Relations of the Mineral Facies of Metamorphic Rocks

BY

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1. *Introduction*

The century old idea that all so-called igneous rocks had crystallized from a molten magma has, in the light of modern knowledge, met with severe criticism. Magmas are not at all abundant in the crust; on the contrary, they would seem to be very rare and local phenomena, perhaps to be compared to abnormal abscesses in the human skin. It is not possible any longer to maintain the idea that all the large batholithic bodies of granites and other coarse-crystalline rocks (anorthosites, etc.) grew by crystallization out of a magma.

In the crust of the continents the most important group of rocks, quantitatively, are those called metamorphic (gneisses, migmatites, granulites, crystalline schists, etc.). James Hutton (1726-97) of Edinburgh was the first to advance the opinion that some of these rocks were ordinary sedimentary strata subsequently altered by heat, and Sir Charles Lyell, who adopted the Huttonian theory, proposed the term metamorphic for the altered strata.

Metamorphic processes in rocks cannot be directly observed in nature, nor have they been adequately investigated by experiments. For this reason we are still very much in the dark as to the mechanism and thermodynamic relations of metamorphic processes. The study of transitional rock series from unmetamorphic to completely altered (recrystallized) rocks is the basis on which the principles of metamorphic geology must be built.

2. *Metamorphism and Metasomatism*

The alteration by recrystallization is generally accompanied by a change in the chemical composition, i.e., export and import of chemical matter resulting in the so-called metasomatic metamorphism, or simply metasomatism. One can often find statements to the effect that metamorphism without chemical change is the normal thing; to be sure, supposed cases of isochemical metamorphism are still currently set down as "normal metamorphism". In harmony with this nomenclature it has become customary, and is perhaps expedient in an attempt to survey and classify the various petrographic types, to distinguish between the "normal metamorphism" (with but small changes in the total chemical composition) and the metasomatic metamorphism (with large changes in the chemical composition). But from a genetical point of view this distinction is illogical and obscures the broader relations. Metamorphic rocks *always* have suffered a change in composition, for transportation and transfer of chemical matter and heat are not only concomitant with, but actually essential parts of, the earth processes constituting metamorphism. In geologic discussions the fact that sediments at the very incipience of metamorphism lose volatile constituents (H_2O, CO_2, etc.), and consequently regularly change their chemical composition, has often been neglected. However, these changes are not to be neglected, and H_2O, CO_2, etc., are just as important as many other of the rock-making constituents, and serve to characterize the rocks in which they occur.

There should be no mistake about the fact that, whether one likes it or not, large scale chemical transport in and through large volumes of rock is the normal thing: gneiss-granites, migmatites, micaschists, etc., all exhibit a chemical composition different from that of the pre-existing rock complex. Similarly, the mineralogical composition changes according to the changing chemical composition and according to variations in temperature and pressure; thermodynamic equilibrium is approached during the course of the metamorphism.

What are the instruments of these changes? Chemical emanations, ichor, or watery solutions circulating in the poor spaces? The question is highly controversial, and I shall not go any further into the problem here, I shall only again emphasize the fact: large-scale chemical changes in solid rocks did take place; and it is no argument against "emanations" or "ichors" that the physicist is unable to explain them, as long as he is equally unable to offer any better solution to the problem.

For the sake of completeness: there is no doubt about the fact that the changes took place in essentially solid rocks — an abundance of evidence show that no melting occurred. Quite decisive is, for instance, the interesting account of Professor Bucher

(1953) on fossils in metamorphic rocks; so prudential were the metamorphic processes that in many cases the most delicate structures have been preserved.

To me it is a reasonable position to base the discussion of recrystallization and evolution of metamorphites on the postulate that free interchange of matter (atoms or ions) can take place over large volumes of rocks existing as essentially solid masses at temperatures well below 650° C. Above 650°, magmas may form, but below this temperature rock magmas do not exist. Thus there is a natural boundary between metamorphism and magmatism (Ramberg, 1952).

3. *The Facies*

It is of paramount importance to get better information about the temperature-pressure conditions of the recrystallization. A large-scale attempt in this direction was the development of the facies classification. The first adumbration exists in the pioneer work on the *étages* by Michel-Lévy (1878-79) and in the corresponding classification of the metamorphic minerals by Becke (1903) and Grubenmann (1904) according to the depth zones. But in the early work of G. Barrow (1893) on the classification of the metamorphic rocks of the Highlands of Scotland according to the so-called index minerals we find the true germ of the facies principle. V. M. Goldschmidt (1911), in his work on the hornfelses of the Oslo region, used the same ideas to contrive a well defined system built on a theoretical fundament. Finally Eskola (1915), in his work on the Orijärvi gneisses, perfected the ideas and shaped them into a tool of the highest value: the system of the mineral facies of rocks.

The concept of a *mineral facies* as defined by Eskola (1921) "comprises all the rocks that have originated under temperature and pressure conditions so similar that a definite chemical composition has resulted in the same set of minerals, quite regardless of their mode of crystallization, whether from magma or aqueous solution or gas, and whether by direct crystallization from solution, or by gradual change of earlier minerals".

In order to determine these associations, in other words, in order to find out which mineral associations are characteristic of high temperature, or of low temperature, each of them combined with high pressure and with low pressure, Eskola had to go into the field and study naturally occurring mineral associations, i.e., rocks.

It has long been known that in an area of progressive metamorphism each successive stage, or each new zone of metamorphism, is reflected in the appearance of characteristic rock types. Rocks within the same zone may be called isofacial, or isograd as proposed by Tilley (1924) who, furthermore, proposed the term isograd for a line of similar degree of metamorphism.

In going from an area of unmetamorphosed sedimentary rocks into progressively more highly metamorphic rocks, new minerals appear in orderly succession. Thus, in a series of argillaceous rocks subjected to progressive metamorphism, the first index mineral to appear is usually *chlorite,* followed successively by *biotite, garnet* (almandite), and *sillimanite.* A line can be drawn on the map indicating where biotite first appears. This line is the biotite isograd. The less metamorphosed argillites on one side of this line lack biotite, whereas the more metamorphosed rocks on the other side contain biotite. An isograd can be drawn for each mineral. Actually the isograds are surfaces, and the lines we draw on the map are the intersections of these surfaces with the surface of the earth.

Further work along these lines resulted in the conclusion that it was possible to single out a well defined series of mineral facies. Sedimentary rocks of the lowest metamorphic grade recrystallized to give rocks of the *greenschist facies*—chlorite and epidote being characteristic minerals. Higher metamorphism produced the *epidote amphibolite facies,* still higher the true *amphibolite facies* in which both chlorite and epidote are forbidden minerals, hornblende and plagioclase mainly taking their place. Representative of the highest regional metamorphic grade is the *granulite facies* in which most of the stable minerals are water-free: pyroxenes, garnets, etc.

Any sedimentary unit will recrystallize according to the rules of the several mineral facies, the complete sequence of events being a progressive change of the sediment by deformation, recrystallisation and alteration in the successive stages:

Greenschist facies ⟶ epidote amphibolite facies ⟶ amphibolite facies ⟶ granulite facies.

During regional metamorphism a stationary temperature gradient is supposed to be established in the mountain masses. By

and large, the outer parts of a geosynclinal region are less affected, and in the ideal case the marginal parts contain unmetamorphosed sediments, clay, sand, limestone, etc., which gradually change into metamorphic rocks of successively higher facies as they extend into the central and deeper parts (depth zones).

This change, as demonstrated by the succession in mineral facies in the present surface rocks, would seem to correspond to the temperature gradient within the original mountain mass, a rapid change in facies indicating a previous steep temperature gradient and *vice versa.* This implied relation of mineral facies and temperature gradient of the metamorphism has been used to estimate the depth of erosion and, indeed, the original heights of eroded mountain ranges.

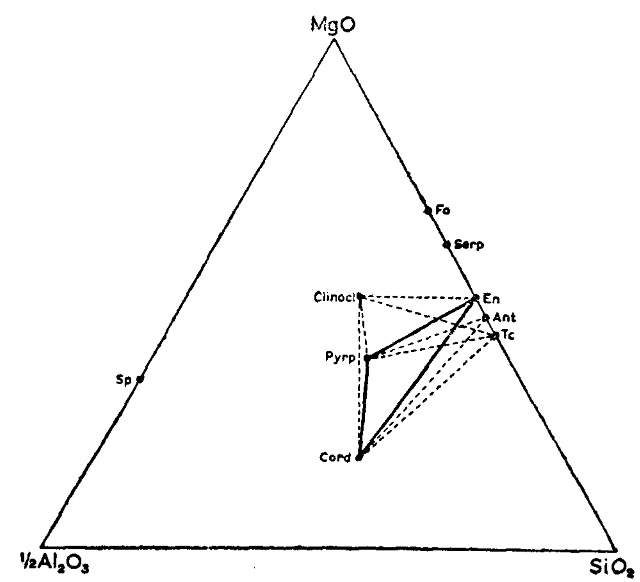

FIG. 1. A one-point projection of the MgO-Al_2O_3-SiO_2-H_2O system showing some of the constituent minerals. Ant = anthophyllite $Mg_7Si_8O_{22}(OH)_2$, Clinocl = clinochlore $Mg_5Al_2Si_3O_{10}(OH)_8$, Cord = cordierite $Mg_2Al_4Si_5O_{18}$, En = enstatite $MgSiO_3$, Fo = forsterite Mg_2SiO_4, Pyrp = pyrope $Mg_3Al_2Si_3O_{12}$, Serp = serpentine $Mg_6Si_4O_{11}(OH)_6 \cdot H_2O$, Sp = spinel $Mg\ Al_2O_4$, Tc = talc $Mg_3Si_4O_{11}(OH)_2$.

The assemblage shown in full lines refers to the anhydrous phases, cord-pyrp-en; the hydrous phases are joined by dashed tie-lines.

So strongly fixed in geological reasoning has become this direct relation between mineral facies and temperature (pressure) that without further reflection the various facies have been accepted as direct indicators of temperature (pressure). Consequently it is possible, graphically, to correlate the facies with temperature and pressure. Using temperature and pressure as axes, each mineral facies can be assigned to a specific temperature-pressure region as shown in Fig. 3.

4. *The Experiments of Yoder*

It must be called almost a shock, then, that one carefully conducted series of experiments by Dr. Yoder (1952) at the Geophysical Laboratory in Washington has given compelling evidence that this relation is not at all so certain and as absolute as has been thought.

Work in the system $MgO—Al_2O_3—SiO_2—H_2O$ gave as one result that at approximately 600° C and 1200 atm. it is possible to have different mineral assemblages suggestive of every one of the now accepted metamorphic facies in stable equilibrium. These different mineral assemblages ("artificial facies") observed by Yoder are the result of differences in the water content, and are not related to variation in temperature and pressure.

As an example: The mineral clinochlore, corresponding to one of the most common rock-making chlorites, shows an upper limit of stability either alone or in association with, e.g., talc, of 680° C. This is, indeed, a super high temperature for any kind of metamorphism—almost a magmatic temperature. But according to the tenets of the mineral facies, chlorite is strictly limited to the Greenschist Facies, around 200° C.

It will take too long to review the whole work of Yoder. But I shall take one example to illustrate the principle: Some of the minerals within the system $MgO—Al_2O_3—SiO_2—H_2O$ are shown graphically in Fig. 1. Let us select the area around the Cordierite—Pyrope—Enstatite association and study this area at a constant temperature-pressure combination: 600° C and 1200 atm., but under varying concentrations of H_2O. The various mineral associations which then develop are shown graphically in Fig. 2. Interpreted in terms of the mineral facies of rocks the associations are:

1. Enstatite—cordierite gneiss = granulite facies (~ 600°).
2. Anthophyllite—garnet gneiss=amphibolite facies (~ 500°).
3. Anthophyllite—talc schists = epidote – amphibolite facies (~ 400°).
4. Talc—chlorite schists = greenschist facies (~ 200°).

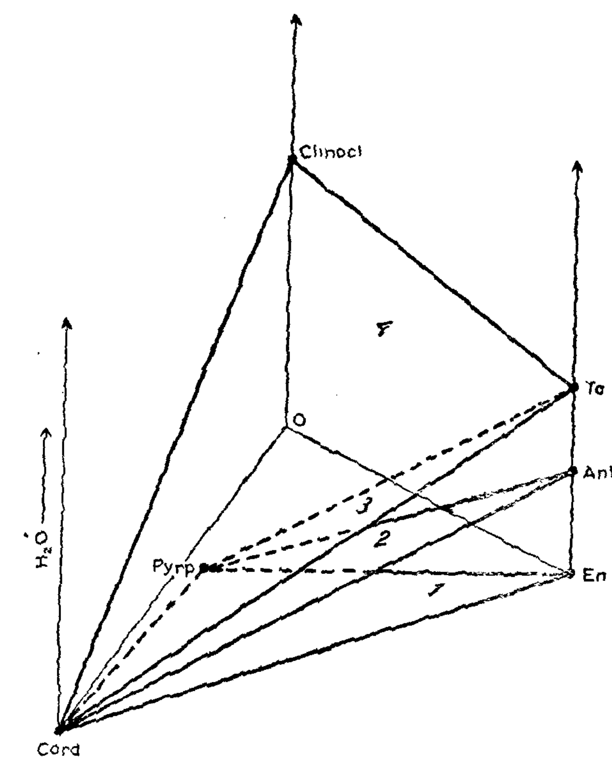

FIG. 2. A perspective projection of the system Cordierite-Pyrope-Enstatite-Water, constructed after observed and inferred data of Yoder (1952). Activity of water increases normal to the bottom face Cord-O-En.

(1) The water-free association is *cordierite-pyrope-enstatite* as shown in the bottom face of the illustration. With a small amount of water first enstatite yields part of itself to hydration (replaced by anthophyllite), with increasing concentration of water eventually all enstatite disappears and the association becomes *(2) cordierite-pyrope-anthophyllite.* With more water talc starts to form at the cost of anthophyllite and the association eventually becomes (3) *cordierite-pyrope-talc.* With still more water pyrope yields to hydration (replaced by chlorite) and the final association stable in the excess-water region is *(4) cordierite-talc-chlorite.*

According to the facies geology we go through a temperature range from 600° to 200° C, while the experiments prove that the temperature actually was constant; chemically we just go through a small range of composition from no water to 5-6% of water. The mineral association corresponding to the granulite facies is water-free. With increasing water content the minerals indicate facies of successively lower grade.

We must conclude, as Yoder has done, that the accepted mineral facies do not represent reliable temperature-pressure indicators. Evidently, the trouble is that the series of mineral facies chosen by Eskola are not isochemical: they differ markedly in their water content, and this difference is sufficient to cause great differences in the mineral associations. What was interpreted by Eskola and others as a change in temperature-pressure, is actually, in some rocks, the result of a change in the bulk composition.

Therefore, a sequence of progressive mineral facies established in one area, cannot be used as temperature indicators in another area. And again: The present composition of a metamorphic rock is not the same as that which prevailed before the metamorphism. During the metamorphism the rock was soaked in pore liquids and vapors which have now escaped, very much in the same manner as the "volatiles" escape from a magma, leaving behind a solidified rock quite different in composition from the magma out of which it crystallized.

These facts, and the correct apprehension of the facts, put the geologist in a position to understand and interpret many of the observations that before had seemed mysterious.

Yoder mentions that the occurrence of eclogite with amphibolite, or even with low-grade rocks, may be understood. To be sure, in an area of isofacial rocks the field geologist may frequently observe abnormal rock deposits indicating a change in mineral facies. As an example I may cite the description of Seitsaari (1954) of a chlorite schist occurring with pre-Cambrian rocks of the amphibolite facies near Tampere, Finland. In this case the feldspar of the chlorite schist is a bytownite, proving, that the chlorite was not formed at the temperatures of the greenschist facies ($\sim 200°$) but actually at higher temperatures ($\sim 500°$ (?)) corresponding to the amphibolite facies.

A similar explanation may, perhaps, be given to the anorthite-bearing chloritoid schist of the Hitachi District, Japan, described by Seki (1955).

5. *Conclusions as to the Relation between Temperature and Mineral Facies.*

I have mentioned that what has been described as a change from one mineral facies to another (= a change in the temperature-pressure conditions) is simply, in some rocks, the result of a change in bulk composition. I have also mentioned a greenschist which does not belong to the greenschist facies. The question then arises: Are the established mineral facies "no good"? Is there no relation between temperature (pressure) and the several mineral facies of metamorphic rocks?

Although Yoder has proved that there is no absolute relation between temperature and facies, and although the greenschist from Tampere recrystallized outside the greenschist facies, I maintain that, to the field geologist, and to the laboratory man as well, the established facies classification will still remain as the best system of classification of metamorphic rocks; and in a majority of cases the facies will indicate the temperature-pressure conditions under which the several rocks recrystallized.

The point is that, generally speaking, there is a regular relation between the chemical activity of H_2O and the facies.

As shown by Yoder (1955) the role of water in metamorphism is determined by at least four variable parameters: rock pressure, temperature, water pressure, and the amount of water present. However, these four variables are geologically related: during a normal progressive regional metamorphism, rock

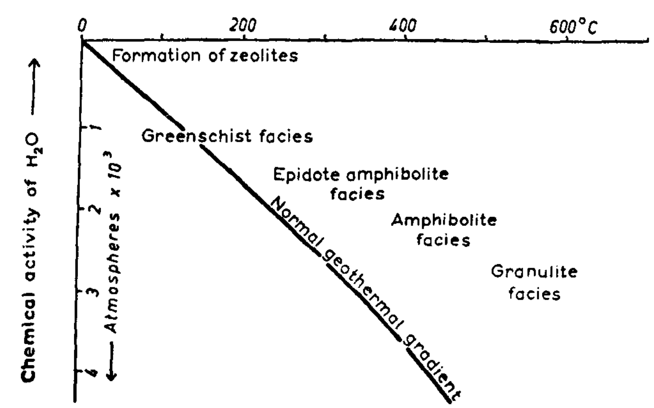

FIG. 3. The mineral facies of regional metamorphic rocks in their normal relation to temperature, pressure, and chemical activity of water.

pressure and temperature are interdependent, and the amount of water and the pressure of water are related to the encasing sediments and to the degree of metamorphism in such a way that, generally speaking, the low-grade metamorphic facies are characterized by the presence of an excess of water, the medium-grade by some deficiency in water, and the high-grade metamorphic facies by virtual absence of water. In the usual diagrammatic illustration of the mineral facies of rocks, temperature and pressure (depth) are taken as coordinates; in regional-metamorphic rocks we may now add a third, dependent coordinate: the activity of H_2O running parallel to, but in opposite direction of, the pressure. See Fig. 3.

Thus, Fig. 3 represents my conclusion to the question of the relation between temperature and mineral facies of regional-metamorphic rocks. It illustrates the usual case but does not take into account all the exceptions that may occur. For the mineral facies of a rock is not a one-valued function of temperature (and pressure). So complex are the geological processes, that in addition to temperature and rock pressure a great number of additional variables enter into the picture: stress, rate of growth, position in the gravitational field, pressure of water, of CO_2, and of other volatiles, absolute amount of water, of CO_2, etc.—thus, at the present state of our knowledge, and for a long time to come, it will be impossible from the simple mineral facies of a rock to infer with certainty the temperature at which the metamorphism took place.

6. *Geological Temperature Indicators.*

The classical mineral facies are, as we have seen, rather uncertain as temperature indicators. But there are other useful properties in the mineralogy of a rock that are applicable in geological thermometry:

1. Polymorphic inversions in minerals: It is well known that the inversion α-β quartz has been successfully used as a geologic thermometer. Other polymorphic inversions are also useful, but if they occur in pure compounds, like in quartz, they can register only one point on the temperature scale. Polymorphic transformations in mixed crystals, including the order-disorder type, are more useful as the high and low modifications co-exist over a temperature range. With increasing quantitative knowledge of the mechanism of polymorphism in, e.g., pyroxenes and feldspars, these minerals will become useful temperature indicators.

2. The exsolution of mixed crystals and, generally, the transformation of a mineral into a mineral assemblage: Sanidine breaks up into perthite, basic plagioclase may break up into sodic plagioclase and either scapolite or epidote; there is always a relation between the break-down temperature and the composition of the produced mineral phases.

3. The ratio of distribution of an element between two solvent minerals: Thus soda (in terms of the albite molecule which is soluble both in orthoclase and in anorthite) will distribute itself between plagioclase and alkali feldspar, and the distribution factor is characteristic of the temperature (pressure). With better knowledge of the distribution factor the chemical composition of the individual feldspar phases would become a geologic thermometer of the highest value (Barth, 1956).

Still simpler temperature relations are obtained in the distribution of the trace elements between the various mineral phases.

4. The fractionation of isotopes between two minerals is probably the most accurate method. It has been used for minerals formed at relatively low temperatures, but recently also applied to quartz-calcite and to quartz-ironoxide associations at higher temperatures (Clayton and Epstein, 1956).

5. There are other, special methods for geologic thermometry, e.g., the observation of the temperature of the filling of inclusions in crystals, and others.

A complete general summary of geologic thermometry has been prepared by Ingerson (1955).

From these briefly mentioned facts, it is seen that prerequisite to a temperature determination come a long series of carefully determined quantitative mineralogical data. The determination of the simple mineral facies is the first step, it gives a first approximation. But today one can and should go much farther, for it is obvious that the ever increasing accumulation of knowledge of the chemical and physical properties of minerals, and of their relation to one another and to the temperature and their origin impose a greater task on modern petrologists than was borne by those of a former generation.*

Today is not enough to list by name and amount the minerals constituting a rock, but for each mineral its physical and chemical properties must be determined. Not until such complete data are available for various rocks can a refined system of mineral facies be worked out, and the mode of origin, temperature, and pressure of the rock be inferred.

* This sentence, slightly differently worded, was pronounced in 1902 in the conclusion of Cross, Iddings, Puison, and Washington's famous "A quantitative chemico-mineralogical classification and nomenclature of igneous rocks."

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On the Structure and Life-History of *Cylindrocapsopsis indica* gen. et sp. nov., A New Member of the Cylindrocapsaceae

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This alga came up in a pond in Madras in January 1938. It grew well in the pond for three months and then disappeared about the beginning of May. The next year, it came up again in the pond in February and disappeared in May as in the previous year. The alga was found in the pond only in a sterile condition.

Material and methods

The living material of the alga was taken to the laboratory and kept in large wide glass dishes with plenty of the pond water in a well lighted part of the room. The alga grew very well in the laboratory for some time in a sterile condition and finally showed several very interesting stages of sexual reproduction.

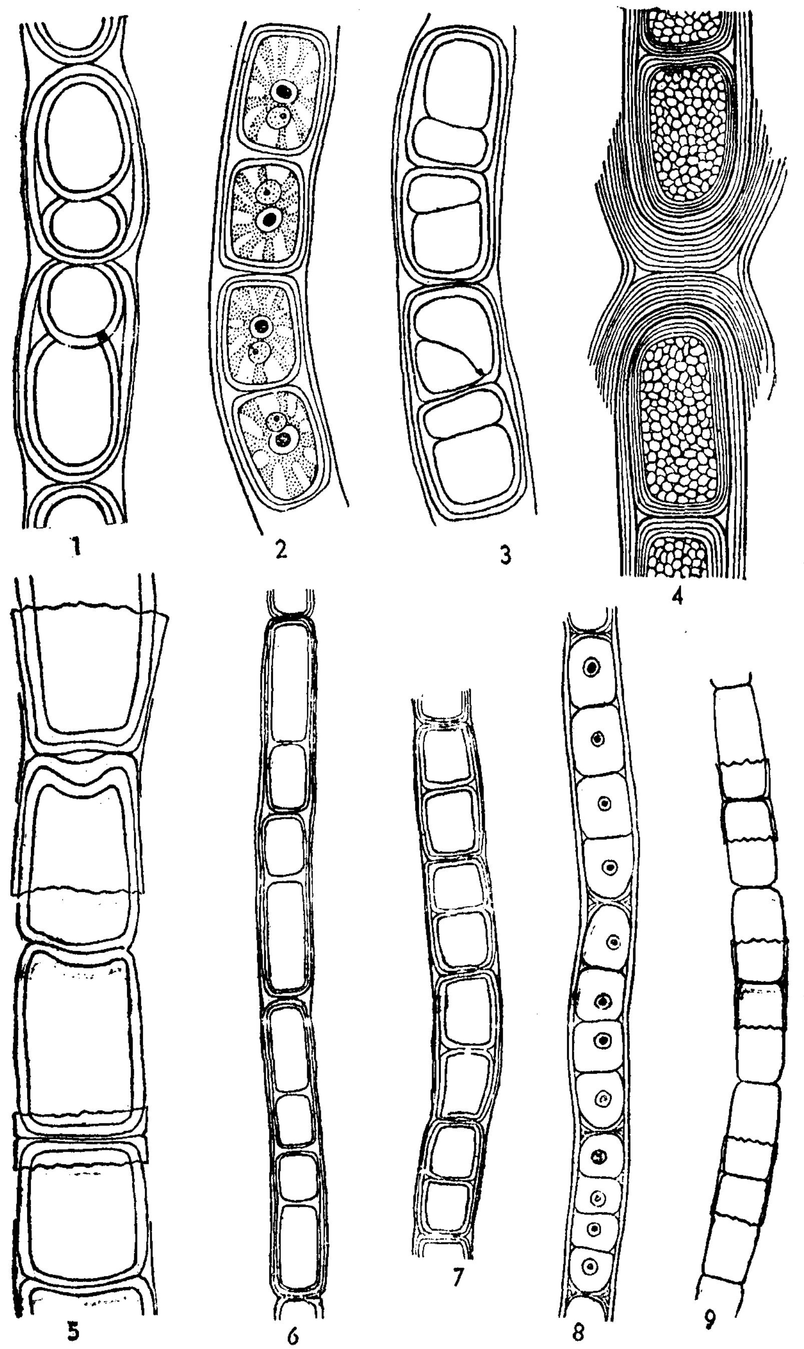
The alga was studied as far as possible in a living condition. The details of cell-structure, nuclear division and cell-division were studied with the help of fixed and stained preparations. The material for such study was fixed in weak chrom-acetic solution, Bouin's fluid (P.F.A. 3) and in Schaudinn's fluid, and stained in Heidenhain's iron-haematoxylin. Material preserved in 4% formalin was also used for the general study of the alga.

Structure of the alga

The alga in its sterile condition shows a close resemblance to *Cylindrocapsa*,[1] but, in the details of its life-history and in the mode of its sexual reproduction, it differs completely from *Cylindrocapsa*.

The alga is filamentous and unbranched. The cells are arranged in single series and are enclosed in a somewhat closely fitting tubular sheath (Pl. I, figs. 7, 8). In the younger filaments, the cells

1. A preliminary account of this alga was published under the name of *Cylindrocapsa geminella* Wolle (Iyengar, 1939).



TEXT-FIGS. 1-9. *Cylindrocapsopsis indica* sp. nov.
FIG. 1. Portion of a filament boiled in caustic potash to dissolve out the cell-contents, showing daughter-cells enclosed inside the mother walls. FIG. 2.

Cells with a single nucleus, and a stellate chloroplast with a pyrenoid. FIG. 3. Protoplasts of cells divided into two unequal daughter-protoplasts. FIG. 4. Old cells with walls made up of several layers. Note: H-shaped portion made up of remnants of mother-walls of several previous generations. FIGS. 5, 9. Cells showing ruptured mother-walls. FIGS. 6, 7. Cells enclosed in their mother-walls and grand-mother-walls. FIG. 8. Portion of a filament with three groups of four cells each, each group consisting of four grand-daughter-cells. FIGS. 1, 3, 5, × 750; FIG. 2, × 725; FIGS. 6, 7, × 370; FIGS. 8, 9, × 350.

are somewhat elongated and oblong with rounded corners. In the older filaments the cells are oblong to quadrate with rounded corners. The terminal cell of the filament is conical and elongated (Text-figs. 25, 27). The basal attaching cell also of the filament is somewhat elongated and roughly obconical (Text-figs. 32, 34, 38). In very old filaments, very often, in some parts of them, the cell-division, instead of being transverse, is oblique. The filament in these places becomes very much bent or contorted in various ways. Since active cell-division generally takes place in these, with the planes of division oblique or diagonal and occasionally also at right angles to the previous division, the filament in such places has a jumbled pseudoparenchymatous appearance, with the cells having all sorts of shapes and placed in a very irregular manner in more than one series (Pl. I, figs. 1, 2).

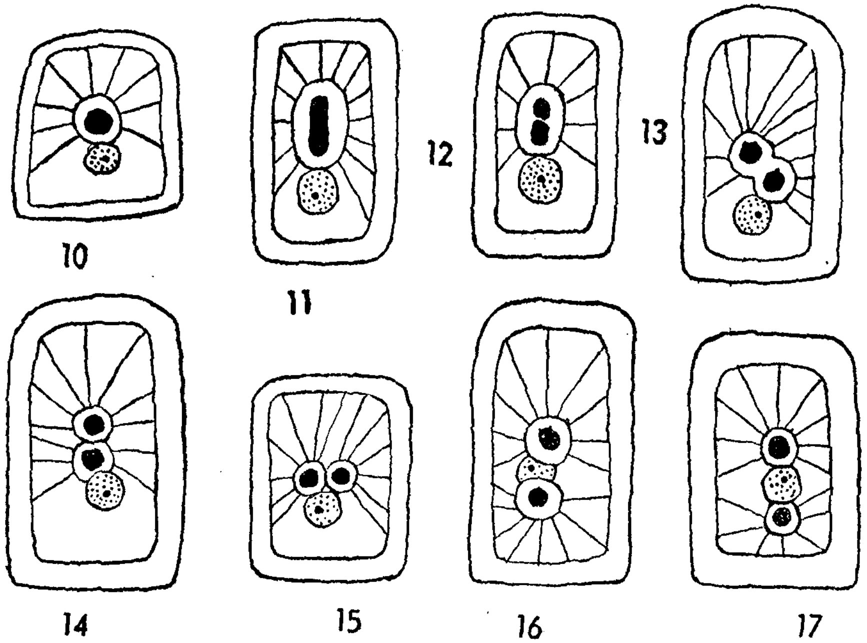
Cell-structure

The cells are 22-28 μ thick, and about three-fourths to two and a half times as long as broad. The cell-wall is somewhat thick and lamellate, with up to four or occasionally more concentric layers, and has a bright refractive appearance. The cell-wall when treated with iodine and sulphuric acid becomes blue in all the layers, showing the presence of cellulose in it. When stained with ruthenium red, the cell-wall layers and the tubular sheath of the filament take a deep red stain, showing the presence of plenty of pectic substances also in them.

The cell contains a single nucleus and a stellate chloroplast in which is embedded a single pyrenoid (Text-figs. 2, 18, 30, 32). Owing to the cells being usually densely filled with starch grains, the nature of the chloroplast is not easily made out, but, if the alga is starved by being kept in darkness for a few days, most of the starch is used up and the stellate nature of the chloroplast is very clearly seen.

Cell-division

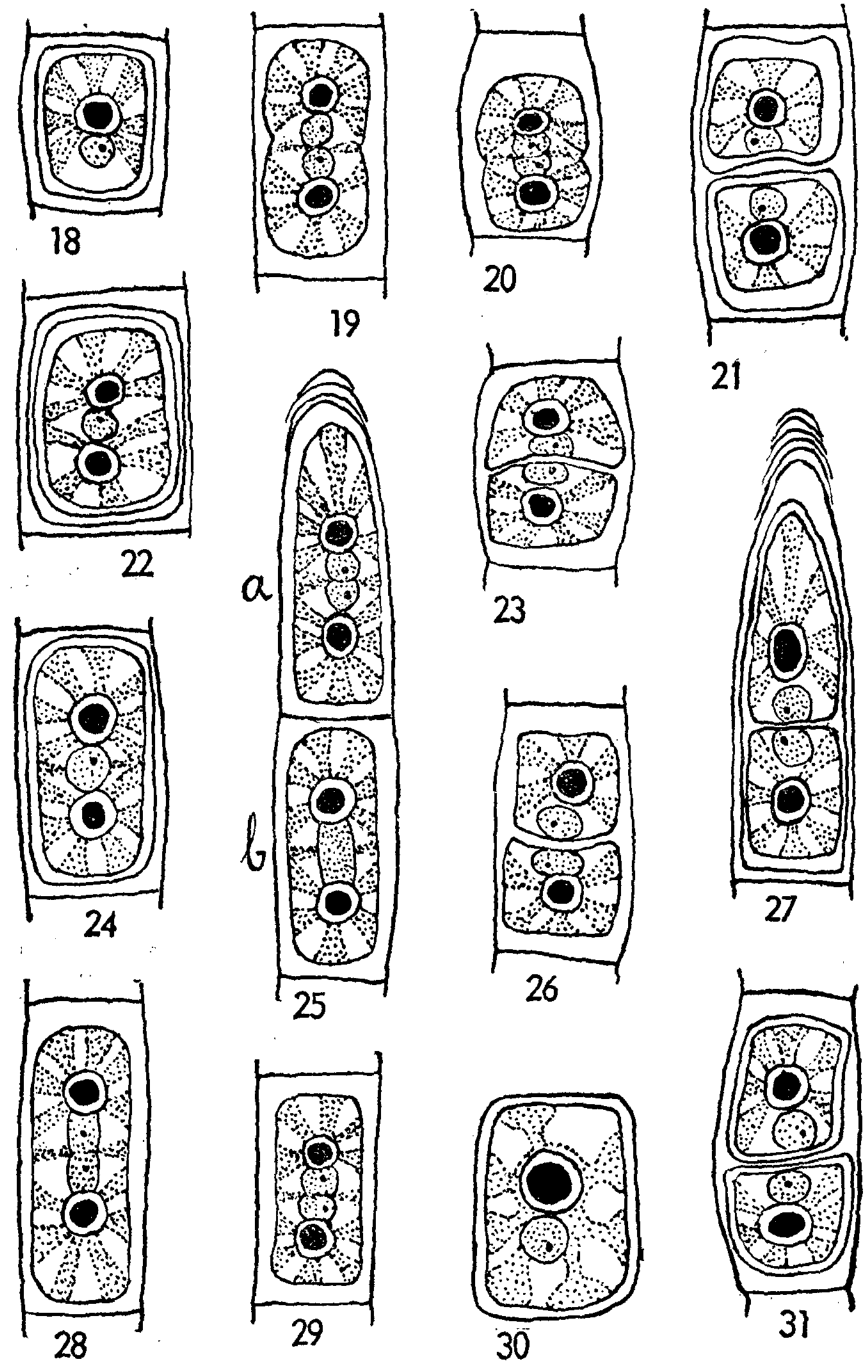
Just before cell-division, the pyrenoid divides into two. The details of the division of the pyrenoid and the movement of the daughter-pyrenoids are shown in Text-figs. 10-17. The pyrenoid *first of all becomes* elongated along the longitudinal axis of the cell (Text-fig. 11) and then the pyreno-crystal divides into two



TEXT-FIGS. 10-17. *Cylindrocapsopsis indica* sp. nov.
Stages showing the division of the pyrenoids and the chloroplast, and their movement in the cell. Note: Nucleus and pyrenoids drawn with the camera lucida; the chloroplasts indicated diagrammatically by radiating lines. All FIGS. × 1000.

(Text-fig. 12). The *pyrenoid then* becomes constricted in the middle (Text-fig. 13) and divides into two daughter-pyrenoids. The two daughter-pyrenoids lie one behind the other as shown in Text-fig. 14. The upper daughter-pyrenoid then moves down so that the two daughter-pyrenoids remain at right angles to the longitudinal axis of the cell and in close contact with the nucleus (Text-fig. 15). After this the upper pyrenoid moves downwards round the nucleus (Text-fig. 16) and finally places itself close to the nucleus on its lower side (Text-fig. 17). As the pyrenoid divides, the chloroplast also divides (Text-figs. 14, 15) and the two daughter-chloroplasts with their respective pyrenoids finally place themselves at either end of the nucleus, as in Text-fig. 17. After this stage is reached the nucleus begins to divide.

During nuclear division in this alga no condensation of the chromosomes is seen, nor is there formed a nuclear spindle. The



TEXT-FIGS. 18-31. *Cylindrocapsopsis indica* sp. nov.
Stages of nuclear division and cell division. All FIGS. × 1125.

nuclear division appears to be amitotic and takes place in the following manner. The resting nucleus is round and has a small, but well defined nucleolus (Text-figs. 18, 22, 30). Just before nuclear division, a slight enlargement of the nucleus is noticeable. At the same time there is an accumulation of the cytoplasm in the median portion of the cell round the nucleus in an equatorial manner as in Text-fig. 24. The nucleus then begins to elongate, and becomes cylindrical, and the equatorial accumulation of cytoplasm becomes more pronounced (Text-fig. 25*b*). The elongated nucleus then develops a slight constriction in the middle, and this constriction gradually increases soon afterwards (Text-fig. 28). Finally the constriction becomes complete and two round daughter-nuclei are formed each with its own nucleolus (Text-figs. 25*a*, 29). When the two daughter-nuclei are fully organised, a small equatorial furrow starts at the periphery of the cell-protoplast at its middle (Text-figs. 19, 20; Pl. II, figs. 5, 6). This furrow extends centripetally inwards until it finally divides the protoplast into two daughter-protoplasts. Each daughter-protoplast has a single nucleus and a stellate chloroplast with a pyrenoid (Text-figs. 23, 26, 27).

As soon as the division of the protoplast is complete, each of the two daughter-protoplasts immediately surrounds itself with a wall of its own inside the old mother-wall (Text-figs. 21, 31). No true septum, i.e., a strip of membrane joined to the middle of the lateral wall of the mother-cell, is formed separating the two daughter-protoplasts. What appears as a septum is only an apparent septum formed by the two adjacent cell-membranes of the two daughter-cells. These two cell-membranes when carefully examined under higher magnifications are seen not connected with the lateral wall of the mother-cell, but are seen clearly to go round the respective daughter-protoplasts.

As the daughter-cells grow longer, the older mother-wall gets distended and could be seen distinctly round the walls of the two-daughter-cells (Text-figs. 1, 2; Pl. II, fig. 12), only, owing to its distended condition, the old mother-wall appears very much thinner. When the two daughter-cells divide in their turn, the grand-daughter-cells, each with its own wall round it, are seen inside the wall of their respective mother-cells, which again are seen inside the old wall of their grandmother-cell (Text-figs. 3, 6; Pl. II, fig. 13). And the same process is repeated in the further generations of cells. If the filaments are stained in dilute aqueous methylene blue, safranin, gentian violet or ruthenium red, the walls of the several generations of cells are very clearly brought

out. If some material of the alga is boiled in strong caustic potash solution and thoroughly washed in water and mounted on a slide, the cell-contents are found completely dissolved, but the walls of the cells are seen quite intact. In such preparations, the walls of the daughter-cells are seen distinctly inside the wall of their mother-cell and quite unconnected with it (Text-fig. 1; Pl. II, figs. 7-9).

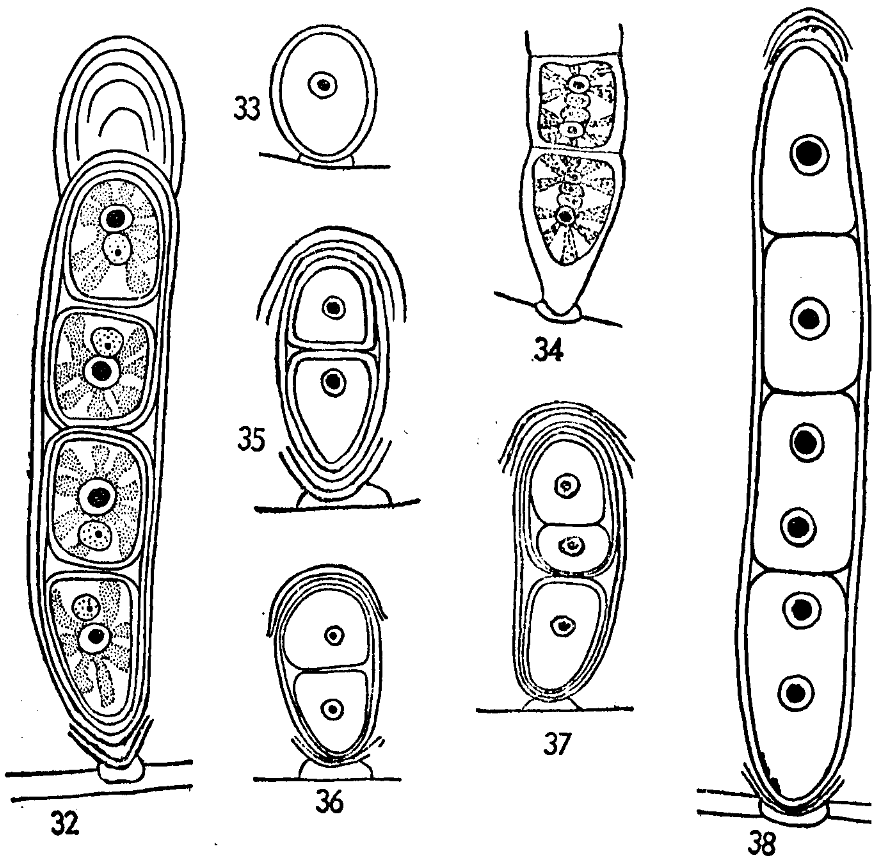
It was mentioned above that the wall of the mother-cell becomes distended and thin as the daughter-cells grow up and elongate. In some cases, the old mother-wall gets ruptured in the middle in a more or less circumscissile manner when it gets distended (Text-figs. 5, 9). In such cases the ruptured old mother-walls appear like H-pieces. After a few generations of cells, the end portions of these ruptured old mother-walls persist at the ends of the cells of the different generations (Text-figs. 4, 8; Pl. I, fig. 10, Pl. II, figs. 1, 13). Such cases show a close resemblance to *Ecballocystopsis,* a member of the Chlorodendraceae which has developed a filamentous habit (Iyengar, 1933). In fact the mode of cell-division and growth of the filament in the present alga is not at all unlike that of *Ecballocystopsis.*

Though in some cases the mother-cell-wall gets ruptured after one or two generations of daughter-cells, what happens more usually is the distended wall of the mother-cell keeps up with the elongation of several generations of cells, before it becomes ruptured in the middle. Such distended and ruptured, very thin mother-walls of several generations of cells lie one over the other and become more or less plastered together, and then their individuality is not easily distinguished. It is these fused distended thin mother-walls of several generations of cells that really form the tubular sheath of the filament of the alga. The composite nature of the tubular sheath of the alga is very clearly seen in old formalin material of the alga. In such material, the tubular sheath appears definitely lamellate with the frayed ends of the ruptured old mother-walls showing very clearly. This is especially seen after staining the material with aqueous safranin, methylene blue, gentian violet or ruthenium red. The end portions of the walls of the several generations of cells are often seen separated as thick H-pieces in old formalin material (Pl. II, figs. 2-4).

During cell-division, the cells usually divide into two daughter-cells of equal size. But very often some of the cells divide into two daughter-cells of unequal size, one very large and the other very small (Text-figs. 3, 6). The significance of such an unequal division is not quite clear. Quite frequently two adjacent cells divide unequally like this, and, when they do so, curiously enough, of the four daughter-cells, the two smaller daughter-cells are invariably side by side, while the two larger daughter-cells are away from each other (Text-figs. 3, 6).

Asexual reproduction

No zoospores were observed by the writer, even though he examined the living material of the alga both from the field and from the laboratory cultures for a long time on several occasions. But germlings of the alga in various stages of development were found growing on the older filaments of the alga and also on filaments of other algae, such as *Oedogonium* and *Pithophora,* in the



TEXT-FIGS. 32-38. *Cylindrocapsopsis indica* sp. nov.
FIGS. 32, 38. Four-celled germlings. FIG. 33. A single-celled germling. FIG. 34. The lowermost two cells of a fairly long attached filament. FIGS. 35, 36. Two celled germlings. FIG. 37. Three celled germlings. FIG. 32, × 1000, FIGS. 33-37, × 730; FIG. 38, × 965.

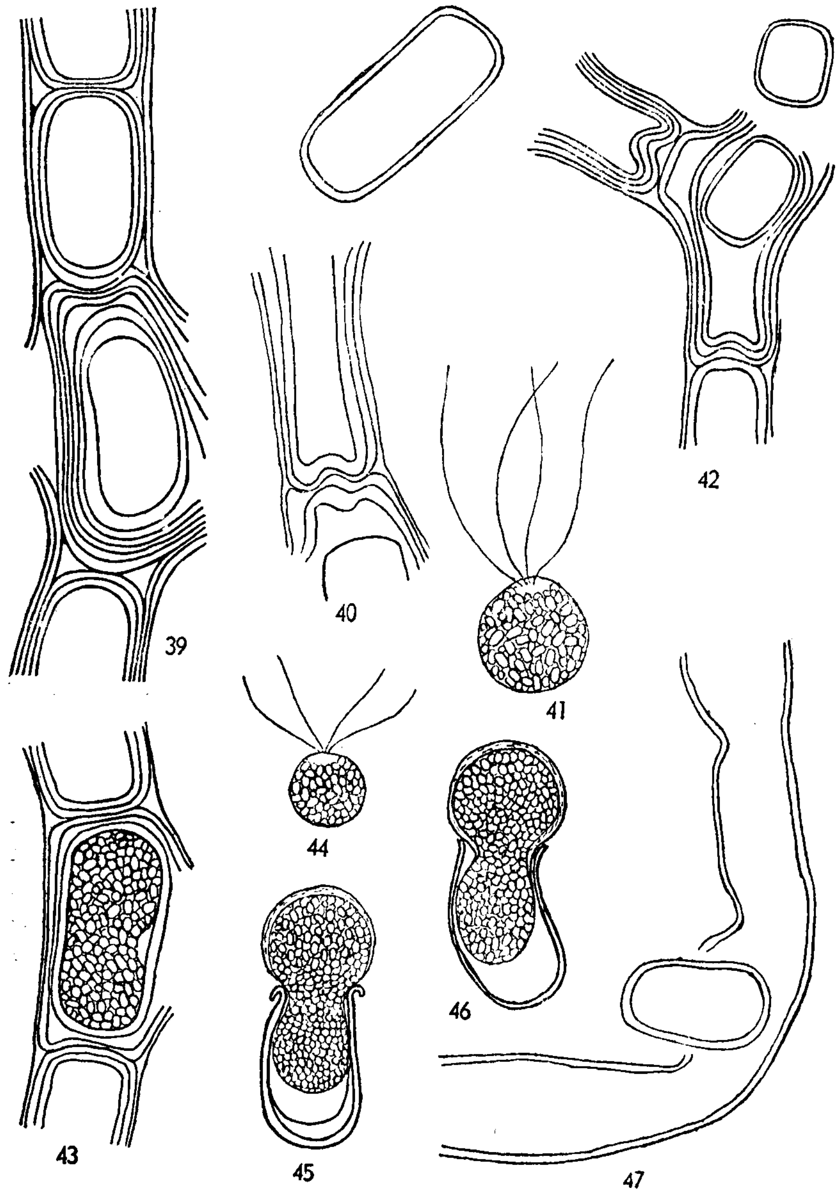
water. The writer evidently missed the time of their formation. The young germling is unicellular and obovate, and is attached to the host filament by a small mucilaginous pad at its base (Text-fig. 33). The germling is covered by a thin but firm wall. As the germling begins to grow and enlarge it secretes one or more new wall-layers below the first formed firm wall-layer. The new wall-layers are slightly thicker and more elastic. The unicellular germling soon grows in length and divides into two cells by a transverse division. Since the first formed wall-layer of the unicellular germling is firm and inelastic, it is unable to cope up with the growth in length of the germling, and so becomes ruptured at its base and remains as a cap at the top of the germling (Text-figs. 35, 36). The cap is seen persisting over the apical cell of even well grown filaments for quite a long time (Text-figs. 25, 27, 32, 38). The germling by further repeated division of its cells grows into a long filament. The young filament remains attached to the host alga for a good while and finally breaks away from it and grows in the water along with the other filaments.

The alga also multiplies vegetatively by the fragmentation of its filaments into shorter pieces.

Sexual reproduction

Sexual reproduction was observed in the alga in the laboratory cultures during two successive years (1938 and 1939). Each year, sexual reproduction commenced only after the alga had lived in a sterile condition for about two months in the cultures. The details of the sexual reproduction are as follows. Some of the cells of the filament form large quadriflagellate motile spores (Text-figs. 41, 44). One motile spore is formed from each cell. The mode of formation of these motile spores in this alga is extremely peculiar and is quite unlike that seen in any other member of the Chlorophyceae, in fact, unlike that seen in any other known alga. The writer has, therefore, taken the liberty of giving it in some detail here below.

The cells which are to form the motile spores first of all become free and escape outside the filament. This escape of the cells from the filament appears like a passive process, but is evidently an active physiological one, being brought about by the gelatinization of the outer cell-wall layers, presumably through the active secretion of some enzymatic substance by the protoplasts of the cells concerned. The portion of

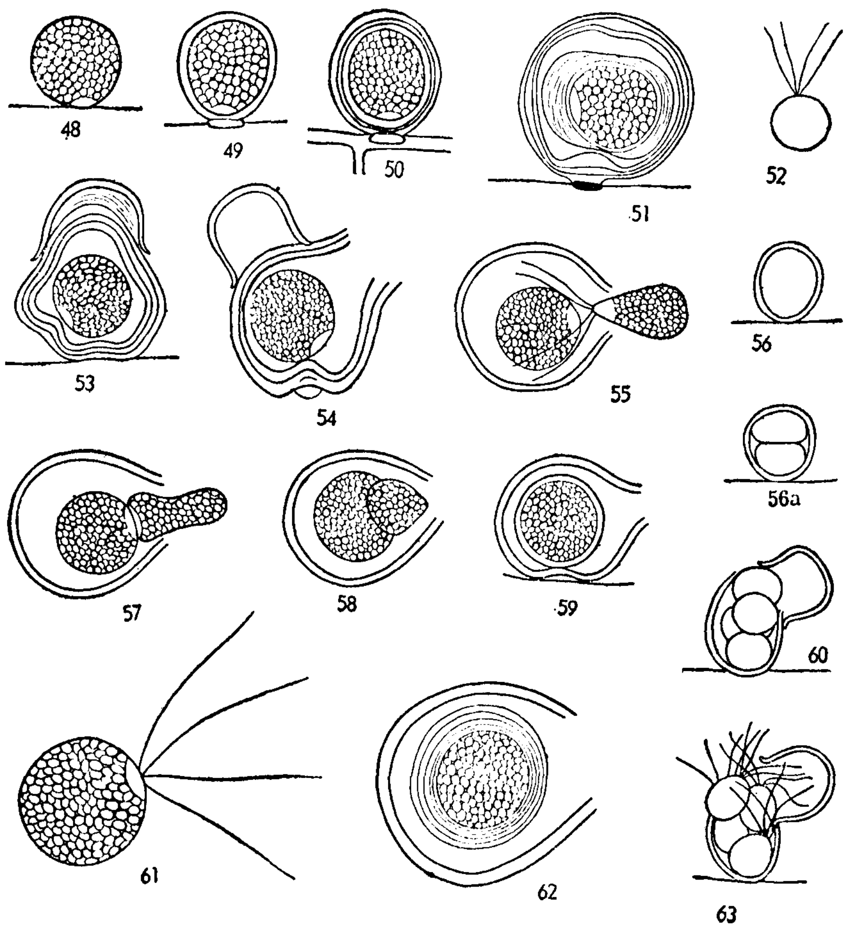


TEXT-FIGS. 39-47. *Cylindrocapsopsis indica* sp. nov.
FIGS. 39, 43. Stages showing the gelatinization of the outer layers of the tubular sheath of the cells before the escape of the whole cell from the filament; FIG. 43 represents an earlier stage, and FIG. 39 a later stage. FIGS. 40, 42. Escape of whole cells, enclosed in their innermost cell-wall layer, from the filament (cell-contents not drawn). FIGS. 41, 44. Gynospores. FIGS 45, 46. The contents of the discharged loose cells escaping outside. FIG. 47. Portion of a filament from which all the cells have escaped out except one cell, which also is just escaping outside. FIGS. 39-40, 43-46, × 750; FIGS. 41, 42, 47, × 550. FIG. 44 × 370.

the tubular sheath of the filament round these cells becomes gelatinized on one side (Text-figs. 39, 43; Pl. II, fig. 11), and at the same time, some of the outermost wall-layers of these cells become rapidly gelatinized with the result that quite a good quantity of mucilage is formed inside the tubular sheath. As more and more mucilage is formed inside the sheath, the cells which form the mucilage are bodily pushed out of the sheath through its wide openings (Text-figs. 40, 42; Pl. II, fig. 10). The cells which are pushed out retain their original shape and are still covered by the innermost layer or layers of their cell-wall. Often good portions of the filament become rapidly emptied of its cells in this way (Text-fig. 47). The gelatinization of the outer layers of the sheath of the filament and the escape of the cells from the filament can be watched clearly under the microscope. The whole process takes place very rapidly and is completed within five to ten minutes. The cells which have been pushed out of the filament very soon form a single quadriflagellate motile spore each in the following manner. First of all the cell-wall at one end of the loose cell, gets gelatinized and then the protoplast escapes outside enclosed in a delicate vesicle (Text-figs. 45, 46). At about the same time, four flagella gradually develop from the protoplast. The flagella soon become active, and the spore begins to move inside the vesicle. Ultimately the vesicle becomes ruptured or gelatinized and disappears, and spore swims away.

The motile spore is large and globose with rich dark-green, granular contents, with a small hyaline portion at the anterior end, and is about 23-28 μ in diameter (Text-figs. 41, 44). The flagella are about one and a half times as long as the body of the motile spore. Owing to the dense contents, no contractile vacuoles could be made out; nor could an eye-spot be made out in spite of very careful examination. It may, however, be mentioned here that in some of the cells which were just escaping from the filament, the protoplast showed a small hyaline portion close to the lateral wall about the middle of the cell (Text-fig. 43), somewhat as is seen in *Oedogonium* during zoospore formation (Hirn, 1900). This very probably represents the anterior flagella-forming region.

The motile spore after swimming for some time finally comes to rest on some filament of the alga or on the filament of other algae in the water, such as *Pithophora, Oedogonium,* etc. It settles down by its anterior end (Text-fig. 48) and soon surrounds itself with a thin, but firm, cell-wall (Text-fig. 49). A small mucilage pad is secreted at the base of the cell to attach it firmly to the substratum (Text-figs. 49, 50). After some time, the protoplast secretes round itself more cell-wall layers inside the first formed wall-layer (Text-fig. 50). These layers, unlike the first formed layer are somewhat thicker and less firm. These latter layers then begin to swell and enlarge. Since the first formed



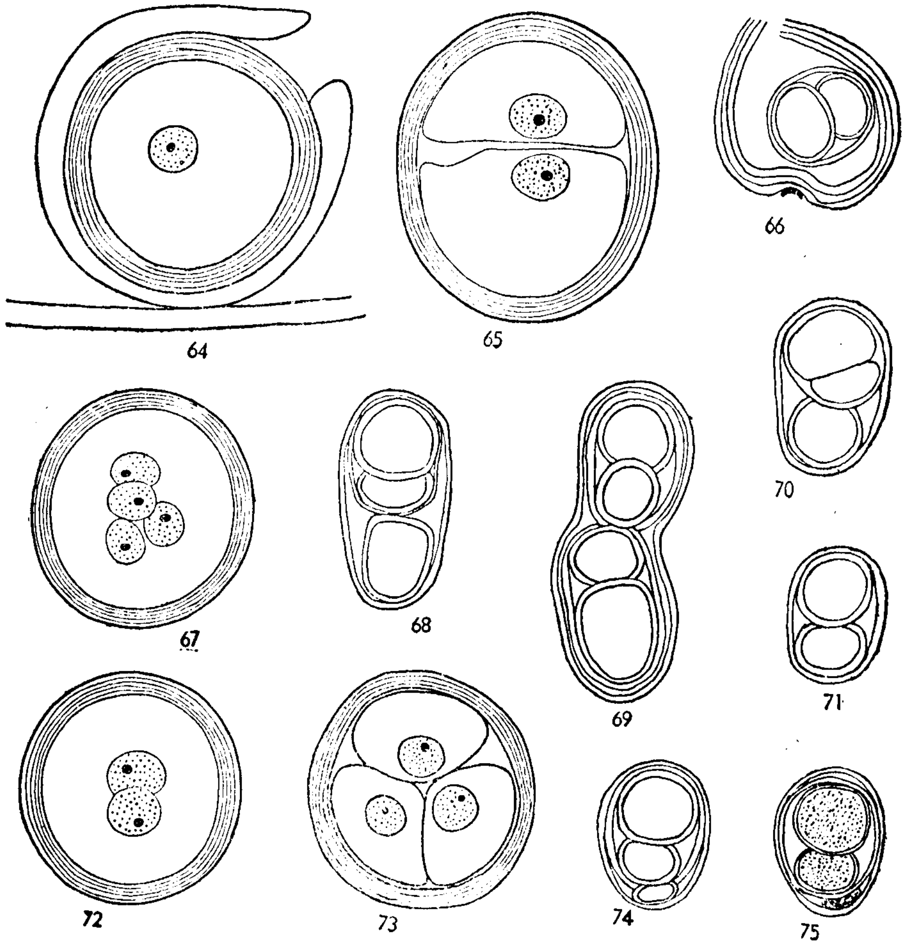
TEXT-FIGS. 48-63. *Cylindrocapsopsis indica* sp. nov

FIG. 48. A large motile spore just come to rest. FIG. 49. A one-celled female plant. FIGS. 50, 51, 53. Stages in the development of the one-celled female plant into a large vesicular oogonium with a loose egg inside. FIG. 54. Oogonium which has formed an opening on one side. FIGS. 55, 57, 58. Stages in the fertilization of the egg. FIG. 59. A fertilized egg which had just surrounded itself with a membrane round it. FIG. 61. A large motile spore. FIG. 62. A fully developed oospore with a thick wall made up of several layers inside the oogonial wall. FIG. 52. A small motile spore. FIG. 56. A single celled male plant which becomes an antheridium. FIGS. 56a, 53, 60, 63. Stages in the formation of antherozoids. FIGS. 61, 62, × 740; the rest × 535.

layer is firm and inelastic, it is unable to keep pace with the enlarging inner layers, and so is ruptured near the base of the cell, and remains as a loose cap at the top (Text-figs. 53, 54; Pl. I, fig. 3). The inner layers swell and enlarge still further, and finally expand into a large balloon-like envelope, while the protoplast lies loose inside as a large green round body (Text-fig. 53; Pl. I, fig. 3). The balloon-like envelope is very firmly attached to the substratum by the mucilaginous pad originally secreted by the motile spore (Text-figs. 51, 54). The large balloon-like cell is the oogonium of the alga and the green round protoplast inside is the oosphere or egg. A very small portion of this round green protoplast is slightly hyaline at one side. This hyaline portion is evidently the hyaline anterior portion of the old swarmspore and probably represents the receptive spot. After some time, a beak-like opening is formed on one side of the balloon-like oogonial wall (Text- fig. 54; Pl. I, fig. 4) and the egg is now ready for fertilization.

From some smaller cells of the filament, smaller quadriflagellate motile spores are formed in the same way as the larger quadriflagellate spores. These smaller motile spores are quite similar to the motile spores formed by the larger cells in all respects (Text-fig. 52).

These smaller motile spores swim for some time and finally come to rest by their anterior end on some filaments of the alga or on filaments of other algae in the water. The motile spore soon surrounds itself with a firm wall and becomes an antheridium (Text-fig. 56). Its protoplast then divides into two (Text-fig. 56*a*) or four daughter-protoplasts (Text-fig. 60), each of which develops four flagella and becomes an antherozoid. The wall of the mother-cell then becomes ruptured and the antherozoids escape outside (Text-fig. 61). The antherozoid swims away seeking an oogonium, and, after reaching it, swarms round it for a long time, and finally enters it through the oogonial opening and fuses with the egg. It may be mentioned here that the antherozoid undergoes gradually a change of its bodily shape. When it is first formed, it is ovate or elliptic. It then becomes more elongate-elliptic. When it enters the narrow opening of the oogonium, it becomes pear-shaped, its anterior end becoming very much narrowed and its posterior end broadly rounded (Text-fig. 55). When, after entering the opening of the oogonium, it comes into contact with the egg, its anterior end becomes flattened against the egg and it then appears somewhat cylindrical (Text-fig. 57). When it closely applies itself to the egg, its anterior end becomes very much broadened while its posterior end becomes somewhat conical (Text-fig. 58; Pl. I, fig. 5). It then pushes itself further against the egg when its protoplast becomes suddenly merged in that of the egg. When the two protoplasts fuse, there is a slight jelly-like vibration



TEXT-FIGS. 64-75. *Cylindrocapsopsis indica* sp. nov.
FIG. 64. A ripe zygospore with a thick lamellated wall inside an oogonium. FIGS. 65, 73. Protoplasts of zygospores divided into two and four daughter-protoplasts respectively. FIG. 66. An oogonium with a zygospore which had germinated and formed two daughter cells inside its old wall. FIGS. 67, 72. Zygospores whose nucleus had divided into four and two daughter-nuclei, respectively. FIGS. 68, 70, 74, 75. Three cells formed in a row through the germination of a zygospore. Note in FIG. 75 the degeneration of one of the cells of the first generation. FIG. 69. Four cells formed in a row from a zygospore. FIG. 71. Two cells formed from a zygospore. FIGS. 64, 65, 67, 72, 73 × 1400; the rest × 470.

of the fused protoplast for a second or so. The fertilized egg is spherical in shape. The actual fusion of the two protoplasts is very rapid and takes hardly a few seconds.

Sometimes after fertilization, the oospore covers itself with a wall. The oospore wall becomes very thick through the secretion of a number of wall-layers by the protoplast of the oospore (Text-fig. 62). These layers are quite firm and not gelatinous in consistency. The contents of the oospore after some days become bright red in colour.

The laboratory cultures of the alga were kept for a long time after the formation of the oospores. The oospores remained quite healthy throughout. In some of these oospores the nucleus had divided into two daughter-nuclei (Text-fig. 72) and in others the protoplast had divided into two daughter-protoplasts each with a single nucleus (Text-fig. 65). In some other oospores, the nucleus had divided into four daughter-nuclei (Text-fig. 67) and in some others again the protoplast had divided tetrahedrally into four daughter-protoplasts each with a single nucleus (Text-fig. 73). The further development of these daughter-protoplasts could not be followed. The division of the oospore nucleus into four nuclei suggests meiotic division, but no details of these nuclear divisions could be observed. But in a number of other cases, the oospores were observed to divide into two daughter-cells (Text-figs. 66, 71; Pl. I, figs. 6, 10), one or both of which divided again, so that there were three or four cells formed in a row (Text-figs. 68, 69, 70, 74, 75). Each of these cells possessed a thick wall and looked like resting cells. These cells were kept for a long time in the laboratory cultures, but they did not develop beyond these stages. The exact significance of these cells is not clear. Whether they represent the actual germination of the oospore or are merely cases of parthenogenetic development of unfertilized egg-cells could not be stated with certainty. Further careful cultural and cytological work is needed to elucidate these points.

General Discussion

The life-history of the present alga is very unique. From some large cells of the filament, large quadriflagellate motile spores are formed. These motile spores form one-celled female plants. Each of these one-celled female plants becomes bodily converted into an oogonium with a single egg inside. From some smaller cells of the filament, smaller quadriflagellate motile spores are formed. These motile spores form one-celled male plants. Each of these male plants becomes bodily converted into an antheridium from which are formed later on two or four quadriflagellate antherozoids. The antherozoids seek the oogonia and fertilize the eggs inside.

The one-celled male plant of the alga may, in a way, be compared to the dwarf male plants of the Oedogoniales, in a number of species of which the dwarf males are unicellular. But the one-celled female plants are without any parallel in any other member of the Chlorophyceae. The motile spores which give rise to the male and the female plants cannot be considered as zoospores, since they do not reproduce the main plant in an asexual manner like all zoospores. They will have to be considered as special motile spores for the formation of one-celled sexual plants. The motile spore which forms the one-celled male plant may be called, following the terminology used for the Oedogoniales, an *androspore*. A new term, *gynospore*, may be created to designate the motile spore which forms the one-celled female plant.

Again, the mode of formation of these motile spores (androspores and gynospores) is very interesting. The cells which are to form these motile spores first of all escape from the filament with their cell-walls more or less quite intact, and then the contents of these loose cells escape outside as motile spores. Such an escape of walled-cells bodily from the thallus as a preliminary to the formation of motile spores is a rather unique feature and is quite unknown in any other member of the Chlorophyceae.

Another important feature of the alga is the amitotic division of its nuclei. Amitosis is considered by some authors as a degenerative or pathological phenomenon, and generally as occurring under abnormal or unfavourable conditions, such as are found in old cultures. But quite a number of authors state that amitosis could be normal and could be seen in cells which are quite healthy and show no signs of degeneration (Sharp, 1934, pp. 183-4). In the present alga, the amitotic division was found both in the material in the laboratory cultures and in the material freshly collected from the pond. The alga was in a very healthy condition and was growing actively in both the places. Amitotis is a very rare phenomenon in plants. Apart from the Characeae which is well-known for the amitotic division of the nuclei of its internodal cells, only a few cases of amitosis have been recorded so far in the Chlorophyceae, for instance, in *Valonia* by Fairchild (1894) and in *Spirogyra mirabilis* by Peterschilka (1923). The occurrence of amitosis in the present alga adds one more instance of amitosis among the Chlorophyceae. But present day opinion is rather suspicious of all reported cases of amitotic division in algae, except in the internodal cells of *Chara*. The author, therefore, proposes to reinvestigate the nuclear division in the present alga using the Feulgen technique at the earliest opportunity, when suitable fresh material of the alga becomes available again.

The cell-division in the present alga is very interesting. In unicellular algae during cell-division the protoplast divides into two or more parts and the daughter-protoplasts cover themselves with new walls of their own inside the wall of the mother-cell. The daughter-cells after a shorter or longer period become free through the rupture or gelatinization of the mother-wall (West & Fritsch, 1927, p. 28; Printz, 1927, p. 6; Fritsch, 1929, p. 110; 1935, p. 17). In filamentous and other higher algae, cell-division is generally considered to take place in quite a different manner from that of the unicellular algae. The cell-division in these higher algae is considered to take place by a type of division known as *vegetative division* in which the parent-cell divides without rupture or gelatinization of its wall, the two daughter-protoplasts that are formed being merely separated by the development of a strip of membrane (septum) which is joined laterally to the membrane of the parent-cell. The two cells that are formed adopt the membrane of the parent-cell except for the intervening septum which is new and common to both (West & Fritsch, 1927, pp. 28, 142; Fritsch, 1929, p. 110; 1935, p. 17; Printz, 1927, p. 7). But according to Pascher (1924, p. 152), cell-divison in filamentous algae also takes place in the same manner as in unicellular algae and not by the formation of an intervening septum which is connected laterally to the parent-membrane. According to him, the protoplast of the cell divides into two, and the two daughter-protoplasts surround themselves with new walls of their own inside the parent-membrane, which consequently becomes suitably distended, so that the filament is composed of a linear series of such cells. The mode of cell-division is, in principle, in no way different from that seen in the unicellular algae except for the fact that only two daughter-cells are formed in each cell, and there is no marked contraction of the protoplast, so that the daughter-cells completely fill out the parent membrane. Cell-division in filamentous algae is nothing more than the formation of two autospores inside a cell. Printz (1927, p. 7) does not agree with Pascher's view. Vischer (1933) supported Pascher's view by giving a number of examples from the Chaetophorales. But Fritsch (1935, p. 18), while not completely rejecting Pascher's view, states that there is some difficulty in fully accepting Pascher's interpretation. He says, "While this interpretation appears to apply to a number of simple filamentous types (some Chrysophyceae; *Dinothrix,* fig. 237 A), it is difficult to harmonise it with the many accounts existing in the literature (cf. e.g. (173)) of the gradual ingrowth of a dividing septum during cell-division in green filamentous algae (figs. 69 D, E, I; 99 A). The data at present published by Pascher, as well as those afforded by Vischer (192), do not include a detailed consideration of such cases and one must await a fuller account before estimating their true value (cf. also (155) p. 6). Each cell of a filament, of course, develops its own appropriate thickening-layers subsequent to cell-division and in later stages the primary septum is often indistinguishable. The question to be settled is whether there is such a primary septum or not, and that can only be determined by a careful study of cell-division."

In the present alga the author made a very careful and detailed study of the cell-division. He found that the cell-division in the alga agreed fully in all details with Pascher's conception of cell-division in filamentous algae. During cell-division in the present alga, the protoplast divides into two and the two daughter-protoplasts then surround themselves with new walls of their own inside the parent-membrane. *No strip of membrane which is joined to the membrane of the parent-cell is formed at any stage in the present alga, nor could there be seen any indication of the formation of a primary septum connected laterally to the parent-membrane.* Whether Pascher's interpretation of cell-division in filamentous algae is true of all filamentous algae or not, it is certainly true in all details so far as the present alga is concerned.

Coming to the systematic position of the present alga, the alga in its vegetative condition shows a close resemblance to *Cylindrocapsa* in having cells with stratified walls, in having lamellated tubular sheath round the cells of the filament, and also in the frequent arrangement of the cells in some parts of the filament in more than one series through the oblique or longitudinal division of its cells. But it differs from *Cylindrocapsa* in its chloroplasts being stellate and not parietal as in *Cylindrocapsa.* The really main difference between the present alga and *Cylindrocapsa* is in its life-history and mode of sexual reproduction. The formation of quadriflagellate motile spores of two sizes, the larger forming one-celled female plants and the smaller forming one-celled male plants, the conversion bodily of these one-celled male and one-celled female plants

into antheridia and oogonia, respectively, and the fertilization of the oogonia outside the filament, are all features which are not found in *Cylindrocapsa.* Again, the motile spores in the present alga (androspores, gynospores and antherozoids) are all quadriflagellate, whereas, in *Cylindrocapsa*, the motile spores (zoospores and antherozoids) are biflagellate. So, except for a certain amount of superficial resemblance in the vegetative thallus, the present alga differs from *Cylindrocapsa* in all other respects.

The author had the privilege of discussing with the late Professor F. E. Fritsch, when the latter visited India in 1938, about the systematic position of this alga. Professor Fritsch, after considering all the different features of the alga, expressed the opinion that the alga could not be considered as a *Cylindrocapsa*, but might be placed in a new genus inside the Cylindrocapsaceae. The author takes this opportunity to express his indebtedness to Professor Fritsch for his great kindness in giving his opinion on the alga. The author agrees entirely with this opinion and accordingly places the alga in a new genus which he calls *Cylindrocapsopsis.* The genus is placed next to *Cylindrocapsa* inside the Cylindrocapsaceae. The alga itself may be called *Cylindrocapsopsis indica* sp. nov.[2]

Cylindrocapsopsis gen. nov.

Thallus, filamentous and unbranched, showing a close resemblance to *Cylindrocapsa;* attached when young, later free. Filaments composed of cells arranged in a single series; in older filaments, in places, cells arranged in more than one series through oblique or longitudinal divisions. Cells having a single nucleus and a stellate chloroplast with a single pyrenoid. Cell-membrane thick and stratified. Asexual reproduction very probably by zoospores. Sexual reproduction oogamous. Oogonia and antheridia unicellular and formed singly outside the plant by one-celled dwarf female and one-celled dwarf male plants, respectively, which again are formed by large quadriflagellate motile spores (gynospores) and smaller quadriflagellate motile spores (androspores), respectively. The large motile spores (gynospores) and

2. Randhawa (1941, p. 292) states that the present alga is the same as *Cylindrocapsa scytonemoides,* a new species described by him from Fyzabad (Randhawa, 1939, p. 275). But, unfortunately, *C. scytonemoides* is a very incompletely known species, and practically nothing is known regarding the structure of its chloroplast or the nature of its swarm-spores or of its sexual reproduction. Until these are clearly known, the question of the identity of these two algae cannot be profitably discussed.

small motile spores (androspores) formed singly from the cells of the filamentous plant. Two or four quadriflagellate antherozoids formed in each antheridium, and a single egg in the oogonium.

Cylindrocapsopsis indica sp. nov.

Characters same as for the genus. Cells elliptic when young and cylindric oblong to quadrate with rounded corners when older. Cells 22 to 28 μ broad and three fourths to two and a half times as long as broad. Antheridium 17 to 19 μ broad and 20-22 μ long. Oogonium 40-46 μ broad and 40-44 μ long. Oospores round, with thick stratified wall, and 23-29 μ in diam.

Hab. In a pond in Madras, growing on filaments of *Pithophora, Oedogonium,* etc., in the water.

Cylindrocapsopsis gen. nov.

Thallus filamentosus atque ramis carens, proxime accedens ad *Cylindrocapsam,* primo fixus, tandem liber. Filamenta constant ex cellulis dispositis in serium unicam; vetustiora filamenta aliquotiens monstrant cellulas dispositas in seriem multiplicem ob divisiones obliquas et longitudinales. Cellulae ornatae unico nucleo atque chloroplasto stellato, pyrenoideo unico. Cellulae membrana crassa atque stratificata. Reproductio asexualis probabilissime per zoosporas. Reproductio sexualis oogama. Oogonia atque antheridia unicellulata, atque evoluta singula extra plantam per unicellulatum minutam femineam plantam atque unicellulatam minutam masculam plantam respective, quae vicissim producuntur a sporis amplis quadriflagellatis sporis (androsporis) respective. Sporae amplae motiles (gynosporae) atque minutae motiles sporae (androsporae) efformatae singulae ex cellulis plantae filamentosae. In singulis antheridiis bina vel quaterna antherozoidea quadriflagellata efformantur, in singulis oogoniis vero ovulum unum efformatur.

Cylindrocapsopsis indica sp. nov.

Characteres ut in genere. Cellulae juniores ellipticae, seniores vero cylindrico-oblongae vel-quadratae angulis rotundatis. Cellulae 22-28 μ latae, et ¾-2·½ plo. longiores quam latae. Antheridia 17-19 μ lata, 20-22 μ longa; oogonia 40-46 μ lata, et 40-44 μ longa. Oosporae rotundae, ornatae parietibus crassis, levibus, stratificatis, dimetientes 23-29 μ in diam.

Habitat in stagnis in Madras, atque crescit affixa filamentis Pithophorae, Oedogonii, etc., in aqua.

Summary

The alga in its vegetative condition shows a close resemblance to *Cylindrocapsa,* except for its chloroplast which is stellate, unlike in *Cylindrocapsa* where it is parietal. It differs from *Cylindrocapsa* in its life-history and its mode of sexual reproduction. In this alga, quadriflagellate motile spores of two different sizes are formed from certain cells of its filament. The larger motile spore forms a single-celled dwarf female plant, which becomes bodily converted into an oogonium with a single egg inside. The smaller motile spore forms a single-celled dwarf male plant, which becomes bodily converted into an antheridium from which are formed later on two or four quadriflagellate antherozoids. The antherozoid seeks the oogonium and fertilizes the egg inside. On account of its unique life-history and its mode of sexual reproduction, it is placed in a new genus *Cylindrocapsopsis* and the alga itself is called *Cylindrocapsopsis indica* sp. nov. The new genus is placed in the Cylindrocapsaceae next to *Cylindrocapsa.*

During cell-division the two daughter protoplasts that are formed cover themselves with walls of their own inside the wall of the mother-cell. No septum is formed which is laterally connected to the parent-membrane. The mode of cell-division in this filamentous alga is very similar to that of the unicellular algae, and conforms to Pascher's interpretation of cell-division in filamentous algae. The nuclear division in the alga appears to be amitotic.

The author's sincere thanks are due to Rev. Father H. Santapau for rendering into Latin the diagnoses of the new genus and the new species.

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Explanation of Plates

PLATE I

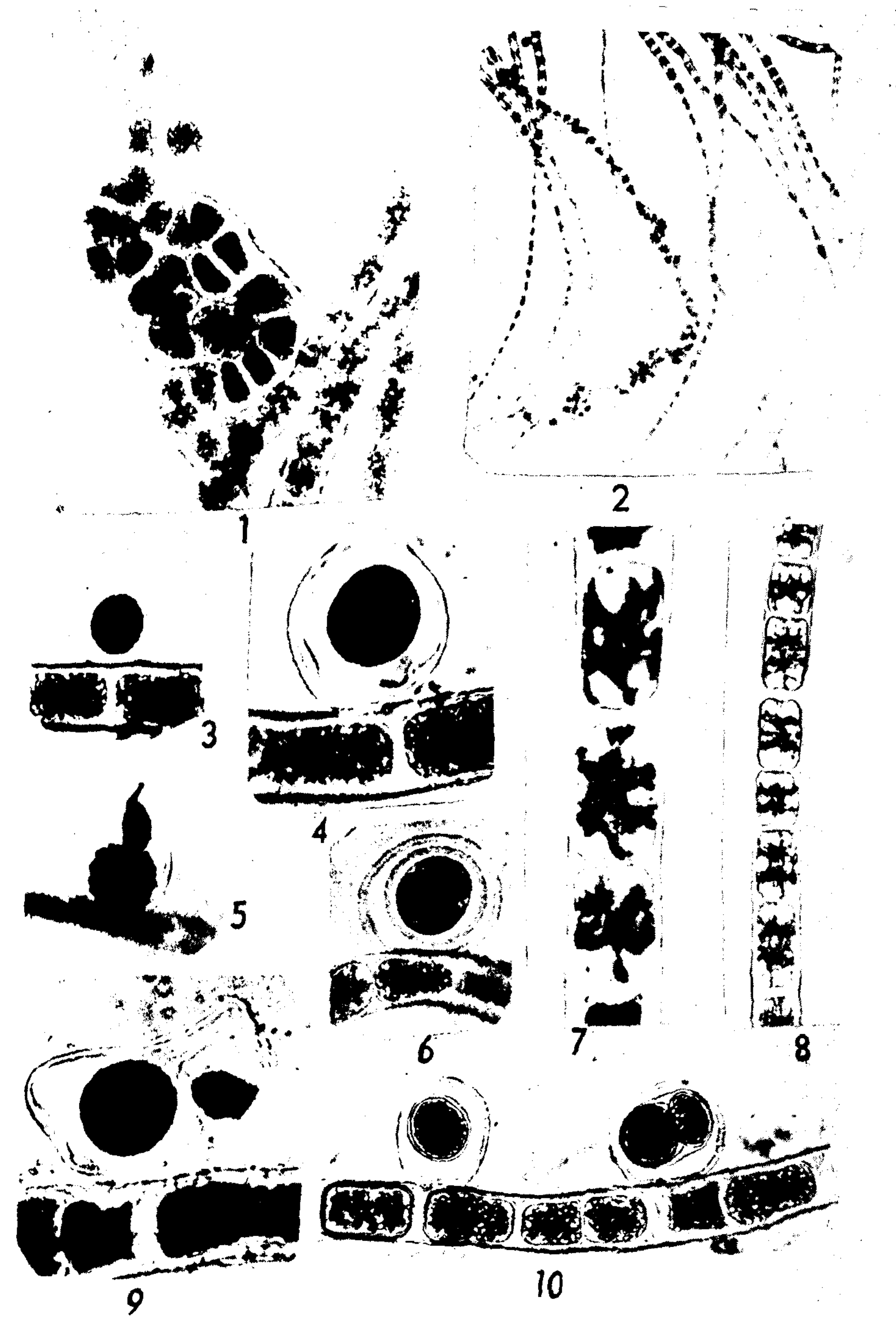
Cylindrocapsopsis indica sp. nov.

FIG. 1. Portion of a filament with pseudoparenchymatous growth. FIG. 2. A number of filaments of which one shows pseudoparenchymatous growth. FIG. 3. An oogonium with a single loose egg inside the enlarged oogonial wall. FIG. 4. An oogonium which has formed an opening in its wall. FIGS. 5, 9. Fertilization of the egg by the antherozoid. FIG. 6. Contents of the zygospore dividing into two. FIGS. 7, 8. Portions of the filament showing the cells arranged in a row inside a tubular sheath. Note the stellate structure of the chloroplast. FIG. 10. Filament of the alga with two oogonia settled on it; in one of which the oospore had divided into two daughter-cells inside its wall.

PLATE II

Cylindrocapsopsis indica sp. nov.

FIG. 1. Portion of a filament showing an H-shaped thickening formed by the remnants of the mother-walls of the earlier generations. FIGS. 2-4. Portion of filament from which the H-pieces have become loose. FIGS. 5-6. Cells showing nuclear division and division of the protoplasts by furrowing. FIGS. 7, 8, 9. Cells of filaments from which the contents have been dissolved out by boiling in caustic potash. FIGS. 10-11. Stages in the escape of cells from the filament through the gelatinization of the tubular sheath of the filament. FIG. 12. A four celled germling growing on a filamentous alga. FIG. 13. Portion of a filament in which the cells of the first and second generations are enclosed in the mother-walls of the respective generations.



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Metamorphic Geology: Reflections on its Past, Present and Future

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The centenary of an institution devoted to all branches of sound learning may fittingly be made the occasion for taking stock of the position reached in the special disciplines. It may be worth while to pause and consider the present position of a science, for example, and to remember the painful and halting steps by which that position has been attained and to suggest the paths along which future progress may be made.

Such periodical assessments are particularly appropriate in the observational sciences where facts, or what pass as facts, accumulate with astounding speed. It must be remembered, however, that these accumulations can often be sorted out, interpreted or correlated only by personal predilection—but, nevertheless, such operations have their value. These conditions apply with special force to that branch of geology concerned with the metamorphic and granitic rocks—with the plutonic rocks, as I call them. In such studies, the personal factor is of profound importance since what has to be interpreted are field-facts and these, derived as they are from disconnected, partial and imperfect observations, constitute a very special class of facts indeed. In this essay, therefore, there must of necessity be a personal flavour—or bias, if you prefer it, about the discussion, but this flavour (or bias) is controlled by nearly half-a-century's fieldwork on the plutonic rocks and may accordingly be condoned.

I propose to deal with the past, present and future of metamorphic geology. Geology is the study of earth-history as revealed in the rocks making the crust—its essential aspect is the historical. I, therefore, have to survey the past, present and future of the study of the metamorphic rocks as historical records and not primarily as chemical, mineralogical or petrographical objects.

What is the past, or the present, or the future of a living science? For my purpose, I arbitrarily define the past as the time before the First World War; I shall be especially concerned with what was put before students when I was one. The present lasts from the First World War to now; as a personal division it is my active period as a metamorphic geologist and is, I trust, not yet quite ended. The future is the active period of the potential metamorphic geologists now students. In what I have to say, I must select ruthlessly from the immense amount of available material and can mention only a few of the great names or the great ideas or the great pieces of work that embellish this branch of earth-history.

The Past

Half-a-century ago, the student of metamorphic geology found the subject simple and confined compared with the complexities and extensions that confront his successor of today. The main divisions had been established. There was a tendency, natural in view of the state of knowledge of the time, to oversimplify metamorphic processes and to explain what we now recognise as complex and diverse operations by a few distinct and separate mechanisms. In the orthodox view, there were two kinds of metamorphism, the one dynamic, the other thermal or contact. Dynamic metamorphism, the transformation of rocks through pressure and movement, had been developed from the early proposals of Lossen (1875) and Lehmann (1884) arising from their studies of German crystalline schists. Another classic of this time that we had before us was Teall's (1885) illustration of dynamic metamorphism by the transformation of diabase into hornblende-schist in the celebrated Scourie dyke in the North-west Highlands of Scotland. In the second kind of metamorphism, the thermal or contact, the modification of the rocks was due to their heating-up by invading igneous magma. The early study by Rosenbusch (1877) of Germany of the aureole of transformation around certain small granites in the Vosges had set the pattern for this class of metamorphic processes.

Rosenbusch, like most investigators of thermal metamorphism, held that no transfer of material had taken place across the contact of the magma with the invaded rocks, and this conclusion was applied to all contacts. But there was opposition from the French School of Michel-Lévy (1893-4), Lacroix (1898-9, 1899-1900) and others who had shown that at *their* granite contacts great transfer took place and that the processes of felspathisation and granitisation were widespread and were, indeed, essential parts of the mechanism

of granite emplacement. The ubiquitous gneisses, accordingly, might not all have been formed by the operations of dynamic metamorphism. The discerning geologist could have realised that metamorphic operations might be more diverse than the masters thought.

Early in this century, Sederholm (1907) of Finland had described the production of mixed rocks, the *migmatites,* by the admixture in various fashions and to varying degrees of granitic magma and country-rock. He considered that granitic magma could be made by ultrametamorphic processes, or anatexis, in the deeper levels of the crust. Adams and Barlow (1910) of Canada in their study of the Haliburton-Bancroft area of Ontario had proposed the formation of granitic magma by refusion. Another classic dealing with the migmatites was Fenner's (1914) interpretation of certain New Jersey gneisses as of mixed origin. In Scotland, Horne and Greenly (1896) had described the intimate penetration of country-rock by granitic material with an associated increase in metamorphic grade. Termier (1912) had introduced the notion of the 'oil-spot' mechanism in regional, widespread, metamorphism and in granitisation—fluids had spread unequally through a pile of strata just as oil does through a pile of cloths. Evidence of transfer and admixture was thus forthcoming from many countries, though Rosenbusch's ideas were dominant in academic circles. Nevertheless, if the student of that time was prepared to take a little trouble, he could indulge in as many heresies as can his successor of today.

In dealing with a broad spread of metamorphic rocks associated with what we would now call migmatites, Barrow (1892, 1912) in the South-east Highlands of Scotland had mapped out zones of progressive metamorphism marked by the appearance of certain index minerals in pelitic rocks, these minerals being, from low grade to high, chlorite, biotite, garnet, staurolite, kyanite and sillimanite. Barrow interpreted these metamorphic zones as something like a gigantic aureole of thermal metamorphism about a core of diffuse (migmatitic) granite. Another style of zoning had been worked out in a fundamental paper by Becke (1913) of Vienna. Becke showed that the mineral-associations and textures of metamorphic rocks depended on the pressure-temperature conditions of their formation and, on this principle, established the so-called depth-zones. These have since been elaborated by Grubenmann and Niggli (1924) into the highest or epizone controlled by low temperature and strong stress, the mesozone by moderate temperature and stress, and the deep katazone by high temperature and low stress.

In the various fields of metamorphic geology sketched out in the foregoing, notable contributions were available from many countries. The student of my day could enlarge his knowledge of thermal metamorphism by study of Goldschmidt's (1911) magnificent account of contact metamorphism in the Oslo district of Norway, or of dynamic metamorphism by Niggli's (1912) description of the crystalline schists of the Gotthard massif in the Alps. A host of American workers had dealt with the phenomena of transfer shown at many of their limestone-granodiorite contacts. These samples of these contributions could be extended very greatly but, taking it by and large as the saying is, the student of that period found metamorphic geology reasonably simple. We had contact metamorphism (without transfer) and dynamic metamorphism as accepted and official, metamorphic zones and depth-zones were established notions, migmatisation was admitted but was to be connected with granitic magma, anatexis was considered rather an advanced idea whilst granitisation was scarcely to be mentioned in polite geological circles. Whatever modifications the present may have produced in these past ideas, the classic papers mentioned above, and many another not mentioned, may still be read with great profit. In them will be found the basis for many of the newest interpretations of metamorphic phenomena.

The Present

Developments in metamorphic geology since the First World War have been immense and varied though, as I have said, they were in many cases further growths of ideas already in existence. I propose to survey what I consider to be the major advances and to comment upon them where I find it appropriate to do so.

We may begin with Barrow's fundamental notion of *metamorphic zones.* In my opinion, Barrow's original Scottish zones have been applied correctly to the rocks of a few areas, but in general they appear not to be for export from their native home. For example, in Dutchess County, New York, they are found to be telescoped, as shown by the work of Balk and Barth (1936). Again, in the diverse metamorphic rocks encountered in Donegal, Ireland, none of Barrow's indexes are valid; garnet, staurolite, biotite, sillimanite and andalusite, for example, all occurring in the same rock. The reason for this is clear—the different minerals

record different episodes in the history of the metamorphic rock. As I emphasize later, time is just as essential a dimension in metamorphic geology as in any other branch of the science. Metamorphic zones can only be properly assessed in relation to the geological history of the associated rocks and dependence on a particular mineral is a hazardous proceeding. This is especially the case in dealing with rocks of different bulk-compositions, as the index minerals appear at different times in different rocks.

The danger of depending upon some key mineral to give the answer is exemplified to my mind in the use of the so-called *stress and anti-stress minerals* of Harker (1932). Since we now know that all the alleged stress minerals can occur in an environment in which no stress can have operated, and anti-stress minerals in a stress environment, history read by such aids is often wrong. Once again we find that the total geological history recorded in all components and all structures and textures is what has to be elucidated.

One of the most fertile of the modern developments in metamorphic geology has been the group of ideas clustered around the *metamorphic facies* principle of Eskola (1922). This principle has much in common with the extension by Grubenmann and Niggli (1924) of the Becke depth-zones. In the metamorphic rocks that have reached equilibrium, characteristic mineral assemblages in an isochemical series are controlled by the pressure: temperature conditions. For example, in Eskola's pioneer Karelian work (1925), he showed that green-schists, epidote-amphibolites and amphibolites formed an isochemical series developed from diabases by metamorphism with increasing temperature. As has been noted, the Grubenmann-Niggli zones are allied to metamorphic facies, as are also related developments by Roques (1941) and others. Properly applied, the facies principle and depth-zones are of great value in metamorphic geology—but they are not of infinite application and, in my opinion, care is needed. Again the time element in metamorphism must receive its due emphasis, and non-equilibrium assemblages may be of as great a significance as any others.

It is to the metamorphic rocks that the modern advances in *petrofabrics* are especially applicable. This branch of petrographical investigation is associated with the name of Sander (1930) of Innsbruck. Most metamorphic rocks show a preferred orientation of their constitutent minerals, either of form or of crystal lattice. This fabric expresses the symmetry of the flow-movement to which the rocks have been subjected. A vast amount of laborious detailed observation is available, but its interpretation is often a matter for discussion. It appears to me that petrofabric studies may often be a valuable ancillary tool in the unravelling of metamorphic history, but they are not the main tool—this is the geological relationships determinable in the field. The proper sequence is, I feel, to use the geological history to interpret the fabric of a metamorphic rock, rather than the other way round.

The opinion just expressed applies with equal force to the interpretation of those structures of the metamorphic rocks that are grouped under the heading *lineation.* These arise by the linear orientation of crystals or crystal-aggregates, of fold or crumpling axes, of the intersection of planes of bedding, schistosity, cleavage, etc. and by other means, and have had the special attention of E. Cloos (1946) and G. Wilson (1946). Lineations in themselves, it appears to me, are rarely capable of supplying the correct interpretation of the geological history of an area; but when the geological history has been worked out from the totality of the phenomena, then the lineations can be correctly interpreted. The lineations mapped in an area, as for example parts of Donegal, Ireland, may as a whole give an appearance of a completely random arrangement, but this arrangement becomes orderly when each episode in the history of the area is found to be marked by the formation of a lineation with a special trend—once again, timing clearly becomes essential in the study of the metamorphic rocks. We have recently found in Donegal that a truly magnificent lineation developed over large expanses is not connected with tectonic movements of the normal kind but with the emplacement of a viscous granite body—the geological history of the region permits the lineation to be correctly interpreted.

Lineations are only one class of *microstructures* that are nowadays very much the concern of the metamorphic geologist. Small structures of all kinds—microfolds, crinkles, cleavages, dragfolds and the like—must all be mapped. Especially important here is the relative dating of the various structures observed, as this makes possible the formulation of the structural history of the area. Such a history can usually be correlated with the metamorphic history and a detailed geological history established. Thus, in parts of the Moine Series of the Northern Highlands of Scotland, Ramsay (not yet published) has related the small-scale

structures to two episodes of large-scale folding. Timing, as always, is an essential in earth-history, as in any other history.

Between the Wars, the notion of *metamorphic differentiation* had the attention of Eskola (1932), Read (1933, 1934B) and others. Material, especially in the juicy setting of the migmatitic complexes, moves around and is regrouped to provide profoundly different arrangements from the original ones. As an example, I may cite the formation of quartz-chlorite veins in chlorite-schists, of quartz-andalusite veins in andalusite-schists, of quartz-kyanite veins in kyanite-schists and so on. Exudation with increased mobility of material has clearly operated.

The regionally metamorphosed rocks are associated in their higher grades with areas of granitisation or migmatisation—granitisation here meaning the production of granitic rocks without their passing through a magmatic state. The relationship between such *regional metamorphism and granitisation* has naturally been the subject of much recent discussion. This is so because of the general debate on the origin of the granitic rocks as a group. I have proposed the Plutonic Series, composed of the metamorphic, the migmatitic and granitic rocks, as expressing a valuable genetic idea, generally valid. Regional metamorphism is to be connected in one way or another with a migmatisation or granitisation centre. If this is indeed the case, then the validity and extent of any proposed granitisation can only be judged by the geological setting in which it is observed. Large-scale granitisation must be accompanied by regional metamorphism and migmatisation. An apparent exception to this rule appears in *orogenic metamorphism,* the development over vast areas of lowly metamorphosed, highly folded, rocks—the 'universal phyllites'. But even this exception fits into the whole drama of orogeny and granitisation.

Time in Metamorphic Geology

We may recall that I have defined geology as earth-history, and in any history time is an essential dimension. In my opinion, the most important advance in metamorphic geology in the last 30 years has come from the increased concern with the timing of events on all scales. It is no longer sufficient to describe a metamorphic rock as, for example, a garnet-staurolite-mica-schist and leave it at that—a whole host of possible time-relationships must also be considered. We now look into this matter a little more closely—I have already made repeated mention of timing in the previous sections of this essay.

The style of metamorphic studies has been profoundly changed in many countries by the *establishment of stratigraphical successions* in completely metamorphosed rocks. This has been done chiefly by the use of original sedimentation structures such as current-bedding and graded bedding—the 'way-up' of the rocks has been determined. With a knowledge of the original stratigraphical order of the metamorphic rocks concerned, the geologist can now interpret with confidence the structure of the most complex areas. As samples of the methods and results, papers by Bailey (1930), Read (1936, 1955B) and Iyengar, Pitcher and Read (1954) may be consulted. The metamorphic geologist now has a weapon in his armoury as powerful as William Smith's two laws are to the stratigrapher.

A series of time-relations exists between the various episodes of crystallisation, deformation, migmatisation, granitisation, magmation and orogeny that may affect a metamorphic rock, and must nowadays be considered by the metamorphic geologist. We can begin with simple cases and lead up to the more complex.

The relation between the *times of crystallisation* of the mineral components of a metamorphic rock must be studied as, for example, in the researches of Cheng (1944) and Hietanen (Cloos and Hietanen, 1941). In different metamorphic rocks, too, *deformation and crystallisation* may bear different time-relations to one another. The familiar example of 'rolled garnets', with spirally arranged inclusions of the groundmass of the rock, indicates the contemporaneity of movement and crystallisation. The three great classes of time-relations of this kind have been established as pre-crystalline, para-crystalline and post-crystalline deformation, with obvious and important meanings.

By proceedings such as these, the *metamorphic history* of complex areas can often be deciphered. As an example, I may cite my own work in Unst, in the Shetland Islands, Scotland, (Read, 1934A, 1937) where it can be shown that a particular block of country has been subjected to three successive metamorphisms of different kinds: a first gave staurolite, kyanite, garnet and biotite in pelitic rocks; during a second this assemblage was unstable and one of sericite, chlorite and chloritoid took its place, to be replaced during a third metamorphism by one of chlorite and sericite. A long metamorphic history under varying physical controls has thus been read, and this history is obvious in the field and obvious under the microscope.

As a second example of this *polymetamorphism,* I may give the investigation of the Lewisian complex of the North-west Scottish Highlands by Sutton and Watson (1951). These workers have shown that an early complex of charnockitic facies has been elevated and cooled sufficiently so that diabase dykes intruded into it are chilled, and then the complex, with the dykes, has been subjected to a second metamorphism giving an amphibolite facies. This kind of investigation gives a new concept of the meaning of a geological era as applied to the metamorphic complexes which is as valid as that employed in more normal stratigraphy.

As the growth of a fold-belt continues, magma or migma becomes involved and the time-relations between *orogeny and the emplacement or manufacture of magmatic or migmatitic rocks* have to be considered. The dating of migmatisation or of the appearance of different kinds of granitic bodies is of great importance in metamorphic or plutonic studies. Intrusions have been classed as pre-tectonic, syntectonic or post-tectonic—terms with obvious implications. I have endeavoured to codify these relationships in what I call the Granite Series (Read, 1949), a series which relates the nature and form of different types of granitic bodies with their place in the fold-belt and the time of their final solidification. The *Granite Series* can be represented thus:—

———————— TIME ————————→

———————— CRUSTAL LEVEL ————————→

Autochthonous granitisation granites, migmatites and metamorphites.	**Parautochthonous granites**	**Intrusive magmatic granites**	**Plutons**

Deep in the fold-belt are formed, at an early stage of the orogeny, great complexes of granitisation granites associated with migmatites and widespread regional metamorphic rocks. As the orogeny continues, a part of these autochthonous granites becomes partly unstuck from its surroundings and moves higher in the fold structure. This process continues with the movement of true intrusive and magmatic portions late and high, and culminates in the emplacement of the granite plutons, highest and latest, pushing their way as almost solid bodies even into the post-orogenic sediments. It seems to me (though, as I foreshadowed in an earlier page of this essay, I may be biassed) that the Granite Series brings into orderly connection orogeny, granitisation, metamorphism and granite emplacement. I have suggested that we have here recorded related aspects of one operation—a down-buckling of the sima below the geosynclinal depression. Such a down-buckling, it is thought, would cause the liquefaction of the sima, to supply the ophiolites and related basic rocks in the geosynclinal piles; with the subsequent consolidation of this melted sima, fluids would be supplied to granitise the geosynclinal sediments, the Granite Series is initiated and, as the fold-belt develops, its members take their places in orderly succession (Read, 1955A).

As I have repeatedly emphasized in the foregoing pages, the timing of the diverse events that make up metamorphic geology is the most valuable aspect of present-day studies of the science. A metamorphic or granitic rock is now seen to record a certain precise stage in crustal evolution. Such rocks are not formed in any haphazard fashion, but arise at definite times in circumscribed places. When we know more about metamorphic geology we shall confirm a previously expressed opinion of mine, namely, that petrogenesis has its role in historical geology as much as has stratigraphy.

The Future

After a not inconsiderable experience of the metamorphic and granitic rocks, I may perhaps be permitted to set out the one main result of that experience and then to go on to suggest what I think would be desirable future developments in this study.

This one conviction is the simple one that no two metamorphic rocks are identical—the variables attending their formation are too many. There are pre-metamorphism variables, variables operating during one or more metamorphic episodes, and post-metamorphism variables. Each area of metamorphic rocks has, therefore, to be approached as if it were a piece dropped from some extra-terrestrial source. It has to be considered on its own merits and its rocks must be permitted to tell their own story, even though this story may be unlike any heard before. Generalisations in metamorphic geology should remain extremely general and the application of results attained in one field to another should be done with eyes exceedingly wide open. How then is the metamorphic geologist to proceed? The answer is that given to geologists in general by the illustrious Charles Lapworth—*map it, my boy, and it will all come out.* Metamorphic geology, like all geology, is based on field-work, and advances will come with more and better and, often, different maps.

But, first of all, a simple reminder is necessary; the value of a geological map depends in the first place on there being rocks to map. The importance of abundant exposure in field-studies of the crystalline rocks cannot be overemphasized. It would be advantageous to the progress of metamorphic geology for authors of papers to state clearly what the nature of visible outcrop was in the area under description and thereon to assess the validity of their results. The same remark applies of course to all enquiries of a statistical type; examination of one thin section or the chemical analysis of one gramme of rock cannot give automatically the composition of a large granite body of thousands of cubic kilometres in volume—the one section and the one analysis are valuable, it is true, but extrapolation from them, without controls, may be dangerous. Dare I venture to suggest that the routine mapping of poorly exposed ground should be left to Government Geological Surveys whose officers, after all, are paid to take the fat with the lean ?

Nevertheless, one quarry in metamorphic rocks properly mapped can yield results of great value. We need maps on all scales and especially maps on very large scales of very small areas. We need too a number of special maps, dealing with the results of one episode in what may be a long and complex history; one fold-system or one metamorphism or the distribution of different metamorphic minerals or of one set of small-scale structures can be dissected and given in separate maps. Such maps can then be assembled to give something like a film, though admittedly a jerky one, of this history.

If well-exposed and extensive areas of metamorphic and granitic rocks are to be investigated in such detail as to give the best possible results for the science, then it seems to me that team-work is essential. It is, for example, certain that one man, however able and energetic, working for a lifetime in Donegal, Ireland, could not have produced the body of knowledge that the team (including I am glad to say, Indian members) from my own College has assembled in half-a-dozen years. Mapping on a uniform basic scale and, with due allowance for personal fancies, in a uniform style, can thus be extended over considerable areas; such mapping all agrees with the geological climate of the time and can be uniformly adjusted to suit the geological climate at any instant in the future. Planning in geological research is essential to progress.

It is evident that an important class of maps of metamorphic areas should deal with the pre-metamorphic characters of the rocks that we now find metamorphosed. This is particularly desirable in studies of the structure and correlation of metamorphic rocks over large regions. The original stratigraphy, the order of succession, the facies changes, the conditions of formation, the different places of deposition in the geosyncline, and similar topics are all essential to the full story of the metamorphic rocks. The present lithology of our rocks must be contrasted with the original lithology. Correlation can be done mainly with the help of this original lithology.

In the future it is desirable that the vast field of inquiry opened up by the development of rapid methods of chemical analysis of rocks and minerals should be extended in the metamorphic and granitic rocks. Such intense chemical investigation is especially necessary in coming to any conclusions concerning changes in composition, whether of rocks or of constituent minerals, during metamorphism or migmatisation. A dozen years ago, Lapadu-Hargues (1945) suggested that marked and significant changes in composition occurred in the series slate to migmatitic gneiss. Such studies can be extended and tested most expeditiously by the rapid methods of analysis now available. The compositional changes in aureoles and in metamorphic and migmatitic sequences, and how such changes are distributed among the mineral components, can now be established in a statistically satisfying manner. A beginning along these lines has been made, for example, by Pitcher, Sinha and Mercy in Donegal.

Another fruitful line of future work will be concerned with the determination of absolute ages of metamorphic and other plutonic rocks. Already valuable results have been achieved by Holmes (1951) and others in the dating of events in the complex histories of the ancient rocks of Africa and India. It must be remembered, nonetheless, that the extension of this work must be controlled by geological and mineralogical timing, but its possibilities appear to be very great indeed.

To my mind still, the fundamental requirement for advances in metamorphic geology remains more intensive, better co-ordinated and more properly assessed field-work. Geochemistry, geophysics, petrofabrics and the like provide invaluable ancillary weapons, but the main tool of the metamorphic geologist is still the 'silly little hammer'. Indian geologists, and especially those of Madras, the home of the charnockites, have magnificent opportunities for fundamental work in this branch of geology. On this auspicious occasion, I salute them and wish them success—they are indeed fortunate in that there is no lack of work ready to their hands.

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Raney Nickel Reductions

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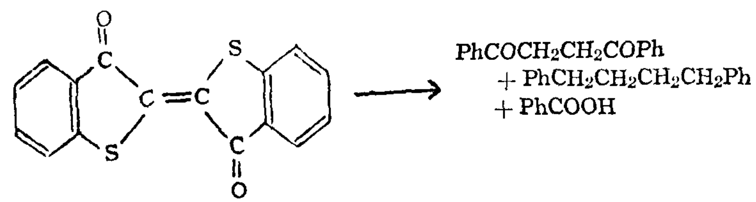
In 1925 and 1927 Raney[1] patented active catalysts prepared by dissolving out the inactive metal from an alloy of a catalytically active and an inactive metal. Raney nickel prepared in this manner by treatment of a nickel-aluminium alloy with caustic soda solution has been extensively used for catalytic reduction, desulphurization, and other purposes. The ability of Raney nickel to effect reductions in the absence of external hydrogen, utilizing the absorbed hydrogen, was demonstrated by Mozingo and his collaborators.[2] They thus removed sulphur from numerous sulphides, sulphoxides and sulphones, and from biotin methyl ester. Following the use of Raney (nickel-aluminium) alloy and aqueous caustic soda by Whitman and others[3] for the reduction of estrone to estradiols, Papa studied this reductive procedure, involving nascent hydrogen and nickel catalyst formed *in situ*, on a variety of organic compounds.[4]

Raney nickel desulphurization appeared to offer a useful approach to problems concerning the constitution of thioindigoids, sulphur dyes and sulphurized vat dyes, and dyes containing sulphonic groups. In a preliminary investigation[5] it was shown that under the Mozingo conditions thiodiphenylamine gave diphenylamine; benzidine-sulphone underwent desulphurization and *N*-alkylation, yielding *N* : *N'*-diethylbenzidine; carbazole gave tetrahydrocarbazole.

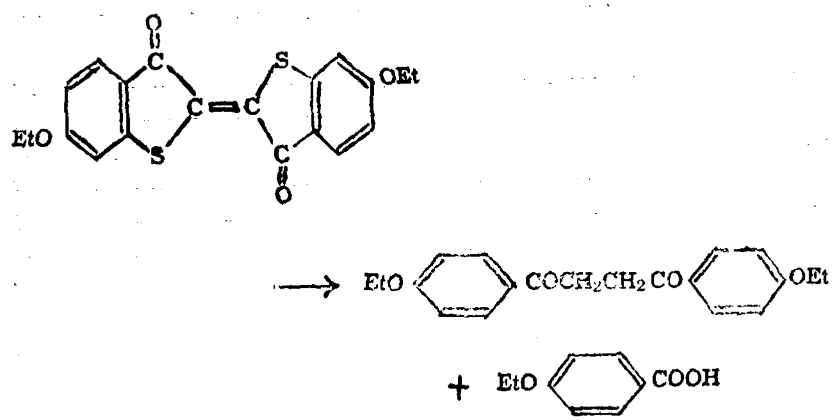
Treatment of thioindigo with Raney alloy and aqueous caustic soda at about 100° yielded diphenacyl (12% under the best conditions), 1 : 4-diphenylbutane and benzoic acid.[6]

1. U.S.P. 1,563,787; 1,628,190.
2. Mozingo, *et al.*, *J. biol. Chem.*, 1942, **146**: 475; *J. Amer. chem. Soc.*, 1943, **65**: 1013; 1944, **66**: 1859.
3. Whitman, *et al.*, *J. biol. Chem.*, 1937, **118**: 792.
4. *J. org. Chem.*, 1942, **7**: 587; *et sequa.*
5. Shah, Tilak and Venkataraman, *Proc. Indian Acad. Sci.*, A, 1948, **28**: 142.
6. Kao, Tilak and Venkataraman, *ibid.*, 1950, **32**: 162; 1953, **38**: 244.

The isolation of compounds in which a carbonyl group attached to the benzene ring remains unaffected after a vigorous Papa reduction has not been recorded so far; Papa found that phenyl ketones,

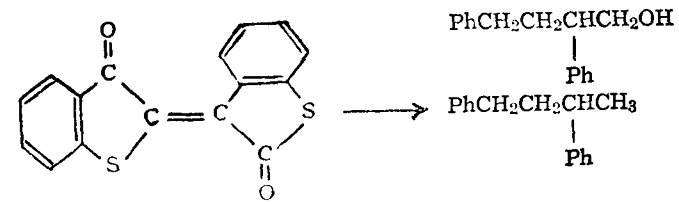


PhCOR, were reduced to the corresponding hydrocarbons, $PhCH_2R$. Deactivation of the catalyst by poisoning with sulphur from thioindigo may account for the stabilization of part of the diphenacyl against further reduction. In connection with the isolation of benzoic acid, which may result from the hydrolysis of diphenacyl, it was noticed that acetophenone gave benzoic acid as one of the products of Papa reduction. 6:6′-Diethoxythioindigo (Durindone Orange R) led to 4:4′-diethoxydiphenacyl in 80% yield, indicating that the desulphurization of thioindigoid dyes is a practicable method for the preparation of diphenacyls, which are otherwise not readily accessible.

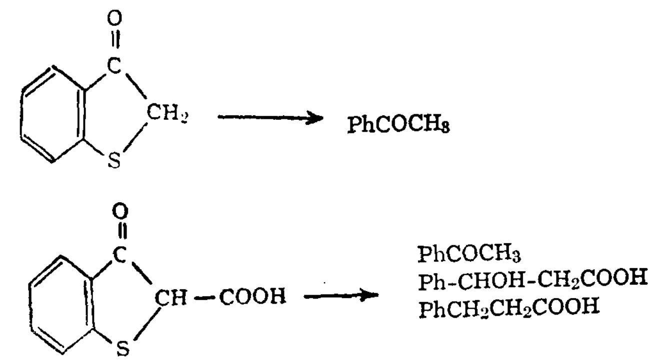


Papa reduction of the naphthalene analogue of thioindigo gave 1:2-di-α-naphthoylethane and a yellow non-fluorescent liquid which analysed for 1:4-di-α-tetralylbutane; a blue-fluorescent isomer of the latter, the two probably being the 1:2:3:4- and 5:6:7:8-tetrahydronaphthalene derivatives, was obtained by Mozingo reduction. The main product of the action of Raney

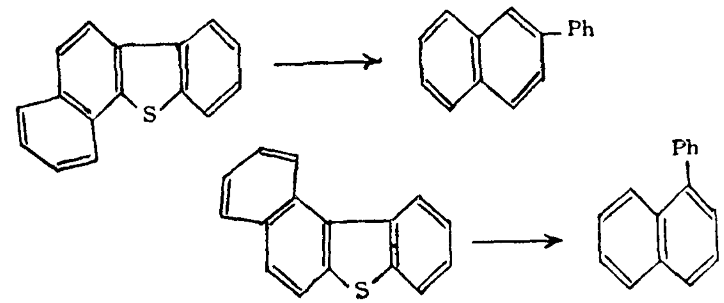
alloy and caustic soda solution on the unsymmetrical dye, 2:3′-*bis*-thionaphthene-indigo was 2:4-diphenyl-1-butanol; the corresponding hydrocarbon was obtained under Mozingo conditions.



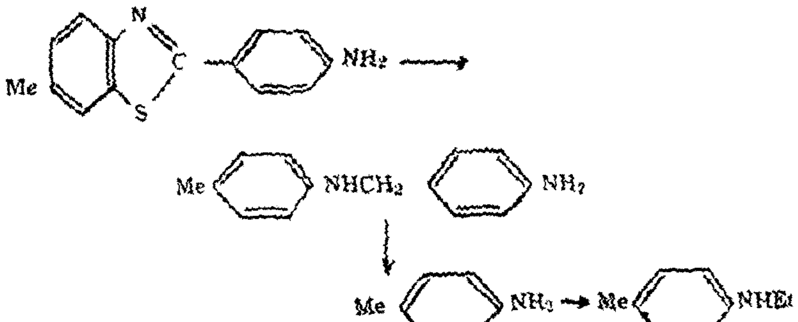
Reduction with Raney nickel and aqueous caustic soda at 0-5° gave very interesting results with thioindoxyl and thioindoxylic acid; the former gave acetophenone in 72% yield; the latter was completely desulphurized in five minutes with the formation of β-phenyl-β-hydroxypropionic acid as the main product, accompanied by acetophenone and β-phenylpropionic acid.



The isomeric 1:2- and 3:4-benzothiafluorenes were readily distinguished by Raney nickel in boiling alcohol, the respective products being 2-phenylnaphthalene and 1-phenylnaphthalene.



Reduction of dehydrothio-*p*-toluidine with Raney nickel in ethanol at room temperature gave *N*-ethyl-*p*-toluidine in good yield; the reaction probably proceeded through the indicated mechanism, since benzylaniline under similar conditions gave *N*-ethylaniline.



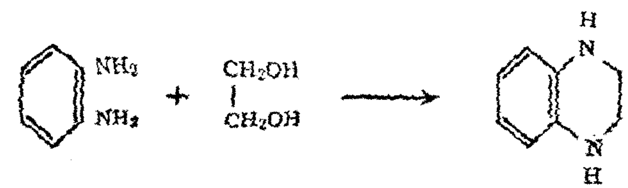
PhNHCH$_2$Ph → PhNHEt

The interaction of arylamines and alkylamines with Raney nickel and alcohol under mild conditions (atmospheric pressure, temperature below 100°, and absence of gaseous hydrogen) was then examined as a general procedure for *N*-alkylation.[7] Several important observations were made. With primary arylamines the exclusive products of the reaction were the secondary alkylarylamines (mono-*N*-alkyl arylamines); thus *p*-toluidine refluxed with ethanol and Raney nickel (1 part) for 2 hours gave *N*-ethyl-*p*-toluidine in 88% yield; the amine was likewise alkylated at room temperature, but the time required was 18 hours. *n*-Propanol, isopropanol, *n*-hexanol and *n*-dodecanol yielded the corresponding *N*-alkylamines, but methanol did not react. *m*-2-Xylidine, presumably because of the steric effect of the *o*-methyl groups, did not react. The *N*-ethyl derivative was obtained in 70% yield from *p*-aminobenzoic acid. When *p*-toluidine was treated with Raney nickel and cyclohexanol on a water-bath, the expected *N*-cyclohexyl-*p*-toluidine was accompanied by 4-methyl-dicyclohexylamine; there is no reference in the literature to the reduction of a benzene ring by Raney nickel under such mild conditions, but the observation was confirmed by repeating the reaction with aniline, when both N-cyclohexylaniline and dicyclohexylamine were obtained.

7. Kao, Tilak and Venkataraman, *J. sci. industr. Res. India*, 1955, **14B**: 624. See this paper for references to relevant literature.

Alkylamines behaved towards Raney nickel and alcohols somewhat differently from the aromatic amines. Thus *n*-butylamine, Raney nickel and ethanol led not only to *N*-ethyl-*n*-butylamine, but also to di-*n*-butylamine (formed by the self-condensation of *n*-butylamine) and a very small quantity of diethylbutylamine. In the absence of an alcohol, *n*-butylamine gave di-*n*-butylamine and tri-*n*-butylamine on treatment with Raney nickel in boiling water.

When o-phenylenediamine was treated with Raney nickel in ethylene glycol on a boiling water-bath, 1:2:3:4-tetrahydroquinoxaline was isolable in low yield; if the conditions can be modified to improve the yield, a new route to quinoxaline derivatives may become available.



I II

After our work was completed, Rice and Kohn[8] and Ainsworth[8a] reported the *N*-alkylation of primary aromatic amines with alcohols, and Raney nickel. Rice and Kohn carried out the reaction for longer periods and Ainsworth used larger amounts of Raney nickel. Rice and Kohn failed to effect *N*-alkylation by isopropanol, but Ainsworth confirmed our observation that prolonged heating resulted in the formation of *N*-isopropylaniline in about 50% yield. Ainsworth found that the reaction of Raney nickel and alcohols with primary aliphatic amines was more complex; 2-phenylethylamine and ethanol gave di-(2-phenylethyl)-amine, and benzylamine gave dibenzylamine.

In connection with attempts to determine the constitution of Cibanone Yellow R and Cibanone Orange R, which are vat dyes prepared by thionation of 2-methylanthraquinone or its halogen derivatives, the action of Raney alloy and caustic soda solution at about 95° on the dyes and on anthraquinone, 2-methylanthraquinone, 2-mercaptomethylanthraquinone, bis-2-anthraquinonylmethyl sulphide (I; AQCH$_2$-S-CH$_2$AQ; AQ = 2-anthraquinonyl), and

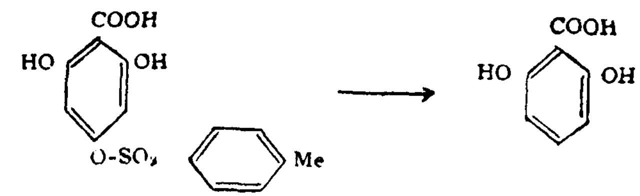
8. *J. Amer. chem. Soc.*, 1955, **77**: 4052.
8a. *ibid.*, 1956, **78**: 1635.

bis-2-anthraquinonylmethyl disulphide (II; $AQCH_2$-S-S-CH_2AQ) was studied.[9] Short heating for an hour was generally adequate. One of the objects was to remove sulphur from the dyes without hydrogenating the anthraquinone residues. Using 2·5 parts of Raney alloy, anthraquinone gave 1:2:3:4-tetrahydroanthroquinone, and 2-methylanthraquinone 1:2:3:4:-tetrahydro-6-methylanthraquinone, as the major products; the constitution of the latter was shown by oxidation with permanganate in acetone to 4-methylphthalic acid and adipic acid. For desulphurization it was convenient to use an equal part of Raney alloy since about 35% of 2-methylanthraquinone remained unchanged. Under these conditions 2-mercaptomethylanthraquinone gave 2-methylanthraquinone, 2-hydroxymethylanthraquinone, anthraquinone-2-carboxylic acid, and *bis*-2-anthraquinonylmethyl sulphide (I). The sulphide (I) gave 2-methylanthraquinone and traces of Anthraflavone (AQ-CH=CH-AQ). The disulphide (II) yielded 2-methylanthraquinone, 2-hydroxymethylanthraquinone and anthraquinone-2-carboxylic acid. The isolation of the carbinol and carboxylic acid from the desulphurization products of 2-mercaptomethylanthraquinone and the disulphide (II) is of interest. From Anthraflavone a small quantity of 1:2:3:4-tetrahydro-6-methylanthraquinone, formed as a result of fission at the ethylene bridge, and a product analysing for decahydroanthraflavone were isolated.

Kenner and Murray[10] found that, when an alcoholic solution of the *O*-tosyl (*p*-toluenesulphonyl) derivative of a phenol, was shaken with Raney nickel and hydrogen at atmospheric pressure, the products were the aromatic hydrocarbon and nickel tosylate ($2Ar\text{-}O\text{-}SO_2C_7H_7 + Ni + H_2 \rightarrow 2ArH + Ni(OSO_2C_7H_7)_2$). Thus *m*-acetamidophenol could be converted to acetanilide (90%), and methyl salicylate to methyl benzoate (80%), via the tosylate. The naphthalene nucleus also underwent hydrogenation under these conditions, β-naphthyl tosylate yielding tetralin. Hydrogenolysis of the tosyl derivatives of phenols is useful for several synthetic purposes. It provides for instance a new and convenient route to γ-resorcylic acid,[11] the sodium salt of which has been stated to be more active than sodium salicylate as a therapeutic agent in rheumatic fever. γ-Resorcylic acid (2:6-dihydroxybenzoic acid) can be readily prepared from phloroglucinol in an overall yield of

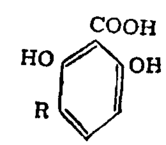
9. Ramanathan, Tilak and Venkataraman, *Proc. Indian Acad. Sci.*, A, 1953, 38: 161.
10. *J. chem. Soc.*, 1949: 178.
11. Ramanathan and Venkataraman, *Curr. Sci.*, 1952, 21: 283.

about 75% by carboxylation, mono-*O*-tosylation to form (III), and treatment of an aqueous solution of the acid (III) and potassium bicarbonate with Raney nickel at room temperature in a current of hydrogen.

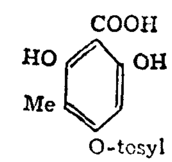


III

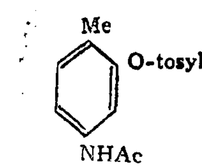
The preparation of 4-methylresorcinol-2-carboxylic acid (IV; R = Me) and 4-*n*-hexylresorcinol-2-carboxylic acid (IV; R = $n\text{-}C_6H_{13}$) was next attempted. Unlike (III), the tosylate (V) was not reducible to (IV; R = Me) by Raney nickel and hydrogen; the product was a mixture of the unchanged compound (V) and methylphloroglucinol resulting from hydrolysis of the tosyl group and decarboxylation. Considering the possibility that the steric effect of the methyl group *ortho* to the tosyloxy group may be responsible for the failure of the hydrogenolysis of (V), the reduction of 4-acetamido-*o*-cresol tosylate (VI) was studied. Under Mozingo conditions, the tosyloxy group was split off giving acet-*p*-toluidide. Hexylphloroglucinol was carboxylated by aqueous potassium carbonate, but the monotosylate could not be prepared, since the acid was unstable and decarboxylated readily.



IV; R = Me or $n\text{-}C_6H_{13}$

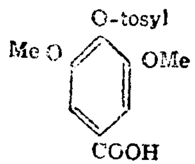


V

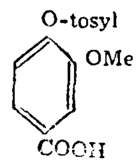


VI

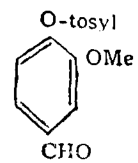
A new route for the preparation of 3:5-dimethoxybenzoic acid, which is normally prepared from benzoic acid by sulphonation, alkali fusion and methylation of the α-resorcylic acid thus obtained, was explored. The tosyl derivative (VII) of syringic acid was prepared in the usual manner in aqueous solution by means of caustic potash and tosyl chloride. This compound on treatment with Raney nickel catalyst and hydrogen did not undergo reduction; hydrolysis took place when aqueous bicarbonate was used as the solvent, giving syringic acid, and in alcoholic solution the unreacted compound was recovered. The tosyl derivative (VII) also remained substantially unaffected under the Mozingo conditions of reduction, a small part being hydrolysed to syringic acid. With a view to study the effect of one o-methoxyl group instead of two, the action of Raney nickel on the tosyl derivative (VIII) of vanillic acid was examined. On treatment of an alcoholic solution with Raney nickel and hydrogen for 6 hours at room temperature, *m*-methoxybenzoic acid was obtained in 30% yield, the unconverted tosyl derivative being recoverable. In aqueous bicarbonate a mixture of vanillic and *m*-methoxybenzoic acids was obtained because of partial hydrolysis of the ester. The Mozingo method, with 4 hours boiling in ethanol, gave a 65% yield of *m*-methoxybenzoic acid, together with 15% of unreacted material. The recovery of some quantity of unreacted material in these reactions shows the slight effect of one o-methoxyl group. The reduction of vanillin tosylate (IX) by the Mozingo method led to *m*-cresol methyl ether (60%) and a trace of a sulphur-containing oil. Under the Kenner-Murray conditions vanillin tosylate (IX) gave *m*-methoxybenzyl alcohol (X) in 80% yield.



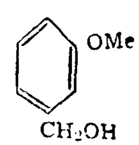
VII



VIII



IX

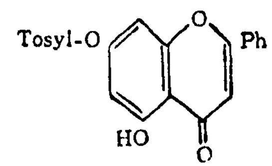


X

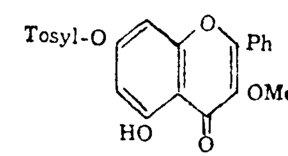
Removal of a phenolic hydroxyl group by hydrogenolysis of the tosylate has proved to be useful in the flavone and xanthone series. Chrysin (5:7-dihydroxyflavone) has been converted to 5-hydroxyflavone, and galangin 3-methyl ether (5:7-dihydroxy-3-methoxyflavone) to 5-hydroxy-3-methoxyflavone.[12] A general method has thus become available for the synthesis of 5-hydroxyflavones, which are of interest because of their possible occurrence in nature and also as intermediates for the synthesis of naturally occurring 5:8-dihydroxyflavones by the Elbs-Seshadri persulphate oxidation. Chrysin and galangin 3-methyl ether readily gave the 7-tosyl ester (XI) and (XII) on treatment with a molar proportion of tosyl chloride and excess of anhydrous potassium carbonate in boiling acetone. It was necessary to carry out the hydrogenolysis of the tosyl derivatives under controlled and mild conditions, leaving a part of the tosyl derivative unreacted to poison the nickel

12. Ramanathan and Venkataraman, *Proc. Indian Acad. Sci.*, A, 1953, 18: 40.

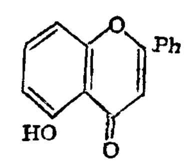
catalyst in order to avoid undesirable side reactions. The crude reaction mixture was treated with alcoholic caustic potash to hydrolyse the unreacted tosyl derivative and the mixture of hydroxyflavones separated by chromatography. Thus by the hydrogenolysis of the 7-tosyl ester (XI) of chrysin, a mixture of 5-hydroxyflavone (XIII) and chrysin was obtained; when the mixed flavones were dissolved in benzene and chromatographed on Florex xxx (an extruded fuller's earth supplied by the Floridin Co., Inc.), development and elution with benzene yielded 5-hydroxyflavone (XIII) in a yield of about 25 per cent calculated on the quantity of the tosyl derivative (XI) consumed in the reaction. Elution with ethyl acetate then led to the recovery of the more strongly adsorbed chrysin. In the case of the 7-tosyl ester (XII) of galangin 3-methyl ether Raney nickel treatment and hydrolysis of the product yielded galangin 3-methyl ether and 5-hydroxy-3-methoxyflavone (XIV), readily separable by chromatography. It was found, however, that galangin 3-methyl ether and 5-hydroxy-3-methoxyflavone can be separated in a simpler manner by taking advantage of the sparing solubility of the former in benzene.



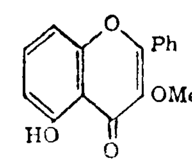
XI



XII



XIII



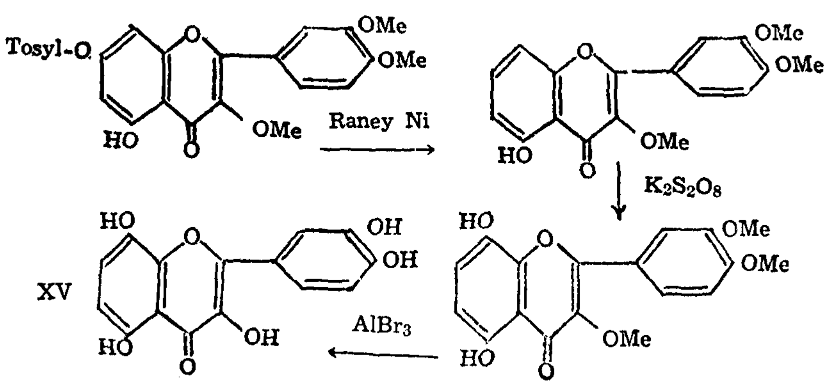
XIV

After the present work was published, Seshadri and co-workers have reported experiments on similar reductions.[13] For the purification of the mixture of flavones obtained after alkaline hydrolysis of the hydrogenolysis product, they first precipitated the coloured impurities from an ethyl acetate solution of the mixed flavones by the addition of petroleum ether. Then the two flavones were

13. Jain and Seshadri, *J. sci. industr. Res. India*, 1953, 12B: 503.

separated by the difference in solubility in aqueous sodium carbonate in which chrysin was soluble, while 5-hydroxyflavone was not. Though this method appears to be simpler, it has been found in the present work that purification through chromatography on Florex is more satisfactory and affords a quantitative separation of the flavones. Florex xxx has been found to be a very useful adsorbent for the chromatographic separation of hydroxyflavones and other coloured phenolic compounds such as the hydroxyanthraquinones.

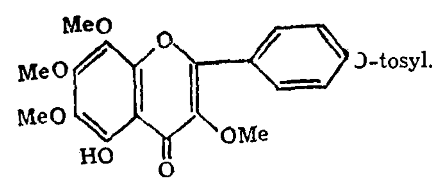
Kurth and Hubbard[14] isolated from *Ponderosa* pine bark a bright yellow colouring matter, to which they assigned the structure 3:5:8:3′:4′-pentahydroxyflavone (XV). The flavone (XV) was synthesized by the indicated route, and found to be different in its m.p. and other properties from the Ponderosa colouring matter.[15] Subsequent work has shown that the latter is a complex mixture, from which quercetin, taxifolin (2:3-dihydroquercetin), and two new colouring matters, 6-methylquercetin (pinoquercetin) and 6-methylmyricetin (pinomyricetin) have so far been isolated.[16]



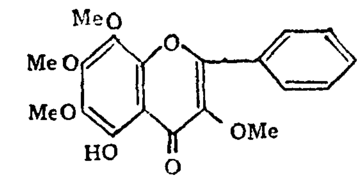
With the object of reducing hydroxyl groups in the 2-phenyl nucleus, the 4′-tosyl ester (XVI) of calycopterin was prepared; Raney nickel treatment and hydrolysis of the product gave calycopterin and 5-hydroxy-3:6:7:8-tetramethoxyflavone (XVII).

14. *Industr. Engng. Chem.*, 1951, *43*: 896.
15. Ramanathan and Venkataraman, *Proc. Indian Acad. Sci.*, A, 1954, **39**: 90
16. Kurth, Ramanathan and Venkataraman, *Curr. Sci.*, 1955, **24**: 157; *J. sci. industr. Res. India*, 1956, **15B**: 139. Contrast Gupta, Kurth and Seshadri, *ibid.*, 1954, **13B**: [illegible]

Extending this procedure to the xanthone series 1:3-dihydroxyxanthone has been converted into 1-hydroxyxanthone. The tosyl ester (XVIII) on hydrogenolysis and hydrolysis gave a product which on direct crystallization gave 1-hydroxyxanthone (XIX) in 80% yield. From these experiments it is clear that the

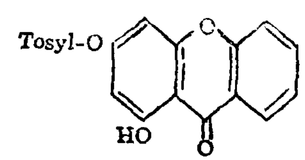


XVI

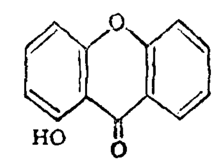


XVII

stability of the pyrone ring to reduction plays a vital part in the yield and purity of the desoxy product. In the case of chrysin, a flavone, the yield of the product is about 25% and it increases through 45% with galangin 3-methyl ether, a flavonol, to 80% in the case of 1:3-dihydroxyxanthone in accordance with the increasing order of stability of the systems.



XVIII



XIX

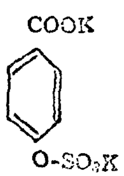
After the present work was completed, Seshadri and coworkers reported the reduction of 1-hydroxy-3-tosyloxyxanthone to 1-hydroxyxanthone, 1-tosyloxyxanthone to xanthone, and 3-tosylgentisein to euxanthone.[17]

The action of Raney nickel on the sulphuric esters of phenols has been studied to determine if sulphuric esters can be used as intermediates in place of tosyl esters for the removal of phenolic hydroxyl groups. *p*-Hydroxybenzoic acid was sulphated using pyridine and chlorosulphonic acid. The sulphuric ester was not isolated, but converted into the dipotassium salt (XX), which was

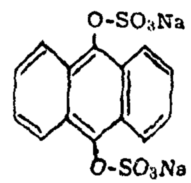
17. Jain, Mittal and Seshadri, *J. sci. industr. Res. India*, 1953, **12B**: 647.

treated with Raney nickel and hydrogen. From the reaction mixture benzoic acid (65%) and a little *p*-hydroxybenzoic acid were isolated.

A new general method for the conversion of quinones to the corresponding hydrocarbons through the disulphuric esters of the leuco derivatives thus becomes available.[18] The cleavage of sulphuric esters by Raney nickel affords an alternative route for the preparation of hydrocarbons and may have advantages over phosphorus and hydriodic acid and zinc dust distillation methods, which use high temperatures and may cause structural rearrangement. Sulphuric esters of leuco derivatives of over thirty vat dyes are available commercially and provide suitable raw materials for the preparation of various polycyclic hydrocarbons, azahydrocarbons, etc., which are of interest in connection with cancer studies.



XX

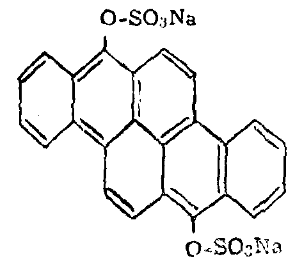


XXI

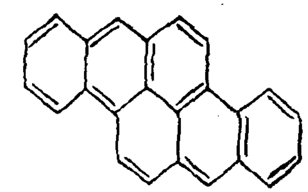
The hydrogenolysis of (XXI), the disodium salt of the disulphuric ester of anthrahydroquinone, was first examined. An aqueous solution of the disulphuric ester was treated with Raney nickel and hydrogen for 4 hr. at room temperature and filtered. Benzene extraction of the nickel residue after deactivation gave a mixture of 1:2:3:4-tetrahydroanthraquinone and hydrogented anthracene; the latter was then dehydrogenated by selenium to anthracene in an overall yield of 30%. From the aqueous filtrate, after oxidation with sodium nitrite and sulphuric acid, a further quantity of 1:2:3:4-tetrahydroanthraquinone was recovered, indicating that hydrogenation of anthrahydroquinone disulphuric ester to 1:2:3:4-tetrahydroanthrahydroquinone disulphuric ester also takes place as a side reaction. The formation of a quinonoid derivative, because of the incomplete hydrogenolysis of the ester even when a large amount of Raney nickel was used, was practically eliminated by carrying out the reaction using Raney alloy

18. Desai, Ramanathan and Venkataraman, *J. sci. industr. Res. India*, 1955, **14B**: 330.

and aqueous alkali instead of Raney nickel catalyst. This modification gave an excellent yield of hydrogenated anthracene (85%) which could be readily dehydrogenated to anthracene.



XXII



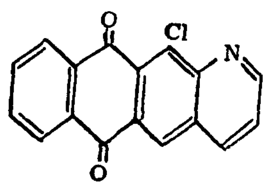
XXIII

Reduction of Indigosol Golden Yellow IGK (XXII), the disodium salt of the disulphuric ester of Indanthrene Golden Yellow GK (2:3:7:8-dibenzpyrene-1:6-quinone), by means of Raney alloy and aqueous alkali afforded an excellent yield (80%) of a mixture of hydrogenated hydrocarbons, which were separated by chromatography into hexahydrodibenzpyrene (m.p. 240-41°) and decahydrodibenzpyrene (m.p. 235-36°). The mixture of hydrogenated hydrocarbons was dehydrogenated to dibenzpyrene (XXIII) by treatment with iodine and sodium acetate in boiling nitrobenzene. 2:3:7:8-Dibenzpyrene (XXIII) has been prepared earlier by other workers from 2:3:7:8-dibenzpyrene-1:6-quinone by zinc dust distillation, Clar reduction, and reduction with phosphorus and hydriodic acid.

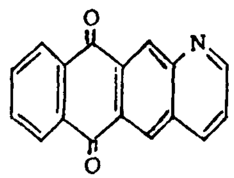
A further application of the Raney nickel method for the reduction of quinones to the corresponding hydrocarbon derivatives is the synthesis of the hitherto unknown 1-azanaphthacene (XXVIII).[19] The Skraup reaction on 2-amino-1-chloroanthraquinone, adding arsenic pentoxide to suppress the benzanthrone reaction, gave a good yield of 12-chloro-1-azanaphthacene-6:11-dione (XXIV). Dechlorination by means of caustic soda and sodium hydrosulphite and air oxidation of the vat yielded 1-azanaphthacene-6:11-dione (XXV). Treatment of the disodium salt (XXVI) of the disulphuric ester of (XXV) with Raney alloy and caustic soda at 100° gave an octahydroazanaphthacene, the absorption spectrum of which showed that it had the structure (XXVII).

19. Desai, Ramanathan and Venkataraman, *ibid.*, 1956, **15B**: 279.

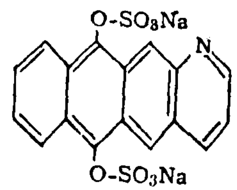
After attempting other procedures which effected only partial dehydrogenation, (XXVII) was ultimately dehydrogenated to 1-azanaphthacene (XXVIII) by prolonged heating with palladized carbon in boiling Dowtherm.



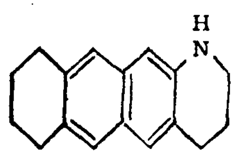
XXIV



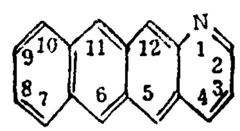
XXV



XXVI

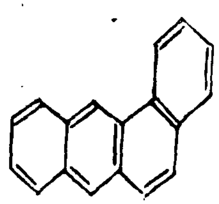


XXVII

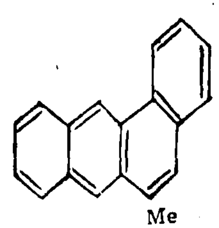


XXVIII

The hydrogenolysis of leuco sulphuric esters of quinones by Raney alloy and aqueous alkali to the corresponding hydrocarbon derivatives has been extended to the leuco sulphuric esters of 1:2-benzanthraquinone and its derivatives for the preparation of benzanthracene and methylbenzanthracenes, which are of interest in connection with their carcinogenic activity. Thus the hydrogenolysis of the sulphuric ester of benzanthrahydroquinone gave a



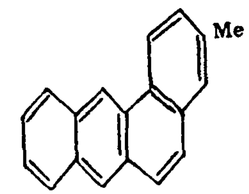
XXIX



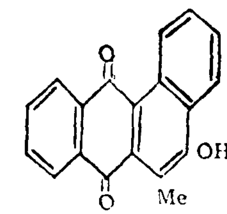
XXX

hydrogenated benzanthracene, which was dehydrogenated to 1:2-benzanthracene (XXIX) in an overall yield of 70%. With the object of preparing 4-methylbenzanthracene (XXX) the hydrogenolysis of the leuco sulphuric ester of the methylchlorobenzanthraquinone, obtained by the Friedel-Crafts condensation of

1-chloro-2-methylnaphthalene and phthalic anhydride and cyclisation of the resulting keto acid, was carried out; the product, however, was 3′-methylbenzanthracene (XXXI), indicating that the phthalic anhydride condensation had taken place in the unsubstituted benzene ring (the 5-position of 1-chloro-2-methylnaphthalene).



XXXI



XXXII

The synthesis of 4-methylbenzanthracene (XXX) through the trisulphuric ester of 3-hydroxy-4-methylbenzanthrahydroquinone is being studied. The desired anthraquinone derivative (XXXII) was obtained by condensing 3-hydroxybenzanthraquinone with aqueous caustic soda, sodium hydrosulphite and formaldehyde (the Marschalk reaction). As a pilot experiment, the trisulphuric ester of the leuco derivative of 2-hydroxyanthraquinone was reduced by Raney alloy and caustic soda to a hydrogenated anthracene, which was then dehydrogenated to anthracene.

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On the Mineral Facies of Charnockites

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CONTENTS

Introduction

The charnockites, thought to be rocks specific for Peninsular India by their first investigator, Sir Thomas Holland (1900), have later on been found to be universally distributed and have attracted general interest among petrologists all over the world. Holland had concluded that the charnockites are magmatic rocks. Later Vredenburg (1918), Groves (1935), Ghosh (1941), J. A. W. Bugge (1943), Ramberg (1948, 1949, 1952, 1956) *et al.* presented theories of their genesis, different one from the other, but agreeing therein that the charnockites are metamorphic in one way or other and not primary magmatic rocks.

Since the Mineral Facies classification (Eskola, 1921) was expanded to include the Granulite Facies, to which all charnockites belong (Eskola, 1939), the charnockite problem took partly a new aspect, as it could be understood that the charnockites like other rocks formed at rather high temperatures may be either magmatic, metamorphic, or metasomatic. More important, in many respects, for the nature of a rock than its mode of crystallization, is the temperature and pressure under which it has crystallized. Therefore, the question whether the charnockites are magmatic or metamorphic is, to a certain degree, irrelevant as compared with the character of their mineral facies.

This article is written in order to make the mineral facies principle familiar to the students of charnockites. This might appear unnecessary, as, after 1939, excellent expositions of the mineral facies classification have been published by Turner (1949), Turner and Verhoogen (1951), Barth (1952), Ramberg (1949, 1952), Rosenqvist (1952) and others. However, it seems to me that discussion on the basis of this principle still can afford elucidation to the charnockite problem. In this short paper I cannot go deep into the genesis of charnockites but must refer to the works cited and especially to Quensel (1951) who gives a fair review of recent literature. I hope later, in another connection, to discuss the genetic problems in the light of the mineral facies principle.

The mineral facies conception was based upon the physico-chemical thesis that, in a rock which has reached chemical equilibrium at constant temperature and pressure, the assemblage of phases, *i.e.*, mineral constituents, will depend solely upon the chemical bulk composition. A certain mineral facies, then, is a group of rocks which, at a given bulk composition, have the same assemblage of minerals but, at varying bulk composition, show mineral compositions varying according to definite rules.

The chief mineral facies classes of rocks separated in the Sial Crust, supposed to represent different temperature and pressure ranges are as follows.

Decreasing temperature ⟶

Increasing pressure ↓

Metamorphic	facies :	Sanidinite	Zeoliths
Magmatic	„	Diabase	
Metamorphic	„	Hornfels, Amphibolite, Epidote amphibolite, Greenschist	
Magmatic	„	Gabbro, Hornblende gabbro	
Metamorphic	„	Granulite	
Magmatic	„	Mangerite	
Metamorphic	„	Eclogite	
Magmatic	„	Griquaite (see Eskola 1921, p. 185)	

Recent experimental research has proved that the phase equilibria of rocks are far less sensitive for pressure than for temperature. Nevertheless, everybody will agree that, in the vertical column of the table, the sequence of rocks is that of in-

creasing depth and pressure. The influence of pressure is partly indirect but, as will be shown later, its direct effect probably is not quite negligible either.

The mineral facies, excepting those of the lowest temperature ranges, occur in magmatic as well as in metamorphic crystallizations. This is also true of the granulite facies. V. M. Goldschmidt (1922) distinguished in the Norwegian Caledonides magmatic charnockites, called mangerites. Recently Rosenqvist (1956) pointed out that this is an appropriate name for the magmatic granulite facies. At present, after the research of Bowen and Tuttle has proved that many granites and charnockites have almost the minimum-melting composition of the haplogranitic system, the existence of magmatic charnockites cannot be doubted.

In a remarkable paper Yoder (1952) published his first results of experimental research on the thermal properties of metamorphic minerals, some of which are important constituents of the charnockites. It is by such investigations that the value of the mineral facies theory can be tested. The theorist has to adjust his conclusions after them. These results, as a matter of course, will be briefly discussed in this paper.

The methods of investigation at high temperatures and pressures have advanced far enough to enable the establishment of phase equilibria under the temperature and pressure conditions prevailing in all parts of the lithosphere where the existing magmatic and metamorphic rocks have originated (Roy and Tuttle, 1956). Thus, it is probable that in the near future the stability conditions of all rock-making mineral systems can be made clear. Then it will be possible to lay an exact basis of the mineral facies classification instead of the empiric methods practicable up to date.

Characteristics of the Granulite Facies

The granulite facies comprises the crystalline rocks which, at a normal granitic composition, are composed of quartz, potash feldspar, sodic plagioclase, and almandine-pyrope garnet. The last mentioned mineral can be formed only when the rock contains alumina in excess over the amount that can be contained in the feldspars, thus substituting the mica of the granite. Almandine-pyrope equals hypersthene + corundum :

$$3\,(Mg, Fe)\,SiO_3 + Al_2O_3 = (Mg, Fe)_3\,Al_2Si_3O_{12}$$

In acid granulites the alumina in excess over the garnet ratio forms sillimanite. In many occurrences, however, the excessive alumina *first gives rise to cordierite:*

$$2\,(Mg,\ Fe)_3Al_2Si_3O_{12} + 4Al_2O_3 + 9SiO_2 = 3\,(Mg,\ Fe)_2Al_4Si_5O_{18}.$$

Cordierite as well as sillimanite in its respective areas occurs in the manner of a stable constituent, so as to suggest distinction of two subfacies. They show, also, some textural and tectonic differences, the sillimanite granulite being foliated and its quartz of the platy quartz type, the cordierite granulite more coarse-grained and massive. Both may represent typical compositions of argillaceous sediments.

When the amount of ferro-magnesium silicate exceeds the garnet ratio, the granulites contain hypersthene. If, at the same time, the rock contains calcium in excess over the ratio required by anorthite with the aluminium present, no garnet is formed.

More extreme types of charnockites are the khondalites of India and Ceylon. They are quartz-sillimanite-garnet rocks of argillaceous composition grading over into quartzites or, at the opposite end, into corundum-bearing rocks equivalent to bauxite. Peculiar to many Indian charnockite provinces are magnetite-quartz rocks.

In lime-rich rocks calcite, dolomite, and meionitic scapolite occur in association with diopside or forsterite. Examples were described from the Aldan Plateau in Siberia by Korzhinsky (1936) who also discussed their thermodynamical significance stressing the idea that they have formed under extremely high pressures. From western Uusimaa, Finland, scapolite-bearing sedimentogeneous charnockitic rocks have been described by Parras (1941). Numerous and most remarkable examples of calcium-rich rocks metamorphosed in the granulite facies are known from India (Ghosh, 1941; Rama Rao, 1945, p. 149; Muthuswami, 1951) and Ceylon (Adams, 1929). Paulose (1956) describes diopside-scapolite granulites and diopside-wollastonite rock from Cape Comorin. Subramaniam (1956) has published a masterful treatise of the Sittampundi complex, Salem district, Madras, where the main rocks are anorthosites, partly with exceptionally pure An, accompanied by eclogites and chromitites. The complex is interpreted as a layered intrusion, while a bytownite-cordierite-corundum rock in it is said to represent a metasediment. The complex, situated

in one of Fermor's charnockite provinces, has suffered a retrograde metamorphism in the amphibolite and epidote-amphibolite facies connected with the emplacement of younger granite, but its preserved relict constituents clearly indicate its original belonging to the granulite and eclogite facies.

It is to be remembered, moreover, that in the charnockite provinces the charnockites frequently alternate with layers of crystalline limestone and quartzite which thus have been metamorphosed in the granulite facies although this does not show in their minerals, as calcite, dolomite, and quartz are "Durchläufer" (Fr. Becke), stable in most facies.

The minerals of the granulite facies have several persistent peculiarities which distinguish this facies from all others. Some of these give important indications of the conditions that were prevailing during the crystallization of the rocks. An almost invariable characteristic of the charnockites is a dirty brownish or bluish hue of their feldspars, giving the rock a darker colour than it would have otherwise on account of its small amount of mafic minerals. This colour is due to pigment-like inclusions, probably of iron and aluminium oxides which have been originally present in the mineral lattices after crystallization at high temperatures, possibly as an iron feldspar (Rosenqvist, 1951). The quartz also is often dark bluish and is seen under microscope to contain slender prisms of rutile. Pichamuthu (1953) stresses the occurrence of "clouded feldspars" in the Indian charnockites.

Another general characteristic is a wider range of diadochy in the series of isomorphic minerals than in other facies excepting the eclogite facies. Thus, the garnets sometimes contain as much as 55 per cent pyrope and up to 20 per cent grossularite, or appreciably greater proportions than the garnets of ordinary amphibolites or granites of the amphibolite facies (Eskola, 1952, p. 150, 153).

The hypersthenes of charnockites are often highly aluminous. In the charnockites of Uganda, Groves (1935) found hypersthene containing as much as 9·39 per cent Al_2O_3. In the granulites of Lapland (Eskola, 1952) the maximum percentage of Al_2O_3 in hypersthene found was 8·26. About a half of the aluminium here replaces silicon in the SiO_4-tetrahedra. Thus, we see here an extended diadochy of cations just as in the granulite garnets. From a charnockite at Bidaloti, India, Rama Rao (1945, pp. 19-21) describes a lilac-coloured mineral called Bidalotite, which otherwise resembles hypersthene in characters and composition, but contains 10·55 per cent Al_2O_3.[1]

The wider diadochy in the orthopyroxene and garnet might be caused by high temperature of crystallization, as is known to be the case in many pairs of isotypic compounds. Thus, solid solutions of diopside and (Mg,Fe)-clinopyroxene, or pigeonite, exist in rocks of the diabase facies. But this kind of widened diadochy does not occur at all in the granulite facies. Naidu (1955), in his monograph of the charnockite minerals, states that pigeonite is present in the non-metamorphic dolerites intersecting the charnockites but not in the latter, and Leelananda Rao (1954) describes pigeonite dolerite dikes at Pallavaram. Therefore, we cannot assume that the extended diadochy in the granulite facies minerals would be effected by higher temperature, especially as the latter also differ from the high-temperature magmatic minerals in their colour and pleochroism. Therefore, the conclusion appears to be well founded that this feature in the charnockites is due to higher pressure (cf. Rosenqvist, 1952).

In many charnockites the hypersthene is strongly pleochroic: α purple violet, β pale reddish yellow, γ pale green. The intensity of pleochroism varies greatly being apparently independent of the Mg/Fe ratio, the rate of oxidation of the iron, and the amount of total iron. The problem of the colours of hypersthene in the charnockites is still unsolved. Possibly the intensity of the colours depends upon the degree of unmixing of iron oxides just as the darkness of feldspar and quartz, though in the hypersthene the pigment remains submicroscopic (cf. Quensel, 1951, p. 10).

The potash feldspar in the Indian charnockites, according to Holland, is invariably microcline, but later on orthoclase has been also reported. In the granulites of Finnish Lapland the potash feldspar according to Eskola (1952) appears to be primarily orthoclase. In many thin sections of coarse-grained cordierite-granulites and garnet-granulites of granite-like appearance the potash

1. Dr. P. R. J. Naidu of the Madras University kindly called my attention to a fact which, unfortunately, I had forgotten, viz., that Dr. J. C. Rabbitt and Professor C. E. Tilley have identified this mineral as anthophyllite (Rabbitt, Am. Min. 33, p. 310). The strong colour and high titanium content of this anthophyllite (or gedrite) seems to place it in a type comparable with the hornblende or hypersthene of charnockites in contrast to the same minerals in rocks of the amphibolite facies.

feldspar shows straight extinction on (001), is clear and free from perthite. Similar orthoclases were also encountered in foliated, more fine-grained granulites with platy quartz. In some specimens the clear orthoclase shows undulating extinction from which gradual passage into typical cross-hatched microcline may develop. Independent of the change to microcline is the appearance of minute sparse perthite spindles. When the perthite contains nearly equal amounts of Or and Ab, as the so-called mesoperthite in Greenlandic charnockites (Ramberg, 1956), it is surely a high-temperature product.

Goldsmith and Laves (1954) have investigated the potash feldspar of the Lappish granulites and stated by means of X-ray studies gradual change of orthoclase into microcline characterized by an increase of triclinity. In some cases the whole range from monoclinic to 100 per cent triclinic variety is represented in a single thin section.

The potash feldspar of the charnockites is mostly developed as extremely fine exsolution perthite called hair-perthite or string-perthite with hair-like threads of plagioclase. Rosenqvist (1952, pp. 81-87) has carried out experiments to determine the diffusion ellipsoid for radium ions in feldspars. He found its longest axis, or the direction of the greatest velocity of diffusion, to be $\perp$ (801) and the anisotropy to increase with temperature. Assuming that the Na-ions behave like the Ra-ions he found herein the cause why the albite in the perthites has formed hairs or strings or veins parallel to (801). The hair perthite, therefore, indicates the highest temperatures whereas the vein and patch perthites, found, *e.g.*, in granite pegmatites, have formed at lower temperatures.

Not infrequently hornblende occurs in association with the typomorphic granulite facies minerals in all charnockite provinces of the world. It is a special variety, greenish brown in colour, rich in titanium and abnormally deficient in hydroxyl, as found by Groves in the Uganda charnockites and as apparently is the case in other charnockites as well. The mode of occurrence of this brownish hornblende in association with hypersthene and garnet is perfectly that of a typomorphic mineral unlike the common green hornblende found as a product of alteration of pyroxene and garnet and representing change to some lower temperature facies. Biotite also occurs in two different manners, as an apparently typomorphic constituent and as a product of alteration. The typomorphic biotite, like the brownish hornblende, also seems to be low in hydroxyl. The stable-looking biotite is common in the rather coarse-grained granite-like charnockites and in the cordierite granulites, but absent in the foliated granulites, especially those containing sillimanite.

Muthuswami (1953) in his meritorious investigation of the mineral facies of hornblende- and biotite-bearing charnockites from Pallavaram near Madras places these to the almandine-diopside-hornblende subfacies of the amphibolite facies. This may be quite correct, but similar rocks from Lapland, Saxony, and Lower Austria known to me and containing that typical brownish hornblende, in my opinion are better grouped as a subfacies of the granulite facies. Al-rich varieties of the same areas usually contain cordierite, so these may possibly belong to the same subfacies.

Epidote is, on the whole, rather an uncommon product of alteration in the charnockites, and so is also sphene, which is typomorphic in the amphibolite facies. The typomorphic titanium minerals in the granulite facies are rutile and ilmenite, the former occurring in the acid charnockites and the latter in the basic charnockites.

Yoder's investigation

Yoder (1952) discusses the metamorphism of the mineral assemblages in the system MgO- Al_2O_3- SiO_2- H_2O on the basis of experimental investigations. He concludes (p. 615) that "at approximately 600° temperature and 1500 psi pressure of water vapour, it is possible to have assemblages suggestive of every one of the now accepted metamorphic facies in stable equilibrium." Yoder continues: "The differences between these facies are the result of variation in bulk composition and need not represent variations of pressure and temperature. This conclusion, based on experimental fact, appears to be at variance with field observations......The sequence of progressive metamorphism established in one area, presumably in homogeneous layers, cannot be directly applied to another area as a temperature scale unless the bulk compositions have been established as identical. For example, the temperature of appearance of enstatite in a bed deficient in water will be different from that in a bed containing excess water. It is necessary, therefore, to construct a new facies classification based on a fixed composition, or on several independent compositions, particularly sensitive to temperature and pressure. This project may have to await further experimental work."

"In no way should these remarks be constructed as detracting from the value of the concept behind the Facies Classification. Eventually sufficient data will be accumulated from which a critical group of assemblages can be selected as an indicative of grades of metamorphism. Until these data have been collected, one should be wary of assigning temperatures and pressures of formation for metamorphic rocks of different bulk compositions which are not continuous in the same pressure and temperature gradients."

Yoder's results were surprising to those who like me had been accustomed to regard the minerals of the different facies to be stable at different temperature ranges. The result, in fact, as he says himself, appeared to be at variance with the field observations.

As a criterion of chemical equilibrium in mineral assemblages I had considered the circumstances that it can be reached both from below and from above. From below at rising temperature, for instance in contact metamorphism, and from above at falling temperature, as in magmatic rocks after consolidation. All crystalline rocks have after their final magmatic or metamorphic crystallization passed through levels representing successive decreasing temperatures. It is to be expected, therefore, that any crystalline rock should, besides its stable main constituents, contain products of alteration formed at successively lower temperatures. This, in fact, is generally the case.

Let us take, as an example, olivine dolerite, a hypabyssal rock, crystallized from a water-poor magma. Its chief minerals, as a rule, constitute an equilibrium assemblage, but in most specimens one will also find a series of products of alteration whose sequence of crystallization can be established with certainty. Yoder found experimentally (1952, p. 608) that the metamorphism of argillaceous sediments in the presence of excess water would give at increasing temperature successively kaolinite, serpentine, forsterite, enstatite (and sillimanite), cordierite, tridymite. Now, this sequence is just the opposite to that observed in the products of alteration, as is to be expected from an equilibrium series at decreasing temperature. Thus there is, in Yoder's own results, clear evidence of the progressive metamorphism in the series of mineral facies from the lowest to the highest.

But, on the other hand, Yoder's experimental result implies that the same sequence of mineral facies could also be reached at a constant temperature by change of bulk composition, in this case the amount of water present. In other words, the products of alteration in the olivine dolerite would be the same, if the temperature was constant and the water concentration increased due to decrease of residual liquid at progressive crystallization. Everybody will agree that in this case fall of temperature has taken place at the same time. To a certain degree this must generally be the case in normal metamorphism.

Charnockite, in contrast to dolerite and most other rocks, mostly contains very small amounts of alteration products, although the rock certainly has cooled. An original deficiency in water must have been an important, sometimes perhaps the only cause to development of the granulite facies.

Occasionally charnockites and granulites, however, may be quite strongly altered to lower facies containing green hornblende, epidote, *etc.* In Lapland, Eskola (1952, p. 166) found in places a peculiar mode of occurrence of amphibolite alternating with granulite, described as follows: "Such rocks in many cases show no relict features from the granulite facies. Their granoblastic texture is very similar to that of the granulites, but the minerals are strikingly different: common green hornblende, sphene instead of rutile or ilmenite, and flame perthite instead of hair perthite."

It is hardly possible to assume different temperatures in such alternating layers, but after Yoder's work it is clear that the amphibolite layers have been more permeable and soaked with water vapor. Tectonized zones are frequently amphibolitized in charnockites. A good example is furnished by the so-called trapschotten granulites in India (Pichamuthu, 1953).

When writing his last exposition of the mineral facies the present author was well conscious of the difficulties resulting from the variation of bulk composition (Eskola, 1939, pp. 343-344). The belonging of a rock to a certain facies is ascertained from the so-called critical minerals or assemblages, stable in one facies only. It is particularly the amount of water and carbon dioxide that causes complications, and this is especially true of the granulite facies. The mineral facies classification, as Yoder says, must be reformed on an exact basis to meet these complications. It seems to me, however, that the experience gained in the application of the facies principle by various workers in many countries has proved its usefulness even in its present, only qualitative state, and that the cases where it has lead to erroneous results are neither numerous nor very serious.

Role of water-deficiency in the genesis of charnockites

One of Yoder's conclusions is that pyrope is stable in water-deficient systems only.[2] He continues the discussion in another paper (Yoder, 1955) objecting to the opinion of Ramberg (1952) that water is universally present and "always in adequate supply". Yoder concludes that often the genesis of hydroxyl-bearing minerals will be prohibited due to lack of water. Argillaceous sediments have "more than enough water to transfer the rock into the most hydrous assemblage of metamorphic minerals", whereas a sediment that "initially consisted of an assemblage of minerals that are completely dehydrated on compaction, as may be the case in some arcoses" have not, "the water-content would then depend on the porosity and permeability of the sediment. In the extreme case of a nonporous, impermeable sediment, only anhydrous minerals could be produced by metamorphism. Granulites, for example, may have formed in the absence of water at low temperatures, or at high temperatures in the presence of water above the stability range of hydrous minerals ...... There are objections, therefore, to the concept of the ubiquitous occurrence and adequate supply of water as a free phase in metamorphism" (Yoder, 1955, p. 518).

To this may be remarked that in many cases the initial rock has been just of the kind that Yoder considers to have been water-rich originally. Thus, the Khondalites have been argillaceous sediments. The same is true of the cordierite granulites of Finnish Lapland which, moreover, are rich in graphite, a probable evidence of their origin as sapropelic sediments (Eskola, 1952, p. 158). Similarly, charnockite pegmatites in India (*e.g.* Rama Rao, 1945), Greenland (Ramberg, 1948, 1956) and Lapland (Eskola, 1952, p. 169), being of an origin like ordinary granite pegmatites, either primary magmatic, as I believe, or metasomatic, as believed by Rama Rao and Ramberg, have probably been hydrated originally, but are now composed of typical anhydrous granulite facies minerals including hypersthene and garnet. The absence of water most probably was a consequence of high temperature which, therefore, appears to be the *prima causa.* In this point I agree with Ramberg.

2. This result suggests, in my mind, the question whether natural pyrope which, in the eclogites and olivine rocks as well as in granulites, invariably contains appreciable amounts of almandine, behaves like pure pyrope in regard to water-deficiency. In Yoder's papers I have found no comment to this question.

From my field experience in the Archaean of Finland I can afford some evidence that in fact water must have been universally present wherever needed in metamorphism. The rocks mostly contain hydrous minerals of the amphibolite or some still lower facies, but many of them have most probably been anhydrous originally, such as basalt or arcose. Yet surrounded by such rocks is the charnockite district of Western Uusimaa where one will find rocks of any primary origin crystallized in the granulite facies with solely anhydrous minerals.

The hydroxyl as well as the oxygen ions tend to migrate upwards in the lithosphere. Szadeczky-Kardoss, in several important papers (1955 a and b), has demonstrated the relations of element migrations to the potentials of ions, atoms and compounds, as well as their specific gravities or "wichtes". For this reason the hydroxyl tends to move upwards until, at the fall of temperature, it is eventually arrested in the lattices of minerals.

Many facts, on the other hand, speak for Yoder's conclusions. Rosenqvist (1952), who like me believes that the granulites and eclogites generally owe their facies to temperatures and pressures higher than those of the amphibolite facies, admits that water-deficiency at low temperature may lead to assemblages of the granulite and eclogite facies and calls this process dipsenic metamorphism (from Greek διψην = thirsty). Such rocks as anorthosites, closely related to the granulite facies (cf. Goldschmidt's "Anorthosit-Charnockit-Stamm"), indeed behave as though thirsty rocks, being often thoroughly saussuritized and otherwise hydrated.

Goldschmidt (1920) probably was the first to seek the cause of water-deficiency of magmatic charnockites (mangerites) in the dryness of the magma and the surrounding older rocks, whereas, according to him, the trondhjemites have differentiated from magmas intruded into folded water-rich argillaceous sediments. In the Turku district, S.W. Finland (Hietanen, 1947), zones of trondhjemite and charnockite alternate. As both rocks occur near each other and both are now similarly injected with younger granite and migmatized, they cannot be assumed to have crystallized at different temperatures, and the water deficiency of the charnockites can in this case only be sought in the dryness of their past materials.

After all, we find that in some cases water-deficiency and in others high temperature causes the genesis of the granulite facies. The two causes do not exclude each other, for crystallization in

dry materials, as in dry magmas, takes place at much higher temperatures than in such soaked with water vapor, while, on the other hand, high temperature promotes drying. Scheumann (1954) also finds that the genesis of the eclogite and granulite facies requires strong pressures and high temperatures. He regards the Saxonian granulites as metamorphic rocks, although largely soaked with magmatic solutions. An important moment in their metamorphism is what he calls phyrasis, or dry grinding of the minerals, apparent in the marginal zones of the granulite massif as the typical lamination with platy quartz. Scheumann, like Eskola (1921), sees the best evidence for the great pressure at the genesis of eclogites and granulites in the great density of many of their minerals, like garnet, jadeite, omphacite, kyanite, rutile, diamond. In later years it has been found that in many cases (jadeite, glaucophane schist) the supposed high-pressure minerals cannot have formed under exceptional hydrostatic pressures. It seems, therefore, now rather that low temperature may act in the same direction as high pressure provided stress or mineralizers, acting as catalyzers, can bring forth reactions at low temperatures. It cannot be doubted, however, that high pressure, in accordance with the equation of Clausius-Clapeyron, has been a general promoter at the genesis of the granulite facies.

Rosenqvist (1952) proposes that phase transitions of the feldspar minerals and the characters of perthites should be used to define the exact boundaries between different facies. As recently much progress has been achieved in the experimental studies on feldspars, this proposal seems worthy of consideration. New geological thermometers and barometers, however, have been found, and may still be found, in other mineral groups as well.

Mode of origin of charnockites

India is the true home of the charnockites. It is quite true, as Pichamuthu says, that the charnockite problem cannot be solved without consideration of the Indian occurrences. The writer has not been in that country and the literature dealing with the Indian charnockites is too comprehensive and partly inaccessible here. Fortunately we now possess the exhaustive, critical review by Pichamuthu (1953). This work for me personally is the more congenial, as his general conceptions closely agree with mine. His book is particularly valuable, because he reviews at length, with numerous quotations, the classical memoirs on charnockites by Holland.

Holland studied the charnockites primarily at St. Thomas Mount and at Pallavaram near Madras. The charnockites occur as great masses, one of them, the Nilgiri Plateau, being 700 square miles. Sometimes they are quite massive and have a uniformity of composition throughout. Holland says there is no equivalent among sedimentary formations or the old metamorphic rocks like the Dharwars for such homogeneous masses of rock. In detail they are, however, schlieric and may contain angular fragments of basic rocks as well as darker schlieren with unsharp contacts. Almost every mass also affords examples of vein-shaped schlieren. According to Holland these represent the consolidation of the more acid residual portions of the magma, being comparable to venitic pegmatites. Except the general schlieric banding there are veins of a much more perfect kind, which, in some cases at least, are due to *lit-par-lit* injection.

The importance of the chemical composition as a criterion of origin was well understood by Holland. He was the first to distinguish acid, intermediate, basic, and ultrabasic charnockites. Each of these types has its counterpart among the common magmatic rocks: granites, diorites, gabbros, and peridotites. This fact was regarded as a strong evidence that the charnockites also are magmatic rocks.

Today, after Bowen and Tuttle, in a work unpublished when this is being written (summarized by Abelson, 1955), have definitely established the crystallization of granite as the end phase of crystallization differentiation from the residual magma, we know the composition of the lowest melting "haplogranitic" magma and, on the other hand, that a great majority of the granites closely approach this composition. A comparison with analyses of charnockites shows that great many acid members of this group also agree with these rocks in their cation ratios, while intermediate, basic and ultrabasic charnockites are like diorites and so forth. These facts afford a firm basis for the assumption presented by Holland that the charnockites in their differentiation behave like the calcalkaline suite of magmatic rocks, and that the charnockites can crystallize directly from magmas.

To this conclusion, however, we must make one important reservation: it is not sure that the charnockites have attained their present mineral composition, or their mineral facies, directly by magmatic crystallization and not by later metamorphism with unchanged bulk composition.

One of the earliest petrologists in India to suggest a metamorphic mode of origin for Holland's charnockite series was Vredenburg (1918). He started from the observation that, in some epidioritic Dharwars, the augite was formed by a recrystallization of uralite. Vredenburg considered this as an example of "a schist caught, so to speak, in the very act of transformation into a granulite". The association of charnockites and khondalites recalls the occurrence of metamorphosed igneous and sedimentary rocks of the Dharwars and would have nothing to surprise us, as it would simply represent an alternation of volcanic and sedimentary beds. In a summary, the charnockites according to Vredenburg are metamorphosed magmatic rocks, primarily like basalts and andesites, and hypabyssals. The khondalites and other clearly sedimentogeneous rocks were not regarded by him as charnockites.

A more extreme transformistic view was taken by Ghosh (1941) in his study of the charnockites of Bastar and W. Jeypore, interpreted as impure calcareous sediments originally. Hypersthene was regarded as secondary after diopside and the change of basic rocks to acid charnockites as a result of the influx of alkalies from granitic magma.

Rama Rao (1945) found in the charnockites of Mysore much more variation in texture, composition and mode of origin than Holland had found in neighbouring areas. He assumed transformations of minerals in connection with their origin, effected by reactions from influx of acidic solutions. For instance, in the Biligirirangan Hill range charnockite has been formed from sedimentogeneous sillimanite quartzites by feldspathization of quartz, and transformation of ilmenite to mafic minerals from the injection of alkaline fluids connected with the intrusion of the younger Closepet granites which, in many cases, have been held responsible for charnockitization of various rocks. Basic charnockites of noritic composition were explained as crystallizations from contaminated gabbroic magmas that had assimilated aluminous sediments, an idea first suggested by H. H. Read.

Pichamuthu criticizes Rama Rao's conclusion concerning the role of the Closepet granite: "Where such basic charnockites have come within the influence of the younger granites, the effect has been for the progressive transformation of minerals in accordance with the reaction series: Hypersthene-augite-hornblende-biotite. By the intrusion of this granite, therefore, far from charnockites being formed, the existing members of this series became degraded or 'decharnockitized'." Indeed, from the mineral facies principle, a granite which itself belongs to a lower facies, cannot cause the appearance of a higher facies. The water-content, normally present in the granite magma, alone prohibits charnockitization.

Holland had described intrusive tongues or apophyses from the charnockite into a biotite gneiss in a quarry near the town of Salem and regarded this as an evidence for the intrusive nature of charnockite. I wish to put on record some of his words in this connection, as they, in my opinion, clearly show that this pioneer in Indian petrology was far ahead his time in objectivity of observation. He has written (quoted by Pichamuthu, 1953, pp. 132-134): "Whilst the tongues of charnockite are easily, at a glance, distinguished from the gneiss they protrude into, close examination of the junctions shows that, instead of there being a sharp line between the two rocks, there is a very rapid, though gradual, transition from one to the other. Besides this, dark patches occur in the charnockite parallel to the dark patches of micaceous mineral which in the biotite-gneiss indicates its foliation. The charnockite veins look, therefore, as if they were pseudomorphs very imperfectly retaining the structures of the rock they have corroded and replaced". After a long discussion he left the problem undecided and reverted to it the following year but could not reach any other conclusion except that "the absence of chilled selvages and the presence in the charnockite of indistinct dark patches parallel to the dark patches in the gneiss show: that the charnockite tongues have not been intruded into fissures in the gneiss after the fashion of a simple igneous injection; but rather that the 'trespass' was more of a nature of corrosion, imperfect pseudomorphs of the old structure being preserved by this corroding charnockite magma".

Pichamuthu (1953, p. 134) expresses Holland's conclusion more in the terminology used at present time as follows: "These facts, especially the last one regarding the presence of gneissic relics in charnockites, are in favour of replacement origin. Charnockitization appears to be the best term for explaining this conversion of biotite gneiss into charnockite".

Pichamuthu's own vision of the genesis of the Indian charnockites seems to be approximately as follows, though I am not quite sure whether I have not therein mixed my own ideas from the study of charnockites and granulites in Finland: in India, ancient Archaean formations, the Dharwars, are mainly metamorphosed in the Amphibolite facies, just as the Svecofennides in Fennoscandia. In South India erosion in Archaean times has laid bare formations metamorphosed at deeper levels and in the granulite facies. These are the Charnockite Provinces of Sir Leigh Fermor. This old complex comprises plutonic, vulcanic, and sedimentary rocks, including hypabyssal dyke-rocks, all disguised as charnockites. Later, but still under the granulite facies conditions, younger magmas were intruded in the charnockites giving rise to the transgressive dykes. They may be palingenic dykes, but whether they are juvenile or palingenic is of no concern for the problem of their genesis. There are "charnockites and charnockites", as Pichamuthu has put it (1953, pp. 126-129).

Among the granulites and charnockites (enderbites) of Finnish Lapland, likewise, the primary character of the rocks is most variegated (Eskola, 1952). The enderbites and many of their pegmatites were interpreted as primary magmatic. Many noritic granulites have originally been hypabyssal dyke-rocks, and there is an abundance of primary argillaceous sediments, now cordierite and sillimanite granulites, and quartzitic granulites. Cordierite-quartz rocks or laanilites were possibly products of magnesium metasomatism originally, while many of the highly tectonized acid granulites by their high and variable silica and chemical abnormities suggest some kinds of metamorphic differentiation.

The charnockite province of western Uusimaa in Finland is another area where rocks of the granulite facies are exceedingly variegated in structure, composition and probable origin. Parras (1941) has published a preliminary report of this district. As his exhaustive investigation is expected to be soon available, I do not wish to anticipate his results.

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The Floral Morphology and Embryology of the Loranthoideae (Loranthaceae)

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Danser (1929, 1933a, b) published several monographs on the taxonomy of the Loranthoideae and revised the nomenclature. He classified this subfamily into 51 genera and erected an additional genus, *Thaumasianthus*. Engler & Krause (1935) followed him in many respects but recognized only 25 genera.

Ernst (1942) pointed out that the divisions of the Loranthoideae into tribes and subtribes by Danser (1929, 1933a, b) and Engler & Krause (1935) should be checked on the basis of embryological evidence.

The first reasonably satisfactory account of the development of the reproductive organs of the Loranthoideae was given by Treub (1881). Working on *Loranthus sphaerocarpus* (= *Macrosolen cochinchinensis*), he reported that the tip of the floral axis grows into the ovarian cavity forming a three- to four-lobed mammiliform structure, the "mamelon", which is fused with the ovary at as many points as the number of carpels. Treub regarded the lobes as rudimentary ovules and the central part as the placenta. Concerning the development of the female gametophyte, he stated that the megaspore mother cell divides to form a row of three cells of which the uppermost[3] gave rise to the embryo sac. Treub also observed the formation of a composite endosperm arising by the fusion of the endosperm of several embryo sacs and the extremely long suspensors carrying the proembryo downwards into the ovary. In *Loranthus pentandrus* (= *Dendrophthoe pentandra*), Treub (1883) found the elongation of the sporogenous cells to result in a slight elevation at the base of the ovarian cavity which remained free from the ovary wall. He interpreted this as a "rudimentary placenta". Six to seven embryo sacs developed in the

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3. Treub regarded the basal megaspore (the one away from the epidermis of the mamelon) as the uppermost.

same ovary and grew up into the style. The zygote divided vertically and further divisions were transverse leading to the formation of a long biseriate proembryo.

Subsequent to Treub's classic work, Rauch and Schaeppi & Steindl, working in Ernst's Laboratory, greatly extended our knowledge of the embryology of the Loranthoideae. Rauch (1936) gave a detailed account of *Scurrula atropurpurea* and *Dendrophthoe pentandra*, while Schaeppi & Steindl (1942) published some notes and observations on *Amyema gravis, Barathranthus axanthus, Dendrophthoe pentandra, Elytranthe parasitica, Helixanthera hookeriana, Lepeostegeres gemmiflorus, Macrosolen cochinchinensis, M. formosus, M. pseudoperfoliatus, Scurrula atropurpurea, S. lepidota, S. montana* and *S. parasitica*. The embryo sac was found to conform to the Polygonum type; its lower end extended down to the collenchymatous pad or tube, but the tip attained different heights in different genera sometimes extending close to the stigma.

Several members of the Loranthoideae have been studied at the University of Delhi: *Helixanthera ligustrina* (Maheshwari & Johri, 1950); *Macrosolen cochinchinensis* (Maheshwari & Singh, 1952); *Dendrophthoe falcata* (Singh, 1952); *Scurrula cordifolia, S. ferruginea, S. parasitica* and *S. pulverulenta* (Agrawal, 1954); *Helicanthes elastica* (Johri & Agrawal, 1954); *Amyema congener, A. miquelii, A. pendula* and *A. preissii* (Dixit, 1954); *Lysiana exocarpi, Dendrophthoe neelgherrensis* and *D. falcata* (Narayana, 1954a, b); *Nuytsia floribunda* (Narayana, 1955a); and *Lepeostegeres gemmiflorus, Tolypanthus lagenifer* and *T. involucratus* (Dixit, 1955, 1956a). Investigations on *Elytranthe capitellata, Taxillus cuneatus, T. sclerophyllus* and *Tapinanthus uhehensis* have already been completed and are awaiting publication. Studies on five other genera (*Atkinsonia, Barathranthus, Phyllodesmis, Struthanthus* and *Tapinostemma*) are in progress.

Of the above plants, *Dendrophthoe falcata* was collected from Agra, Bareilly and Lucknow; D. *neelgherrensis* from Kodaikanal (Madras) and Ceylon; *Elytranthe capitellata* from Bombay; *Helicanthes elastica* from Courtallam (Madras), Changanacherry (Kerala) and Mahabaleshwar (Bombay); *Helixanthera ligustrina* from Nepal; *Macrosolen cochinchinensis* from Dacca; *Scurrula cordifolia* from Kakinada (Madras), Courtallam and Hyderabad (Andhra); *S. parasitica* from Dacca; S. *pulverulenta* from Dehradun, Mussoorie, Courtallam and Mahabaleshwar; *Tolypanthus involucratus* from Gauhati (Assam); *T. lagenifer* from Khandala and Bombay; *Taxillus cuneatus* and *T. sclerophyllus* from Ceylon; and *Barathranthus lagenifer* and *Lepeostegeres gemmiflorus* from Indonesia.

In addition, material of *Amyema congener, A. miquelii, A. pendula, A. preissii, Atkinsonia ligustrina, Lysiana exocarpi* and *Nuytsia floribunda* was obtained from Australia; *Phyllodesmis kaempferi* from Japan; *Scurrula ferruginea* from Singapore; *Struthanthus androstylus, S. marginatus* and *S. stphylinus* from Rio de Janeiro (Brazil), *Tapinanthus uhehensis* from Bakoba (Africa) and *Tapinostemma acaciae* from Sudan (Africa).

Some of the more important results obtained during the last several years are discussed below in the light of earlier interpretations.

Calyculus—The morphological nature of the calyculus has been an object of much controversy. Roxburgh (1874) and Bentham & Hooker (1883) considered it to be a true calyx. Danser (1931) too uses the term calyx for the outer floral envelope, but Eichler (1878), Engler (1889), and Schaeppi & Steindl (1942) regard it as a special organ.

Eichler (1878) considered the calyculus to be an axial structure and this view was accepted by Engler (1888-1889) and Engler & Krause (1935). Schaeppi & Steindl (1942), who agree with the above interpretation, emphasize that the calyculus is never calyx-like, and the lobing of its margin, wherever present, is always irregular. Besides, the absence of any vasculature in the calyculus led them to conclude that there is no justification for regarding the calyculus as the calyx.

Working at Delhi, Narayana (1955a) has, however, reported the presence of vascular bundles in the five- to seven-toothed calyculus of *Nuytsia floribunda*. There is an outer whorl of six traces in the ovary and five of these enter the lobes of the calyculus whereas the sixth fades away. While further work is necessary, it now appears likely that the calyculus may in fact represent the calyx.

Mamelon—The ovary does not contain any normal ovule, but several species show a special mammiliform structure, called the mamelon, which arises from the base of the ovarian cavity (Schaeppi & Steindl, 1942; Maheshwari & Singh, 1952; Johri & Agrawal, 1954).

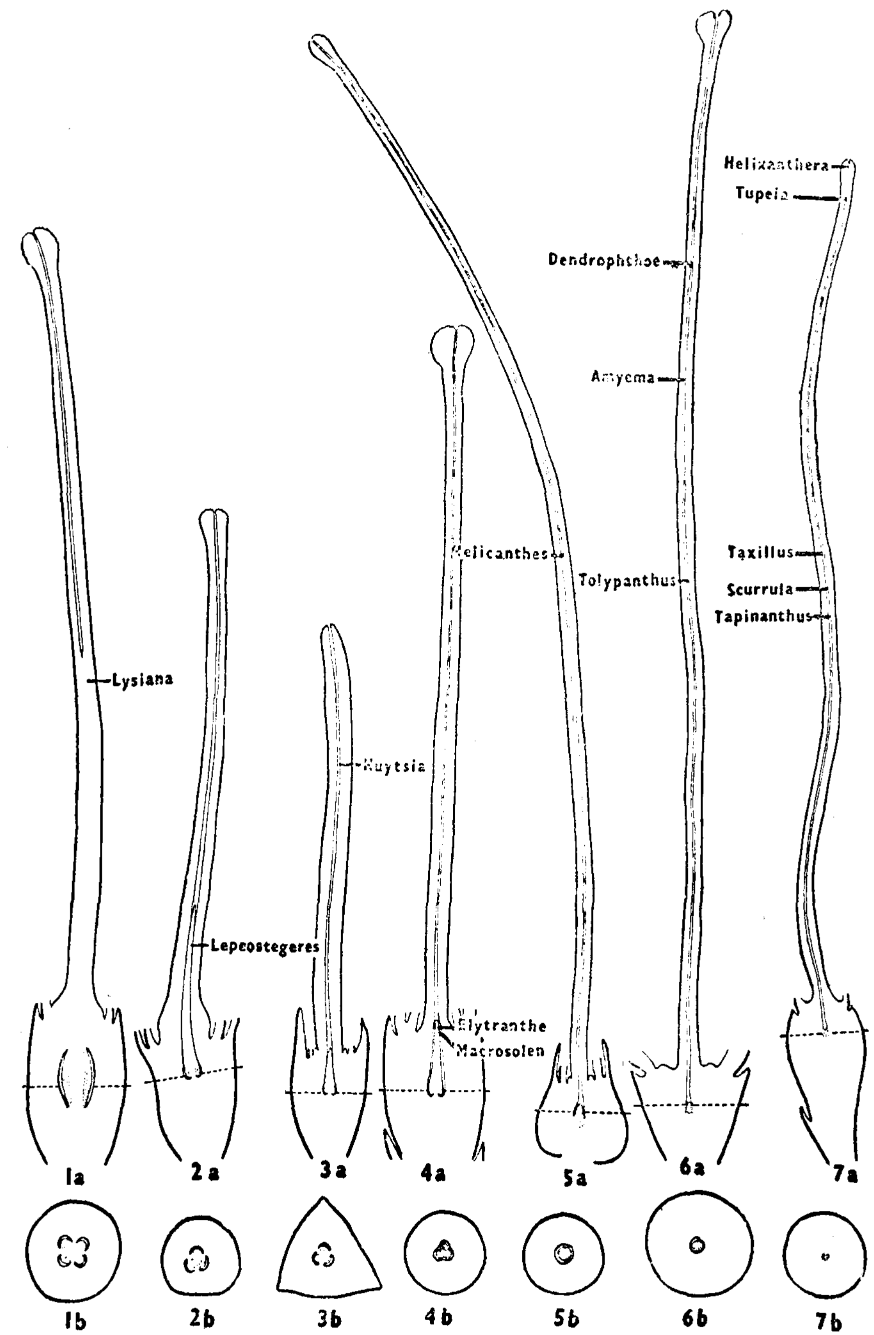
Griffith (1836, 1844) called the basal swelling in the ovary of "*Loranthus*" as the free central placenta, and in *Hyphear europaeum*, Hofmeister (1859) considered it equivalent to a single erect ovule. Treub (1881) interpreted the mamelon of *Macrosolen cochinchinensis* as a free-central placenta and the three to four basal lobes as equivalent to rudimentary ovules. Schaeppi & Steindl (1942), and Maheshwari & Singh (1952) agree with this view.

A feature of considerable significance is the presence of vascular elements in the mamelon. Isolated tracheids were first reported by Dixit (1954) in *Amyema miquelii* and since then they have also been recorded in *Dendrophthoe neelgherrensis* (Narayana, 1954b) and *Nuytsia floribunda* (Narayana, 1955a). It would be desirable to check up this feature in other species of the Loranthoideae, but on present evidence the vascular tisssue in the mamelon seems to represent the vestiges of the ventral bundles of a free central placenta.

Starting from a hypothetical inferior ovary with axile placentation and a single ovule in each locule, one may visualize the disappearance of the integuments and the reduction of the ovules to result in a condition similar to that of *Lysiana* (Figs. 1a, b). The next step in reduction is the retention of the partitions only in the lower region of the ovary, as in *Lepeostegeres* (Figs. 2a, b) and *Nuytsia* (Figs. 3a, b). In *Elytranthe* and *Macrosolen* the partitions have disappeared completely, but the mamelon retains a lobed appearance (Figs. 4a, b). In *Helicanthes* the lobes are already lost (Figs. 5a, b). In *Amyema, Dendrophthoe neelgherrensis, D. pentandra, Scurrula montana* and *Tolypanthus* (Figs. 6a, b) there is only a transitory swelling at the base of the ovarian cavity formed by the enlargement of the sporogenous tissue, and in *Helixanthera, Tapinanthus, Taxillus, Tupeia* and several species of *Dendrophthoe* and *Scurrula* there is a virtual disappearance of the mamelon (Figs. 7a, b).

Megasporogenesis—One to four archesporial cells differentiate in *Elytranthe* (Schaeppi & Steindl, 1942), *Macrosolen* (Maheshwari & Singh, 1952), *Lepeostegeres* and *Tolypanthus* (Dixit, 1955, 1956a), while there is a much larger number in *Dendrophthoe* (Singh,

Lysiana; 2a, b. ***Lepeostegeres***; 3a, b. *Nuytsia*; 4a, b. *Elytranthe* and *Macrosolen*; 5a, b. *Helicanthes*; 6a, b. *Tolypanthus, Amyema* and *Dendrophthoe*; and 7a, b. *Tapinanthus, Scurrula, Taxillus, Tupeia* and *Helixanthera*. The levels to which embryo sacs rise in the style are indicated by the names of the genera.



FIGS. 1a-7a. Diagrammatic representation of gynoecia (l.s.); note the mamelon in FIGS. 1a-6a. FIGS. 1b-7b. Cross sections of the ovary at levels indicated in longisections. The dotted regions represent sporogenous tissue. FIGS. 1a, b, 1952), *Scurrula* (Agrawal, 1954), *Helicanthes* (Johri & Agrawal, 1954), *Lysiana* and *Nuytsia* (Narayana, 1954a, 1955a). The sporogenous cells elongate and function as megaspore mother cells. The reduction divisions are normal and linear tetrads are formed.

Treub (1881) observed only a row of three cells in *Macrosolen cochinchinensis* of which the uppermost[3] developed further. Rauch (1936), Schaeppi & Steindl (1942) and Smart (1952) also describe the formation of 'triads' in *M. cochinchinensis, Scurrula atropurpurea* and *Tupeia antarctica* respectively. Maheshwari & Singh (1952) have criticised the observations of Treub and Rauch and have demonstrated undoubted linear tetrads in *M. cochinchinensis.* Occasionally, wall formation may be delayed in the dyad cell towards the epidermis and a triad may be formed. Such a behaviour has also been reported in *Dendrophthoe* (Singh, 1952; Narayana, 1954b) and *Scurrula* (Agrawal, 1954). Sometimes ⊥-shaped tetrads occur in *Amyema* (Dixit, 1954). Usually the basal[4] megaspore of the tetrad produces the gametophyte but Singh (1952) mentions that in *D. falcata* all the megaspores of a tetrad excepting the one lying towards the upper part of the ovary have the power of further growth. In *Amyema* and *Tolypanthus* (Dixit, 1954, 1956a) sometimes all the megaspores develop concurrently up to the two-nucleate stage.

Embryo Sac—Treub (1881) reported a three-nucleate stage in *Macrosolen cochinchinensis* but this has been contradicted by Maheshwari & Singh (1952). They have shown that a four-nucleate embryo sac is formed as usual (*see* also Schaeppi & Steindl, 1942). However, the two lower nuclei divide earlier resulting in a six-nucleate condition. Subsequently, the upper two nuclei also divide and the two quartets organize in the usual manner.

Smart (1952), working on *Tupeia antarctica,* was unable to follow the fate of the lower nucleus of the two-nucleate embryo sac. She stated that probably it divides once, but whether both the nuclei divide again or one of them functions directly as the lower polar nucleus could not be ascertained.

Pienaar (1952) also observed a three-nucleate embryo sac in *Loranthus rubromarginatus* (= *Tapinanthus rubromarginatus*).

3. Treub regarded the basal megaspore (the one away from the epidermis of the mamelon) as the uppermost.

4. The megaspore facing the epidermis of the mamelon should be regarded as the uppermost.

The two nuclei at the upper end divide to produce the egg apparatus and the upper polar nucleus. However, Pienaar was unable to follow the further fate of the nucleus at the lower end of the embryo sac.

Several embryo sacs may develop simultaneously in the same ovary (Figs. 8, 10); during their growth they digest the contents of the adjacent cells which are rich in starch.

The embryo sacs extend down up to the collenchymatous pad. Upward they go up to the base of the style or still higher (Figs. 1a-7a). In *Macrosolen cochinchinensis* (Fig. 4a) (Maheshwari & Singh, 1952) the tips of the embryo sacs extend only to the base of the style; up to one-fifth the length of the style in *Lepeostegeres gemmiflorus* (Figs. 2a, 8, 9a-c) (Dixit, 1955); half the style in *Helicanthes elastica* (Fig. 5a) (Johri & Agrawal, 1954), *Lysiana exocarpi* (Fig. 1a) (Narayana, 1954a), *Taxillus cuneatus, T. tomentosus* (Fig. 7a) (Narayana, 1955b), *Tolypanthus lagenifer* (Fig. 6a) (Dixit, 1956a), and *Tapinanthus uhehensis* (Fig. 7a) (Dixit, 1956b); and to two-thirds the height of the style in *Taxillus sclerophyllus* (Schaeppi & Steindl, 1942), *Dendrophthoe falcata* (Singh, 1952), *D. neelgherrensis* (Fig. 6a) (Narayana, 1954b), *Amyema congener, A. miquelii, A. pendula, A. preissii* (Fig. 6a) (Dixit, 1954), *Nuytsia floribunda* (Fig. 3a) (Narayana, 1955a) and *Tolypanthus involucratus* (Dixit, 1956a). In *Helixanthera hookeriana* (Fig. 7a) (Schaeppi & Steindl, 1942) and *Tupeia antarctica* (Fig. 7a) (Smart, 1952) the apex of the embryo sac reaches up to the stigma and in *Helixanthera ligustrina* (Figs. 10, 11) (Maheshwari & Johri, 1950) it grows as far as the stigmatic epidermis.

The antipodal cells appear to be ephemeral and have been missed in a number of species. Occasionally, only two cells are organized, one being binucleate, e.g. *Lepeostegeres gemmiflorus* (Fig. 9c) (Dixit, 1955). Persistent antipodal cells have been reported in *Macrosolen cochinchinensis* (Maheshwari & Singh, 1952), *Helicanthes elastica* (Johri & Agrawal, 1954) and *Lepeostegeres gemmiflorus* (Dixit, 1955). Schaeppi & Steindl (1942) misinterpreted the antipodal cells of *M. cochinchinensis* as the three non-functioning megaspores. Those of *L. gemmiflorus* were mistaken for a part of the proembryo (*see* Dixit, 1955).

Polar fusion has so far been observed only in *Macrosolen cochinchinensis* (Maheshwari & Singh, 1952) and *Lysiana exocarpi* (Narayana, 1954a) but may be presumed to occur in other species also. It is the lower polar nucleus which migrates to the upper part of the embryo sac and fuses with the upper polar.

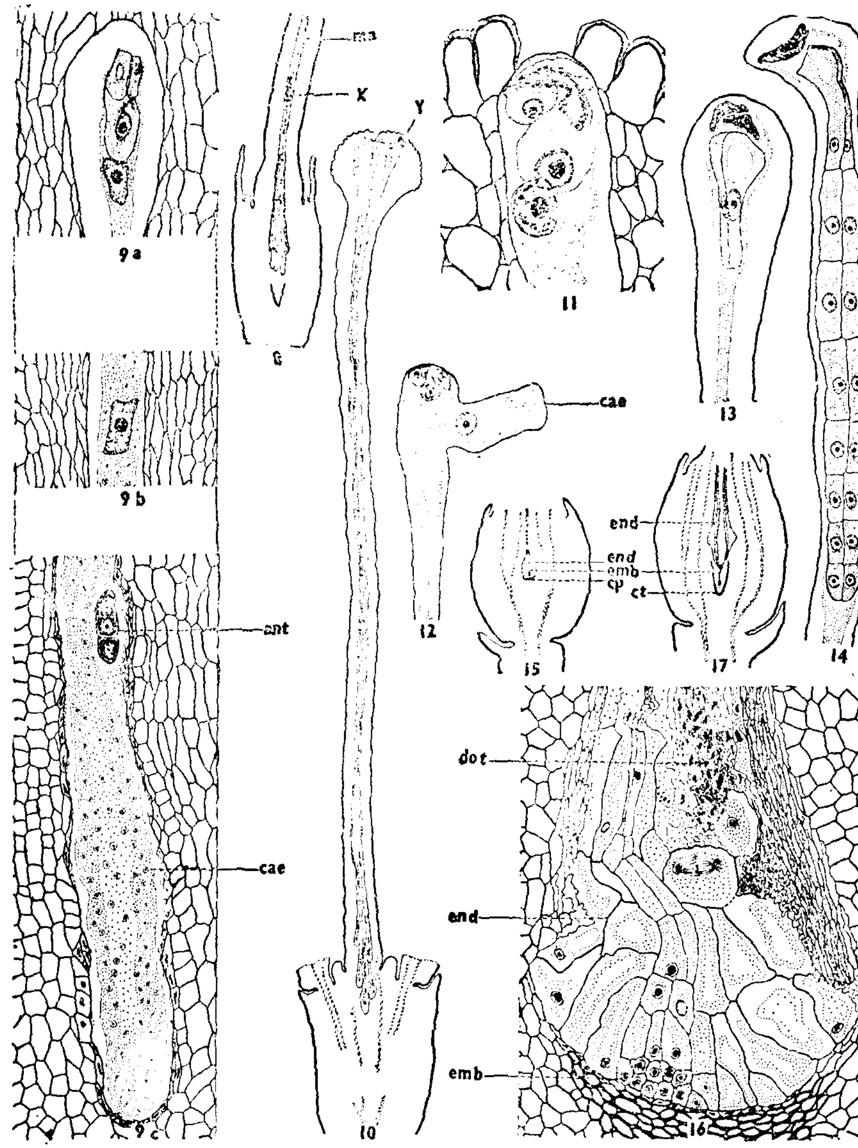
Maheshwari & Singh (1952) showed that in *Macrosolen cochinchinensis* a lateral pouch arises slightly above the level of the antipodals and progresses downwards as far as the collenchymatous tube forming a caecum. This has since been confirmed also in *Lysiana* (Narayana, 1954a) and *Lepeostegeres* (Dixit, 1955) (Fig. 9c). In *Nuytsia* (*Narayana*, 1955a) a lateral process also develops from the upper end of the embryo sac and is directed towards the wall of the style (Fig. 12). This feature has not been observed in any other member of the Loranthoideae and is comparable to the condition met with in *Comandra* (Santalaceae) (Ghosh, 1955).

Endosperm—The earliest observations on the development of the endosperm are by Griffith (1844) on *Dendrophthoe falcata* and *Macrosolen cochinchinensis*, and Hofmeister (1859) on *Hyphear europaeum*. A more detailed account has been given by Maheshwari & Singh (1952) in *Macrosolen* and Singh (1952) in *Dendrophthoe* (*see* also Rauch, 1936; Schaeppi & Steindl, 1942).

The initial stages in endosperm formation are known only in *Macrosolen cochinchinensis* (Maheshwari & Singh, 1952). The primary endosperm nucleus travels to the lower end of the embryo sac and the first division is followed by a transverse wall. Further divisions produce a four-seriate arrangement followed by additional divisions. Endosperm formation occurs in several embryo sacs in the same ovary and finally all of them fuse to form a composite structure (Figs. 15, 16—*Amyema preissii;* Fig. 17—*Lysiana exocarpi*). The mature endosperm is vase-shaped and its appearance largely depends on the vascular skeleton of the ovary (Figs. 18-31). During these changes the collenchymatous pad may often be shifted to a lateral position (Figs. 30, 31—*Tolypanthus lagenifer*).

Pienaar's (1952) description of the endosperm of *Tapinanthus rubromarginatus* leaves many doubtful points. According to him the upper polar nucleus degenerates soon after the differentiation of the egg. The large nucleus situated at the lower end of the embryo sac is regarded as the lower nucleus of the two-nucleate

Nuytsia floribunda (Labill.) R.Br. Upper end of the embryo sac with lateral caecum. (After Narayana, 1955a). × 194. FIGS. 13, 14. *Tolypanthus lagenifer* (Wight) Van Tiegh. (After Dixit, 1956a). FIG. 13. Two-celled proembryo. × 305. FIG. 14. Biseriate proembryo. × 305. FIGS. 15, 16. *Amyema preissii* (Miq.) Van Tiegh. (After Dixit, 1954). FIG. 15. Outline diagram of l.s. ovary showing endosperm and proembryo. × 10. FIG. 16. Same, enlarged. × 117. FIG. 17. *Lysiana exocarpi* (Behr.) Van Tiegh. L.s. ovary showing endosperm and embryo. (After Narayana, 1954a). × 6.



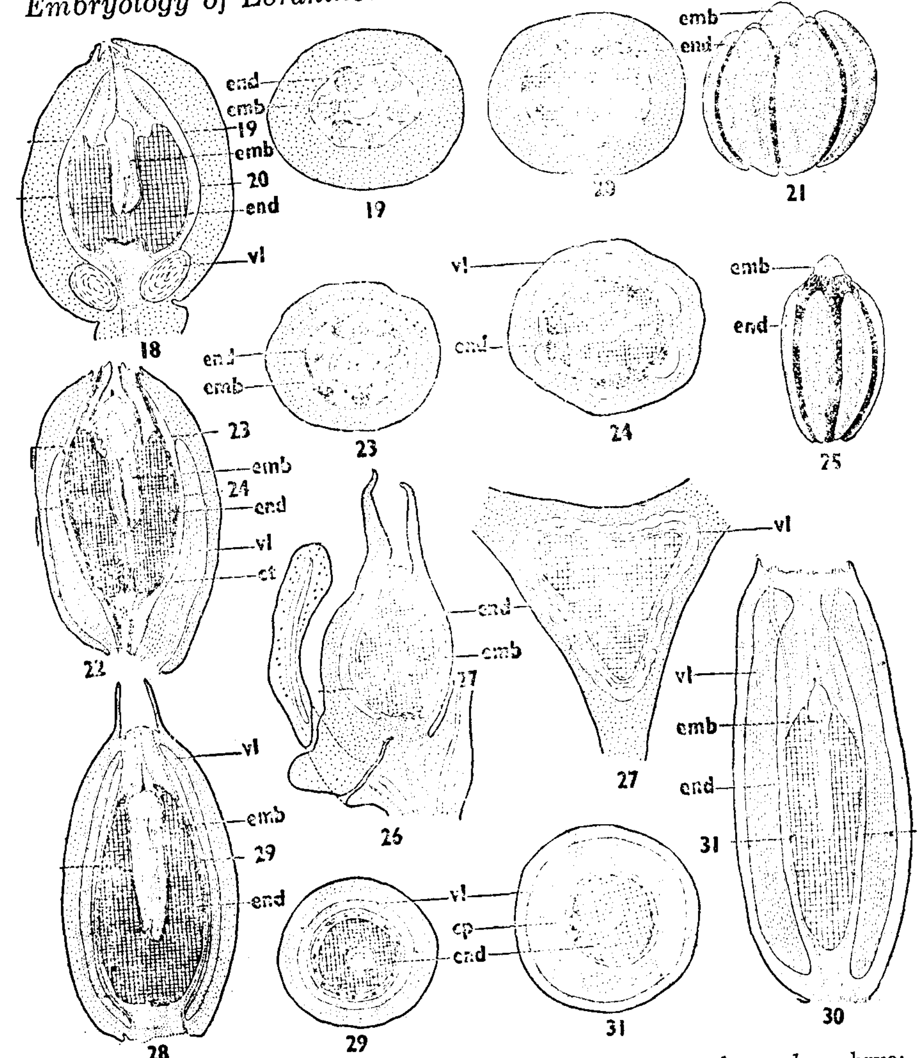
FIGS. 8-17. (*ant*, antipodal; *cae*, caecum; *cp*, collenchymatous pad; *ct*, collenchymatous tube; *dot*, degenerated ovarian tissue; *emb*, embryo; *end*, endosperm; *ma*, mamelon). FIGS. 8, 9. *Lepeostegeres gemmiflorus* Bl. (After Dixit, 1955). FIG. 8, L.s. ovary and lower portion of the style showing embryo sacs. × 10. FIGS. 9a, b, c. Upper, middle and lower parts of the embryo sac marked X in FIG. 8; note the caecum in FIG. 9c. × 384. FIGS. 10, 11. *Helixanthera ligustrina* (Wall.) Dans. (After Maheshwari & Johri, 1950). FIG. 10. L.s. carpel, tips of five embryo sacs are seen in the stigma. × 9. FIG. 11. Embryo sac (marked Y in FIG. 10) in contact with stigmatic epidermis. × 273. FIG. 12.

embryo sac. Since this cannot be equivalent to the lower polar nucleus the endosperm is considered to be homologous more to the antipodal cells of angiosperms than to the tissue arising after triple fusion, although its formation is said to commence only after the proembryo starts developing. Since Pienaar was unable to observe a close series of stages, it seems probable that he wrongly interpreted the primary endosperm nucleus as the lower nucleus of the two-nucleate embryo sac.

Embryo—Griffith (1844) recorded that in *Dendrophthoe falcata, Macrosolen cochinchinensis* and *Scurrula parasitica* the first division of the zygote is vertical. Treub (1881) confirmed it in *M. cochinchinensis* and since then it has been found to be the normal condition in the Loranthoideae (Fig. 13—*Tolypanthus lagenifer*). The vertical division of the zygote is rather rare in angiosperms but is also known in the Balanophoraceae (*Balanophora*—Zweifel, 1939; *Langsdorffia*—Fagerlind, 1945) and Santalaceae (*Comandra*—Gosh, 1955).

The second and subsequent divisions are transverse resulting in a long biseriate proembryo (Fig. 14—*Tolypanthus lagenifer*). In *Helicanthes elastica* (Johri & Agrawal, 1954), sometimes two proembryos, derived from different zygotes, may develop in a common cavity formed by the fusion of adjacent embryo sacs. According to Narayana (1955a) the embryos themselves might fuse in *Nuytsia.*

Several proembryos develop simultaneously in the style but only a few grow down to the ovary. They pass through the endosperm and reach as far as the collenchymatous pad or tube (Figs. 15, 16—*Amyema preissii;* Fig. 17—*Lysiana exocarpi*). The terminal tier of the proembryo undergoes repeated divisions forming a mass of cells. Due to the growth of the endosperm below the embryonal mass, the latter is eventually seen to occupy a more central position (Fig. 18—*Lepeostegeres gemmiflorus;* Fig. 22—*Lysiana exocarpi;* Fig. 26—*Nuytsia floribunda;* Fig. 28—*Helicanthes elastica*). Normally only a single embryo reaches maturity but two well developed embryos have been seen sometimes in *Dendrophthoe* (Singh, 1952; Narayana, 1954b) and *Lepeostegeres* (Dixit, 1955). The embryo is dicotyledonous but the cotyledons may fuse for part of the distance resulting in a pseudomonocotyledonous condition - Examples: *Helixanthera, Dendrophthoe, Scurrula, Helicanthes* (Figs. 28, 29), *Amyema* and *Tolypanthus* (Figs. 30, 31). A true radicle is absent and the radicular end has endarch collateral bundles (Singh, 1954). In *Lysiana*



FIGS. 18-31. (*cp*, collenchymatous pad; *ct*, collenchymatous tube; *emb*, embryo; *end*, endosperm; *vl*, viscid layer). FIGS. 18-21. *Lepeostegeres gemmiflorus* Bl. (After Dixit, 1955). FIG. 18. L.s. fruit. × 4. FIGS. 19, 20. T.s. at levels marked in FIG. 18. × 4. FIG. 21. Mature endosperm and embryo from whole mount. × 5. FIGS. 22-25. *Lysiana exocarpi* (Behr.) Van Tiegh. (After Narayana, 1954a). FIG. 22. L.s. fruit. × 4. FIGS. 23, 24. T.s. fruit at levels marked in FIG. 22. × 4. FIG. 25. Mature endosperm and embryo from whole mount. × 4. FIGS. 26, 27. *Nuytsia floribunda* (Labill.) R.Br. (After Narayana, 1955a). FIG. 26. L.s. fruit × 3·5. FIG. 27. T.s. at level marked in FIG. 26. × 4. FIGS. 28, 29. *Helicanthes elastica* (Desr.) Dans. (After Johri & Agrawal, 1954). FIG. 28. L.s. fruit. × 4. FIG. 29. T.s. fruit at level marked in FIG. 28. × 4. FIGS. 30, 31. *Tolypanthus lagenifer* (Wight) Van Tiegh. (After Dixit, 1956a). FIG. 30. L.s. fruit. × 4. FIG. 31. T.s. at level marked in FIG. 30. × 4.

(Figs. 22, 23) and *Helicanthes* (Fig. 28) it shows papillate outgrowths whose significance is not quite clear. Perhaps they may form lateral roots but this has to be confirmed by a study of germination stages.

Fruit—The structure of the fruit is more or less uniform. The pericarp is distinguishable into four distinct zones. The outermost is leathery (*Amyema, Dendrophthoe, Helicanthes, Tapinanthus, Taxillus* and *Tolypanthus*) or sometimes fleshy (*Lepeostegeres, Lysiana, Macrosolen* and *Nuytsia*). The next is the viscid layer followed by a parenchymatous and vascular zone. In *Lepeostegeres* (Fig. 18—Dixit, 1955) the viscid layer is limited only to the base of the fruit.

The seed is 'naked' in the sense that it lacks a testa and the pericarp directly surrounds the endosperm (Figs. 18-31). The latter is massive and is deeply lobed in *Macrosolen, Lysiana* (Figs. 22-25) and *Lepeostegeres* (Figs. 18-21). In *Dendrophthoe falcata, Macrosolen, Lysiana* (Fig. 25) and *Lepeostegeres* (Fig. 21) the apical portion of the endosperm is drawn out into five or six prongs and the base is also truncated.

Summary and Conclusion

The family Loranthaceae has been classified into the subfamilies Loranthoideae and Viscoideae (Engler, 1888-1889; Danser, 1929, 1933a, b). Danser (1929) states: "Before Van Tieghem, only Miers seems to have divided the Loranthaceae into more than one family, taking the Viscoideae as a family apart under the name Viscaceae, and he was followed in this respect by Miquel. I do not see the necessity of any of these subdivisions." In view of the embryological data available since Danser's statement, the question needs a fresh study (*see* also Maheshwari, 1954).

In the Loranthoideae the flower may be unisexual or bisexual but a calyculus is invariably present. The ovary may contain a lobed mamelon which may be fused with the ovary wall in between the lobes, e.g. *Lepeostegeres; Lysiana* and *Nuytsia*; or the mamelon may be free as in *Elytranthe* and *Macrosolen*. A free mamelon but without any lobes occurs in *Helicanthes;* it is extremely short in *Amyema, Dendrophthoe neelgherrensis* and *Tolypanthus;* and is absent in *Barathranthus, Dendrophthoe falcata, Helixanthera, Scurrula, Tapinanthus, Taxillus* and *Tupeia*. The presence of a collenchymatous pad or tube in the ovary is also a characteristic feature of the Loranthoideae. The embryo sac is of the Polygonum type. Many embryo sacs may develop simultaneously in the same ovary and their tips grow up into the style. The lower end of the sac sometimes produces a caecum, e.g. *Amyema, Lepeostegeres, Macrosolen* and *Tolypanthus*. The endosperm is a composite structure formed by the fusion of all the endosperms developing in the same ovary. The first division of the zygote is always vertical and is followed by transverse divisions resulting in a long biseriate proembryo. The fruit shows four distinct layers and the viscid layer is situated outside the vascular bundles of the 'corolla' (*see* Danser, 1931).

In the Viscoideae, the flowers are unisexual (Danser, 1931), and the calyculus is generally absent but is known to be present in *Viscum orientale* and *V. articulatum* (Schaeppi & Steindl, 1945). The central ovarian papilla has two or more archesporial cells, each of which divides to form two dyad cells. Of these, the upper dyad cell is the larger and functions, while the lower soon degenerates. Thus the development conforms to the Allium type and has been described in *Ginalloa* (Rutishauser, 1937), *Korthalsella* (Rutishauser, 1935, 1937; Schaeppi & Steindl, 1945) and *Viscum* (Schaeppi & Steindl, 1945). A peculiar feature is that after the four-nucleate stage there is a slow but steady curvature of the embryo sac, which causes its lower end to bend out of the papilla and proceed upwards into the carpellary tissue. The egg apparatus differentiates from the quartet in the originally lower pole, which is, however, now situated at a higher level than the upper — Examples: *Dendrophthora* (York, 1913), *Phoradendron* (Billings, 1933) and *Korthalsella* (Rutishauser, 1935, 1937). The embryo sac is straight in *Viscum* (Schaeppi & Steindl, 1945), *Arceuthobium* (Thoday & Johnson, 1930) and *Ginalloa* (Rutishauser, 1937). Generally only one embryo sac develops which is said to show inverted polarity. Maheshwari (1948) draws attention to the fact that the embryo sacs "although apparently inverted, are not really so." The endosperm is derived from the primary endosperm nucleus of a single embryo sac. The first division of the zygote is usually transverse but sometimes vertical as in *Korthalsella* (Rutishauser, 1935) and the embryo lacks a suspensor (Thoday & Johnson, 1930; Schaeppi & Steindl, 1945). The viscous part of the fruit is situated within the vascular bundles of the perigone (Danser, 1931).

Thus, the Loranthoideae and the Viscoideae show important differences in floral structure, mode of development of the embryo sac, endosperm and embryo, and in the location of the viscid zone of the fruit. These differences adequately warrant the raising of the two subfamilies to the rank of families. As proposed by Miers (*see* Danser, 1929), the name Loranthaceae may be retained for the Loranthoideae and the Viscoideae may be designated as Viscaceae.

We are grateful to several fellow botanists who very kindly provided the material on which the said investigations are based, particularly to Dr. R. D. Adatia (Bombay), Miss A. M. Baird (Australia), Dr. C. M. Eardley (Australia), Dr. R. E. Holttum of Singapore (now at Kew), Dr. K. Wilson Jones (Sudan), Dr. T. S. Mahabale (Poona), Dr. H. S. McKee (Sydney), Mr. A. Nagaraja Rao (Bangalore), Prof. Y. Ogura (Tokyo), Mr. V. Raghavan (Gauhati), Prof. M. S. Raghavachari (Kerala), Dr. C. Rizzini (Rio de Janeiro), Mrs. E. L. Robertson (Adelaide), Rev. Father H. Santapau (Bombay), Prof. T. S. Sadasivan (Madras) and the Director of Agriculture, Dar-Es-Salam, Bakoba (Africa). Thanks are also due to Mr. M. B. Raizada, Forest Research Institute, Dehradun, and the Director of the Royal Botanic Garden, Kew, for identification of the specimens, and to Miss Sudha Garg for the assistance in the preparation of this paper.

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Some Early British Contributions to Essential Oil and Terpene Chemistry

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One hundred years ago the University of Madras was founded. It is an interesting coincidence that in this year the centenary of Perkin's discovery of the first synthetic dyestuff, mauveine, is also being celebrated.[1] The opening of a factory by Perkin to manufacture this dyestuff inaugurated the first organic chemical industry thus stimulating an intensive study of the chemistry of organic compounds. It appears, therefore, not to be without interest to place on record the early contributions of British chemists to essential oil and terpene chemistry.

From very early times essential oils have provided the main source of materials for the manufacture of perfumes and cosmetics, whilst they have also found an extensive use in pharmacy and as ingredients of spices. In mediaeval literature India is frequently mentioned as the source of such well-known perfumes as attar of roses and sandalwood. It is, however, only during the last hundred years that any detailed knowledge of the constituents of essential oils has been obtained. This is perhaps not surprising in view of their complexity and the difficulties involved in the separation and the purification of their constituents since, apart from camphor and borneol, they are liquids.

A perusal of the articles in the standard text-books would lead to the conclusion that our knowledge in this important field of chemistry has been due in the main to the researches of foreign chemists and that British chemists made only minor contributions. Whilst not desiring to minimise the important investigations associated with the names of Aschan, Baeyer, Barbier, Berthelot, Komppa, Semmler and Wallach it is the purpose of this brief article to direct attention to the pioneering researches of British chemists to whom are due many of the experimental methods so

1. Robinson, *Endeavour*, 1956, 15: 92; Simonsen, *Research*, 1956, 9: 166.

successfully applied in this difficult field. To these chemists are undoubtedly due (i) the first method for the characterisation of essential oil constituents, (ii) the use of dehydrogenating reagents for their conversion into aromatic hydrocarbons, later identified by oxidative degradation and (iii) the introduction of the use of physical constants as a means of identification. In considering these early investigations it must be borne in mind that at the time they were undertaken knowledge of structure, as we now understand it, was extremely limited.

The first important investigation to which attention may be directed was by Greville Williams,[2] who, by the pyrolysis of rubber and guttapercha, obtained a hydrocarbon, cautouchcene, $C_{10}H_{16}$. He recognised that this hydrocarbon was isomeric with the hydrocarbon present in oil of turpentine and he proceeded to investigate the action of bromine on the two hydrocarbons. He found that they both gave bromo derivatives which, after treatment with sodium, furnished the same hydrocarbon, "cymol", yielding on oxidation with potassium dichromate and sulphuric acid an acid, "isolonic acid". In this early communication we find the first use of methods later applied with such success, namely, dehydrogenation to an aromatic hydrocarbon followed by oxidative degradation. The method employed was essentially the same as that generally associated with the names of Baeyer and Villiger.[3] They were probably unaware of the work of Greville Williams since they do not refer to it. As is well-known, the use of sulphur for dehydrogenation is attributed to Vesterberg[4] but as will be shown later (p. 140) Alder Wright[5] treated an alcohol, absinthol, $C_{10}H_{18}O$, from wormseed oil with potassium pentasulphide obtaining thereby a mixture of cymene and thiocymene. The first use of this reagent, phosphorus pentasulphide, as a dehydrogenating agent was apparently due to Pott,[6] whilst Kelbe[7] studied the action of sulphur on colophony (abietic acid).

At this time an increasing interest was being shown in the chemistry of essential oils and under the aegis of the British Association for the Advancement of Science a committee was formed

2. *Proc. roy. Soc.*, 1860, **10**: 517.
3. *Ber.*, 1892, **25**: 1401; 2067.
4. *ibid.*, 1903, **36**: 4200.
5. *J. chem. Soc.*, 1874, **27**: 1.
6. *Ber.*, 1870, **3**: 422.
7. *ibid.*, 1878, **11**: 2174.

with Dr. J. H. Gladstone as the Chairman and Dr. Alder Wright as Secretary. Stimulated by this committee important results rapidly accrued. In his first major memoir Gladstone[8] described the fractionation of a number of oils and the isolation of their main constituents. From the wide range of oils which he examined he isolated three hydrocarbons (i) $C_{10}H_{16}$, b.p. 160-176°, (ii) $C_{15}H_{24}$, b.p. 242-265° and (iii) $C_{20}H_{32}$, whilst from the oil of *Matricaria Chamomilla* he separated a blue hydrocarbon, "coecula", which he subsequently found to occur in the high boiling fractions of many other oils. This is probably the first mention of the hydrocarbon now known as azulene. Gladstone introduced a novel method for the characterisation of the $C_{10}H_{16}$ hydrocarbons. He determined their densities, refractive indices for the lines, A, D and H and their rotatory powers. He noted that the densities of the lower boiling hydrocarbons did not differ greatly from 0·9, the refractive indices lying between 1·46 and 1·5, there was, however, a marked variation in their rotatory powers. In attempting to differentiate the hydrocarbons he introduced the constant "specific refractive energy", which was the product of the division of the value for the refractive index by the density. From this constant, Gladstone deduced that the $C_{10}H_{16}$ hydrocarbons present in the oils from orange, citrus and lime were identical but that they differed from those present in the oils from wormseed, anise, thuja, mace and laurel, the latter hydrocarbons being identical with that occurring in oil of turpentine. Gladstone was therefore apparently the first chemist to make use of a physical constant to show the identity of hydrocarbons, a method which was later to find such wide application. Some years later[9] he extended the use of physical constants by the determination of vapour densities and he compared also their solubility in ethanol and their reaction with hydrogen chloride. From some of the lower boiling hydrocarbons he prepared a crystalline product, $C_{10}H_{16}$, 2HCl, and from the higher boiling hydrocarbons a similar product, $C_{15}H_{24}$, 2HCl, the yields in the latter case being very poor. In this second memoir he discussed for the first time oxygenated derivatives. He isolated from citronella oil, citronellol, b.p. 202-205°, incorrectly formulated as $C_{10}H_{16}O$. He also obtained an oxygen derivative, cajupetol, from the oils of wormseed, absinthe and cajeput. He was able to confirm from their physical

8. *J. chem. Soc.*, 1864, **17**: 1; *Brit. Assoc. Rept.*, 1862, Pt. 2; 47.
9. *ibid.*, 1872, **25**: 1.

constants the identity of "carvol" and "carotol", whilst from spearmint oil he obtained menthol and from oil of nutmeg myristol. He further recognised that the carvols from dill oil and from caraway seed oil were identical by the preparation of their derivatives with hydrogen sulphide and that this carvol differed from menthol which did not react with this reagent. In considering Gladstone's work we must bear in mind that he did not distinguish between an alcohol, an aldehyde and a ketone.

As the Secretary of the British Association Committee Alder Wright carried out a long series of experiments[10] which would appear to have been somewhat overlooked although he obtained results of considerable interest. Unlike Gladstone, Alder Wright was not specifically interested in the physical constants of the various products which he described and he studied mainly their chemical reactions, more especially their oxidation products. Thus, for example the hydrocarbon, hesperidine b.p. 178°, from orange oil yielded on oxidation with potassium dichromate and sulphuric acid a substance, $C_{10}H_{18}O$, b.p. *ca* 215°, together with carbon dioxide, acetic and formic acids. Since, as we now know, hesperidine is identical with limonene, this oxygen product must have been α-terpineol, a hydration and not an oxidation product. Results of much greater interest, however, accrued when, following Greville Williams, he treated the hydrocarbon with bromine when he found that the bromo derivative gave, on distillation, cymene. He also obtained cymene from the hydrocarbon present in oil of nutmeg but of much greater interest was his conversion of the alcohol, myristol, b.p. 212-218°, from the same oil, into cymene. For this purpose he employed a somewhat different method. He converted the alcohol into the chloride, $C_{10}H_{17}Cl$, by the action of phosphorus pentachloride, the chloride yielding on distillation cymene. Alder Wright considered myristol to be a secondary alcohol, isomeric with camphor which at that time was thought to be in aldehyde. [Myristol is now known to be a mixture of α-terpineol, borneol and terpinen-4-ol.]

Whilst in their later extensive experiments Alder Wright and his colleagues were able to correct the formulae given by previous investigators to some of the essential oil constituents, they were mainly concerned in establishing the fact that they all gave on

10. *Brit. Assoc. Rept.*, 1871, Pt. 2; 83; 1872; 311, 313, *J. chem. Soc.*, 1872, 25: 549; 1873, 26: 686; 1874, 27: 1, 317, 619; 1876, 29: 5; 1877, 32: 548; *Pharm. J.*, 1873; 2: 135; 1874, 4: 317; 5: 233.

dehydrogenation the same aromatic hydrocarbon, cymene, from which they obtained on oxidation p-toluic acid. They were thus able to prove that cymene could not be a diethylbenzene[11] *but that it must be methyl isopropyl (or propyl) benzene.*

It has already been emphasized that one of the main difficulties encountered in the study of essential oil constituents was that in the majority of cases they were liquids from which no crystalline derivatives had been prepared suitable for their identification and differentiation. It is true that Gladstone had used their physical constants but obviously the preparation of crystalline derivatives would be far more satisfactory. A solution to this problem was provided by the science master at Clifton College, W. A. Tilden. In 1874 he prepared nitrosyl chloride.[12] He did not undertake the preparation of this substance with the object of contributing to our knowledge of inorganic chemistry but in order to investigate its reactions with organic substances. Thus, he found that it reacted with phenol to yield chloroanil. In the following year[13] he made the very important observation that if nitrosyl chloride was allowed to react at − 10° with oil of turpentine, b.p. 158-161°, $\alpha_D - 15°$, a crystalline product was obtained. For this new substance he recorded no melting point but he showed that on treatment with ethanolic potassium hydroxide it furnished "nitrosoterpene", m.p. 120-130°. He regarded this new substance to be of sufficient importance to have its crystalline form described by Maskelyne.

Tilden in collaboration with Shenstone[14] now proceeded to examine the action of this new reagent on the hydrocarbons present in a great variety of essential oils. It is beyond the scope of this brief article to discuss in detail their important results. It will suffice as an indication of their importance to mention that they were able to show the identity of the hydrocarbons present in the French and American oils of turpentine since they gave the same "nitrosoterpene"; they differed, however, from the Swedish oil of turpentine from *Pinus sylvestris* which did not give a crystalline derivative with nitrosyl chloride. The hydrocarbon, hesperidine, from caraway and bergamot oils was different from that in oil of turpentine yielding a nitrosochloride, m.p. c. 103° and a

11. *c.f.* Oppenheim, *Ber.*, 1874, 7: 628.
12. *J. chem. Soc.*, 1874, 27: 670, 851.
13. *ibid.*, 1875, 28: 514.
14. *ibid.*, 1877, 31: 554.

"nitrosohesperidine", m.p. 71°. The value of this new reagent having thus been established Tilden in subsequent communications[15] proceeded to examine the hydrocarbons in a great variety of essential oils. Based mainly on the fact that they all gave on dehydrogenation cymene, he suggested formulae for them. These suggestions are now only of historical interest.

It is not possible to over-emphasise the importance of the introduction by Tilden of nitrosyl chloride as a reagent in the study of the chemistry of the terpenes. It ranks in importance with the application by E. Fischer of phenylhydrazine in his investigations on the chemistry of the carbohydrates. Following its introduction the chemistry of the terpenes was studied by many investigators and our knowledge is now very complete. Tilden himself in a series of lectures has given an excellent summary of his early work.[16] Many years later a British chemist was to provide the final rigid proof of the structure of a simple terpene when Perkin in 1904 synthesized dipentene and the related alcohol, α-terpineol.[17]

We have now dealt with the past, what of the future of organic chemistry? We seem to be at the beginning of a new epoch. Whilst there is no doubt that from the apparently limitless natural sources new substances will be isolated and their structures elucidated, this task, with the techniques now available, is comparatively simple. Surely the future now lies in applying the great skill and originality of the organic chemist to a study of the problems of the living organism. Here, there lies before him an almost virgin field of undoubted interest, if of great complexity. Can we doubt that in the future he will provide a solution to these problems as he has in the past solved the problems of the structures of so many natural products? Is it too much to hope that when the bicentenary of the University of Madras is celebrated the names of her alumni will be famous for their contributions to this field of scientific research?

15. *Pharm. J.*, 1877 [iii], 8: 191; *J. chem. Soc.*, 1878, 33: 80, 247.
16. *Perf. Ess. Oil Rec.*, 1912.
17. *J. chem. Soc.*, 1904, 85: 416.

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An Essay on Computation

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Mathematicians generally have little fondness for computation, and are inclined to regard the need for lengthy routine calculations as an unpleasant but inescapable concomitant of more interesting features of mathematics and its applications. I am sure that no good mathematician has ever shirked for long the calculations essential to his researches, but I am equally sure that until recently very few mathematicians have been inspired to devote much time or effort to exploring the art of computation. The invention of the high-speed electronic computer has, however, begun to alter the mathematician's attitude toward this art and has already been responsible for a good deal of professional mathematical interest in its modern aspects, both practical and theoretical. The possibilities being opened up by the development of the modern computing machine, even though it is too soon for us to begin to delineate them with any clarity, are indeed an astonishing challenge to the professional interest and skill of mathematicians as well as to the curiosity of the general public. That is why I venture to write this short essay, in an attempt to describe some of these new vistas from a mathematician's point of view.

The two characteristics of the modern electronic computer which mark it as a truly revolutionary invention are speed and versatility. Speed gives the machine its power to complete in a few days or weeks calculations so massive that in a lifetime even a large staff of mathematicians and computers working with ordinary manual aids and mechanical devices would be unable to finish the task. Versatility renders the machine adequate for handling an almost unlimited variety of problems, not excluding those of a very high degree of complexity. The opportunity for building machines with these two important characteristics was created by the fortunate confluence of two quite disparate and otherwise unrelated scientific developments—the perfection of the vacuum tube, and the logical analysis of the structure of mathematics which is associated above all with the names of Russell and Whitehead. The attainment of the extremely high operating speeds necessary in handling voluminous or exceptionally complex calculations within acceptable limits of time depends upon the ingenious application of electronic techniques. On the other hand, the achievement of versatility results from the implementation, by means of a few simple electronic devices, of our modern knowledge of how to reduce the complexity and variety of mathematics to a small number of elementary logical operations. Looking backward, we can see how the invention of the high-speed multi-purpose computer might have sprung from this opportunity, by virtue of a conscious effort to join these two scientific components. However, the fact appears to be that sporadic and more or less unrelated advances, of a practical rather than a theoretical inspiration, provided the actual basis for modern computer design. Indeed, some of these advances were undoubtedly prompted by the realization that the development of mathematics and its applications had reached a point where the associated computational programs could no longer be handled with the available human and mechanical resources. Thus need as much as opportunity inspired invention in this particular instance.

If the origins of the modern developments in the field of computation are to be examined more closely, it will be necessary to assemble historical materials from a good many different sources, some of them perhaps obscure or difficult to get at. Some twenty five years ago I had occasion, in lecturing on Fourier series, to discuss the principles involved in the design of harmonic analysers; and I well remember how meagre was the material I could bring together about the history of computing machines in the nineteenth and twentieth centuries up to about 1930. Of course, a considerable variety of mathematical instruments had been invented over that period for carrying out arithmetical calculations and for performing other more elaborate mathematical tasks. Many of these machines, such as integraphs, differential analysers, and harmonic analysers, were based on special applications of kinematical principles; and all were mechanical in nature, consisting of more or less numerous moving parts which in the interests of computational accuracy had to be designed and fabricated with care. Of these early mathematical machines, the one which marks the highest achievement is perhaps the harmonic analyser, so useful in analysing and predicting the tides. A development which seems, in a historical sense, to constitute a transitional link between the early period and the modern was the construction by Dr. Vannevar Bush and his associates at the Massachusetts Institute of Technology of a series of differential analysers, machines designed to solve differential equations of a fairly broad type. While these machines involved no sharp break with traditional techniques, their power and usefulness were impressive enough to kindle a wide interest in the potentialities of machine computation. Because of this stimulating influence of Bush's work it may be considered as inaugurating the modern phase of the computing art, despite the fact that it did not point out the paths later followed in order to achieve speed and versatility. A very different approach to the problem of mathematical computation was made in the early thirties by Dr. W. J. Eckert of Columbia University, who showed that extremely elaborate and voluminous astronomical calculations could be carried out rather rapidly be a skilful use of Hollerith machines alone. The origins of this approach can be found in the theoretical contributions of the mathematician Charles Babbage (1792-1871), some of whose ideas found their embodiment in the machine actually constructed at a later time by Hollerith. The Hollerith machine is essentially a simple device for sorting punched cards into specified classes—in other words, it is a machine which mechanically performs the basic logical operation of classification and which, therefore, should in principle serve to carry out all kinds of mathematical calculations. In three or four years' time Dr. Eckert was able to run through all the definitive calculations made upon the motions of the moon by the celebrated mathematician and astronomer E. W. Brown in the course of his entire life. This was a conclusive practical demonstration of the versatility and mathematical power of a logical machine. To what extent this demonstration may have influenced subsequent developments, I am simply unable to say. So far as I am aware it did not enter into the thinking of Dr. Howard Aiken of Harvard University, to whom should go much of the credit for the initial advances in modern high-speed computation. Dr. Aiken conceived the idea of applying the complex electrical techniques developed by the telephone engineers to the design of a large and elaborate multi-purpose computing machine which could be set up to carry out at high speed and in a fully automatic manner any desired program of mathematical calculations. He had to overcome many difficulties and some fortuitous obstacles before he won an opportunity to build the first model of his machine, but today the Computation Laboratory he created at Harvard University has been functioning for more than a decade and has earned its world-wide renown.

To tell the truth, I am not certain that Dr. Aiken's first machine was completed earlier than the ENIAC, a machine constructed at the University of Pennsylvania during World War II. It should be emphasized that the earliest types of high-speed machine were built and operated under conditions of secrecy as part of the war effort, with the consequence that the historian eager to pin down the facts may be faced with a fairly complicated task of documentation. Be that as it may, the ENIAC embodied some important technical advances over Dr. Aiken's original conception, as it achieved much greater operating speeds through the use of electronic rather than mechanical switching. The first pioneer models have been followed by others in fairly rapid succession, with many technical improvements designed to increase speed, capacity, and reliability of operation. The distinguished mathematician Professor John von Neumann of the Institute for Advanced Study (Princeton) played the leading part in the design and construction of one of the later machines. Although the design and operation of modern computers are now sufficiently well understood that various models are currently in commercial production, it is almost certain that further technical and theoretical advances of a fundamental kind lie ahead. Indeed, the replacement of tubes by transistors is already in view, opening up the prospect that future machines will be more compact and more economical in respect to energy-consumption.

The new machines have been seized upon as extremely valuable instruments by research laboratories and industrial establishments making use of applied mathematics. As a result there has been a rapid and large-scale expansion of computing facilities, particularly in the United States. This expansion, contrary to what the public may have been led to believe by newspaper accounts of these new scientific wonders, has opened up a whole new field of employment for mathematicians trained at intermediate and higher levels. The fact is that the machine can do nothing until it has received instructions in the form of a carefully worked out program drawn up in terms suited to the structure of the machine itself. Thus the preparation of mathematical material for machine computation requires a thorough knowledge of the underlying mathematical theories and a specialized skill in casting them into efficient programs for computation. The large-scale use of computers has, therefore, added heavily to the demand for mathematical services already in short supply. A few years ago I had occasion to discuss this point with Dr. John Curtiss, who was then directing the mathematical activities of the United States Bureau of Standards. My recollection is that his estimate of the staff requirements for governmental computing programs alone indicated an immediate need for about four hundred mathematicians trained up to the master's degree level or above. In the future there will very likely be a reduction and modification in the demand per machine, but the certainty of further rapid increase in the number of machines in use guarantees a rising total demand for a rather long time to come.

The introduction of high-speed electronic computers has augmented man's mathematical powers in so spectacular a fashion that it is necessary to remind ourselves of some of the limitations affecting present and future uses of the machine for mathematical purposes. Some of these limitations can perhaps be overcome by technical developments, others may have to be accepted as permanent bars to progress in certain directions. There seems to me to be a fundamental difference between computing machines and the machines which constitute our present industrial apparatus, a difference which is reflected in an essential difference in the limitations to which they are respectively subject. To make the point somewhat too sharply, it is that the computing machine is devised to utilize time more efficiently while most industrial machines are designed to tap and utilize the sources of energy known to us. To be sure, many of our modern technological aims involve speeding up the use of some of our natural stores of energy and accelerating other forms of human activity, so that more can be accomplished in a given time. However, it is now widely recognized that the principal achievement of the industrial revolution has been to increase the per capita utilization of energy in human affairs and that in the long run the only sources of energy on which we can count for the maintenance and development of a technological society are those, like the sun and the nucleus of the atom, which supply us at rates beyond our power to affect or control. Thus the ultimate limitation upon the industrial use of machines is set by considerations of energy. Beyond the foreseeable time when our coal and our oil will have been exhausted and our water power fully exploited, our hopes rest upon the discovery of new ways to employ nuclear and solar energy. On the other hand, the essential function of the modern computer is to enable us to do in a relatively short time tasks so complex that their completion by ordinary means would be possible but only by dint of coordinated efforts scheduled over inacceptably long periods of time. The ultimate limitations in the field of computation must, therefore, include the limitations upon speed of machine performance. The latter arise from two factors, one of a logical nature, the other physical. When any reasonably difficult mathematical calculation is analysed into its elements, it appears as a complicated pattern made up of interrelated sequences of simple operations. The number of steps in the longest such sequence occurring in the pattern obviously is one of the determinants of the time which the machine will need to carry out the calculation in question. The other major determinant is the speed with which the machine can perform the individual steps into which all computations are to be analysed. For a given calculation logic must evidently set a limit below which we cannot force the number of steps needed to carry out the calculation. For a given basic machine operation, Nature, so far as we now know, sets a limit below which we cannot hope to reduce the time-span requisite for effecting the operation. Of course we can hope to apply our knowledge of logic and of physics so as to choose the best possible calculation patterns and the best possible combinations of machine elements within the ultimate limitations to which we have alluded; but we cannot expect to overcome them altogether. So far as the machine-components are concerned, the fact that to attain the present operating speeds we have already had to utilize electronic devices suggests that future improvements may have to be sought in some sort of nuclear engineering. From some of the reports which have been published, like the one stating that the ENIAC could compute the trajectory of a bullet in less time than the bullet would take to complete its motion, it might be thought that the limitations which we have been considering are theoretical rather than practical from a computer's point of view. However, this is by no means the case, as the problems of short-term weather forecasting clearly show. To predict tomorrow's weather from today's observations over an area as large as that of the continental United States poses the practical problem of collecting a huge volume of data, carrying out upon them the necessary calculations, and disseminating the results to potential users, all within twenty-four hours' time. Evidently the computing machines used must be capable of completing their share of the work in only a fraction of a day. Existing machines can handle the numerical data currently supplied in an hour or so, it is said. While this speed is entirely acceptable, it seems quite possible that the machines could prove to be

inadequate if more computations were required of them in this connection—either because of an increase in the number of weather stations, or because of the introduction of forecasting methods requiring more calculations with the data made available. Thus the fundamental limitations which we have been discussing here are already felt at the practical level.

The complexity of the calculation-patterns arising in the applications of mathematics offers a serious challenge to the machine-designer. In principle this challenge might be met by enlarging the machine, by enabling it to handle segments of the computation seriatim, or by combining both expedients. As the present machines are not very bulky and may soon be replaceable by similar but less bulky machines based on the transistor, there does not seem to be any immediate practical obstacle to building much larger and more complicated machines than any now in operation. However, there is an important technical difficulty which becomes apparent when an attempt is made to arrange the segments of a computation in series, and which proves to be inherent in the nature of mathematical calculation. The point is that in complicated calculation-patterns, results obtained at one stage may have to be stored for use at various later stages. The machine has, therefore, to be provided with a memory, capable of retaining information conveyed to it and of making this information readily available as required. Thus mere enlargement is not enough to produce machines capable of handling more complex computations; it must be accompanied by an enlargement of the memory with which the machine is equipped. Here the technical obstacles have been discovered to be quite serious indeed. They constitute a genuine limitation upon progress in the art of machine computation at the present time, though one which we can hope eventually to overcome in large measure. Of course, even if there were no technical barriers to the indefinite enlargement of the machine or of some particular part of it, such as the memory, the construction and maintenance of very large machines would surely be impractical. Apart from the obvious inconveniences of sheer size, it seems likely that increases of size and complexity may be subject to a law of diminishing returns in the case of computing machines as well as elsewhere. In conclusion, it seems that some limitation upon size must be accepted, although this appears to be a less serious and a less fundamental one than the limitation on speed which has been discussed earlier in this essay.

Before turning to some aspects of the modern art of computation which hold a special interest for the mathematician, I must mention, if only briefly, one of its ramifications which bids fair to develop into an independent sister art under the name of "Automation". Throughout this discussion emphasis has been laid on the versatility of the modern types of computing machine. Their ability to handle the complex patterns of arithmetical operations involved in computing numerical answers to mathematical problems extends to patterns composed of other operations, mathematical or non-mathematical. In particular, the electronic techniques applied in building a high-speed computer are now finding application in the construction of automatic controls of manufacturing and managerial operations. The new industrial revolution which such applications portend has been vividly described in Professor Norbert Wiener's book "Cybernetics". The fully automatic factory and the fully automatic counting-house are no longer unrealizable dreams; pioneering realities today, they will be tomorrow's commonplaces. For a long time we have known how to mechanize individual operations, even highly complex ones, such as the machining of a metal part, the production of a light-bulb, or the writing and mailing of a cheque. What we can now do is to mechanize the coordination and control of the logical pattern in which the component operations of a complete manufacturing or managerial process are to be performed. An essential feature of this mechanization is that it provides for the automatic correction or suspension of component operations which may drift from the prescribed operating norms. This aspect of control is important in the case of computing machines, but very much more so in the case of an automatic factory. It requires that the control mechanism be capable of recording certain information about the execution of the process while under way and acting upon this information in an appropriate manner. At the very least it must be able to stop the whole process when something goes badly wrong and to signal an attendant who can then put matters right and start up the process again. In the case of a computing machine, for instance, the failure of a single tube may throw the entire computation off, and so should be detected and remedied at once. Some of the modern machines have, therefore, been so designed as to check their own operations and to suspend computing whenever the check shows something out of line. Long ago the invention of the governor for steam-engines established the basic principles of automatic control. It is the subtle elaboration of these principles through

modern electronic techniques which has given us a new vision of man in his industrial world.

While the mathematician may be intrigued and duly impressed by modern developments in the field of computation, it is natural that he should take a somewhat detached attitude towards them until he can relate them to the problems on which he is personally engaged. For the majority of mathematicians this means raising the question "Can modern machine methods be of genuine help in carrying out fundamental mathematical investigations, not directly related to finding numerical solutions to problems of applied mathematics?" The answer is certainly in the positive, though our experience is so far very limited. Perhaps I may first cite an occasion many years ago when in my own work I noted how convenient it would have been to possess a small electrical device for checking the properties of certain finite algebras. I was studying Boolean algebras at the time and wished to discuss the logical independence of certain of their properties. This involved setting up various finite algebras *ad hoc* and laboriously checking the validity or failure of the various properties in question. It seemed evident to me that under pressure of necessity the task could be mechanized and that to this end electrical means would be preferable because they would greatly facilitate the change-over from one algebra to another. There are certainly many situations, of which this one is typical, where the mathematician will find modern machine methods a great boon to him in his work, and some will shortly be cited as instances where such methods have actually been applied to research problems of pure mathematics. Logically, however, it may be more fitting to begin with some interesting results in the theory of numbers which depend only on the increased arithmetic power of the newer machines. Like most of the results which we shall mention here, the computations were performed on the SWAC, a high-speed machine which was built at the University of California in Los Angeles by the Bureau of Standards and which was made readily available to mathematicians interested in using its services. Professor D. H. Lehmer used SWAC to test the primality of various Mersenne numbers, $2^p - 1$ where p is a prime, and found that $2^{2281} - 1$ is indeed a prime. I believe that this number, with nearly seven hundred digits in its decimal development, is still the largest known prime. Professor Lehmer also tested a hypothesis based on a remark of Fermat, finding that the huge number $2^{2^{16}} + 1$ is not prime as surmised. In collaboration with Professor H. S. Vandiver of the University of Texas, he also verified the truth of a very large number of special cases of Fermat's Last Theorem not yet amenable to theoretical treatment. More recently, Professor Marshall Hall of the Ohio State University, also using SWAC, has carried out the computations involved in verifying the Desarguesian character of the finite projective planes of all orders through 9. This problem is essentially an algebraic problem analogous to the one referred to above. Another program, reported on by Dr. George E. Forsythe, determined all semi-groups of order 4, finding that there are 3492, of which 126 are distinct under isomorphisms and anti-isomorphisms. These results coincide with those obtained independently by Professors Takayuki Tamura and M. Yamamura in Japan, working by hand. Calculations like these are interesting in themselves and they throw a certain amount of light on important problems of number theory, geometry, and algebra; but they are obviously incapable of settling any but finite questions. For example, the machine cannot give a definitive treatment of Fermat's Last Theorem simply by calculating a number of special cases, however large, and so long as the machine does not turn up a failure of the Theorem the most it can do is to strengthen the feeling that the Theorem is perhaps true. It might appear, therefore, that the role of the machine in mathematics may be positive for the case of finite systems but is condemned to be negative in the case of non-finite questions about infinite systems. Logically this is perhaps true, but in the case of one branch of mathematics, analysis, we have a great deal of empirical and mathematical evidence that the structure of infinite systems can often be satisfactorily approximated by that of well-chosen finite systems. In such instances, therefore, we are justified in drawing some tentative conclusions, either qualitative or quantitative within known limits of error, about the infinite system as soon as we have calculated enough information about the approximating finite system. It has been pointed out by Professor von Neumann that we may hope to learn a great deal about the theory of partial differential equations by using modern computing machines to provide ourselves with this kind of approximate empirical information. Certainly, one of our difficulties in studying partial differential equations from a general point of view is that we have very meagre knowledge of the behavior of their solutions, even in a numerical sense, and thus lack guidance in formulating fruitful questions. I am unable to cite any case where the machine has helped us increase our knowledge to the point that it could be used as the base for deeper

theoretical investigations, but I can well imagine that such cases will become part of our mathematical experience as time goes on.

When a mathematician is engaged in making a theoretical study of the properties of a mathematical system, finite or infinite, he aims at establishing general propositions of interesting content by applying in a systematic and appropriate way the basic principles of logic. Thus a machine designed to imitate what the mathematician does would have to be capable not only of carrying out various numerical or algebraical calculations but also of executing logical manipulations. As we have already pointed out, the work of formalizing logic was carried so far that since the fundamental contributions of Russell and Whitehead we have known how to reduce these manipulations to a routine and hence how to mechanize them. The modern high-speed electronic computers could certainly be set the task of carrying out such routines and thereby proving theorems. Thus in principle the only parts of logic and of mathematics which we cannot turn over to machines are those, if any, which somehow escape the reduction to a routine. Since in the present state of the art we can confidently equate the phrase "reducible to a routine" with "mechanizable", all that we have said here emerges as a tautology. We see, therefore, that the problem we are trying to discuss is, when purely practical limitations are put to one side, a problem of logic which does not become precise until we have defined more precisely what we mean by a routine. To go into this matter more fully would involve us in subtleties which would be out of place in an essay of this kind. They are of such a nature that it has taken logicians much time and effort to clarify them and to explore their implications. The work of logicians, particularly the monumental contribution of Gödel, has made it clear that there are indeed aspects of logic and of mathematics which cannot be routinized. In the present context it will be most fruitful for us to examine briefly some results established independently by Professor Alonzo Church of Princeton University and A. M. Turing of Cambridge University. In order to objectify the particular logical problems he wished to treat, Turing described a conceptual machine and determined what it could or could not compute; but Church proceeded without making such an appeal to the concrete. It is of interest to note that Turing's researches were pursued in the thirties, before the modern computational developments were well launched. At that time Turing very likely had no thought that anything resembling his machine would ever be built. As a matter of fact, I believe that no Turing machine has yet been built, though the marked current interest in it suggests that sooner or later one will be. For a description of a Turing machine, reference may be made to Turing's original paper in volume 42 of the Proceedings of the London Mathematical Society (with a theoretical correction in the following volume). It should be noted that the machine works with an infinite tape, on which it prints symbols and carries out operations of other kinds, thus being equipped in effect with a memory of unlimited capacity. Needless to say, such a conceptual machine transcends the practical limitations we have already noted, and only practical modifications of it can ever be realized. Although Turing described a machine which in this and other respects achieved a maximum of flexibility and versatility, he was able to show that there are real numbers definable in terms of a specified logic which the machine cannot compute; and also that in pure logic, as formalized by Hilbert and his school, there is no standard procedure which could be carried out by the machine and which would suffice to decide the truth or falsity of the formal statements expressible in that logic. Thus it appears that neither the Turing machine nor any modification of it which anyone has yet been able suggest could be expected to replace a skilful mathematician in finding proofs for theorems. In short, a close examination of formal logic brings us back to the thought from which we started—namely, that finite methods are in general insufficient for handling infinite systems—with the additional knowledge that they are in particular insufficient for handling the infinite systems of classical logic. This outcome may serve to remind us that a good many years ago the great mathematician Poincaré advocated the point of view that mathematics cannot be fully formalized. I believe that the intuitionists, led by Brouwer, entertain a similar point of view towards both mathematics and logic.

If these considerations do indeed point to the conclusion that there is a gulf between the mind and the machine, we are nevertheless well aware that in many respects the mind does function mechanically. In consequence we see that we cannot leave these questions without trying to square whatever we have said about the nature of mind with whatever is known about the physiology of the nervous system. The illuminating studies of McCulloch and Pitts have shown how certain known features of the nervous system enable it to function as a logical machine, which could be simulated by an electronic device. A very careful discussion of the logical power of such a machine has been given by Professor

S. C. Kleene of the University of Wisconsin in a paper published in "Automata Studies" (Princeton University Press, 1956; C. E. Shannon and J. McCarthy, editors). He finds that the machine is subject to certain explicitly determined limitations, and remarks that it is necessarily less versatile than a Turing machine because the latter has the advantage of using an infinite tape, as mentioned above. In their theory of nerve nets, McCulloch and Pitts suggested a possible mechanism to perform the function of a memory, but the best evidence shows that human memory cannot be explained in terms of it. As a matter of fact the nature of memory remains essentially a mystery. The same may be said, of course, about other functions of the mind. In an effort to understand some of these, such as learning, much thought has been devoted in recent times to the design of mechanisms which might simulate various features of human behavior. Several such conceptual machines are described in the volume "Automata Studies" mentioned above. While these descriptions demonstrate that a great many different aspects of the mind may well be explainable in mechanistic terms, and suggest that some, at least, will eventually be so explained, they clearly leave unaltered the position which we have reached in this discussion—namely, that in its logical faculties, and probably in others as well, the mind transcends the machine.

Our exploration of the subject of computation, practical and commonplace though it may have seemed at the outset, has thus brought us to a point where technology, mathematics, logic, physiology, psychology, and philosophy can be seen to meet and to interact. We have seen how success in solving the simpler and more immediate problems raised in the art of computation has opened up deeper and more intriguing problems in these various disciplines, how the dissipation of the more superficial difficulties and mysteries has disclosed others of a more fundamental nature. What we have thus observed in the case of computation seems to me to be somehow characteristic of the stage of knowledge we have now reached. Perhaps this is an illusion created by my own personal experience of science and learning, but I do not think it is. Wherever we may look in the natural sciences today we see the merging and interpenetration of disciplines which twenty-five or fifty years ago either did not exist at all or did not touch one another; and we see that the problems we want to solve become more complex and profound as we master more aspects of reality. The nineteenth century dream of a closed system of knowledge has had to be abandoned for the adventure of working in what appears instead to be an open system with infinite possibilities. Nowhere is this clearer than in the discipline we have essayed to examine here, or than in the modern physical theories of the constitution of matter, but our point can also be illustrated in the case of biology by reference to recent work on the nature of viruses. In physics the study of the elementary particles—electrons, positrons, protons, mesons, neutrons, and so on—has reached a critical stage where a serious maladjustment between physical facts, mathematical tools, and working metaphysical principles prevents the evolution of a satisfactory theory of microscopic events. In biology the pioneering work of Professor W. M. Stanley and his associates on the viruses has brought us to the mysterious borderline which separates living from inert matter. In his laboratories at the University of California in Berkeley the recent synthesis of a virus from apparently inert components is but the latest in a series of remarkable discoveries showing how finely Nature has drawn this line. On these widely separated frontiers of science we thus find that our deepening knowledge invests with new meaning and new relevance the ancient questions of philosophy—"What is matter?", "What is energy?", "What is life?", "What is mind?" Far from being alien to the proper concerns of science, these questions are inseparable from its essential fabric, and are not without significance even in its practical applications.

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Fifty Years of Chemistry in Indian Universities

BY

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Fifty years of chemistry in Indian Universities is a theme of surpassing interest for a study in retrospect.

My study of chemistry was initiated in the Calcutta University 52 years ago and I have now had the privilege of teaching the subject in two of the premier universities in India, viz., the Universities of Calcutta and Madras. It is an unique experience and it seems appropriate that on the occasion of the centenary celebrations of the old Universities, I should relate some of it and try to present a picture of the conditions of scientific education which prevailed in our universities fifty years ago.

Science was mostly neglected in our schools in the early years of this century. The subjects which were taught compulsorily for all in the Entrance Examination of the Calcutta University, i.e., the examination at the end of the school final course, were English, Sanskrit or French or Latin or any other foreign language, Mathematics, including arithmetic, algebra and geometry, History of England and of India, and Geography. In the paper in Geography one or two questions in Elementary Science were set from a small text book prescribed for study in the final year of the course, but the subject, as far as I remember, was seldom taught seriously in the class, and there was no provision in the schools of a laboratory for experimental work by the students. Chemistry as a distinct subject first appeared in the curriculum of studies for the so-called First Examination in Arts equivalent to the Intermediate Examination of the present day. The course included English and Sanskrit or a foreign language, History of Rome and Greece, Logic, Physics, Chemistry and Mathematics which included Trigonometry and Conics. All these subjects were compulsory except in the case of Logic which could be substituted for Roman and Greek History. There was no practical examination in the sciences at the end of the course and no laboratory was provided for the students to do any experimental work. The lectures too were illustrated mostly with chalk and blackboard and it was only on rare occasions that some simple experiments were performed in the class, such as the determination of the composition of air by burning phosphorus in a closed volume of air, or the separation of sulphides of metals from the solutions of their salts by passing sulphuretted hydrogen gas from a Kipp's apparatus. These were red-letter days for the students who eagerly awaited the experiments and watched their performance with keen interest and excitement. The B.A. degree course in the Calcutta University was grouped into "A" course comprising humanities and "B" course consisting of science and mathematics. Even in the latter course, laboratory work was not compulsory, and the candidates were not subjected to a practical examination at the end. It was in the B.Sc. degree course which was opened by the Calcutta University in the year 1902, that practical work in science was first introduced. The only college affiliated for this course at that time was the Presidency College, Calcutta, as the other private colleges in the city and outside were unable to satisfy the conditions of having the requisite well-equipped laboratories and competent staff for the purpose.

The B.Sc. degree course comprised Physics, Chemistry, Mathematics (Statics, Dynamics, Hydrostatics and Astronomy) and either Botany and Physiology or Geology and Mineralogy and there was a good practical examination in each science at the end. The private colleges teaching science even up to the standard of the B.A. degree had no laboratories worth speaking of, and most of their scientific apparatus were stored in a few almirahs kept in the lecture theatre. It was only after some twelve years, i.e., towards the middle of the second decade, that some of these colleges in the city began to equip themselves with the necessary laboratories and staff and seek affiliation to the B.Sc. degree course.

The teaching of Chemistry even in the highest standards was confined in those days almost entirely to the Inorganic branch of the science and little attention was paid either to Organic or Physical Chemistry. The practical course, too, consisted of only inorganic analyses, both qualitative and quantitative, the acme of perfection being supposed to have been reached by a student who could detect the presence of as many as twelve different radicals in a mixture of salts, and estimate accurately the quantities of two or three different metals present in an ore or an alloy. Organic preparations and analyses were unknown, and there was no proper syllabus

drawn up for experiments in Physical Chemistry. The little Physical Chemistry that was taught was in connection with the theoretical portions of Inorganic Chemistry.

The M.Sc. degree course was first instituted in the Calcutta University in 1908. It was a very comprehensive course in which one of the branches of Chemistry, either Inorganic or Organic or Physical, had to be offered by the candidate as his special subject and the other two branches as subsidiary. A heavy syllabus both in theory and practical was drawn up and the list of text books prescribed for study included almost all the advanced text books that had been published at the time. The two volumes of Advanced Organic Chemistry by Cohen and the series of books in Physical Chemistry edited by Sir William Ramsay as well as Soddy's Radioactivity and Lehfeld's Electrochemistry were to be found in this list. While the standard aimed at for the Master's Degree in Science was reasonably high, little provision was made for imparting effective instructions to the students on the high standard prescribed. Indeed, until comparatively recently, the universities in India did not take any active part in teaching, and were content merely with laying down curricula and conducting examinations. The teaching was provided exclusively by the colleges affiliated to the universities. In this respect, the Presidency Colleges in Calcutta and Madras, as Government institutions, held special positions in those days. They had well equipped laboratories and highly qualified staff, enabling them to provide instructions in the different sciences up to the highest standards.

The two members of the higher staff in science in the Presidency Colleges in Calcutta and Madras respectively, who were brought out from England as early as 1875, were Professor (Sir) Alexander Pedler and Doctor W. H. Wilson. The former was a student of the old Royal College of Science in London and Prof. Wilson appears to have had his training under Bunsen in Heidelberg.

Both these professors belonged to the old school and were brought up in the traditions of teaching only inorganic or mineral chemistry. They had both been known to be excellent teachers in their way and to have taken great pains in preparing their experiments for purposes of lecture demonstrations. Many of the apparatus set up by them are still preserved in the chemical laboratories of the Presidency Colleges of Calcutta and Madras, and bear testimony to their excellence as teachers and their skill in experimentation. Professor Pedler's tradition was continued by Acharya (Sir) Prafulla Chandra Ray who had studied chemistry in Edinburgh under Professor Crum Brown. He confined his teaching and research also mostly to the inorganic branch of the science. In Madras, Prof. W. Erlam Smith who succeeded Dr. Wilson in 1907, also carried on the same tradition of teaching inorganic chemistry. As a consequence, there was a great dearth fifty years ago of teachers who could sponsor the exposition of the other two equally important branches of organic and physical chemistry. The writer had the distinction to belong to the first batch of students who prepared for the then new M.Sc. degree examination of the Calcutta University. The students numbering about six were largely left to themselves to learn these subjects both in theory and practice, but the way in which they combined to a well-knit team for the purpose of teaching themselves and overcame their many deficiencies and difficulties particularly in the guidance of their experimental work, remains to this day a vivid memory and an unforgettable experience. The knowledge gained by the students in this way left an abiding impression which was of invaluable help to them in later life. Notwithstanding the defects of teaching pointed out, the knowledge of theoretical science acquired by the Indian student was not inferior to that of a good honours graduate of a British university; his real weakness lay in his acquaintance with practical science in which he found himself at a disadvantage. This fact impressed itself on the mind of the writer when he went for higher studies to London in 1911 after taking his Master's Degree in science and doing post-graduate research in the Calcutta University for a year. While he acquitted himself with credit in theory, the confidence and ease with which his British fellow-workers did their experimental work filled him with envy. It was not perhaps without reason, therefore, that the old universities in Great Britain did not consider the standard of the degree examination of an Indian university to be any higher than that of their Matriculation examination, and refused to grant the Indian graduate, even though the latter might possess the Master's degree, exemption from their Intermediate examinations. It was only as a special case that the writer, by virtue of his published researches and an exacting preliminary test, was permitted for the first time to register himself as a candidate for the higher degree in science (D.Sc.) of the University of London without passing the examinations for the lower degree. The reasons for the real superiority of the English student in his practical equipment can be readily understood when it is

remembered that the majority of the students of science there had begun their careers in school where they had well equipped laboratories where experiments formed the basis of their scientific training, whereas in India no scientific education worth the name existed in the schools and no facilities were available for the students to engage themselves in experiments. It is very necessary that science teaching in our schools is raised to a healthy level without which our efforts to stimulate and encourage the development of science in the universities and technological institutes may be largely frustrated.

I have tried to give a general idea of the way in which chemistry was taught in our college days early in this century. Although the phenomena of radioactivity had been studied and understood, the Daltonian conception of the atom as the smallest indivisible particle of an element still continued to all intents and purposes to be the basis of teaching chemistry, and Mendeleeff's Periodical Law of classification of elements based on atomic weights as their unalterable physical constants, continued to serve as the sheet-anchor of the chemist. The new conception of the structure of the atom and its consequences on atomic numbers and isotopes and the electronic theories of valency, etc., did not seriously invade chemistry in our undergraduate days. The old traditions of teaching began slowly to crumble only in the second decade of this century and gave way to the new ideas making chemistry more and more of an exact science and less of empiricism. In our universities, too, the old order changed slowly and the subjects of Organic and Physical chemistry were assigned their legitimate places of importance in the scheme of general education. The improvements which occurred mostly during the second decade of this century were helped by several circumstances which may be worth recording. In the first place, the University of Calcutta, through the energy and inspiration of its great Vice-Chancellor, Sir Asutosh Mookherjee, changed from an examining to a teaching University. This was made possible primarily through the munificent benefaction of two of India's great lawyers, Sir Rashbehari Ghosh and Sir T. Palit, who gave their life's savings for the purpose of establishing a college of science and technology for the University. A post-graduate council in science was established next, and teaching and research for the Master's and other higher degrees in science was undertaken by the University in co-operation with the Presidency College and some of the other bigger colleges in the city. This marked the beginning of teaching and research in science by an Indian university, and other universities were not slow to follow the example of the University of Calcutta. Secondly, some of the British professors who came out to India at this period, of whom the names of Dr. J. L. Simonsen (Madras), Dr. E. R. Watson (Dacca) and Dr. A. N. Meldrum (Bombay) may be mentioned as most prominent, were all specialists in Organic Chemistry, and vigorously pursued teaching and research in this branch in the universities to which they were attached. As regards Physical Chemistry, a number of young men who had offered this as their special subject of study for their Master's degree in science acquired a real taste and aptitude for post-graduate research in this field. Several of them went abroad for higher studies in Physical Chemistry and took up, on their return, teaching and research in our universities. Among those may be mentioned the names of Professor Nil Ratan Dhar (Allahabad), Dr. J. C. Ghosh (Dacca and Bangalore), Dr. J. N. Mukherjee (Calcutta) and the late Dr. S. S. Bhatnagar (Banaras and Lahore). There were two other events which must be considered here, as they had an important bearing on the development of chemical research in India. The first All India Institute for research was established in Bangalore about 1912, thanks to the great vision of the late Mr. J. N. Tata. Sir William Ramsay was brought out to India to choose a site for the Institute and draw up a programme of research and he selected Bangalore as the most suitable, and deputed later his co-worker, Dr. Morris William Travers as its first Director. With Travers came several other distinguished scientists such as Dr. J. J. Sudborough, Dr. Gilbert J. Fowler, Dr. H. E. Watson, Dr. Alfred Hayes and others. The presence of these men in the country was undoubtedly responsible for ushering in an era of great change for the better in the attitude of our universities to advanced studies and research in science. The other important factor was the inauguration of an annual Indian Science Congress, the first session being held in Calcutta in 1914. The annual meetings have been held up to the present day in various different university centres where men engaged in scientific and technological research in different parts of India have opportunities of meeting and discussing the results of their work in special fields and comparing notes.

The writer had opportunities of attending several of these meetings since 1916, and can testify to the great stimulation of thought and endeavour which these meetings created among the young scientists of our country.

I joined the Presidency College, Madras, in the summer of 1920, after serving the Calcutta University for nearly four years as Professor of Chemistry in the Presidency College, Calcutta, and participating in the activities of the newly started post-graduate council in science of the University. The conditions of teaching and research prevailing in Madras at the time were found to be not dissimilar to those in Calcutta during my college days (1906-1910). The only course in science offered by the University of Madras was that of the B.A. Degree. This was divided into two groups which were called the II-A and the II-B, respectively. Physics was the main and chemistry was the subsidiary subject of study in the II-A, and vice versa for II-B. The standard of main chemistry in the II-B group was comparable to that of the old B.Sc. degree of the Calcutta University, but the standard of subsidiary chemistry in II-A was only a little higher than that of the Intermediate Examination. Honours courses in chemistry were not introduced till as late as 1911, and the Presidency College remained for thirty years and more the only college in the whole province which was permitted to teach this course in chemistry. The usual practice in those days was to admit about four students in the Honours classes in a year, and as it was a three-year course, the maximum number of students at any time in this course rarely exceeded a dozen. The best students of the year competed for admission to the Honours classes in chemistry, and it thus became possible to maintain a high standard for the Honours degree in Madras which approached that of the M.Sc. degree of the Calcutta University. The B.Sc. degree course (Pass and Honours) which did not differ materially from the old B.A.—II-B course except in the enlarged syllabus for practical work, was not begun till 1932, and the Presidency College as usual was the pioneer in being affiliated to the new course, while the other colleges followed suit gradually. The M.Sc. degree course was introduced simultaneously and was awarded entirely by research on the merit of a thesis submitted by the candidate. As a rule, only Honours graduates were accepted for this course and there were not more than one or two candidates in a year for this degree.

In Madras no tradition had been built up for research either in physics or in chemistry, until Dr. Simonsen joined the Presidency College in 1910. The Calcutta University was more fortunate in this respect. The two professors, Sir J. C. Bose and Sir

P. C. Ray, who adorned the chairs in Physics and Chemistry respectively in the Presidency College, Calcutta, during the years 1890 to 1915, developed lines of research of their own and trained students for research. Professor W. H. Wilson who taught chemistry in the Presidency College in Madras from 1889 to 1907 and Professor W. Erlam Smith who succeeded him do not appear to have seriously engaged themselves in research or encouraged students to do so. Dr. Simonsen who acted as additional professor of chemistry during the years 1910 to 1918 engaged himself in researches in organic chemistry and made valuable contributions in the chemistry of terpenes which he made his special field for study. He also appears to have created enthusiasm for research among his students, some of whom, like the late Mr. M. Gopala Rao, who died unfortunately very early in his career, gave brilliant promise for research. Researches in organic chemistry have been continued to the present day and nearly a hundred publications of original memoirs have resulted from the researches in the course of the past thirty years. The problems ranged from synthetic chemistry to those of natural products and enzymes and about a score of students at different times have taken part in the investigations. During the past decade, the Council of Scientific & Industrial Research in Delhi had subsidised two distinct lines of research in the chemical laboratory of the Presidency College, Madras, viz., (a) the chemistry of gland products for which the raw materials were supplied by the slaughter houses, and (b) the electro-synthesis of dye-intermediates. Two teams of researchers had been engaged in these investigations and their results, published in many scientific journals, have attracted the attention of well known workers in these fields outside India. Many of these students have now made their mark in the world of research and some have attained positions of eminence in academic life. The present Chief Professor of Chemistry in the Presidency College is himself a product of this school and is now vigorously pursuing researches in organic chemistry.

From the rather gloomy retrospect with which I began this article I come now to a period when India is emerging into an era of glorious prospect in matters of research and advanced studies in pure and applied science. Where there was sometimes not even a single scholarship available for chemical research in a university or a province, we have now a multiplicity of scholarships and fellowships provided for the purpose. For these, not only are the funds of the university available, but liberal grants are also being

made by the Ministry of Education at the Centre, by the Council of Scientific & Industrial Research, by the National Institute of Sciences of India and even by private commercial firms like the I.C.I and the Burmah Shell Company. There is almost a glut of these research fellowships and scholarships, and the problem is not so much one of lack of funds as of their utilization to the greatest advantage to the country. People are beginning to view with anxiety not only the increase at times in the duplication of research, but also of spurious work masquerading in the name of research. There is great need to-day for the creation of healthy public opinion in matters of science and research and of vigilance for the prevention of waste. There should be better and more intensive co-ordination of efforts made in the various research establishments such as the universities, the research institutes and the dozen National laboratories of India of which no less than seven are being devoted to problems of different aspects of chemical research.

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Biological Study of Mechanism of Carcinogenesis—I

BY

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> The answers to the questions of *why* and *how* things happen are the keys that unlock the doors of all scientific mysteries, for they enable one to understand *the processes* instead of being satisfied with *the facts*— Berenblum (2).

Cancer is essentially a problem of abnormal growth; abnormal in the sense that it appears purposeless and devoid of a self limiting propensity. One of the usual characteristics of cancer is the transformation of some cells from a relatively static to a rapidly proliferating condition. Almost all cells of the body, with few exceptions, are endowed with a capacity for division and multiplication and are, therefore, possessed of an inherent potentiality for persistent or malignant growth. The mechanism which initiates and sustains this unusual property has intrigued many investigators and has interested us for some time. Much research in other countries had suggested that the causation of cancer in experimental animals depended on an interplay of cancer producing stimuli and a susceptibility of a particular tissue to react to them. The susceptibility was mainly determined by the genetic constitution of the individual. The stimuli for any particular type of cancer could either be elaborated within the body (intrinsic) or could operate from sources outside it (extrinsic). The problem before us, therefore, was to unravel the tangled skein of fact and theory which had been wound round during the last quarter of a century of cancer research.

A study of the mechanism of carcinogenesis in experimental animals was, therefore, started in our laboratories by Ranadive and has been continued by her, with a batch of young colleagues for the last ten years. It is now intended to review briefly the work which has been carried out in our laboratories without entering into details of microbiological techniques or commenting upon the statistical significance of experimental data. We shall limit ourselves to the general object, design and sequence of experiments and refer occasionally to an interpretation of some of the salient observations.

Two types of cancer were selected for our study.

1. Cancer of the breast (spontaneous and induced).
2. Cancer of the skin (induced by chemical substances).

This review is confined to the work on the cancer of the breast in mice.

For the type of work we wished to undertake it was essential to determine certain objective criteria to commence with and later to assess the role of the various intrinsic and extrinsic factors in the production of this particular type of cancer in mice. The problem was, therefore, attacked along three different lines of approach:

(a) Evaluation of the role of intrinsic and extrinsic factors in the production of tumours.

(b) Behaviour of the tumour in a new host on transplantation.

(c) Behaviour of tumour cells in tissue culture.

In planning our experiments it was decided to work with genetically pure strains of mice, with known incidence of spontaneous breast cancer, to study the morphology of mammary glands at stated periods of their normal life and to investigate the naked eye and microscopic structure of the glands, the vaginal mucous lining and the endocrine glands, particularly the ovaries, adrenals and the pituitary. For the purposes of our experiments four pure strains of mice obtained from the U.S.A. and bred by brother-sister mating over a period of several years, in our laboratories, were mainly used. One other strain LC (Paris) obtained from Europe and later maintained as a separate line L (P) was also employed for certain special studies and will be referred to later in the text. The following table summarises some relevant information concerning the strains.

TABLE 1.

Strain	Abbreviation used in the text.	*Etiological Factors* Heredity	Hormonal Factor	Milk Factor	Reported present tumour incidence from the laboratories of origin. Virgins	Breeders
1. C_3H (Bar)	C_3H	P	P	P	95-100	95-100
2. dba (Bar)	dba	P	P	P	55	55
3. Strong A	A	P	A(V) P(B)	P	4-5	83
4. C_{57} (Bl)	C_{57}	A	A	A	—	0·5
5. L. (Paris)	L(P)	P	A(V) A(B)?	A	—	—

P — Present A — Absent V — Virgin B — Breeders

Cancer of the breast happens to be the commonest type of spontaneous tumour in laboratory mice and for that reason is probably the most thoroughly investigated subject in experimental studies on cancer. As a result of much work, it had been established that three intrinsic factors are mainly responsible for the development of breast cancer in mice. They comprise of a genetic susceptibility, hormonal stimulation and a milk-borne tumour agent (MTA), an ultra-microscopic particulate material having the chemical properties of a nucleoprotein and possessing characteristics suggestive of a "virus". It needs to be stated that the genetic factor "cannot be considered as the cause of the development of the tumour, but rather as the determinant of what the tissue could or could not do when submitted to the cancer producing agent" (2).

The first series of our experiments was designed to study the morphology of mammary glands by whole mount preparations in males and females at different age periods in the four strains of animals, and to identify differences in the architecture of their mammary glands. These studies formed the basis of reference in all our later investigations. The developmental differences in the breast glands of strains C_3H, A and C_{57} revealed a positive correlation between the structure of the mammary ducts and acini and the degree of the susceptibility of mice to cancer. Precancerous lesions in the form of focal acinar clusters were seen only in the highly susceptible strain C_3H and were absent in the mammary glands of virgins in the other two strains (18).

The complement of the three intrinsic factors in the three strains of mice and the incidence of breast cancer in them differ markedly. It was, therefore, considered advisable to study the action of these factors individually. In this next series of experiments, about six hundred mice belonging to these three strains were used.

For the purposes of studying the comparative response of the mammary glands to sex hormones, a large number of mice of the cancer susceptible and cancer resistant strains were gonadectomised soon after birth and their mammary glands examined when they were 5 to 7 months old, after an identical treatment with sex hormones. With such treatment the mammary gland morphology as well as the urogenital reaction presented significant differences. The pattern was determined by the amount of the gonadal hormone which was administered as well as, by the reactivity of the mammary tissue in the particular strain of mice. The tissue susceptibility appeared to be strain specific and was mainly influenced by its genetic constitution (21).

The action of the milk-borne tumour agent (MTA) in mammary carcinogenesis was studied by foster-nursing new born mice of each of the three strains on mothers of the other two strains. The litters were exchanged within 17 hours after birth and the effect of cross suckling was traced in adults when they were 7-8 months old. These experiments showed that foster-nursing distinctly altered the morphology of the mammary structure in the direction which was characteristic of the foster mother (15).

The part played by these three factors in the production of cancer was studied in the highly susceptible strain C_3H and the one resistant to it, C_{57}. The new born mice were ovariectomised soon after birth and foster-nursed on the mothers of the opposite strain. When they reached maturity they were divided into two groups. A pellet of estradiol, approximately weighing 0·9 mg. was introduced subcutaneously in mice of one group whereas the other received a balanced dose of 0·2 mg. estradiol and one mg. testosterone. At the age of five to seven months the mammary pattern and the urogenital response was compared in these experiments, where the hormonal factor and the MTA were kept under control. It was found that the genetic susceptibility had little or no effect on the mammary pattern. The breast glands of C_{57} mice nursed on C_3H milk showed the same extent of acinar proliferation as the C_3H mice nursed by their own mothers. On the other hand, C_3H and C_{57} mice which were reared on C_{57} milk presented only bare mammary ducts. It became, therefore, evident that the ductal pattern was determined by the hormonal influence and the acinar proliferation (indicative of abnormal growth) by the milk-borne agent (MTA). Our observations indicated the dominant role of the MTA over the other intrinsic factors in the development of mammary cancer in mice and confirmed the opinion that the nodular overgrowths which had been commented upon by other workers were definitely precancerous in nature. It could also be concluded that although the hormonal stimulation was necessary for an orderly development of the breast tissue, the agent transmitted through the milk in the early stages of life acted invariably as the initiating, as well as, the promoting factor for this particular type of cancer in mice (22).

Many workers have repeatedly considered heredity, hormones and the MTA as separate factors working along three parallel lines, each equally important and designated as 'mammary tumour preparatory influence or inciter' (3). The genetic constitution of the animal occupies a more fundamental position, at the base of the three pathways involving the milk factor, the hormonal stimulation and the susceptibility of mammary tissue. It controls the potency of the milk factor and the degree of hormonal stimulation (11). However, our experiments suggested that the milk factor exerts a definite influence on the general metabolism of experimental animals.

The influence of the MTA on the hormonal metabolism of the animal was first indicated in our preliminary observations on a group of 'intact' foster-nursed virgins. During the course of these experiments, it was often observed that the female mice of the cancer susceptible strain C_3H when foster-nursed on the milk of the resistant strain continued in a state of long diestrus, whereas, the resistant strain females fostered on the milk of the susceptible strain remained in a long estrus. These findings invited a systematic study of the ovaries of the foster-nursed mice. It was noticed that foster-nursing significantly altered the number of corpora lutea in the ovaries (20).

TABLE 2.

Strain	Total number of females studied.	Number of corpora lutea per largest section available (average)
Group I:		
C_3H/C_3H	10	$10{\cdot}0 \pm 1{\cdot}24$
C_3H/C_{57}	12	$4{\cdot}5 \pm 0{\cdot}47$
Group II:		
C_{57}/C_{57}	12	$4{\cdot}4 \pm 0{\cdot}48$
C_{57}/C_3H	13	$9{\cdot}6 \pm 0{\cdot}66$

The letters following the / indicate the strain of foster mother and those preceding it the parentage of offspring, thus C_3H/C_{57} indicates a C_3H new born foster-nursed on C_{57} mouse.

The striking differences in the number of corpora lutea of the cancer susceptible and the resistant strains had been reported by other workers. The average number of corpora lutea in C_3H decreased from 10 to 4·5 after foster-nursing on the C_{57}—while the average of 4·4 in the C_{57} increased to 9·9 when nursed on the C_3H milk. The number of corpora lutea is indicative of the degree of hormonal stimulation in an animal. Our observations demonstrated for the first time a definite change in the maturation of ovaries—indicating a change in the hormonal stimulation—after foster-nursing. This, to our mind, was a finding of some considerable importance and invited further experimentation for confirming our hypothesis. A third series of experiments was, therefore, designed to study the mode of action of the milk-borne agent. Four hundred mice of four strains were utilized for these experiments. The milk-hormone relationship was studied both in 'intact' virgins and in ovariectomised mice. Bittner, during the course of his extensive studies on 'milk factor', had suggested that a comparison of endocrine organs of two lines of a strain, one possessing the milk factor and the other devoid of it, would constitute the simplest method for testing the influence of the milk borne agent on

the endocrines. Three lines of strain dba (Bar), dba (new) possessing the milk factor, dba (—MTI) a line free of the milk factor raised from full term foetuses removed from the uteri of young breeders of dba (Bar) and fostered on C_{57} Milk, and dba (old), another old line of dba (Bar) presumed to have lost the milk factor during years of intense inbreeding, were used for these studies. A comparative study of the maturation of ovaries in these three lines presented significant differences in the average number of mature corpora lutea. Under the conditions of our experiment such differences could only be attributed to the presence or absence of the milk-borne agent (MTA) in the three lines. The mammary pattern also presented corresponding differences, so that hyperplastic nodules were present only in the first line and absent in the other two. Such observations, specially the gradation of differences in the three lines of dba, confirmed the view that although the hormonal factor is primarily conditioned by the genetic constitution of the animal, the virus received through the milk exerts a secondary influence on the hormonal metabolism. We were, therefore, led to the conclusion that the milk-borne agent probably acts on the mammary tissue in two ways, directly on the glandular epithelium and indirectly through its action on the ovaries leading to a more intense luteal stimulation (26).

If the milk factor acted through the agency of the gonads, it was felt that it may be worth investigating the mode of its action in the absence of ovaries. The first step in this direction was to follow the effect of gonadectomy in the three strains of mice C_3H, C_{57} and A. New born mice of these strains were castrated within 36 hours of birth. It was observed that such mice from C_3H strain at the age of 8 months showed continuous keratinisation of the vaginal mucosa, a profuse multiplication of mammary ducts and a marked adrenal hyperplasia. This manifestation of hyperactivity of the adrenal cortex and an estrogen-like stimulation of secondary sex organs was completely absent in the gonadectomised mice of the other two strains, viz., C_{57} and A. It was, therefore, assumed that in the absence of the gonads a well regulated hormonal brake was not being applied to the relevant activity of the pituitary gland and culminated in an excessive secretion of pituitary gonadotrophins. If the tissue is genetically susceptible, the increased gonadotrophins act on the adrenal cortex and induce cortical hyperplasia. An "inherited hormonal influence" is probably associated in some manner with the adrenal tissue susceptibility to pituitary gonadotrophins (4, 5, 12). A susceptibility to spontaneous development of mammary cancer does not necessarily induce a response in the adrenal cortex, as the mice of A strain which are genetically susceptible to breast tumour formation are lacking in the "inherited hormonal influence" and do not react by adreno-cortical hyperplasia after gonadectomy (25).

The next step was to study effect of the milk-borne agent (MTA) on the endocrine system after gonadectomy. The new born mice of C_3H and C_{57} after castration were foster-nursed on the milk of the opposite strain. The next table shows the results of the experiment.

TABLE 3.

Strain	Total Number of Mice.	*Number of Mice with* Adreno-cortical Hyperplasia.	Normal Ductal Development.	Calcium Deposits.
C_3H/C_3H	16	14	11	7
C_3H/C_{57}	14	6	13	6
C_{57}/C_{57}	12	—	4	1
C_{57}/C_3H	12	6	6	9

One other striking observation deserves particular mention. The adreno-cortical hyperplasia in C_3H strain of mice is invariably associated, not only with a profuse burgeoning of mammary ducts, but also with a heavy deposition of calcium salts in the stroma, in which the ducts lie embedded. The phenomenon of calcium deposition in stroma of C_3H mice was observed and reported for the first time by Ranadive in 1949. We have been interested in this finding and the influence of gonadectomy and foster-nursing has been investigated in some detail in our laboratories since that time (25). Adreno-cortical hormones were known to have a depressant action on bone formation. Adrenal hyperplasia or an excessive stimulation of adrenal cortex in gonadectomised animals probably sets up a steroid imbalance and may lead to a decalcification of bones followed by a deposition of calcium salts in the vascular stroma of the breast and the interstitial tissue of the kidneys.

The adrenal response to gonadectomy appears to be strain specific. There was no appreciable change in the adrenal response, breast development or calcium metabolism in the castrates of the C_3H mice after foster-nursing on the C_{57}. However, C_{57} castrates foster-nursed on the C_3H milk, presented adreno-cortical hyperplasia and calcium deposition in more than half the number of animals (17). The agent received through the milk might have some effect on the adrenals through excessive gonadotrophic stimulation. The direct effect of the agent on the pituitary is at present being investigated. We are of the opinion that these experiments have thrown some light on the mode of action of the milk-borne agent. The agent appears to have a two-fold action—partly an 'initiating' action directly on the breast tissue and partly a growth promoting action by stimulation of the endocrines.

Several spontaneous breast tumours in mice are known to have originated in different laboratories, in lines of mice which were free of the milk factor, particularly after forced breeding. This would not militate against the assumption that although the milk factor is probably responsible for 'initiating' the formation of these tumours, the "promoting stage" of the disease is mainly maintained by an excessive hormonal secretion which was partly induced by the agent itself.

As a continuation of our studies on the 'intrinsic' factors of mammary cancer it was essential to investigate the role of 'extrinsic' factors, such as chemical carcinogens in the production of mouse mammary carcinoma. Although American and European workers (1, 16, 6, 13, 14, 7) have studied in great detail the different aspects of chemical carcinogenesis in breast tumours, the manner in which the chemical substance induces the development of cancer, is still not very clearly understood. A systematic study was, therefore, planned to investigate the action of methylcholanthrene (MCA) in different strains of mice, varying in their content of known 'intrinsic' factors. The main problem was to ascertain if a chemical carcinogen like methylcholanthrene could replace any or all the intrinsic factors, in the production of breast cancer and later to study the pathways along which it acts (10).

Two lines of dba (Bar) besides the two strains A and C_{57} were selected for these experiments. The skin of one hundred female mice was painted twice a week with a 0·25 per cent methylcholanthrene dissolved in thiophene free benzene, at an age of 2½ months. The paintings were continued till the animals looked too weak, either because of the development of breast tumours or skin lesions. The females were kept either as normal or forced breeders. After autopsy, whole mounts of mammary glands, and histological sections of breast tumours, ovaries and adrenals were prepared for examination. The following table summarises the results in different groups of experimental mice.

TABLE 4.

Strain	Type of Breeder	Number of Animals.	Animals showing palpable breast tumours and microscopic cysts in the breast.	*Ovaries.* Average No. of Corpora Lutea.	*Ovaries.* Early granulosa cell lesions.
Dba (new)	Painted Breeders	16	10/16	5·34 ± 0·28	7/16
	Control Breeders	10	2/10	10·31 ± 0·44	0/8
Dba (-MTI)	Painted Breeders	20	13/20	9·9 ± 0·30	7/20
	Control Breeders	6	0/6	6·24 ± 0·08	0/6
A	Painted Breeders	37	1/37	2·51 ± 0·15	7/37
	Control Breeders	6	1/6	2·16 ± 0·66	0/6
C_{57}	Painted Breeders	10	0/10	5·72 ± 0·49	3/10
	Control Breeders	4	0/4	3·12 ± 0·62	4/4

Similar studies were also carried out on another new strain of white mice L (P) (24) which was imported from Paris in the year 1948. Even on intense breeding this strain had never developed a single spontaneous breast tumour in our laboratories and had not evinced the presence of the milk-borne agent on biological testing. The inherited hormonal influence is lacking in the virgins of the strain and hormonal stimulation is not adequate to induce hyperplastic nodules in the mammary glands of the breeders. A complete biological study of the mammary glands and endocrine organs at different age periods presented a picture closely comparable to that of the cancer resistant strain C_{57}. The mammary glands developed bare mammary ducts without any acinar proliferation in young and old virgins and breeders. The strain presented marked deficiency of the 'luteal factor'. The ovaries exhibited a typical picture of an organ very deficient in luteal stimulation, as the average number of corpora lutea was particularly small.

The virgins as well as breeders of strain L (P) were given biweekly paintings of methylcholanthrene from maturity till death. The following table summarises the results of such treatment.

TABLE 5.

Strain L(P)	Number of Animals.	Number of animals showing a palpable breast tumour and microscopic cysts.	*Ovaries.* Average No. of Corpora Lutea.	*Ovaries.* Early granulosa cell lesions.
Painted Virgins	8	0/8	0·43 ± 0·18	0/8
Control Virgins	10	0/10	1·20 ± 0·20	1/10
Painted Breeders	26	17/26	4·28 ± 0·09	14/26
Control Breeders	22	0/22	2·04 ± 0·18	2/22

On comparing the results on four strains of mice the following facts stand out—(i) In the dba possessing all the three intrinsic factors, methylcholanthrene only accelerated the tumour production. (ii) In the dba (-MTI), methylcholanthrene induced the same proportion of tumours as in the last group, dba with many multiple tumours. It was noticed that the tumours appeared slightly later. It could, therefore, be concluded that the milk-borne agent was not required for chemical carcinogenesis. The MCA breeder group developed the largest number of multiple tumours and showed a significant increase in the number of corpora lutea as well as granulosa cell lesions. (iii) The genetically susceptible strain A after being subjected to excessive hormonal stimulation of forced breeding failed to develop palpable tumours in any of the treated animals except one. Although the strain possessed the genetic susceptibility for tumour production, the luteal stimulation was probably insufficient for developing tumours after treatment with MCA. This is also suggested by the appearance of the ovaries. (iv) In the C_{57} with an absence of all the three intrinsic factors, hormonal stimulation by forced breeding was insufficient to induce cancer even after MCA painting.

The observation on the dba and A confirm the view that although genetic constitution determines the tissue susceptibililty to carcinogen treatment, the susceptibility to spontaneous breast cancer and the susceptibility to carcinogen induced tumours are two different conditions. The milk-borne agent has no essential role in chemical carcinogenesis but there is an indication in the strain dba (-MTI) that it is the increased 'luteal stimulation' in the breeders which acts as a developing factor. Bonser (6) and Jull (14) have reported the special susceptibility of strain 'IF' virgins to methylcholanthrene treatment, which could also be attributed to particularly heavy luteal stimulation as indicated by the appearance of its mammary ducts which were studded with acinar buds closely comparable to a gland during pregnancy and giving the appearance of a 'tree in flower'.

The importance of the 'luteal factor' in chemical carcinogenesis was further confirmed by our observations on the new strain L (P). The mammary glands of strain L (P) as well as, the ovaries suggested a marked inadequacy of luteal reaction at different age periods, in both virgins and breeders. In the animals treated with methylcholanthrene the tumours developed (17/26) grew rapidly and occurred in all the breast glands of the affected animals. The ovaries also gave some indication of increased luteal stimulation. The nature of this action is still obscure and is not cleared up from these experiments. It may, however, be surmised that MCA possesses growth stimulating properties in view of its chemical structure which closely simulates some steroid hormones and its hormono-mimetic action (13). In our experiments methylcholanthrene appears to act first as an initiating and on continued treatment as a developing factor in the production of mammary tumours. The hormonal stimulation during pregnancy, particularly by the progesterone appears to be one of the essential 'developing' factors. Investigations on the role of the pituitary gland might elucidate further the mode and mechanism of action of methylcholanthrene.

Methylcholanthrene has an additional effect on the reproductive function of the ovary besides its effects on its endocrine functions. Ova during their process of maturation or probably later during fertilisation are affected by MCA. The effect of MCA is reflected in the abnormalities observed in the progeny of animals painted with the chemical. Interesting strain differences have been observed in the progeny and are briefly tabulated (Table 6).

These studies on the mechanism of carcinogenesis in the spontaneous and chemically induced breast cancer reveal that although the etiological factors differ, the fundamental process of carcinogenesis is essentially the same. It consists of three stages 'initiation', 'promotion' and 'development' of the disease.

TABLE 6.

Observations on the Progeny of Painted Breeders.

Strain	Number of Breeders Painted with MCA	Total No. of young ones born.	Total No. survived.	Number observed till death.	Breeding behaviour of progeny.
Dba	16	168	7	4 ♀s, 3 ♂s	Females did not mate.
Dba (-MTI)	20	193	0	0	
A	13	260	221	10 ♀s, 6 ♂s	Normal healthy Breeders.
C_{57}	4	38	26	8 ♀s, 4 ♂s	Normal healthy Breeders.
L(P)	6	62	42	10 ♀s, 4 ♂s	Normal healthy Breeders.

In spontaneous carcinoma, the virus like agent (MTA) which is conveyed through the mother's milk is the 'initiating' factor. It acts on the breast parenchyma cells and on the hormonal system. The hormonal stimulation specially the estrin stimulation—acts as the 'promoting' and the 'developing' factor. A high dose of estradiol can promote cancerous growth in the breasts of the susceptible castrates possessing the milk-borne tumour agent. In chemical carcinogenesis, the chemical substance instead of the virus in the milk acts as an 'initiating' and to a certain extent as a 'developing' agent when the treatment with it is prolonged. Whatever may be the 'initiating' factor of the disease (MTA or MCA) the promotion and development of the mammary tumour once it has started is essentially controlled by adequate hormonal stimulation. The voluminous literature on this subject has repeatedly stressed the importance of estrin stimulation in mammary carcinogenesis. In the chemical carcinogenesis, however, effective progesterone stimulation in female appears to function as an important developing factor.

Tumour Metastases:

An action and interaction of intrinsic and extrinsic factors initiates the process of carcinogenesis which finally results in the development of a carcinoma. Once the cancer has been launched on its career there follows a spread of the tumour in the body. The process of metastatisation and the factors affecting it need careful investigation. At attempt is being made to study the role of the reticuloendothelial system in this process of metastasis. Some work in our laboratories (9) suggests that after blocking the reticulo-endothelial system with agents like trypan blue and cortisone, it has been possible to induce secondary growths of the tumour in many organs like liver, kidney, lung, etc., as seen in the table below.

TABLE 7.

	Total Number of animals.	Metastases in			
		Liver only	Lung only	Liver & Kidney	Lung, Liver & Peri-nephric region
Trypan blue treated	29	3	4	1	1
Control	28	0	0	0	0

It appears that the R.E.S. plays a dominant role in preventing a metastatic scattering of the tumour in mice.

Tumour Transplantation:

What has been stated above refers to the behaviour of the mammary tumour in the animal in which it originates, grows, spreads and scatters. The nature and behaviour of the tumour could be further studied by transplanting it in other hosts. Fifteen spontaneous and methylcholanthrene induced breast tumours from lines of mice with and without (MTA) have been studied for more than 30 generations of transplantation. The milk factor adenocarinoma is not noticeably altered through transplantation but the agent free carcinoma simplex has developed into highly anaplastic type in its 25th generation and the methylcholanthrene induced tubular adenocarcinoma has shown a sarcomatous transformation of its

stroma very early during repeated transplantation. It may be mentioned here that in these studies, besides recording the local growth rate, site of metastases and microscopic structure of the tumour at each transplantation, detailed "in vitro" observations have been carried out. Growth rate, growth pattern, cell morphology and cytology of different tumours have been compared in 'hanging drop cultures' and significant differences have been observed in the behaviour of different tumour types (23). Twelve adenocarcinomas, one carcinoma simplex, one adenoacanthoma and a carcinosarcoma have been thus standardised as a valuable material for later use in experimental chemotherapy.

Experimental Cytology:

Studies on the biological mechanism of carcinogensis would be incomplete unless it is explained at cell level. An evaluation of the direct action of cancer inducing substances on normal cells, viz., the effect on their morphology, cytology and intracellular enzymatic activities may shed further light on this phenomenon of a transformation of healthy into malignant cells. It is possible to undertake these studies on living tissue cells of different origin, grown in tissue culture. The possibility of growing successfully and maintaining indefinitely different cell-types in appropriate nutritive media of known chemical composition (tissue farming) constitutes the main obstacle in these studies. Different normal and cancer cell lines of mouse and human origin are being maintained in our laboratories for investigations in experimental cytology. There are many facets to these studies (biological and biochemical). For instance, it may be fruitful to study the nutritional requirements and the metabolism of different cell types under controlled conditions. Several mouse mammary tumours besides mammary glandular tissue from adult virgins and pregnant female mice have been grown and maintained by different techniques in tissue culture in our laboratories. It is intended to use this material for studying the direct effect of various hormones on the normal and malignant breast tissue.

An attempt has been made in this review to give a bird's eye view of the several investigations which have been completed or are at present in progress in one department of our laboratories. The work reveals a persistent effort to unmask one of the unsolved riddles in cancer research and the different directions in which it has led us so far.

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Note: No illustrations and photomicrographs are included in this review. They may be consulted in the publications cited above.

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Cultivars of the Fungus, *Fusarium*

BY

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The use of variety names for plants arose in ancient times when man began to recognize the advantages of one planting stock over another. When he found that a certain grape tasted better, yielded more heavily, or made a choicer wine than another grape, he needed a distinguishing name for it. Such a name is our horticultural variety or, preferably, cultivar, of today. It preceded formal botanical classification, which is a product of modern time, and has survived. The cultivar provides a means of informally naming plants. It has nothing to do with taxonomy, or classification, and, therefore, is entirely independent of the botanical variety which implies relationship and position in a scheme of plant classification. These two systems of naming serve different purposes, and may supplement one another, but neither takes the place of the other.

The role of the simple, convenient name of the cultivar is as important today as it was centuries ago. Actually it is more important now because of the development and use of more and more cultural varieties.

The more we learn about plants and the more we use them, the more variation we recognize in them. And the more variation we see, the more opportunity we find for the selection and perpetuation of new cultural varieties, and thus grows the need for more variety names. As it is with the grape, so is it with all plants. And so it becomes with fungi. Indeed, so must it be with all kinds of plants and animals the cultivation or husbandry of which serves man.

The cultivation of fungi today is increasing phenomenally. We are learning rapidly, now, how better to grow fungi, and we understand more fully their variability. This enables us to utilize them to greater advantage, to select superior variants for the production of vital medicines, chemicals, foods; and to approach more intelligently the control of those which destroy our crops and which in other ways are harmful to man. We need names for the subspecific entities or variants within the species, for the clone or group of clones the cultivation of which is in some way important to man. The situation now arising in fungi is analogous to that which arose in crop plants a long time ago, and the solution seems the same, i.e., the employment of cultivar names. This paper is submitted in support of the wider use of cultivar names in fungi.

Need of cultivar names in fungi

The better we know an organism the broader becomes the species concept applied to it, and the greater the need for names for intra-specific categories. Man, perhaps, knows more about his own species, *Homo sapiens,* than any other. He accepts without question a wide range of stature, skin color, behavior, and racial characteristics in this species. He provides names not only for all categories from the species to the individual but even gives one or more names to every individual. In no other species on earth can every individual boast a name. The dog, *Cannis familiaris,* probably comes nearest to man in this respect. This species, too, has been known long and well, and here again a broad species concept has evolved. Some of the variations in this species have been selected and perpetuated under such names as Poodle, Great Dane, and Mexican Hairless, just as Perfection, Green Giant, and Marvel have been selected for culture out of the pea species, *Pisum sativum.* All of these names of dogs, and of peas, are in effect "horticultural" varieties or cultivars, that is, they are the cultivated intra-specific variants of species.

Another organism man has known long and well is wheat. He has cultivated it for at least 3000 years. When taxonomists began to classify wheat botanically they tended to regard the different forms of wheat as distinct species, and so named them. They separated, taxonomically, awned from awnless, winter from spring, and red from white wheats. It has been only since the knowledge of the inheritance of these features in wheat that many such species were merged together. Now taxonomists agree that most common varieties of wheat belong to one species, and the former species, botanical varieties, etc., have given way to one or more cultivar names. Now wheat, *Triticum aestivum* L., is a large species composed of a wide range of variants, the more important of which have been designated by cultural variety names.

Less well-known species of organisms are apt to be narrow and small. This is because the first step in classification, after collection, is analysis, where the different collections are searched especially for differences from the then described species. At this stage any differences are apt to be seized upon to make a new species, and a sounder classification must wait the accumulation of knowledge which finally permits the recognition or synthesis of fewer but better species.

The science of mycology is growing up. Knowledge acquired through genetical and other experimental disciplines is beginning to reflect this advance in the fungi. Already there has developed a marked trend toward classifying fungi into fewer and larger species. And it is only natural that following upon this trend there should be an increasing need to provide cultural names to the ever-growing number of variants within these species to which man is now turning his interest.

Examples of cultivars in fungi

When man selects from nature a particular edible mushroom for cultivation he has started a cultivar of it, whether it is so named or not. Through mutation or other variation superior strains or clones are selected again, and these become additional cultivars. Similarly, clones in *Aspergillus* and *Penicillium* species are selected for their superior production of citric acid in one case and penicillin in the other. These, again, may be cultivars by definition. Although not generally named as such, it is clear that cultivars already are in wide use in industrial mycology.

But there are other fields of economic mycology where the use of cultivars is just as soundly indicated. One of these fields is plant pathology.

If one wanted, for some reason, to produce sclerotia of *Sclerotinia sclerotiorum,* using agricultural methods, he might grow such crops as the crucifers, forage legumes, and lettuce on infested land. Were he to do this he probably would find that he was obtaining a variety of sclerotial sizes following parasitism of these crops. If the uses for the sclerotia called for small sclerotia, he might select lettuce for the propagating crop, if large sclerotia, cauliflower. Such procedures would be recognizing variation in *Sclerotinia sclerotiorum* and mean the selection of cultivars of the fungus by controlled propagating methods. That such horticultural varieties in *Sclerotinia sclerotiorum* do exist, and are of economic importance, has been recognized already by Purdy (3) who has named the small, intermediate, and large sclerotial forms of

Sclerotinia sclerotiorum as cultivars Minor, Intermedia, and Major, respectively.

In the genus *Fusarium* similar examples of cultivars exist, and only remain to be named, for the same reasons. In the species *F. oxysporum* both Gordon (1) and Snyder and Hansen (4) agree on the taxonomy and nomenclature of its component variants except for the former species *F. redolens.* Gordon considers this species to be sufficiently distinct from the range of morphology in *F. oxysporum* to warrant making it a botanical variety, *F. oxysporum* var. *redolens,* rather than to make it a synonym of *F. oxysporum* as Snyder and Hansen have done. The present writers acknowledge that there are features in *F. redolens* which are on the level of the cultivar and propose to recognize these features by naming the eariler species, *F. redolens,* as a cultivar: *F. oxysporum* "Redolens" with description as given for his botanical variety.

Similarly, Gordon (1) is in essential agreement on the taxonomy and nomenclature of the species *F. solani,* except that he retains separately from this species *F. coeruleum,* which Snyder and Hansen (5) merge with *F. solani.* Because of the economic importance of the fungus formerly known as *F. coeruleum,* but at the same time recognizing that its distinguishing features are unsuited for nomenclatural distinction on a species or even a botanical variety level, it is proposed here to give this fungus a cultivar name, *F. solani* "Coeruleum," with description as provided for *F. coeruleum.*

The most striking cultivars are, perhaps, in the species *F. roseum.* Into this species Snyder and Hansen (6) merged such former species as *F. graminearum, F. culmorum, F. avenaceum, F. acuminatum, F. equiseti,* and *F. sambucinum.* The basis for this consolidation of species was provided by Oswald (2) and on the grounds of the wide variation obtained from crosses made by Gordon and Snyder and Hansen with component clones of *F. roseum.* However, in spite of similar experimental evidence in the hands of the proponents of both taxonomic schemes, Gordon prefers to keep as acceptable species several of those which Snyder and Hansen prefer to combine into *F. roseum.* It seems to us that these differences of judgment may be resolved by the use of cultivar names for those differences in morphology which all of us recognize, but which are given different weight taxonomically. It is proposed here, then, that the following cultivars be recognized in the species *F. roseum*: Culmorum, Graminearum, Avenaceum, Acuminatum, Equiseti, and Sambucinum. These cultivars are recognized chiefly on appearances, and are independent of such biological characteristics as are indicated in forma and race names. (The forma, and its subdivision, race, represent distinctions in behavior rather than primarily in appearance).

These cultivars may be written, therefore, in the following fashion, when no pathogenesis is indicated:

F. roseum "Graminearum"
" " "Culmorum"
" " "Avenaceum"
" " "Acuminatum"
" " "Equiseti"
" " "Sambucinum"

and as follows when pathogenesis is indicated:

F. roseum f. cerealis "Graminearum"
" " " " "Culmorum"
" " " " "Avenaceum"

It seems to us that the designation of the transitory or minor variations in conidial morphology or appearances, which are too unstable to find a place in botanical classification, are best labeled in the above fashion as cultivars.

Other cultivars in *Fusarium* which we believe at this time should be named are as follows.

F. episphaeria	"Dimerum" for the small-spored forms
" "	"Gigas" for the large-spored forms
F. moniliforme	"Subglutinans" for those forms of the species which usually do not produce microconidia in chains.

These cultivars in *Fusarium* may not be cultured directly by man, nor intentionally. Nevertheless, they are a direct result of man's selective crop culture. If he intended to produce the cultivars of *F. roseum* he could do no better than he is already doing unintentionally. Graminearum, Culmorum, and Avenaceum represent variants in *F. roseum* which man, inadvertently or not, selects out and propagates in the course of selecting out and cultivating agronomic varieties of *Triticum aestivum.*

Are these differences too great for cultivars?

Some may object that the morphological differences between the cultivars Graminearum, Culmorum, and Avenaceum, in the species *F. roseum*, are too large, that it is better to recognize these differences on a species level.

To explore this situation, let us look at cultivars in, for example, their host plant, wheat, as shown in Plate I A.

The differences here appear far greater than those shown between the pathogenic and non-pathogenic cultivars of *F. roseum*, often associated with wheat culture, illustrated in Plate I B and C, respectively.

Certainly the differences between cultivars in *F. roseum* are a great deal less than those commonly accepted in onion Plate II A, in squash Plate II B, or in radish Plate III.

Some of the cultivars of the higher plants shown here are based on vegetative structures, as in *F. roseum*, others on the fruit.

And we should remember that some of these cultivars of wheat were at one time species, as were the cultivars of *F. roseum*.

Some may feel we are not justified in drawing a parallel between fungi and higher plants. Why not? Why not draw comparisons in the taxonomy and nomenclature of all living things, whether plant or animal, whether they are higher or lower forms of life? Might not the classification of one group of living things benefit from the knowledge acquired in classifying and naming another group of living things? Wheat, *Triticum aestivum*, has been studied longer, more intensively, by more individuals than the fungus, *Fusarium roseum*. Is it not desirable for one who is studying *Fusarium* to look to those who have studied *Triticum* for guidance and ideas? More than this, actually no comparison is being made between fungi and higher plants, the comparison is between the man-made procedures or systems of classifying and naming organisms. Is there anything wrong with man being consistent about such procedures? Rather, how can he afford to be inconsistent in applying all his knowledge and his most proven concepts in the classifying and naming of *all* organisms? And finally, were we to compare the morphological differences of cultivars of wheat, and of *F. roseum*, we should have to remember that the variability in the diploid sexual fruit of a plant is less than that of a haploid vegetative stage.

Discussion

The cultivar is an informal device for naming subspecific clones, or group of clones of living things which have no taxonomic standing and the use of which conveniently serves man's everyday need. Examples of established cultivars are Poodle, in the dog, *Cannis familiaris;* Perfection, in the pea, *Pisum sativum;* and Minor, in the fungus, *Sclerotinia sclerotiorum.*

The need for cultivars increases with the consolidation of many species into one, such as in wheat. The cultivars of today are often the species of yesterday. Unrecognized variability in living things brings into existence innumerable man-made species. Recognition of variability, on the other hand, eventually brings down sharply the number of species. The younger or less studied the taxonomy, the greater the number of species and the fewer cultivars to be found in it, and conversely. Most fungi are little known and are vastly over-speciated. The trend among the most intensively studied genera of fungi is towards the recognition of fewer species. This trend brings about the need for cultivar names by which to indicate certain former species and any other subspecific forms man has had reason to learn to recognize, as a plant breeder has reason to learn to distinguish between common wheat varieties, whether directly cultivated or not.

Some pathologists have reason to distinguish between cultivars Culmorum and Graminearum, even though both may cause the same diseases of wheat and taxonomically are in the same species, *F. roseum*, because the latter produces perithecia in the field and, therefore, having ascospores, is readily wind-borne. Other pathologists may not have need for this specialized knowledge, but are more concerned with distinguishing between the foot rots caused by *Helminthosporium sativum* and *Fusarium roseum*. For them the use of species names in place of cultivar names would delay species diagnosis.

The adoption of cultivar names in fungi is a step towards the simplification of fungus identification. An example of great need in this respect is in the Actinomycetes. Progress has been so rapid in the industrialization of these fungi used in the manufacture of antibiotics that taxonomy and nomenclature have been outstripped and confusion is the result. It seems inevitable that in *Streptomyces*, as in most economic genera of fungi burdened with large numbers of species, the solution will lie in the delimitation of very few, broad species, with their biologically distinct formae and races, and with sufficient cultivars to take care of the every day needs of the economic mycologist.

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Explanation of Plates

PLATE I

Cultivars of wheat, and of the *Fusarium roseum* often associated with its culture.

A. Wheat cultivars, left to right: Sonora, Onas 53, Ramona, Poso and Kanred.
B. Cultivars of *F. roseum* pathogenic to wheat, left to right: Graminearum, Culmorum, and Avenaceum.
C. Non-pathogenic cultivars of *F. roseum*, left to right: Sambucinum, Equiseti, and Acuminatum.

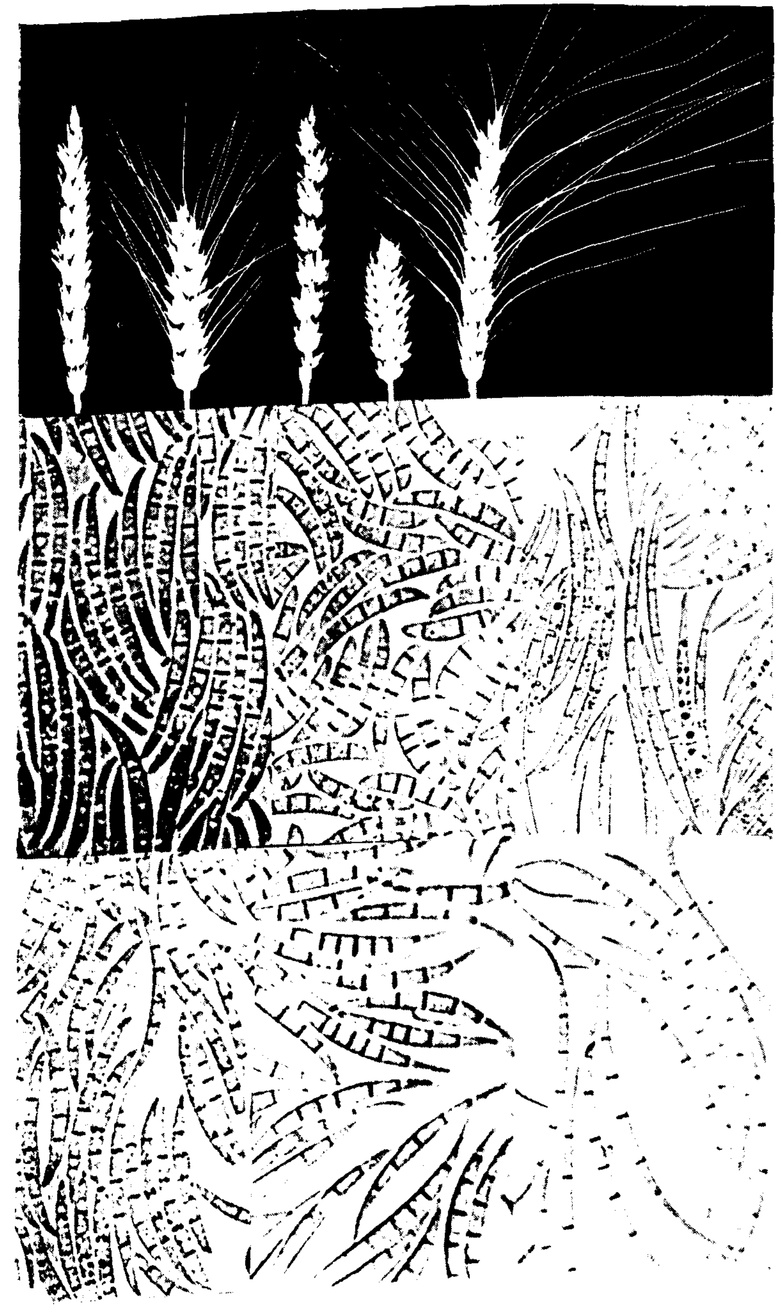
PLATE II

Cultivars of onion and of squash.

A. Left to right: California Early Yellow, Italian Red, and Extra Early Flat White onions.
B. Left to right: White Bush Scallop, Yellow Summer Crookneck, and Dark Green Zucchini squashes.

PLATE III

Radish cultivars. On the left, White Icicle; on the right, Cherry Belle.



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Volcanic Episodes in Indian Geology

BY

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It is now generally agreed that the earth passed through a stage when its surface temperature was high enough to melt the rocky material of which it is made, or at least to soften it to a viscous state. The heat of the original earth was gradually radiated out and a solid crust began to form. During a period of many million years, until its surface became cool enough to collect large pools of water, the crust was composed entirely of partly crystallised molten rock whose constituents were probably much the same as the rock-forming minerals we now find in the igneous rocks exposed at the surface.

At the present time, we cannot be sure about the constitution of the primordial crust. It had probably the mineral composition of a gabbro or basalt. Among the shield areas of the world, i.e., those containing the oldest rocks, confined to a few limited regions, the more important rock types are granitoid gneisses containing mixtures of acidic and basic materials in varying proportions. From what we know of the phenomenon of radioactivity, the earliest formed minerals which have been preserved in the shield areas—and therefore the rocks containing such minerals—are about 2300 to 2500 million years old. As the radioactive minerals occur generally in granitic and pegmatitic rocks which are later in age than the gneissic and schistose host rocks it is likely that the host rocks are many million years older than the age indicated by the radioactive minerals contained in the pegmatites.

The stratification of the earth into various shells inferred from seismological studies leads us to believe that the core, which occupies more than half of the volume, is of the nature of nickel-iron. This idea is indirectly supported by iron meteorites which fall to the earth from outer space and which represent the original material out of which the planets of the solar system were made. Surrounding the core is a shell of metallic sulphides and ferro-magnesian silicates, perhaps resembling the material of the stony meteorites which also come from inter-planetary space. The stony meteorites are related to such rocks as peridotites, pyroxenites and eclogites. Still nearer the surface is another shell of the composition of the basic igneous rocks (dolerite or basalt) which make up the bulk of the great lava flows found in many parts of the world. The outermost shell is apparently of rather mixed character but predominantly acidic and granodioritic in composition. The crust itself is only a few kilometers thick and composed of sedimentary rocks containing large patches of metamorphic and igneous rocks. The bulk composition of the earth would therefore approximate to that of basic igneous rocks.

The vast span of time covering the Archaean and pre-Cambrian era must have witnessed repeated igneous action. As the cooling of the earth continued and sedimentary basins became established, there would have been a slowing down of the phenomenon of intrusion and extrusion until stable conditions were established when this phenomenon assumed a periodic character.

The existence of radioactive material in the earth and its comparative concentration in the outer shell is an important factor in the temperature status of the earth and in the preservation of heat in spite of ceaseless radiation from the surface into space. Calculations based upon various assumptions about the quantity of heat generated by radioactive materials in the earth's crust and its interior have enabled geologists and cosmologists to infer that enough heat accumulation occurs to produce igneous action, in some part of the earth or other, every 20 to 30 million years.

Stratigraphical data indicate that three or four major mountain building movements took place since the last movement before the beginning of the Cambrian. Several earlier movements are known, but only in an imperfect way. The four movements are:—

(1) The post-pre-Cambrian movement after which the Cambrians with their rich fauna were deposited. Evidences of this movement, which is about 550 to 600 million years old, are seen in several parts of the world.

(2) The next movement occurred in the Silurian and is called the *Caledonian*. Effects of this movement, which is about 350 million years old, are seen in Central and Western Europe as well as in North America.

(3) The succeeding important movement is called the *Variscan* or *Hercynian*, of Carboniferous age. Evidences of this movement which took place about 250 million years ago resulting in the Karakoram—Hindukush mountain ranges to the north of India, and several other ranges in Northern Asia, are seen in other parts of the world also.

(4) The last great mountain building activity which is called the *Alpine-Himalayan* movement, commenced in upper Cretaceous about 60 or 70 million years ago and lasted through the Tertiary era right down to the Pleistocene Ice Age.

Very little work of high quality has been done on age determinations of radioactive minerals in Indian rocks. The earliest rocks so far known are in the Mysore State where some magnetites indicate ages of the order of 2300-2500 million years. The minerals from the pegmatites of Nellore district of Andhra State indicate an age of around 1650 million years, while some radioactive minerals from the mica pegmatites of Gaya and Hazaribagh in Bihar give an age of 950 million years. Minerals from some post-Delhi pegmatites of Rajasthan indicate an age of 730 million years. No further data are available but it should be possible to determine the ages of the various sedimentary systems in India by careful investigation of radioactive minerals present in igneous rocks associated with them. It will be noticed that there are large gaps in the ages which will have to be filled up by data to be obtained by further investigations.

Periods of mountain building are intimately connected with igneous activity. It would be of interest to state here that the precursor of the birth of a mountain range in geological history is a *geosyncline*. A geosyncline is a depression in the earth's crust of fairly large dimensions occupied by sea in which sediments are washed down from the neighbouring land masses. Geosynclines may also form parts of large oceans. The accumulation of sediments is accompanied by the gradual sinking of the basin. The blanketing effect of the sediments at the bottom leads to the heating of the basal portions which soften and give access to molten igneous materials from the basaltic shell of the earth, these forming sills and dykes. Contemporaneous volcanism found in geosynclinal sediments is probably to be explained in this manner. When the sedimentary basin has been in existence for several million years and has received considerable thickness of sediments, there comes a stage at which the basin is subjected to horizontal compression which affects the segment of the crust containing the geosyncline. The cause of such compression is not known but has been explained as due to the contraction of the earth or to the effect of convection currents acting beneath the crust. As a result of the compression, the strata formed in the geosyncline are pushed down deeper and deeper, breaking the crust and inducing even rocks from the ultramafic or peridotitic shell to intrude into the sediments near the surface. Such ultramafic intrusions are found generally in the root zone of mountains which were raised up in the region formerly occupied by the geosyncline. At an early stage of the compression, a part of the outer zone of the geosyncline on the ocean side (i.e. away from the land mass) is raised up as a wrinkle to form an *island arc* which may partly be submarine and partly above the sea waters. Violent volcanic activity is manifested in such island arcs as is now seen in the East Indian Archipelago and in the strings of islands in the Pacific ocean bordering Asia.

H. H. Hess (1938) states that all major occurrences of ultramafic rocks in the world are confined to the root zones of recent or ancient folded mountain ranges. Basaltic rocks are also extruded, and occur as sills and contemporaneous flows in the geosyncline during the operation of the compression, for this might last for as much as 30 to 50 million years. During the later stages of compression the sediments at the base of the geosyncline, which become depressed to depths of several scores of kilometres, are more or less completely melted or reduced to a viscous stage and are extruded as granite batholiths in the root zone. The intrusive activity may persist throughout the period of compression, for we find that the granites are followed, at a somewhat later date, by aplites, pegmatites and mineralising solutions which often produce metalliferous mineral deposits containing workable amounts of gold, tin, tungsten, copper, lead, zinc, mercury, etc.

Volcanic action may also be manifested in areas in which the crust is subject to tension, producing cracks and fissures. Such tensional cracks developed in parts of the Gondwanaland during the Jurassic period and ultimately led to its disruption and separation into the various continental units which are now found scattered in the Southern hemisphere. This type of activity is exemplified in the Stormberg lavas of South and Southeast Africa and the Rajmahal volcanics of Bengal which are of Jurassic

age, and the Deccan Traps which welled out from fissures in western parts of Peninsular India in Upper Cretaceous times.

This introduction will give some idea of the mode of formation of volcanic rocks, including both hypabyssal and extrusive phases. A brief account of the various episodes of volcanic activity, deciphered in the different periods of the geological history of India, follows.

PRE-CAMBRIAN

More than half of Peninsular India is occupied by gneisses amidst which there are bands of dominantly schistose rocks, usually referred to the Dharwar System. It is now recognised that the schistose rocks may include materials of different ages. As our knowledge of individual areas is still sketchy, our remarks will apply broadly to regions rather than to limited districts.

Mysore: The Dharwar System consists of various types of schists, quartzites, ferruginous quartzites and subordinate crystalline limestones. The schists are dominantly chloritic in the north and hornblendic in the south. Granulitic texture is prominent where the hornblendic schists are in contact with or included in granitic and gneissic rocks. A stage of alteration intermediate between the two is probably represented by epidiorites. In the Shimoga schist belt, B. Rama Rao (1940) has divided the rocks into three divisions each of which contains effusive igneous rocks. Post-Dharwar volcanism has also been deciphered, as shown in the accompanying table.

Post-Dharwar	Felsites and porphyries, generally unaltered, occasionally sheared. Amphibolite and norite dykes.
Upper Dharwar	Some basic sills and other igneous materials.
Middle Dharwar	Rhyolites, tuffs, felsites. Basic intrusives, mainly sills and chloritic schists.
Lower Dharwar	Basic flows and sills. Amphibolites, Hornblende schists, chlorite schists, greenstones; Keratophyres, rhyolites and tuffs often sheared and schistose.

The lower Dharwars are considered to be mainly of igneous origin, made up of amphibole and chlorite schists, amphibolites etc., and flows and tuffs of more acidic character. Where highly metamorphosed, the basic lavas have been converted into granulites. The felspars are of generally medium plagioclase showing ophitic relation to the amphiboles; while biotite, titaniferous magnetite and ilmenite are also present. *Occasionally pyroxene schists* occur, as at Javanhalli. The fine-grained schistose types may represent tuffs or volcanic flows but some of the chlorite schists may be sedimentary in origin also.

In the middle Dharwars of the Chitaldrug schist belt, there are basic lavas some of which are spilites and pillow lavas, which show vesicles filled with secondary calcite, silica etc. The rocks have not been altered to schistose or granulitic types. Some of the norite, porphyry and felsite dykes appear to be of post-Dharwar age as they do not show much alteration.

Cuddapah Basin: In the Cuddapah basin of Andhra, the Vempalle limestone belt as well as some younger zones contain thick sills, dykes and sheets of basic rocks which are doleritic or basaltic, and generally somewhat altered. One sill traversing the Vempalle dolomitic limestone has produced workable deposits of chrysotile at the contact zone. These dolerites carry besides augite and plagioclase (andesine-labradorite), hornblende, biotite, magnetite, apatite and pyrite. They are similar to the newer dolerites of Singhbhum and Keonjhar and differ from the Deccan Traps in not containing pigeonite and are perhaps differentiates of a tholeitic magma. They are of Upper Cuddapah age, contemporaneous with the Nallamalai or Kistna series (Coulson, 1933).

Rajasthan and Gujarat: The pre-Cambrian formations known here are the pre-Aravalli gneisses, the Aravalli System, the Banded Gneissic Complex, the Delhi System and the Gwalior System. The Bijawar Series of Central India is also considered to be equivalent of the Delhi System. In Western Rajasthan, fairly large areas are occupied by acid igneous extrusives (rhyolites, felsites) which are considered to be of Lower Vindhyan age. In the pre-Aravalli schists there are some amphibolites and hornblende schists which may represent altered or reconstituted ultramafic rocks.

In the Aravalli System, which is generally correlated with the Dharwars, there are intercalated bands of amphibolite and dolerite. These amphibolites are schistose and are composed largely of green pleochroic amphibole, plagioclase, felspar and some titaniferous magnetite.

The banded gneissic complex is considered by A. M. Heron (1917) as older than Aravalli while N. L. Sharma (1953) and H. Crookshank think that they are later in age and intrusive into the Aravallis; the basic inclusions and streaks in them being derived from the Aravallis. The rocks vary from foliated amphibolites to hornblende-schists and epidiorites. The constituent minerals are actinolite, granular quartz, magnetite, chlorite and epidote, the last two being alteration products of the earlier amphibole. Microcline and calcite are found in some varieties.

There are some dolerite dykes traversing the Aravallis which are only partially altered. They contain amphibole, labradorite, a little quartz, occasional hypersthene and biotite, with apatite, zircon and magnetite as accessory minerals. There are also some dykes in this region, the rocks in them containing some amphibole and a little partly altered augite, in addition to quartz, microcline and oligoclase.

In the succeeding Delhi System, which is upper pre-Cambrian, there are contemporaneous as well as intrusive basic igneous rocks intercalated with sediments of both the Alwar and Ajabgarh Series. Amidst the thin quartzites and phyllitic mica-schists, there are layers of amphibolites. Streaks of amphibolites considered to be either thin sills or contemporaneous flows or ash beds are also found in the Alwar quartzites. These rocks consist of green amphibole, clear plagioclase and interstitial quartz with sphene, apatite and biotite as accessory or varietal constituents.

The Gwalior System and the exposures at Ranthambhor are away from the Aravalli mountain belt so that their age is in doubt, but they are perhaps equivalent to the Delhis. In the Ranthambhor syncline there are five horizons of basic igneous rocks of doleritic or basaltic character. The rocks which are more or less uniform-grained do not contain vesicular bands and may represent contemporaneous intrusions as sills. The thickest sill is 200 ft. thick in which the rock is mostly dolerite without olivine or glassy matter. The felspars and augite are partly altered.

According to N. L. Sharma (1953) there are only three important groups of basic intrusives (dykes and sills) in the Aravalli-Delhi succession of Rajasthan. The earlier group, consisting of amphibolites, epidiorites and hornblende-schists is intrusive into the Aravallis but is of pre-gneissic age. The next group consisting of meta-dolerite is post-gneissic but of pre-Erinpura granite age, the Erinpura granite being slightly younger than the Delhi system. The third group mainly consists of dykes and occasional sills which are all of post-Erinpura granite age and may be pre-Malani.

The Bijawar series occurring in the Bijawar district in Central India (V.P.) consists of a sedimentary sequence of quartzites, conglomerates, sandstones, siliceous limestones and hornstone-breccia with basic lava flows, tuff-beds and dykes. The dyke rocks are doleritic with micro-pegmatitic patches but some are of the nature of olivine dolerites. The Bijawars are generally correlated with the Cuddapahs and Delhis.

V. S. Dubey (1950) has proposed a threefold division of the Bijawars. He regards the Lower Cuddapah and Delhi rocks as Lower Bijawars; the Middle Bijawars as including those with contemporaneous basic igneous activity as in the Bijawars of the type area and the Upper Cuddapah of the Andhra area; the Upper Bijawars as including the Semris (generally referred to the Lower Vindhyans) of the Son valley which contain acid flows and tuffs, and the Lower Vindhyans of Rajasthan with their Malani igneous suite, as well as the ultrabasic pipes in Bundelkhand containing diamonds. He advocates that the base of the Cuddapahs should be fixed at about 900 million years (Holmes' upper Pre-Cambrian to correspond to Cuddapah); that the Erinpura granites and their pegmatites giving an age of 735 million years, and also the Malani igneous rocks should all be included in the Cuddapahs. A point in favour of this idea is that all Cuddapah and post-Cuddapah igneous activity would be relegated to the Cuddapahs and that the Vindhyans of Northern India would be the equivalents of the Kurnools which do not show any contemporaneous volcanism. There is also a well marked unconformity between the Semris and what are now regarded as the Upper Vindhyans.

Semri Series: The rocks immediately underlying the Vindhyans of the Son Valley, consisting of shales and sandstones, contain dykes of doleritic character. These rocks show both monoclinic as well as rhombic pyroxenes together with andesine, some ilmenite and pyrite and a few cloudy interstitial patches. Amygdular cavities are occasionally present. The Semris are separated from the Vindhyans by a distinct unconformity; they have been somewhat metamorphosed, in contrast with the unmetamorphosed Vindhyans which overlie them. It is, therefore, possible to assign a Cuddapah age to them.

Malani Igneous Rocks: The Lower Vindhyans of Rajasthan are intruded by acid igneous rocks (Jalor and Siwana granites) whose extrusive phases are rhyolites, tuffs, felsites, etc., which are found over a fairly large area in Western Rajasthan. The upper Vindhyans, which contain a large thickness of sandstones, shales and limestones do not contain any igneous rocks and there is also a hiatus between the lower and upper Vindhyans.

Lower Vindhyans Semris	Dolerite dykes. Malani rhyolites, felsites etc. Pre-Malani dolerites.
Erinpura granite	
Bijawar & Delhi	Meta-dolerites and epidiorites, mainly contemporaneous.
Granitoid Gneiss and Banded Gneissic complex	
Aravalli System	Sills of amphibolite, epidiorite etc.

Bihar and Orissa: In the Singhbhum district of Bihar and in the neighbouring Sundargarh district (Gangpur) of Orissa, the pre-Cambrian succession is fully developed and it has been studied in recent years. The major units of the succession are shown below.

Newer Dolerite		Dolerite dyke systems traversing the Chota Nagpur and Singhbhum granites.
Arkasani granophyre		Acid granophyric rock formed mainly in the shear zone of North and East Singhbhum.
Singhbhum Granite		
Dhanjori and Dalma volcanics		Basic lavas (flows and sills) and tuffs, all metamorphosed to amphibolites, epidiorites and schists.
Iron-ore Series	Iron-Ore Stage	Phyllites, quartzites etc., with basic igneous rocks in the lower portion.
Iron-ore Series	Chaibasa Stage	Schists of different types partly derived from tuffs and lavas.

In the Gangpur series which occupies the greater part of the Sundargarh district there are a few important sills composed of metamorphosed basic igneous rocks—amphibolites, epidiorites and hornblende-schists. They are generally schistose and contain hornblende, actinolite, tremolite, zoisite-clinozoisite, plagioclase, some quartz; also magnetite, ilmenite, calcite and sphene. Occasionally the amphibolites are garnetiferous. These are probably to be correlated with the Dalma volcanics of Singhbhum as they are earlier than the Chota Nagpur granites (Krishnan, 1937).

In the succeeding Iron-ore Series the lower stage (Chaibasa Stage) contains mica schists, quartz schists, hornblende schists, and tuffs, the last two apparently of igneous origin. The tuffs consist of angular grains of felspar, quartz, slate, etc. In the lower beds of the succeeding Iron-ore Stage also there are well-marked sills of ultramafic igneous rocks. Sometimes the tuffs contain large fragments of foreign rocks and are occasionally finely schistose. Most of the chloritic phyllites in North Singhbhum are considered by J. A. Dunn (1929) as representing original tuffs. There are zones of epidiorite and amphibolite as well as of amphibole and chlorite schists which are interbedded with other rocks and may therefore be sills. Along the major thrust zone there are layers of talc rocks and serpentines.

The Dalma and Dhanjori lavas form a unit in the succession and they overlie the Iron-ore stage. In the east, this volcanic belt is marked by coarse agglomerates representing fragmental products which show numerous angular or rounded pieces of foreign rocks several inches across. The common type of lava is an amphibolite or epidiorite with hornblende, andesine, epidote and leucoxene. Other rock types found here are chlorite schists, ferruginous phyllites and epidosites. The lavas have been severely folded and metamorphosed. They are older than the granites, in which they are found as inclusions, which have been partly assimilated to produce hybrid types.

Finally, there are the basic dykes traversing the granites, in Singhbhum, Keonjhar and Ranchi. They are of the nature of quartz dolerites with interstitial granophyric patches. The thicker dykes, which may be occasionally several hundred yards wide, show coarse gabbro in the centre. The rocks show only a slight alteration and resemble similar dyke rocks in the Cuddapah formation in Andhra (Krishnan, 1935).

Assam: Shillong Series: In the Shillong Series, occurring on the Assam plateau, there occur sills and lenses of amphibolite, hornblende schists, chlorite schists, etc., which are metamorphosed basic lavas. The Khasi greenstones intrusive into the Shillong Series have also been metamorphosed and folded in pre-Cambrian times.

PERMO-CARBONIFEROUS TO TRIASSIC

Panjal Volcanics: Thick lava flows occur in the Pir Panjal as well as in the Kashmir valley. The earliest manifestations of volcanic activity were of the explosive type, consisting of agglomerates and ash beds. They are exemplified by the Agglomeratic Slates which are greywacke-like and grade into slate. They contain angular fragments of quartz, felspar, quartz-porphyry, granite, limestone and slate. They overlie the Syringothyris Limestone or Fenestella Shales and are to be found even in the upper part of the same limestones which are of Middle Carboniferous age.

The volcanic flows, which are later, have ages varying from Lower Permian to Upper Trias. The flows overlap beds of different ages in different places. In some localities they underlie the Zewan beds or the Gangamopteris beds. Beyond the Wular lake they are associated with various horizons of the Trias. They consist of bedded flows of green, brown and dark colours and include rhyolites, trachytes, dacites, andesites and basalts. They are to a large extent altered, the felspars and ferro-magnesians being changed to epidote and chlorite. Their equivalents are found in the lavas overlying the infra-Trias of Hazara which attain a thickness of 100 ft. or so, and are of Carboniferous to Permian age. The volcanism which gave rise to these rocks is probably connected with the Hercynian revolution which is known to have affected large areas in Central and North-east Asia and raised up the Karakoram and Hindukush ranges.

It is likely that there are other areas of similar volcanic rocks in parts of the Himalayas and Tibet. It is known that the Everest Pelitic Series in Mt. Everest (of Carboniferous age) is profusely injected with granitic rocks which are probably connected with the Hercynian revolution. Little is known regarding the geology of the Trans-Himalayan range in Tibet which is known to contain granites and metamorphic rocks of Mesozoic and earlier ages, for they have contributed materials to the Mt. Kailas conglomerate, forming part of Mt. Kailas. It is probable that igneous activity in the Trans-Himalayan region as well as some of the materials now inextricably mixed with the rocks of the Central and Sub-Himalayas are of Hercynian age.

GONDWANA

The Gondwana strata are mainly shallow water estuarine and continental sediments. Their age ranges from Permo-Carboniferous to Jurassic, but the plant beds of Umia in Kutch are also included in the Gondwanas. Two types of igneous rocks are intrusive into these strata, viz., mica lamprophyres and dolerites, as dykes and sills. Contemporaneous volcanism is seen in the Rajmahal hills in North Bengal where the Rajmahal Traps are intercalated with plant-bearing sediments of lower or middle Jurassic age.

The Rajmahal Traps are mainly of doleritic character but there are also a few acid flows in them. The lavas attain a thickness of about 2000 ft. and have been extruded as a series of flows between some of which there are sedimentary beds containing well-preserved plant and animal fossils. The typical Rajmahal Trap resembles the Deccan Trap closely.

Doleritic rock of similar character is found as dykes traversing the coal-bearing lower Gondwana sediments in all the coal-fields of the Damodar Valley. The dykes are up to 150 ft. thick and some of them are several hundred yards long. Occasionally they form sills following the bedding planes. As they cut across the faults without showing any displacement they must have been intruded after the main faults were formed. Occasionally they are found to be affected by a few cross-faults which are evidently later than the major faults. The age of the main faulting is considered to be post-Mahadeva, i.e., Rajmahal.

The usual rock types in the above mentioned dykes are normal dolerites without olivine, but a few dykes contain olivine dolerite. The felspars are somewhat turbid and the pyroxene is monoclinic showing ophitic relationship to the felspars. Glassy interstitial patches are noticed in some rocks.

Mica lamprophyre (usually called mica peridotite) is seen mainly as sills in the coalfields of Damodar valley and the Darjeeling foot-hills. This rock generally follows the coal seams, often intimately penetrating them as thin anastamosing veins, lens-like masses, and thin flat sheets at the junction of coal seams and sandstones, or in the coal seams themselves. These rocks must have been emplaced in a highly fluid state at a moderate temperature, as they have destroyed the coals at the contacts converting them to a type of coke (called *jhama* by the miners) which is rich in phosphorus. The phosphorus may perhaps have been contributed by the intrusive which is rich in that element. In some places the intrusive rock has filled faults and may therefore be partly contemporaneous with the faults and partly slightly younger. It is definitely older than the dolerite which is sometimes found cutting across the lamprophyre sills or dykes. The lamprophyre is a grey to brown or greenish rock of coarse- or fine-grained texture and is generally highly altered. It consists largely of olivine which is almost always completely altered to serpentinous matter, some altered felspar, calcite or dolomite, quartz, mica, and chlorite, and abundant grains of apatite. As the rock is rich in potash it is likely that the original felspar was largely orthoclase.

CRETACEOUS

Exotic Blocks of Hundes: The Mesozoic rocks of the exotic facies found in Johar and Hundes must originally have been deposited somewhere in Tibet but are now found thrust over the earlier rocks to the south. They are intimately penetrated by intrusive igneous rocks which have metamorphosed them to some extent at the contacts. It would appear that the igneous rocks were injected during thrust movements into all available spaces like bedding planes and joints. The intrusives comprise ultramafic rocks such as peridotites and pyroxenites and basic rocks like dolerite, basalt, spilite and greenstone. The ultramafic rocks which are generally serpentinised and found associated with radiolarian cherts of Middle or Upper Cretaceous age, are thought to be of upper Cretaceous age.

Southern Tibet: In the Kampa-Dzong region there are serpentinised ultramafic and greenstone intrusives in the Cretaceous rocks. These may be of Upper Cretaceous or Lower Eocene age.

Kashmir: In the Borzil-Dras region of Kashmir, serpentinites and other ultramafic rocks are intercalated with or intrusive into the Cretaceous rocks. They are associated with sediments containing *orbitolinae* which are upper Cretaceous or early Eocene. According to D. N. Wadia, the associated granites in the region are presumably of Eocene age.

Baluchistan: There are abundant manifestations of volcanism in the Calcareous zone of Baluchistan. According to H. Crookshank (1952) the earliest manifestations contain agglomerates and tuffs found as contemporaneous materials in the Belemnite shales of Neocomian age. The agglomerates contain rolled pebbles, probably derived from islands formed at this time (presumably an Island arc). These are followed by pillow lavas and spilites with shale intercalations in the Parh Limestone (Barremian to Aptian). Similar basic rocks, apparently products of contemporaneous volcanism, as also ash beds are found in the Olive Shale (Senonian) and the Pab Sandstone (Senonian-Maestrichtian). It may, therefore, be said that the geosyncline in Baluchistan witnessed igneous activity through a greater part of the Cretaceous. Mountain building probably commenced here in Upper Cretceous times though an island arc seems to have come into existence in the early Cretaceous.

Indo-Burma Frontier: Evidences of late Cretaceous volcanism also exist in the hills of the little known Indo-Burma frontier tract, where both ultramafic and basic intrusive rocks are known to occur. The activity seems to have continued in the Arakan region and in the Andamans, in the succeeding Eocene period.

The Deccan Traps: The Deccan Traps, which cover nearly 200,000 sq. miles of western and west central parts of Peninsular India, are composed of layers of volcanic flows erupted from fissures. They reach a maximum thickness of some 7000 ft. near the Bombay coast, and are mainly of the composition of dolerite and basalt. Ash beds are often seen in the upper parts of the traps. Some flows are vesicular, the amygdular cavities being filled with chalcedony and other forms of silica and also various zeolites and calcite. The dolerites are composed of labradorite and monoclinic pyroxene (pigeonite). Interstitial glassy matter rich in iron is present in the basaltic types while granophyric or micrographic patches are occasionally present. Olivine is found in some types which are, however, comparatively rare. In parts of Kathiawar, Kutch and Gujarat there are a few places where the traps are associated with acid, intermediate (rhyolites, trachytes, etc.), and ultrabasic rock types derived through differentiation of the original magma.

There are numerous dykes traversing the lava sheets in certain areas. In Kathiawar the dyke systems are radially arranged around volcanic centres. Dykes are common in eastern Kathiawar, Narmada valley, Gujarat, Satpura region in Madhya Pradesh, and N. W. Hyderabad.

In Sind and in the Godavari valley in Andhra, the Deccan Traps are overlain by beds containing *Cardita* (*Venaricardia*) *beaumonti*. They are, therefore, thought to have been formed in late Cretaceous, extending into Paleocene and Lower Eocene. The intercalated inter-trappean beds contain plant and molluscan fossils of Lower Eocene age. The volcanism which gave rise to the Deccan basalts is of the fissure-eruption type caused by the formation of tension cracks in the crust connected with a later phase of the disruption of Gondwanaland.

TERTIARY AND QUATERNARY

Baluchistan: There is an igneous belt just west of the Calcareous zone of Baluchistan associated with the Khojak zone which is largely of Oligocene age. Further west, near the Afghanistan and Persian frontier, there are also products of geologically-recent volcanism, including the sulphur deposits of the Nushki desert region.

Burma: Abundant evidence of contemporaneous igneous activity are found in the Irrawaddian (mainly pliocene) and in the Pleistocene of the median Tertiary belt of Burma. The lava flows and associated ash beds have been found to have been folded by the tectonic movements at the end of the Tertiary era. The volcanic activity should have continued up to the sub-recent times as there are numerous fairly well-preserved volcanic craters, the volcanic materials from which are occasionally intercalated with Pleistocene and sub-recent fossils.

The localities at which this activity is seen are the Jada Mine area, Kabwet and other places in Shwebo and Mandalay, Mount Papa, the Pegu Yomas in Prome and Tharrawaddy. The products of the activity are agglomerates, rhyolites, trachyandesites, trachytes, dolerites and basalts, found as contemporaneous flows with occasional occurrences of pyroclastics. There are several volcanic craters in these places probably arranged along fault lines. This line connects Barren Island and Narcondam which were active volcanoes during the last century.

Another set of volcanic craters of Plio-Pleistocene age is to be found around Tang Yuch in Yunnan and Loi Han Hun in Northern Shan States, in which basaltic flows, ash and tuff beds are seen.

Summarising, it may be stated that volcanic activity is generally manifested in the later stages of the growth of a geosyncline beginning with the formation of an island arc at the commencement of the period of compression. As the compression proceeds, contemporaneous volcanic products are either injected into the sedimentary basin or ejected at the surface. These products are largely of basic character but acidic materials are also to be found, especially in ash beds and in material ejected at the surface. In the earlier phases of compression ultramafic rocks are formed along the mountain roots and these often rise to considerable heights into the sedimentary basin. They include peridotites, pyroxenites, eclogites and serpentines. Granitic intrusions come in only in the later stages of compression when the depressed parts of the geosyncline have had time to ultimately melt and form granite and granitic gneiss. The accompanying table indicates the various geological periods in India when there was volcanic activity.

Recent	Volcanic rocks of Barren Island, Narcondam & Baluchisthan-Persian frontier.
Pleistocene Pliocene	Volcanic cones of the median belt of Burma, Yunnan & N. Shan States.
Paleocene to Upper Cretaceous	Deccan Traps. Basic rocks of Indo-Burma frontier. Basic rocks and ash beds of Dras, Kashmir. Volcanics in Cretaceous of Kampa-Dzong.
Lower Cretaceous	Basic ultramafic rocks intrusive into Exotic blocks of Hundes. Agglomerates, basic flows and sills in Baluchistan.
Gondwana (Jurassic?)	Mica Lamprophyre and Dolerite-basalt dykes & sills in Gondwanas; Rajmahal Traps.
Mid-Carboniferous to Trias	Basic volcanic in Everest Pelitic Series. Panjal volcanics of Kashmir (Agglomerates, rhyolites, felsites, meta-dolerites etc.).

Lower Vindhyan	Malani rhyolites and felsites; volcanics in Semri Series, Diamond-bearing ultramafics & agglomerates.
Delhi-Cuddapah	Amphibolites, ash beds etc., in Delhis; Basic sills in Cuddapahs of Andhra, in the Bijawars of Central India; Newer Dolerite of Singhbhum.
Upper Dharwarian	Rhyolites, felsites, meta-dolerites & chlorite schists; Basic rocks in Iron Ore Series of Bihar; Dalma & Dhanjori volcanics.
Lower Dharwarian	Amphibolites, hornblende-schists, greenstones, chlorite schists etc., of Mysore; Basic sills in the Aravallis and in the Shillong Series; Khasi greenstones, etc.

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The International Geophysical Year *

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Geophysics is characteristically an observational science in all its phases, where nature performs the experiments and men observe as a preliminary to understanding. In this way it differs from fields of science which can be investigated under laboratory controls.

The International Geophysical Year, the greatest cooperative scientific undertaking of all time, is dedicated simply to the observation of man's environment—the land on which he lives, the oceans which he fishes and sails, and the atmosphere that he breathes and the influences from outside the earth, particularly the sunshine that supports all life. It is designed to help us understand our environment better so that we may be better able to withstand some of its majestic vicissitudes—earthquakes, ocean tidal waves, atmospheric storms and the vagaries imposed by solar flares and sunspots. It is the vastness of the geophysicist's laboratory—the earth—that lends to geophysics its fascination, that causes the study of geophysics to be a combination of the ideas conjured up in the word combinations, science and art, invention and imagination, research and exploration, doubt and the probing of unknown reaches where as yet we cannot go. It is this same vastness of our environment which necessitates an international cooperative effort on its problems. The oceans belong to no one nation; solar activity and the ionosphere affect all on earth and are problems of such a scale that they transcend international boundaries; droughts, cold and great storms recognize no political lines and blow aside curtains even of iron. This is why the excellent partnership between forty-eight participating nations, and ten or twenty more who will assist in the program, has been achieved. Indeed, the International Geophysical Year of 1957-58 is the third

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such cooperative attack on geophysical problems. The first, in 1883, was a joint international effort to collect as simultaneously as possible geophysical data on the then little-known north polar region. This first International Polar Year contributed mightily to our knowledge of geomagnetism and aurora. So successful was it that a Second International Polar Year was held almost exactly fifty years later. With the advances of engineering during those fifty years, the poles had become reasonably accessible and the observations led to many advances in understanding. Now, almost exactly twenty-five years since the second international effort, further advances in engineering and in instrumentation permit us to probe hitherto unknown regions of our environment which should leave no part of our planet geophysically unknown. Instruments which extend, add to, and complement man's own senses and powers of observation play one of their most dramatic roles in the field of geophysics. The deep recesses of the ocean, the impenetrable interior of the lithosphere, and the rarefied reaches of the upper atmosphere are challenging regions for modern imaginative instrumentation.

Because many features of our environment on earth, particularly in the lower and upper atmosphere, are caused or influenced by the sun, one of the unifying features of all the programs in the Geophysical Year is the observation of solar activity. Indeed, it is because this period will be one of near maximum sunspots that it was chosen. One might say that nature picked the date.

The enthusiasm for the International Geophysical Year and the magnificent cooperation of all, not only in our country but in the many others, has far exceeded the most optimistic expectations of those who took part in the early planning. Over five thousand scientists and engineers have been, and are still, preparing throughout the world for the eighteen months of observation, and the total research effort is estimated at about 250 million dollars, with the direct United States appropriation by Congress of nearly 40 million dollars. Just as important as the direct participation of these research workers is the interest and support of lay people. Without this interest the necessary governmental support of the plan conceived by private scientists could hardly come about.

The United States program is but one, though a great one, of the total world effort. It contains thirteen groupings of disciplines and areas of activity. These thirteen may, in turn, be grouped

under three main categories: *physics of the upper atmosphere* (rocket studies, the satellite studies, ionospheric physics, cosmic rays, geomagnetism, aurora and airglow, and solar activity); *lower atmosphere and surface and interface geophysics—the earth's heat and water budget* (meteorology, oceanography, and glaciology); and thirdly, *the earth's crust, interior* and figure (seismology, gravity, and longitude and latitude program). In bearing its share of the coverage of the earth, our program will cover not only the continental limits of the United States and Alaska but will cooperate directly in observations with nations of North and South America and will extend into the waters of the Atlantic, Pacific, and equatorial Pacific Oceans. In addition, the United States will make a tremendous contribution through its program in the Antarctic.

It is interesting to indicate the coherence and essential entity of the United States International Geophysical Year Program. All the elements are global in character and all the fields of geophysics in the program interact with one another and most bear ultimately on a relationship to solar energy fluctuations and disturbances to a greater or lesser degree. Furthermore, fields selected are those in which the solution of major problems will be aided by simultaneous and synoptic observation during the eighteen-month IGY period so that the inter-relationships of the fields, one with another, and with solar activity may be studied. Emphasis is also given to little known regions. The interactions between the fields can best be indicated in terms of major categories.

Interaction of hydrosphere, lithosphere and atmosphere at the interfaces between land and air and land and sea

The interaction is shown by the continual cycle of water from the oceans carried to the continents by the atmospheric winds and back to the sea in the rivers, there to be re-evaporated. "All rivers run into the sea, yet the sea is not full." Also in this process it is couneracting mountain-building forces in the restless interior and crust of the earth which battle with erosion processes to keep land's head above water.

Man's primary dependence on weather is for heat and water, both of which are distributed by the winds of the atmosphere driven by the sun's energy. The total water on earth is primarily in the oceans; on the land in lakes and rivers and in glaciers and ice deposits; and in the atmosphere as vapor and as condensate in clouds. To understand the over-all interaction in the budget of water and heat it is clearly necessary that a simultaneous closely-knit program in meteorology, oceanography and glaciology be carried out.

Meteorology in the International Geophysical Year will emphasize making up deficiencies of data in the Southern Hemisphere where the relatively unknown ocean regions together with Antarctics comprise over ninety percent of the total area of that hemisphere. It is in this meteorological incognita that we will establish about sixty stations during the IGY. These, in conjunction with already established networks on the inhabited land areas, will give us a suitable network of data for the first time. A second unknown region in meteorology upon a global scale is the high atmosphere up to about a hundred thousand feet. Balloon-borne instruments will fill this gap. The third major objective of the meteorological program is to provide new information on the large-scale global wind circulation. Because the global circulation is predominantly zonal, it will not be able to pass these fences unobserved. Three fences of stations along three meridians will be established from pole to pole to obtain data from the surface up to high altitudes. One of these lines of stations is primarily continental and another almost entirely oceanic.

Just as every heat engine has a warm and a cold side to its workingfluid, so does the atmosphere and the Antarctic program will provide us with daily weather maps of that huge continent which constitutes the major cold pole in the atmospheric heat engine. These, together with the supplemental data for the rest of the Southern Hemisphere, should go far toward a better understanding of the general circulation of the atmosphere.

The oceans which cover four-fifths of the surface of the globe form a huge thermo-accumulator or bank where heat is deposited and stored and withdrawn in times of cold, thus exerting a tempering effect on world climate. The reason that the ocean is able to store great quantities of heat is due to the stirring by the winds. It is the winds too that primarily drive the great oceanic surface circulations which distribute this heat in a manner profoundly affecting climate. The oceanographic program centres on two main objectives—first, to study the very deep ocean currents about which practically nothing is known. This may provide clues for long-range weather and climatic trends and for an understanding of how the fertility of the ocean with its sink of nutrients at the bottom

is maintained by the exchange of water between its surface and the depths. While studying the deeps, a part of the effort will be devoted to delineating the shape of the sometimes craggy ocean floor and the constitution of the earth beneath that floor. Another major effort will be to measure sea level at about a hundred new stations located to fill out the existing tide gauge stations. Sea level is a misnomer perpetrated to confuse. Sea surface height varies from place to place, changes with the season, with the amount transported by the great ocean currents and due to other factors. This study will, among other things, provide valuable information on the transport of water near the surface of the sea.

The meteorological and oceanographic programs will join in attempts to establish how fast the ocean can absorb the great quantities of carbon dioxide which industrialization is pouring into the atmosphere at ever-increasing rates. If this adjustment is not quick enough, man, by changing the infra-red radiation balance, may accelerate the warming up of climate with consequent opening up of water-ways, rise in sea level, and he may unwittingly be embarked on a collosal geophysical control experiment.

Whenever at the surface of the earth the interface with the atmosphere is an ice sheet, the ice, by reflecting incident radiation, where other surfaces absorb, exerts a profound influence on climate. Glaciology is an essential part, therefore, of these interface problems. The amount of glaciation in the past has given us indications of major fluctuations of climate in geological time and an understanding of the retreat or advance of glaciers at present should aid in assessment of climatic trends. In IGY the United States program will attempt to observe not only the condition of that greatest of all ice sheets in Antarctica but will also study many glaciers and ice deposits in the Northern Hemisphere.

The upper reaches and influences from beyond

The denser atmosphere in the troposphere and lower stratosphere is the protective shield against radiations from extra-terrestrial sources, some of which would otherwise be lethal and, as we have seen, it too is the vehicle in the regulation of our heat and water. But many phenomena, fundamental in our environment, occur primarily in the high atmosphere over fifty miles above the earth, where the atmosphere is so rare that an ordinary vacuum tube would burst outwards. It is in this region, of course, that the sun's activity in the form of flares and eruptions has the most profound effect on the ionosphere, on aurora and on geomagnetism, and it is at these heights that certain of the cosmic rays which are absorbed by the denser atmosphere below can be studied best. The basic study, therefore, in the upper reaches is that of the solar activity in the period near maximum of sunspot activity. The surface of the sun will be scanned in the visible frequencies and its noise will be listened to at radio frequencies on a world-wide, twenty-four hour watch basis to count the number and size of the sunspots and of the flares which shoot out hundreds of thousands of miles and to observe the activity of the corona. The systematic recording of solar events will provide the basis of correlations with ionospheric, geomagnetic, auroral and cosmic ray perturbations. A warning service and special world intervals are planned for those periods of unusual solar activity and solar eclipses when other high atmosphere observations of the associated unusual consequences should be accelerated.

When Marconi sent the first radio signal from Europe to our continent, it was not understood how the radio waves bent around the spherical earth. The existence of the radio wave mirror, the ionosphere, which made this first and, indeed, makes all long-distance radio transmission possible, was only demonstrated experimentally in 1925. Since then the importance of the ionosphere and its study has been intensified.

The objective of the ionospheric program will be to develop a network of both vertically-scanning and oblique-scanning stations which can provide ultimately a global picture of the ionospheric layers much like a world weather map. From such a global picture, prediction of ionospheric conditions with its ultimate application to frequency selection and "routing" of long-range communications is possible. The number of vertical incidence ionospheric stations now operating around the world will be doubled in IGY. The United States likewise will bear its share by doubling the stations which it now operates. The additional stations are carefully located to fill out a world-wide network. Particular emphasis will be placed on the 70° to 80°W. longitude fence (in the same position as one of the meteorological fences); a program in the region of the geomagnetic equator; and a program in Antarctica of particular interest in the long Antarctic night when all radiation from the sun and its influence on the ionosphere is absent.

Both northern lights and southern lights will be watched in the two polar regions. Data on the aurora can tell us a great deal about the streams of ionized particles from the sun which give rise to these magnificent visible displays. Spectroscopic and visual photographic observations of the distribution of aurora made simultaneously with the observations of the face of the sun and of the earth's magnetism will provide the three elements needed for further understanding. At the same time the ionization associated with the aurora, and which also affects radio communications, can be studied by radar. Aurora borealis and aurora australis, if observed simultaneously at the opposite poles, can establish time correlations and show whether occurrences are simultaneous. Time correlation studies such as these will aid in understanding the effects of the earth's magnetic field upon aurora.

The airglow, or weak light, which shines palely from the night sky, which is believed to be caused (in contradistinction to aurora) from chemical reaction in the high atmosphere, varies in time, place and intensity. Airglow will be measured in IGY with highly sensitive instruments distributed along somewhat the longitudinal chain as the ionospheric stations; that is, from the Arctic through North, Central, and South America to the Antarctic. A few other stations will also be located at different longitudes. While not as dramatic in its manifestation as some other atmospheric phenomena, the processes causing airglow may be stimulated by the introduction of catalysts foreshadowing another conceivable geophysical control.

The earth's magnetic field

The eighty magnetic observatories, now spread over the world, record continuously the earth's behaviour as a great magnet. Its magnetic field, while fairly stable and unchanging, not only shows slow variations which, like the permanent field, are connected with dynamo-like interactions of the crust and the interior of the earth, but also rapid fluctuations which are believed to be caused by external influences. What causes this geomagnetic storminess and how it relates to other variations in the upper atmosphere—solar, ionospheric, and auroral—is the main objective in IGY in this field of science. Twelve stations outside the United States (in Alaska, Antarctic and the equatorial Pacific), together with eight stations in the United States, arranged in an east-west north-south cross, will be the networks of the program in geomagnetism.

In cosmic rays, emphasis will be placed on measurements at high altitudes where the masking effect of our layer of protective atmosphere is at a minimum. Here, too, inter-relations of the various high atmospheric phenomena are intimate but not entirely understood so the disturbances and great variations of cosmic ray showers and variations of the magnetic field of the earth each throw light on the understanding of the other. The magnetic field is a way of analyzing energy of cosmic rays and cosmic rays, in turn, give clues to the distribution of the magnetic field and in particular the location of the geomagnetic equator, and the relationship of both of these to solar flares and periods of sunspot maximum. The origin and nature of cosmic rays are still uncertain and reflect its uncertainty both on the geometrically immense field of astrophysics and the geometrically minute field of the structure of the atomic nucleus.

Crust, core and shape

Seismology, gravity measurements, and the determination of latitude and longitude are three inter-related programs to tell more about the interior of the earth, the disturbances which occur in the interior, and the precise shape and size of our planet. Internal stresses and strains give rise dramatically to earthquakes, ranging from those of small intensity to those which rupture the crust and devastate human communities by their shattering forces and by the resultant floods and tidal waves. Seismology joins with meteorology in the field of microseisms where atmospheric disturbances through oceanic waves cause small tremors to jar the earth. Shall man-made earthquakes by the use of explosives enable seismological techniques to aid glaciology in the determination of the thickness of ice in Antaratica and the as yet unknown profile of the underlying continent, and seismology joins in the same with oceanography to provide knowledge of what is beneath the ocean bottom? The size of the earth, more precise distances between continental and island points separated by oceans (now uncertain by anywhere from 200 feet to a mile) and problems of uniform time and irregular earth turning rate will be some of the objectives of the latitude and longitude program which will use both astronomical techniques, a new technique involving the moon, and possibly the artificial satellite as well.

The shape of the earth is quite complex, departing from a true sphere, and measuring the pull of the earth (which varies from place to place) can tell us much about the shape and the density of materials in the earth's crust. IGY will concentrate on the use of pendulums which are the absolute way to determine gravity in order to provide a gravity standard throughout the world. To tie together the various international networks measurements on ships, on the bottom of oceans, on submarines, and in the Antarctic will all contribute to a greatly enlarged and more comparable world picture of the pull of the earth.

Rockets, rocoons, and rockairs

It is only within the last ten years that the engineering tools have been provided to make direct measurements at altitudes above the ceiling of balloons and up to heights of 200 miles and more. The United States has planned an impressive program using some 600 rockets during the period to measure directly a number of the events in the various inter-locking fields of interest in the high atmosphere. Surface launched rockets to reach 200 miles and up, rocoons (which are smaller rockets launched from balloons and which may be launched from shipboard), and rockairs (which are small rockets released from high-flying airplanes) will all be used—the rocoons for those parts of the program which can be satisfied with a sixty mile altitude and the rockairs to be ready for periods when the sun breaks out in flares and increased activity. In all cases provision will be made for special firings when the sun decides to perform some particularly interesting experiment. While we still make good use of balloons for the lower altitudes, the need to go higher and higher has made the use of rockets common enough to be referred to as a conventional rocket program; but the trouble about conventional rockets is that they only spend a very short time at high altitudes at one small part of the upper atmosphere before they fall back to earth. And for many of the proposed investigations a longer time and greater coverage is needed. It is for this reason that the ambitious and difficult satellite program was added. The need for satellites for high altitude geophysical research has been urged by several international bodies. In contradistinction to the conventional rocket, the satellite will circle the earth in its orbit and make geophysical measurements with world-girdling scope and at greater leisure as it hurtles along at 18,000 miles an hour. Even taking into account the expense and effort needed to make these initial satellites successful, if one were to assess the cost of the measurements per unit time at high altitude, the satellite would emerge as the cheapest way of obtaining this data.

So much has been written about the satellite that it will suffice here to summarize the main features of this ambitious experiment. Vanguard, the vehicle to carry the satellite up, over 70 feet long and weighing about 11 tons, will be launched from Cape Canaveral in Florida approximately at the end of next year. The first stage of the three-stage rocket carrying the twenty-pound, twenty-to-thirty-inch spherical satellite, is a reworked and improved finless Viking. Liquid oxygen and alcohol and gasoline will thrust the assembly off the earth with a force of 27,000 pounds. Starting up vertically a movable thrust chamber in gimbals will control the direction and gradually tilt the system so that two minutes (140 seconds) and 35 miles up from take-off, when this first stage separates from the system, it will be travelling roughly 45° to the vertical at from 3,000-4,000 miles an hour. The second stage will then ignite immediately and burn nitric acid and dimethyl-hydrazine for an additional two minutes in another gimbal mounted thrust motor. At about 140 miles high, when the system has reached 11,000 miles per hour, the second stage will burn out but will continue with the assembly to control the direction by means of a set of jet reactors while it coasts onward and upward to about 300 miles altitude, 700 miles from the launching point. During this coasting time, the jet reactors will place the last stage in its correct position, and the final stage rocket will be spun to provide directional stability in the manner in which the spin of a rifle bullet provides stability.

The second stage has then done its work and separates. The third stage, an unguided solid propellant rocket, will then fire to speed up the satellite into its orbit at 18,000 miles per hour, which is required so that the centrifugal force offsets the earth's gravitational pull. When the third stage burns out, the bottle will be separated from the little satellite sphere at a relative velocity of only a few feet per second compared to the absolute velocity of 26,000 feet per second. The satellite and this separated bottle will really then form two satellites circling the earth. If the satellite could be launched precisely horizontally, then the launching point could be the point nearest to the earth. But because of inevitable errors it must be launched from a height of 300 miles if the nearest point to the earth is to be not less than 200 miles; and if the satellite dips lower than 200 miles at its nearest point, its life time will be seriously shortened. The farthest point of the elliptic orbit away from the earth will be less than 1500 miles. The orbit and speed is such that the satellite will circle the earth in a plane chosen to be inclined 40° to the equatorial plane. Every part of the earth between latitudes 40° N. and 40° S. will pass under the satellite once every 24 hours, or every 15 revolutions of the satellite. The lifetime of the "little moon" depends on how thin the very rare atmosphere at these heights really is, and so wide are the limits of our ignorance in this respect that estimates of the lifetime range from a minimum of a few days to a maximum of a few years. The most important and immediate result from the first satellite will be the closing of these limits and a real knowledge of the density of the atmosphere at these great heights. The end of the satellite's life comes as the drag of the atmosphere slows down its circumferential speed and as gravity accelerates its motion inwards toward the earth. When it spirals inwards and reaches the denser atmosphere, it will burn up like a shooting star and perhaps leave a trail which itself may give us valuable new data on the winds. Even in a short lifetime the satellite can provide information which it will relay by radio, not only on the atmospheric density but on the earth's shape and size, on the sun's shine in the ultra-violet, on cosmic rays, on the distribution of mass in the earth and numerous other matters.

There is one facet of the program which appeals to me as being of particular and unique significance. This is the effort to excite the interest of amateurs, both here and abroad, to watch the satellite either visually or with radio receivers. The involvement of large groups of amateurs actually performing most important work in the International Geophysical Year will give a further impetus to the general understanding and support of geophysics.

Throughout the program I have stressed the importance that is attached to extending observations in all the geophysical fields to the little-known region of Antarctica. Eleven nations will cooperate directly in the Antarctic program with the United States portion being no less than six stations, including the important one at the South Pole which will serve as a central point not only for its own important scientific work but to aid all other participants. To be ready for the period of intensive observation our expeditions have already established aircraft facilities and carried instruments, supplies, and other materials to Antarctica in anticipation of the Geophysical Year period.

From the scope of these programs and their inter-relationships, it is clear that a great deal of attention must be given to the best ways in which the millions of observations which will result can be recorded and processed to give maximum availability and usefulness. A center to do this will be put in the United States to supplement centers elsewhere in the world.

Uses and outcome

When we are asked what uses will result from this tremendous effort, it is a difficult question to answer, not because the uses are few but because they are so many. The direct and obvious contributions of the increased knowledge toward questions such as climatic trends, melting of glaciers with the consequent rise in sea level, improved long-range radio transmission, improved understanding and possibly prediction of violent events (such as storms, earthquakes, tidal waves and the like) which affect the daily life and activity of everyone including world commerce and industry, and transport by land, sea and air. But in addition to these and many others that you may add, suggestions for the answers of thousands of other questions will emerge and results of the International Geophysical Year will lay a new groundwork of understanding that will be practically exploited in world-scale engineering applications in the future. There are many instances of man exerting, through lack of understanding, inadvertent and sometimes harmful control of his environment. It is not out of the question to suggest that with the far greater understanding that will result from this tremendous international effort he should be able to better predict, and therefore exert some planned beneficial control on some of the environmental factors which determines his living.

I have emphasized that the International Geophysical Year achieved its successful co-operation through the efforts of non-governmental international organizations. This is not surprising because co-operation is essentially voluntary. But it is well also to stress that it gains strength by the tremendous support in our country, as in others, of the unique government laboratories in the various fields, without which support it is quite clear that many of these programs would not be possible. It is interesting, too, to

note in the International Geophysical Year, it is the most modern engineering tools and vehicles and instruments which made them possible—the rockets, the satellites, the calm occupation of the Antarctic using every boon of modern engineering to overcome the rigors of nature in that inhospitable part of the world. The new understanding of fundamental geophysical processes which should result will in turn lead to applications which we cannot foresee.

Finally, I believe that the International Geophysical Year may set a pattern in world science which might well be emulated in other areas. The medical people are beginning to talk of an International Geopathological Year. If this and others can have a measure of the success which we anticipate in the IGY, the sum total cannot fail to make its impact felt toward the improvement of international co-operation in general.

J. Madras Univ., B, 27, No. 1. Centenary Number, 1957.

Zur Vollständigen Reduzibilität Der Linearen Darstellungen Halbeinfacher Gruppen und zum E. E. Levischen Satz.

VON

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Für die vollständige Reduzibilität der linearen Darstellungen halbeinfacher Gruppen kennt man den Weylschen Integrationsbeweis und rein algebraische Beweise — im Infinitesimalring — von H. Casimir und B. L. v. d. Waerden[1] und von J. H. C. Whitehead.[2]

Der hier folgende Beweis, den ich 1947 auf einer Konferenz in Strassburg vorgetragen habe, bringt methodisch kaum etwas Neues. Am meisten ähnelt er dem Whiteheadschen. Trotzdem möchte ich es wagen, ihn zu publizieren.

Zum Schluss beweise ich nach dem Whiteheadschen Vorbild in diesem Zusammenhang auch den Satz von E. E. Levi.

1. Γ ist eine halbeinfache Lie-Algebra der Dimension r, $\operatorname{ad} Z \cdot X = [Z, X]$, $(X, Y) = \operatorname{sp} (\operatorname{ad} X \operatorname{ad} Y)$ ein nicht-entartetes inneres Produkt, das gegenüber den Transformationen der adjungierten Algebra invariant ist:

$$([Z, X], Y) + (X, [Z, Y]) = 0.$$

ad Z und das innere Produkt lassen sich in der k-fachen Tensoralgebra T^k über Γ definieren; man braucht das nur für die $X_1 \times \dots \times X_k$ † zu tun:

$$\operatorname{ad} Z (X_1 \times \cdots \times X_k) = \operatorname{ad} Z \cdot X_1 \times \cdots \times X_k + \cdots + X_1 \times \cdots \times \operatorname{ad} Z \cdot X_k,$$
$$(X_1 \times \cdots \times X_k, Y_1 \times \cdots \times Y_k) = (X_1, Y_1) \cdots (X_k, Y_k).$$

Dieses innere Produkt ist nicht-entartet und gegenüber den ad Z invariant.

† Für das Tensorprodukt habe ich das Zeichen $\times$ verwendet, da das übliche "Rad" in der Druckerei nicht vorrätig war.

1. *Mathematische Annalen*, 111 (1935); 1-12.

2. *Proc. Camb. phil. Soc.*, 32 (1936): 229-237; *Quart. J. Math.*, 8 (1937): 220-237.

Der symmetrische Teil S^k von T^k besteht aus den linearen Kombinationen der

$$X \times X \times \cdots \times X.$$

Er ist gegenüber den ad Z invariant.

Zu einer auf S^k definierten linearen Funktion f definiert

$(F, P) = fP$ für alle $P \varepsilon S^k$

eindeutig ein Element $F \varepsilon S^k$. Ist f gegenüber den ad Z invariant, also

$$\begin{array}{lll} & f(\operatorname{ad} Z \cdot P) = 0 & \text{für alle } P \varepsilon S^k, \\ \text{so ist auch} & (F, \operatorname{ad} Z \cdot P) = 0 & \quad ,, \qquad , \\ \text{also} & (\operatorname{ad} Z \cdot F, P) = 0 & \quad ,, \qquad , \end{array}$$

also

$$(1 \cdot 1) \qquad \operatorname{ad} Z \cdot F = 0.$$

Ein gegenüber den ad Z invariantes f erhält man, wenn eine lineare Darstellung

$$X \to \hat{X}$$

von Γ in einem Raum R gegeben ist und man

$$f(X \times X \times \ldots \times X) = \operatorname{sp} \ (\hat{X}^k)$$

setzt. Speziell wichtig ist der Fall, dass $k = 2$, $R = \Gamma$ und $\hat{X} = \operatorname{ad} X$ ist. F ist dann der Casimir-Operator G.

Durch die lineare Darstellung von Γ im Raum R,

$$X \to \hat{X},$$

wird eine lineare Abbildung

$$P \to \hat{P}$$

von T^k in den Raum R^R der linearen Abbildungen von R in sich induziert mit der Eigenschaft

$$X_1 \times \cdots \times X_k \to \hat{X}_1 \cdots \hat{X}_k.$$

Gehört F zu einem invarianten f, so gilt nach $(1 \cdot 1)$

$$[\hat{Z}, \hat{F}] = 0;$$

ist die Darstellung irreduzibel, so ist $\hat{F}$ also eine Multiplikation mit einem Skalar, de sich für den Fall des Casimir-Operators mittels des höchsten Gewichtes p und der Summe δ der positiven Wurzeln zu

$$(p, p + 2\delta)$$

berechnet,[3] also (ausser für die Nulldarstellung) positiv ist. Die Spur von $\hat{G}$ ist demnach ausser bei der Nulldarstellung immer positiv.

Man kann das Vorige in verschiedenen Richtungen verallgemeinern.

Gegeben seien k lineare Darstellungen von Γ im *selben* Raume R

$$X \to \varrho_i(X), \ i = 1, \cdots, \ k.$$

Durch

$$X_1 \times \cdots \times X_k \to \varrho_1(X_1) \cdots \varrho_k(X_k)$$

wird wieder eine lineare Abbildung

$$P \to \hat{P}$$

von Γ in R^R induziert. Will man nun $1 \cdot 1$ anwenden, so muss man beachten, das

$$\sum_i X \times \cdots \times \operatorname{ad} Z \cdot X_i \times \cdots \times X_k \to \sum_i \varrho_1(X_1) \cdots [\varrho_i(Z), \ \varrho_i(X_i)] \cdots \varrho_k(X_k)$$

zu setzen ist.

3. H. Freudenthal, *Proc. Kon. Akad. Wet.* A, 57 (1954): 369-376.

Noch allgemeiner: Man braucht nicht einmal zu wissen, dass die $X \to \varrho_i(X)$ Darstellungen von Γ sind. Es genügen lineare Abbildungen von Γ in R^R; nur darf man dann in

$$\sum_i \varrho_1(X_1) \cdots \varrho_i([Z, X_i]) \cdots \varrho_k(X_k)$$

$\varrho_i([Z, X_i])$ nicht durch $[\varrho_i(Z), \varrho_i(X_i)]$ ersetzen.

2. Seien nun zwei lineare Darstellungen von Γ im selben Raum R gegeben,

$$X \to \hat{X} \varepsilon R^R,$$

$$X \to \tilde{X} \varepsilon R^R.$$

Durch

$$X \times Y \to \hat{X}\tilde{Y} - \tilde{X}\hat{Y}$$

wird eine lineare Abbildung von T^2 in R^R bestimmt, bei der

$$G \to \Phi$$

abgebildet wird.

Wir wählen in Γ zwei Basen

$$X_1, \ldots, X_r \text{ und } X^1, \ldots, X^r,$$

so dass

$$X_i = \text{sp } (\text{ad } X_i \text{ ad } X_j) X^j$$

ist (Einstein-Konvention!). Dann wird

$$G = X_i \times X^i = X^i \times X_i,$$

$$\Phi = [\hat{X}_i, \tilde{X}^i] = [\hat{X}^i, \tilde{X}_i],$$

und (1·1) liefert

$$[[\hat{Z}, \hat{X}_i], \tilde{X}^i] + [\hat{X}_i, [\tilde{Z}, \tilde{X}^i]] = 0.$$

Auf den ersten Summanden wenden wir "Jacobi" an und erhalten:

$$[[\hat{X}_i, \tilde{X}^i], \hat{Z}] + [[\hat{X}_i, \hat{Z}], \tilde{X}^i] = [\hat{X}_i, [\tilde{Z}, \tilde{X}^i]],$$

also

$$(2\cdot1) \quad [\hat{Z}, \Phi] = [\hat{X}_i, [\tilde{X}^i, \tilde{Z} - \hat{Z}]].$$

3. Wir betrachten nun eine Darstellung von Γ in R,

$$X \to \tilde{X},$$

mit einem invarianten Teilraum L. Es gibt dann einen linearen Teilraum M und eine Darstellung von Γ in R,

$$X \to \hat{X},$$

so dass $L + M = R$, $L \cap M = (0)$,

$$\hat{X}M \subset M,$$

$$\tilde{X} = \hat{X} \text{ auf } L,$$

$$(\tilde{X} - \hat{X})\, M \subset L$$

ist. Es ist unsere Aufgabe, die Äquivalenz beider Darstellungen zu erweisen. Dabei dürfen wir noch die Annahme machen:

$$\tilde{X} \text{ irreduzibel auf } L,$$

$$\tilde{X} \text{ irreduzibel auf } M.$$

Der Raum der linearen Abbildungen von R in R, bei denen M in L und L in 0 abgebildet wird, heisse **P**. Es ist $\mathbf{P}\mathbf{P} = 0$, also $[\mathbf{P}, \mathbf{P}] = 0$. Die $\tilde{X} - \hat{X}$ sind in **P**. Wir suchen ein $K \varepsilon \mathbf{P}$, so dass

$$(1 - K)\, \hat{X}\, (1 + K) = \tilde{X} \text{ für alle } X \varepsilon \Gamma$$

ist; wegen $(1-\mathrm{K})\ (1+\mathrm{K})=1$ genügt das zum Beweise. Die Bedingung für K kann auch

$$(3\cdot1)\quad [\hat{\mathrm{X}}, \mathrm{K}] = \tilde{\mathrm{X}} - \hat{\mathrm{X}}$$

geschrieben werden.

In **P** definiert man eine Darstellung von Γ;

$$\mathrm{X} \to \check{\mathrm{X}}$$

durch

$$\check{\mathrm{X}}\mathrm{P} = [\hat{\mathrm{X}}, \mathrm{P}]\ (= [\tilde{\mathrm{X}}, \mathrm{P}]).$$

Dann kann man (2·1) auch

$$(3\cdot2)\quad \check{\mathrm{Z}}\Phi = \check{\mathrm{X}}_i \check{\mathrm{X}}^i (\tilde{\mathrm{Z}} - \hat{\mathrm{Z}}) = \check{\mathrm{G}}(\tilde{\mathrm{Z}} - \hat{\mathrm{Z}})$$

schreiben, und die Forderung (3·1) wird

$$(3\cdot3)\quad \check{\mathrm{X}}\mathrm{K} = \tilde{\mathrm{X}} - \hat{\mathrm{X}}.$$

Mit 3·2 haben wir das Ziel 3·3 schon beinahe erreicht; wir müssen $\check{\mathrm{G}}$ noch wegschaffen.

Nach (1·1) ist

$$(3\cdot4)\quad \check{\mathrm{G}}\check{\mathrm{X}} = \check{\mathrm{X}}\check{\mathrm{G}}.$$

Wir werden versuchen, die Gleichung

$$(3\cdot5)\quad \check{\mathrm{G}}\mathrm{K} = \Phi$$

zu lösen; setzen wir das in 3·2 ein, so ergibt sich nämlich

$$(3\cdot6)\quad \check{\mathrm{G}}\check{\mathrm{X}}\mathrm{K} = \check{\mathrm{G}}(\tilde{\mathrm{X}} - \hat{\mathrm{X}}),$$

und das heisst, dass

$$(3\cdot7)\quad \check{\mathrm{X}}\mathrm{K} - (\tilde{\mathrm{X}} - \hat{\mathrm{X}})$$

durch $\check{\mathrm{G}}$ annulliert wird, also jedenfalls gelegen ist im Teilraum **N** von **P**, der zum Eigenwert 0 von $\hat{\mathrm{G}}$ gehört.

Wegen (3·4) ist **N** bei den $\check{\mathrm{X}}$ invariant. $\check{\mathrm{G}}$ hat in **N** die Spur 0. Nach 1 ist $\mathrm{X} \to \check{\mathrm{X}}$ da die Nulldarstellung, also

$$(3\cdot8)\quad \check{\mathrm{X}}\mathbf{N} = 0,$$

$$\hat{\mathrm{X}}\mathrm{P} = \mathrm{P}\hat{\mathrm{X}} \text{ für } \mathrm{P}\,\varepsilon\,\mathbf{N},\ \mathrm{X}\,\varepsilon\,\Gamma.$$

Wegen $\mathrm{PM} \subset \mathrm{L}$ und der Irreduzibilität von $\hat{\mathrm{X}}$ in L und M bedeutet das:

$\mathrm{P} = 0$, oder P vermittelt eine Äquivalenz zwischen den Darstellungen in L und M. Im ersten Fall ist $\mathrm{N} = (0)$, im zweiten Falle besteht es aus den skalaren Vielfachen eines $\mathrm{P} \neq 0$.

Im ersten Fall besitzt $\check{\mathrm{G}}$ ein Inverses, 3·5 ist lösbar, und 3·7 verschwindet, womit der Forderung 3·3 genügt ist. Im zweiten Fall ist 3·5 wenigstens mod **N** lösbar, aber das führt nach 3·8 immer noch zu 3·6 und dann zu

$$(3\cdot9)\quad \check{\mathrm{X}}\mathrm{K} = \tilde{\mathrm{X}} - \hat{\mathrm{X}} + \alpha(\mathrm{X})\mathrm{P}.$$

Berechnet man

$$[\mathrm{XY}]^{\vee}\mathrm{K} = \check{\mathrm{X}}\check{\mathrm{Y}}\mathrm{K} - \check{\mathrm{Y}}\check{\mathrm{X}}\mathrm{K},$$

so erhält man wegen 3·8 in 3·9 rechts

$$[\hat{\mathrm{X}}, \tilde{\mathrm{Y}} - \hat{\mathrm{Y}}] - [\hat{\mathrm{Y}}, \tilde{\mathrm{X}} - \hat{\mathrm{X}}]$$

$$= [\tilde{\mathrm{X}}, \tilde{\mathrm{Y}} - \hat{\mathrm{Y}}] - [\hat{\mathrm{Y}}, \tilde{\mathrm{X}} - \hat{\mathrm{X}}]$$

$$= [\mathrm{X},\mathrm{Y}]^{\sim} - [\mathrm{X},\mathrm{Y}]^{\wedge}.$$

Also verschwindet α auf der Kommutatoralgebra von Γ, die aber mit Γ identisch ist.

Hiermit ist der Forderung 3·3 Genüge geleistet und der Beweis der vollständigen Reduzibilität erbracht.

4. Γ sei eine Lie-Algebra linearer Transformationen des linearen Raumes R. Γ lasse einen linearen Unterraum L invariant. Man kann dann einen linearen Unterraum M von R finden und eine homomorphe Abbildung $X \to \hat{X}$ von Γ auf eine geeignete Lie-Algebra $\hat{\Gamma}$ linearer Transformationen von R, so dass

(4·1) $L + M = R, \; L \cap M = (0),$

(4·2) $\hat{\Gamma} M \subset M,$

(4·3) $X = \hat{X}$ auf L,

(4·4) $(X - \hat{X})\; R \subset L$

ist. $\hat{\Gamma}$ ist bis auf Äquivalenz eindeutig bestimmt.

Wir nehmen nun an, dass $\hat{\Gamma}$ halbeinfach und auf L sowie auf M irreduzibel ist.

Wir behaupten dann: Man kann $\hat{\Gamma}$ auch als Unter-Lie-Algebra von Γ wählen.

5. Der Raum der linearen Abbildungen, die R in L und L in 0 abbilden, heisse wieder **P**.

Dann ist also $X - \hat{X} \,\varepsilon\, \mathbf{P}$. Es gilt $\mathbf{P}\mathbf{P} = 0$, also $[\mathbf{P}, \mathbf{P}] = 0$.

Der Kern von $X \to \hat{X}$ heisse Δ. Für $X \,\varepsilon\, \Delta$ ist $\hat{X} = 0$, also $X \,\varepsilon\, \mathbf{P}$. Somit $\Delta \subset \mathbf{P}$, Δ abelsch.

$\tilde{\Gamma}$ sei ein linearer Unterraum von Γ mit

$$\tilde{\Gamma} + \Delta = \Gamma, \; \tilde{\Gamma} \cap \Delta = (0).$$

Zu $X \,\varepsilon\, \Gamma$ gehört ein wohlbestimmtes $\tilde{X} \,\varepsilon\, \tilde{\Gamma}$ mit $\tilde{X} \equiv X$ mod Δ. Es ist dann auch $\tilde{X} - \hat{X} \,\varepsilon\, \mathbf{P}$.

$$\widetilde{[X, Y]} = [\tilde{X}, \tilde{Y}] + A(X, Y) \quad \text{mit} \quad A(X, Y) \,\varepsilon\, \Delta.$$

Wir werden das gesuchte neue $\hat{\Gamma}$ konstruieren, indem wir (für alle Z) $\hat{Z}$ ersetzen durch

$$\hat{Z} + [\hat{Z}, Q] \text{ mit geeignetem } Q \,\varepsilon\, \mathbf{P}.$$

4·3-4 wird dadurch nicht beeinträchtigt. Wegen

$$\begin{aligned}[\hat{X} + [\hat{X}, Q], \hat{Y} + [\hat{Y}, Q]] &= [\hat{X}, \hat{Y}] + [\hat{X}, [\hat{Y}, Q]] - [\hat{Y}, [\hat{X}, Q]] \\ &= [\hat{X}, \hat{Y}] + [[\hat{X}, \hat{Y}], Q]\end{aligned}$$

ist auch das neue $\hat{\Gamma}$ eine Lie-Algebra. Man muss nur dafür sorgen, dass

$$\hat{Z} + [\hat{Z}, Q] \,\varepsilon\, \Gamma$$

ist. Ein neues M, das 4·2 genügt, findet sich dann von selber wegen der vollständigen Reduzibilität von $\hat{\Gamma}$.

Wir wählen zwei Bases für $\hat{\Gamma}$ wie in 2, und entsprechend für $\tilde{\Gamma}$ und setzen

$$\Phi = [\hat{X}_i, \tilde{X}^i] = [\hat{X}_i, \tilde{X}^i - \hat{X}^i] \,\varepsilon\, \mathbf{P}.$$

Dann wird

$$[[\hat{Z}, \hat{X}_i], \tilde{X}^i] + [\hat{X}_i, \widetilde{[Z, X^i]}] = 0.$$

$$[[\hat{Z}, \hat{X}_i], \tilde{X}^i] + [\hat{X}_i, [\tilde{Z}, \tilde{X}^i] + A(Z, X^i)] = 0.$$

Anwendung von "Jacobi" im ersten Summand ergibt

$$[\hat{Z}, \Phi] + [\hat{X}_i, [\tilde{X}^i, \hat{Z} - \tilde{Z}]] + [\hat{X}_i, A(Z, X^i)] = 0.$$

Wie in 3 definiert

$$\check{G}C = [\hat{X}_i, [\hat{X}^i, C]] = [\hat{X}_i, [\tilde{X}_i, C]] \quad \text{für } C \,\varepsilon\, \mathbf{P}$$

eine lineare Abbildung $\check{G}$ von **P** in sich, deren Nullraum aus den skalaren Vielfachen eines P (eventuell $= 0$) besteht. P kommutiert mit den $\hat{Z}$. $\check{G}$ kommutiert mit den $\hat{Z}$ und lässt Δ invariant. Man kann also die Gleichungen

$$\Phi \equiv \check{G}\, Q \bmod P, \qquad Q \,\varepsilon\, \check{G}\, \mathbf{P},$$

$$A(Z, X^i) \equiv \check{G}\, Q^i \bmod P, \qquad Q^i \,\varepsilon\, \Delta \cap \check{G}\, \mathbf{P}$$

befriedigen und erhält wegen $[\hat{Z}, P] = [\hat{X}, P] = 0$:

$$[\hat{Z}, \check{G}\, Q] + \check{G}(\hat{Z} - \tilde{Z}) + [\hat{X}_i, \check{G}\, Q^i] = 0.$$

Wegen der Vertauschbarkeit von $\check{G}$ mit den $\hat{Z}$ ist dann auch

$$\check{G}([\hat{Z}, Q] + \hat{Z} - \tilde{Z} + [\hat{X}_i, Q^i]) = 0,$$

$$\tilde{Z} - [\hat{X}_i, Q^i] = \tilde{Z} - [\tilde{X}_i, Q^i] \,\varepsilon\, \Gamma,$$

also $\hat{Z} + [\hat{Z}, Q] + \alpha(\hat{Z})\; P \,\varepsilon\, \Gamma$

für eine gewisse lineare Funktion α. Bildet man von zwei solchen Ausdrücken den Kommutator, so sieht man, dass $\alpha([\hat{X}, \hat{Y}]) = 0$ ist, also bereits

$$\hat{Z} + [\hat{Z}, Q] \,\varepsilon\, \Gamma,$$

was wir erreichen wollten.

6. Der Satz von E. E. Levi besagt:

Ist Γ eine Lie-Algebra und Δ ihr maximales auflösbares Ideal, so gibt es eine (halbeinfache) Unter-Lie-Algebra Ω mit $\Gamma = \Delta + \Omega$, $\Delta \cap \Omega = (0)$.

Γ mod Δ ist jedenfalls halbeinfach.

Annahme 1: Γ mod Δ ist obendrein einfach.

Sei Δ_0 ($\neq (0)$) ein minimales auflösbares Ideal von Γ.

Annahme 2: $\Delta = \Delta_0$ (also sicher abelsch).

Wir wollen 4 anwenden, wobei ad Γ die Rolle von Γ aus 4 spielen soll. Δ ist bei ad Γ invariant und entspricht L. Für $X \,\varepsilon\, \Delta$ ist (ad X) $\Delta = 0$, also ad $\hat{X} = 0$. Dem $\hat{\Gamma}$ aus 4 entspricht also Γ mod Δ, das halbeinfach ist. Wegen der Minimalität von Δ ist ad Γ auf Δ irreduzibel. $\hat{\Gamma}$ auf M ist im Wesentlichen ad (Γ mod Δ), also auch irreduzibel.

Die Voraussetzungen von 4 sind erfüllt. Das ergibt für ad Γ eine Zerlegung $\Delta' + \Omega'$, wo Δ' maximal auflösbares Ideal, Ω' eine Lie-Algebra und $\Delta' \cap \Omega' = (0)$ ist. Die Originale von Δ', Ω' bei dem Homomorphismus $X \to$ ad X seien Δ_1, Ω_1. Dann ist $\Gamma = \Delta_1 + \Omega_1$, $\Delta_1 \cap \Omega_1$ ist das Zentrum von Γ, $\Omega' \cong \Omega_1$ mod $(\Delta_1 \cap \Omega_1)$ ist halbeinfach, also gibt es eine Lie-Algebra Ω mit $\Omega_1 = \Omega + (\Delta_1 \cap \Omega_1)$, $\Omega \cap \Delta_1 = (0)$. $\Gamma = \Delta_1 + \Omega$. Damit ist der Satz unter den Annahmen 1-2 bewiesen.

Wir machen nun statt Annahme 2 die

Annahme 2': $\Delta \neq \Delta_0$.

Wir führen einen Induktionsschluss hinsichtlich dim Γ. Insbesondere dürfen wir die Richtigkeit des zu beweisenden Satzes für Γ mod Δ_0 voraussetzen. Es gibt also eine Lie-Algebra Ω' mit $\Gamma = \Delta + \Omega'$, $\Delta \cap \Omega' = \Delta_0$. Ω' mod Δ_0 ist mit Γ mod Δ isomorph, also halbeinfach, also ist Δ_0 maximal auflösbares Ideal von Ω', also existiert bereits (wegen dim $\Omega' <$ dim Γ) eine Lie-Algebra Ω und eine Zerlegung $\Omega' = \Delta_0 + \Omega$, $\Delta_0 \cap \Omega = (0)$. Nun ist $\Gamma = \Delta + \Omega$ die gewünschte Zerlegung von Γ.

Statt Annahme 1 machen wir nun

Annahme 1': Γ mod Δ ist nicht einfach.

Wir verfahren wieder induktiv. Es gibt nun echte Ideale Γ_1, Γ_2 von Γ mit $\Gamma = \Gamma_1 + \Gamma_2$, $\Gamma_1 \cap \Gamma_2 = \Delta$. Induktiv ist die Existenz einer halbeinfachen Lie-Algebra Ω_1 mit $\Gamma_1 = \Delta + \Omega_1$, $\Delta \cap \Omega_1 = (0)$ gegeben. Die adjungierte Darstellung von Γ_1 induziert in Γ_2 eine Darstellung von Ω_1. Wegen der vollständigen Reduzibilität und wegen $[\Omega_1, \Gamma_2] \subset [\Gamma_1, \Gamma_2] \subset \Delta$ gibt es einen linearen Unterraum K von Γ_2 und eine Zerlegung $\Gamma_2 = \Delta + K$, $\Delta \cap K = (0)$, mit $[\Omega_1, K] = (0)$. K erzeugt eine Lie-Algebra K', für die auch noch $[\Omega_1, K'] = 0$ gilt. $K \subset K' \subset \Gamma_2 = \Delta + K$, also gibt es einen linearen Unterraum $\Delta' \subset \Delta$ mit $K' = \Delta' + K$. Nun ist $[\Delta', \Delta'] \subset \Delta$, aber auch $\subset K'$, also $\subset \Delta'$. Daher ist Δ' maximal auflösbares Ideal von K', und $K' = \Delta' + \Omega_2$ mit $\Delta' \cap \Omega_2 = (0)$, $[\Omega_2, \Omega_2] \subset \Omega_2$. Ferner war $[\Omega_1, K'] = (0)$, also $[\Omega_1, \Omega_2] = 0$. $\Omega = \Omega_1 + \Omega_2$ ist die gesuchte Lie-Algebra.

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The Elementary Theory of Population Growth

BY

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This article demands an apology. I ignore much previously published work, since the biological journals in which it has been published are not available in this Institute, and are scattered through various libraries in India.

I shall only deal with the following elementary problem. "How quickly would a population increase or decrease if mortality and fertility as a function of age remained constant over a period of several generations?" This may seem hopelessly artificial. However, animals introduced into a new area do, in fact, sometimes increase in geometrical progression for five or ten generations. Lack gives examples. And we can reasonably ask how quickly the population of India would increase at the present levels of fertility and mortality, even if we hope that both will fall in the next twenty years. We can make similar calculations for hypothetical fertility and mortality rates.

Annual plants or animals:

Many plants and animals have a maximum life of one year. They reproduce during a short period of a few days or weeks, and then die. There is usually some stage in the life cycle when they are most easily counted. For example, the Lepidoptera which occasionally increase to such an extent that they defoliate European pine woods often spend the winter in the soil as pupae. The pupae can be counted in some hundreds of separate square metres of soil, and the density in different years compared. It would be vastly harder to count all the caterpillars even on a single tree, and impossible to count all the flying insects, though their numbers might be estimated by systematic capture, marking, release and recapture. A biologist would like to be able to estimate the number of eggs laid in a given area, which is difficult, or the number of seeds produced, which is much easier, and then to follow up their

Lack, D. (1954). *The natural regulation of animal numbers*, Oxford.

mortalities from various causes through a year; and also to estimate the number of eggs laid per adult female. This has only been done thoroughly in one case. Varley (1947) studied a gall-forming insect, examining the content of over 50,000 galls. Only about 1% of the eggs laid developed into adults, and these laid about 200 eggs each on an average. If it were possible to follow up the life of several thousand female eggs, tabulating the number of female eggs, r_k, laid by the female arising from the k-th egg, we should find that was usually zero, but occasionally several hundred, but that the average value R was not far from unity, though it might be 5 in a very favourable year, and 0·2 in a very unfavourable one. If we followed up females as they emerged as adults, counting the number r'_k of their female progeny emerging next year, we should probably find that in most years r'_k was only zero in about half of all cases, and very rarely exceeded ten, its average value R′ being again near to unity.

When an insect is studied in an area where its ancestors have lived for some time and where conditions are fairly steady, the values of R or R′ may be large or small in any particular year, but their geometric mean must be very close to unity, or the mean of their logarithms very close to zero. For example, if the geometric mean of R were 1·01 over 1000 years, the density would increase more than 20,000 times. Long before this occurred, hunger, disease, predation, or some other cause would prevent further increase.

But if an insect is put in a new environment, either because it is introduced into a new area, or because a new crop or a new enemy is introduced into the area where it has lived for some time, R may differ from unity, and remain fairly steady for some years. If d_n is the density per unit area in year x (e.g., 23,000 per hectare in 1953); then

$$d_{n+1} = Rd_n,$$

$$\text{and } d_{n+k} = R^k d_n,$$

$$\text{or } d_n = AR^n.$$

The density increases in a geometric progression if R exceeds unity, and falls off in a geometric progression if R is less than unity. Thus, with a new crop R might be about 2. The density would double in each year, and increase 1000 times in ten years, so that the insect became a serious pest.

Birds:

It is not difficult to count the number of nests and, therefore, the number of adult pairs, of many bird species in a given area. This has been done in many parts of Europe and North America. It could and should be done in India both for conspicuous birds such as vultures and cattle egrets, and for small birds with conspicuous nests such as weaver birds. One can also count the numbers of eggs and young birds in a number of nests, and estimate the mortality by putting metal rings on the legs of nestlings, and counting the numbers of these rings collected in subsequent years. If a small reward is offered for each ring sent to a given address this method becomes possible as soon as a rural population is literate. The fraction of rings returned in Britain varies from under 1% for some small birds to 15% for fairly large ones. It is found that the mortality is high in the first year, but after this it remains constant. Birds do not die of old age in nature. A starling (a bird related to your mynah, of about the same size) is no more likely to die in the next year when it is six years old than when it is one year old, though since only about half the adult birds survive till next year, not many live till the age of six years. The annual survival varies from about 35% for some small birds to 80% or more for some sea birds which lay one egg per year.

Let us consider a very simple case. Suppose that a bird can breed at the age of one year, as most of our song-birds can, that a fraction s of adults survives till next year, and that on an average a pair produce f progeny which survive for one year. Then if the sexes occur in equal numbers, and there are P_n adult pairs in year n,

$$\begin{aligned} P_{n+1} &= s P_n + \tfrac{1}{2} f P_n \\ &= (s + \tfrac{1}{2} f) P_n. \end{aligned}$$

For a fraction s survive till year $n+1$, and in addition there are $\frac{1}{2}f$ new pairs for each pair in the preceding year. So $P_n = A(s+\frac{1}{2}f)^n$.

Thus, the population increases or decreases in a geometrical progression. In fact, after a year of heavy mortality f increases since more food is available, so the population density soon returns to a nearly constant level. But in the long run $s + \frac{1}{2}f = 1$ nearly. So, for example, if $s = \frac{1}{2}$, $f = 1$. The statistics bear this out. Thus, for the starling s is lower in Switzerland than in England, but the average number of eggs laid is higher.

Large birds do not become mature and begin to nest till they are more than a year old. The age is about 4 for some British sea birds, and 9 for the albatross. The mathematical theory is more complicated, and has been given by Capildeo and Haldane (1954). Let me give an example of its application. The fulmar (*Fulmarus glacialis*) is a sea bird which only lays one egg per year and matures at 4 years. About 20 years ago the British ornithologist James Fisher asked me a ridiculous question. "If fulmars were immortal, and we started with a population of ten nesting pairs, how many nesting pairs would there be after 5, 10, 15 and 20 years?" I gave him the answer. It turned out that the number of pairs nesting on a particular headland of an island off Scotland had increased more rapidly than the rate given by my calculation. Thus, it was certain that birds had immigrated into the community counted. This is of interest, because some animal communities will not admit immigrants.

Continuous reproduction

Many animals, including human beings, can reproduce at any time of the year, and, what is more important, at any age within a certain range. If fertility is merely a function of age, the following analysis holds. Let t be the time, e.g., 1953-1956.

Let x be the age from fertilization, or from some other well defined event, e.g., emergence from a pupa or first menstruation. *For the moment* we shall consider this event to be birth.

Let $N(t)$ be the number of females in an area at time t.

Let $B(t)\,\delta t$ be the number of females born (or reaching the age taken as zero) between times t and $t+\delta t$.

Let l_x be the probability of a female surviving to age x.

Let $F(x)\,\delta x$ be the probability that a female will bear a female child between the ages x and $x+\delta x$.

Let $R = \int_0^\infty F(x)\, l_x dx$.

Let $\rho = \log_e R$.

Let $f(x) = R^{-1} F(x)\, l_x$.

Then $N(t) = \int_0^\infty B(t-x)\, l_x dx$. .. (1)

For at time t a fraction l_x of the females born x years ago, that is to say at time $t-x$, are still alive.

Consider the females born x years ago. Only a fraction of them are alive now, and the number of females born between ages x and $x+\delta x$ to n females born x years ago is $n l_x F(x)\,\delta x$. So in the course of their lives these females bear n R daughters. $F(x)$ is called the gross fertility at age x, $l_x F(x)$ is called the net fertility, and R is called the net reproductive index. If R exceeds unity the population will ultimately increase, even though it may fall temporarily if most of the females are immature. Similarly, if R is less than unity the population will ultimately fall.

To find out how quickly it will increase or decrease we note that $B(t) = \int_0^\infty B(t-x)\, F(x)\, l_x dx$

$$= R \int_0^\infty B(t-x)\, f(x)\, dx \qquad .. \quad (2)$$

For the females born between times $t-x$ and $t-x+\delta x$ have a net fertility $F(x)\, l_x$. We see that $\int_0^\infty f(x)\, dx = 1$ so $f(x)$ is a distribution function. It can be called the maternal age distribution function. It is not, however, the distribution function for the ages of mothers bearing daughters in a given year. It is the distribution function for the ages at which all women born, say, in 1900, bore daughters. The two distributions are only the same if the population is stationary. In an increasing population such as that of India the mean age of mothers who bore children in 1955 is less than the mean of the maternal age distribution because the fraction of young mothers is greater than it would be in a stationary population.

To solve equation (2) we note that it is a linear equation. For it is easily shown that if $B_1(t)$ and $B_2(t)$ are solutions, $B_1(t) + B_2(t)$ is also a solution. Let $B(t) = Ae^{-\lambda t}$ be a solution. Then

$$Ae^{-\lambda t} = R \int_0^\infty Ae^{\lambda(x-t)} f(x)\, dx,$$

$$\therefore \text{ or } \int_0^\infty e^{\lambda x} f(x)\, dx = R^{-1} \qquad .. \quad (3)$$

The left hand side of equation (3) is the moment generating function of the distribution $f(x)$. It is a monotone increasing function of real λ, so it has only one real root of λ, though in general an infinity of complex roots. To solve it we take logarithms. The natural logarithm of the moment generating function is the cumulant generating function. So

$$K_1\lambda + \frac{K_2\lambda^2}{2!} + \frac{K_3\lambda^3}{3!} + \frac{K_4\lambda^4}{4!} + \ldots = -\varrho + 2k\pi i.$$

Here K_1, K_2, K_3, etc., are the cumulants of the distribution of maternal ages. K_1 is the mean, K_2 the variance, K_3 the third moment about the mean, and so on. k is any integer. This equation is due to Lotka.

The general solution is as follows. The real root is

$$\lambda_o = \frac{-\varrho}{K_1}\left[1 + \frac{K_2\varrho}{2!K_1^2} + \frac{(3K_2^2 - K_1K_3)\varrho^2}{3!K_1^4} + \frac{(15K_2^3 - 10K_1K_2K_3 + K_1^2K_4)\varrho^3}{4!K_1^6} + \ldots\right] \quad \ldots (4)$$

The k-th pair of complex roots are

$$\lambda_{\pm k} = \lambda_o + \frac{2k^2\pi^2}{K_1^3}\left[K_2 + \frac{(3K_2^2 - K_1K_3)\varrho}{K_1^2} + \right] \pm \frac{2k\pi i}{K_1}\left[1 - \frac{K_2\varrho}{K_1^2} - \frac{(3K_2^2 - K_1K_3)\,(3\varrho^2 \times 4k^2\pi^2)}{6K_1^4} + \ldots\right] \quad (5)$$

In the long run $B(t)$ approximates to $A_o e^{-\lambda_o t}$. When this is so $B(t)$ increases or diminishes exponentially with time. It increases by a factor R in a time T given by $e^{-\lambda_o T} = R$, so

$$T = K_1\left[1 - \frac{K_2\varrho}{2K_1^2} - \frac{(3K_2^2 - 2K_1K_3)\varrho^2}{12K_1^4} - \frac{(6K_2^3 - 6K_1K_2K_3 + K_1^2K_4)\varrho^3}{24K_1^6} \ldots\right] \quad \ldots (6)$$

T may be called the equivalent generation time. It is generally less than the mean maternal age K_1 if ϱ is positive and the population increasing, and greater if the population is diminishing. The general solution is

$$B(t) = A_o e^{-\lambda_o t}\left[1 + \sum_{k=1}^{\infty} B_k e^{-\alpha_k t}\cos(\beta_k t + C_k)\right] \quad \ldots (7)$$

where A_o, B_k, C_k are real constants and $\lambda_k = \lambda_o + \alpha_k + \beta_k i$, as in equation (5). The complex root represents damped oscillation about the exponential increase or decrease. The slowest oscillation has a period $K_1\left(1 - \frac{K_2\varrho}{K_1^2} - \ldots\right)$, or about the mean maternal age, and is damped by a factor of about $e^{\frac{-2\pi^2K_2}{K_1^2}}$ per period. The quicker oscillations are more strongly damped.

It is easy to give solutions when $f(x)$ approximates to a known distribution. Thus, if the maternal age distribution is normal,

$$\lambda_o = \frac{\sqrt{K_1^2 - 2K_2\varrho} - K_1}{K_2}$$

If the maternal age distribution is a Gamma or Pearson Type III distribution, of the form $f(x) = \frac{a^c}{\Gamma(c)} x^{c-1} e^{-ax}$ which is nearly true for some insects,

$$\lambda_o = a(1 - R^{1/c}),$$

$$\lambda_k = a\left[1 - R^{1/c}\left(\cos\frac{2k\pi}{c} + i\sin\frac{2k\pi}{c}\right)\right]$$

So if c is a positive integer the number of complex roots is finite. It can readily be shown that the expression for $N(t)$ is of the same form as that for $B(t)$. We should like to know the value of R and the form of $f(x)$ for the human population of India as a whole, and for various populations within it. There are, unfortunately, no very satisfactory data. Das Gupta, Som, Majumdar and Mitra (1955) have studied couple fertility on the basis of sample survey data. Their results are inadequate for two reasons. The ages of the parents are very uncertain. The years of birth of children are less so. Further, a very large fraction which could even exceed half, of all infant deaths was not reported.

The results are remarkable. The data summarized in their Diagram (6·1) and (6·2) make it clear that $F(x)$ per couple rises sharply after marriage or the wife's fifteenth birthday, reaches a steady level of about 0·12 (daughters per year) at about 2 years after this time, and does not fall off greatly till the marriage has lasted for 22 years. Even then the fall is not very great before 30 years. Mr. Ajit Ray is now undertaking a similar investigation among the Juangs, a tribal people of Orissa believed to number about 12,000. His results will be of great value, being the first such study of a relatively large endogamous primitive community. Since they are based on the work of a single anthropologist rather than of a number of enumerators trained primarily for economic work, it is possible that they will be more accurate than the sample survey data.

However, the sample survey data could, I think, be utilized *to obtain rough estimates of* R, *and the first few* moments of the distribution of maternal ages. If $F(x)$ is taken as approximately constant from 16 to 45 years, it must be multiplied by $l'x$, which is not the probability of a woman surviving for x years after marriage, but that of a woman and her husband both surviving, since the remarriage of widows may be neglected.

If it is concluded that a large number of dead children are forgotten, as seems to be the case with the sample survey data, it might be better to consider female lives as starting at 15, and ask the question. "Among a group of women who reach the age of 15, what is the average number of daughters who reach the age of 15?". We could also ask "Among a group of women who marry, what is the average number of daughters who live long enough to marry?". Either of these would give an approximate value of R, though the second would give rather too low a value if the daughters, on an average, marry later than the mothers.

I think it might be desirable to try both the above methods, along with the methods which are usual for European and American data.

It would be possible to calculate the increases in R and λ_0 resulting from hygenic measures reducing death rates both before and after marriage. It is not, I think, desirable that the population of India should increase at much more than its present rate.

The possible effects of birth control could be calculated if we supposed for example, that, after the birth of the first two (or three) children, the fertility of couples were reduced to half.

Discussion

I am fully aware of the inadequacy of this discussion. Fertility and mortality change with time. One, but only one, of the causes responsible for changes in them is change in population density. In animal populations it may be possible to allow for such changes by averaging over a number of generations, though if R is very variable this average will be too high, and it is better to average ϱ. In human populations the values of R in the past can be roughly calculated from the total population and approximate values of l_x, K_1, and so on. It is much harder to predict changes in the future. In India it seems likely that R will increase as the result of lower mortality, but it may decrease in twenty years or so as a consequence of industrialization.

I would, however, urge Indian workers to obtain approximate figures on population growth and decline for Indian animals both under natural and artificial conditions. It is not difficult to study insect reproduction in the laboratory, but surprisingly little accurate work has been done on it. Varley's (1947) work is a model of what can be done under natural conditions, but it would be better to spread such work over at least five years.

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A Hyper-Isogonal Cremona Involution of Conic-Envelopes

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I. The well-known Cremona quadratic involution of point-pairs PP′ in the plane consists of pairs PP′ conjugate w.r.t. all conics S through four points I_0 I_1 I_2 I_3 forming a proper quadrangle. It is clear that the conics S are all the conics apolar to the four squared points I_0^2, I_1^2, I_2^2, I_3^2; it follows that the system of conic-envelopes apolar to all the conics S is the system of all linear combinations $\lambda_0 I_0^2 + \lambda_1 I_1^2 + \lambda_2 I_2^2 + \lambda_3 I_3^2$. If ABC is the harmonic triangle of $I_0 I_1 I_2 I_3$, it is clear that the system of conics inscribed in ABC belongs to Σ. Hence the system Σ may also be considered as the set of all linear combinations.

$$\mu_1 (BC) + \mu_2 (CA) + \mu_3 (AB) + \mu_0 \Omega,$$

where Ω is any particular point-pair PP′. In particular, if the pair of circular points belongs to the involution, and is denoted by Ω, $I_0 I_1 I_2 I_3$ become the in-and ex-centres of ABC, and the quadratic involution reduces to the system of isogonal point-pairs PP′ of the triangle ABC.

II. It is a remarkable fact, which does not appear to have been noted before, that this involution of point-pairs induces a Cremona quadratic involution among all the ∞^5 conic-envelopes in the plane. This may be gathered from the following considerations. The family Σ of conic-envelopes contains 4 linearly independent members. Thus, the product of any two conics Σ is a 6-dimensional subspace of the 14-dimensional space of all quartic envelopes. Also, this subspace contains $4 + 6 = 10$ linearly independent members, and hence generates a 9-dimensional flat subspace of the space of all quartic envelopes. Hence there is a linear ∞^4-system of quartic curves σ, apolar to all products of pairs of conic envelopes Σ. Hence if S is *any* conic-envelope in the plane, there is in general a unique conic S′, such that that SS′ is inpolar to the 5 linearly independent curves determining the system σ. The involution between the conic-envelopes S, S′ is precisely the involution referred to, as induced by the quadratic involution defined by $I_0 I_1 I_2 I_3$.

To obtain explicitly the transformation from S to S′ we may without loss of generality use trilinear coordinates with ABC as reference-triangle, and assume that the basic Cremona involution is the involution of isogonal pairs. The system Σ has then the linearly independent members:

$$mn,\ nl,\ lm,\ \Omega \equiv l^2 + m^2 + n^2 - 2\,mn \cos A - 2\,nl \cos B - 2lm \cos C,$$

(where l, m, n are tangential coordinates). The ten linearly independent products of two Σ's are then:

$$m^2n^2,\ n^2l^2,\ l^2m^2,\ l^2mn,\ lm^2n,\ lmn^2,\ \Omega mn,\ \Omega nl,\ \Omega ml,\ \Omega^2.$$

The 5 linearly independent quartics apolar to these 10 are immediately verified to be:

$$y^4 - z^4,\ z^4 - x^4,\ y^3z - yz^3,\ z^3x - zx^3,\ x^3y - xy^3.$$

The quartic curves of the system σ, have, therefore, the equation

$$\alpha x^4 + \beta y^4 + \gamma z^4 + p\,(y^3z - yz^3) + q\,(z^3x - zx^3) + r\,(x^3y - xy^3) = 0 \quad (\alpha + \beta + \gamma = 0).$$

If

$$S \equiv AL^2 + Bm^2 + Cn^2 + 2\,Fmn + 2\,Gnl + 2\,Hlm$$
$$S' \equiv A'l^2 + B'm^2 + C'n^2 + 2\,F'mn + 2\,G'nl + 2\,H'lm,$$

the conditions that SS′ is apolar to all curves σ become:

$$AA' = BB' = CC'$$
$$BF' + B'F = CF' + C'F$$
$$CG' + C'G = AG' + A'G$$
$$AH' + A'H = BH' + B'H.$$

Thus, the equations to the transformation $S \to S'$ are

$$A' = BC$$
$$B' = CA$$
$$C' = AB$$
$$F' = AF$$
$$G' = BG$$
$$H' = CH.$$

The geometrical significance of these equations is immediate. For, the tangents from the vertex A of the triangle of reference to the conics S, S′ are given by:

$$Bm^2 + 2\,Fmn + Cn^2 = 0,$$
$$B'm^2 + 2\,F'mn + C'n^2 = 0.$$

and the transformation equations say that the latter two tangents are the reflections of the former in the bisectors of the angle A.

The transformation equations also show that

Discriminant S′ = ABC × Discriminant S.

Hence when S or S′ is a pair of points, so is the other, as is indeed obvious from the geometrical interpretation for the transformation $S \to S'$. Another remarkable property is that *S′ is a circumconic of the triangle of reference whenever S is.* For writing

$$A = a_1^2,\ B = a_2^2,\ C = a_3^2,\ F = -a_2a_3,\ G = -a_3a_1,\quad H = -\,a_1a_2,$$

we have

$$A' = a_2^2a_3^2,\ B' = a_3^2a_1^2,\ C' = a_1^2a_2^2,\ F' = -\,a_1^2a_2a_3,$$
$$G' = -\,a_1a_2^2a_3,\ H' = -\,a_1a_2a_3^2$$

Thus, *if S is the polar conic of a point P (a_1, a_2, a_3), S′ is the polar conic of the isogonal conjugate P′,* $(a_2a_3,\ a_3a_1,\ a_3a_2)$.

III. This conic-transformation may be applied to prove a rather intriguing property.

Let (p, q, r), $(p'q'r')$ be a pair of the quadratic involution defined by the four points I_0ABC. Then $(pl + qm + rn)\ (p'l + q'm + r'n)$ must be apolar to $x\,(y - z)$, $y\,(z - x)$ and $z\,(x - y)$. This gives

$$qr' + q'r = rp' + r'p = pq' + p'q.$$

Solving these equations we obtain:

$$p' : q' : r' = p\,(q + r - p) : q\,(r + p - q) : r\,(p + q - r).$$

We know that the transformation of the point-pair $(pl + qm + rn)$, $(p'l + q'm + r'n)$ must also be a point-pair. This transform is

$$\Sigma qq'rr'l^2 + \Sigma pp'(qr' + q'r)\, mn = 0.$$

Substituting the values of p', q', r', this point-pair becomes:

$$\Sigma\, q^2r^2\ \{p^2 - (q-r)^2\}l^2\ + 2\,pqr\ \Sigma\, mnp^2(q + r - p) = 0.$$

If we subtract from this $p^2q^2r^2(l + m + n)^2$ (which is the expression for the squared point I_0), we obtain

$$- \Sigma\, l^2q^2r^2(q-r)^2 + 2\,pqr\,\Sigma\, mn\ \ \{p^2(q + r - p) - pqr\} = 0.$$

We may immediately verify that this is the tangential equation of a conic circumscribed to the triangle of reference. For instance, putting $l = 0$, we verify that

$$p^2q^2r^2\,\{p^2(q + r - p) - pqr\}^2 = p^4q^2r^2\ (q-p)^2(p-r)^2$$
$$= \text{product of coefficients of } m^2,\ n^2.$$

The meaning of this is evidently the curious fact that the isogonal conjugates of the two points (pqr) $(p'q'r')$, which are themselves mates in the quadratic involution determined by I_0ABC, are two points which are *the points of contact of tangents from I_0 to a conic circumscribed to ABC.* It is clear that we may also assert the converse, namely, *the isogonal conjugates of the two points of contact of tangents from I_0 to a circumconic are mates in the quadratic involution defined by I_0ABC.* It may be noted that the actual relation between the two points of contact would be a Cremona involution of much higher degree than the Second.

This theorem gives a relation between the quadratic involutions defined by $I_0I_1I_2I_3$ and I_0ABC. A deeper elucidation of this relation is a matter for further research.

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The Theory of Turbulence

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I

It is a matter of common knowledge that hydrodynamic flow manifests itself in one of two qualitatively distinct forms: the laminar and the turbulent. In the laminar state, the velocity is a continuous function of position and time and is uniquely determined by the equations of motion and certain prescribed boundary conditions. In contrast to this, in the turbulent state the velocity exhibits variations with position and fluctuations with time which do not seem to be related in any discernible way with the particular conditions under which the motion has been set up. Whether the laminar or the turbulent state prevails depends on circumstances; but, it may be stated that as a general rule, motions in systems with large linear dimensions are more likely to be turbulent than not. Somewhat more precisely, we may state that the condition for the occurrence of one or other of the two states depends on the value of a certain non-dimensional constant, the Reynolds number,

$$R = \frac{\varrho v l}{\mu} \tag{1}$$

where ϱ is the densitiy, μ is the coefficient of viscosity and v and l are measures of the velocities present and the linear dimension of the system, respectively. If R so defined exceeds a certain critical value, then the laminar state which can prevail at lower values of R ceases to be stable and other modes of motion compatible with the equations of the problem are excited; and as the Reynolds number increases still further, more and more new modes are excited. A state of turbulence which thus comes to be established is characterized by two essential facts: first there are many different modes of motion which are simultaneously present; and second, there is a constant exchange of energy between the different modes.

And it is a prime requirement of a theory of turbulence that it describe quantitatively, in some way, the different coexisting modes and the mechanics of the energy exchange between them.

II

Since a state of turbulence follows the breakdown of a laminar state, it might appear natural to begin the study of turbulence by examining the stability of simple patterns of laminar motion—such as that between two parallel plates or between two rotating cylinders—and establishing the critical Reynolds number for the onset of instability. Several successful investigations along these lines are now available. It is perhaps not altogether surprising that these investigations have not helped in any material way our basic understanding of the turbulence phenomenon: for, the fundamental characteristic of turbulence is the continuing exchange of energy between the different modes of motion and no linear theory (as a theory of stability necessarily is) can be expected to throw light on a phenomenon which basically owes its existence to the non-linearity of the governing equations. For these reasons it would appear more profitable to start the discussion by an analysis of a state of turbulence already well established, rather than attempt to trace all at once the development of turbulence from the initial state when the laminar state ceases to be stable to the final state as the Reynolds number tends to infinity.

III

We have seen that a state of turbulence eventually results from the instability of a laminar state. But there are many other ways in which turbulence can be set up. In nature, for example, one of the commonest causes for turbulence is thermal instability; and in the laboratory, one of the easiest methods of producing turbulence is by letting air flow through a grid in a wind tunnel. On account of this very diversity of ways in which turbulence arises and can be created, it is convenient to have a fairly specific model which we may visualize and to which we may refer in our subsequent discussion.

IV

The model we shall have in mind is the following: A volume of air (say) is confined inside a large vessel. The air inside this vessel is kept continually stirred by a number of fans attached

to the inside walls. In this manner we set up violent motions near the walls. It is, however, clear that these motions will pervade the whole vessel and we shall concentrate our attention on the state of motions which prevails in the central regions of the vessel far from the walls and the fans.

V

In a general way we may characterize the motions in the model we have described as follows: We supply energy, principally, to air elements—"eddies"—of the dimensions of the vessel. This energy is in some way transferred to air elements of smaller scales; and in a steady state which we envisage, the rate at which energy is dissipated in the air in the form of heat must equal the rate at which energy is supplied to the system. The process which is taking place is clearly described by the following rhyme due to L. F. Richardson:

Big whirls have little whirls
    That feed on their velocity,
Little whirls have lesser whirls
    And so on into viscosity.

In other words: energy is supplied at a constant rate to the big whirls; these whirls transfer their energy to the smaller whirls; the smaller whirls transfer their energy to still smaller whirls; and this process continues until the energy is finally dissipated as heat by viscosity in the smallest whirls in which the sheer is the greatest.

The foregoing remarks bring out certain basic facts which must be kept in mind in discussions of turbulence: That an external agency supplying energy to the systems must be pre-supposed; that the energy is principally supplied to the largest eddies; that there is a cascade of this energy to the smaller eddies; that in a stationary state energy must be dissipated at the same rate at which it is supplied.

The fundamental problem of turbulence is this: What is the distribution of energy among the eddies of various sizes in stationary turbulence; and what is the mechanics of the cascade process which transfers energy from the larger to the smaller eddies?

VI

We shall now formulate more precisely the questions raised in the preceding paragraph. It is clear that for this purpose it is convenient to express the velocity field as a superposition of plane waves i.e., analyze it in a Fourier series in the form:

$$\mathbf{u}(\mathbf{r}, t) = \Sigma\, \mathbf{u}(\mathbf{k}, t) \ \exp\ (i\,\mathbf{k}\,.\,\mathbf{r}) \tag{2}$$

where the summation is over all k.

The mean square velocity is given by

$$< |\mathbf{u}|^2 >_{Av} = \tfrac{1}{2}\, \Sigma < |\mathbf{u}(\mathbf{k})|^2 >_{Av} \tag{3}$$

From equation (3) it is clear that $< |\mathbf{u}(\mathbf{k})|^2 >_{Av}$ is a measure of the intensity with which the mode of motion characterized by the wave numbers (k_x, k_y, k_z) occurs in the system; it defines the spectrum of turbulence. The specification of $< |\mathbf{u}(\mathbf{k})|^2 >_{Av}$ is therefore the first question to which we must address ourselves. It is, however, necessary to emphasize that a description of turbulence in terms of the spectrum only cannot be a complete one. A description in terms of the spectrum only would be complete, if, as in the case of the black-body radiation, there are no phase relationships between the different Fourier components of the field. In turbulence this is not the case. Phase relationships must exist: without them there would not be the exchange of energy between the different Fourier components which is in the essence of the phenomenon.

VII

Before we can proceed further, it is necessary to write down the fundamental equations which govern the motions and to point out the terms in the equations which are responsible for the different processes which are taking place.

In writing down the equations of motion we shall suppose that the fluid is incompressible. This may be considered as an adequate approximation so long as the velocities are small compared to the velocity of sound.

The equations governing an incompressible viscous fluid are the equation of continuity,

$$\text{div}\ \mathbf{u} = 0, \tag{4}$$

and the equation of motion

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}.\ \text{grad})\ \mathbf{u} = -\ \text{grad}\ \tilde{\omega} + \nu\, \nabla^2 \mathbf{u} \tag{5}$$

where $\mathbf{u}$ is the velocity, $\tilde{\omega} = p/\varrho$, where p is the pressure and ϱ is the density, and $\nu = \mu/\varrho$ is the coefficient of kinematic viscosity. These are the Navier-Stokes equations.

In equation (5) we distinguish three terms: the term $\nu\, \nabla^2 \mathbf{u}$ which expresses the role of viscosity, the term $-$ grad $\tilde{\omega}$ which expresses the role of pressure and the term (**u.** grad) **u** which is non-linear and which is called the *inertial term.* We shall see that these three terms play very different roles for turbulence.

VIII

By expanding **u** in a Fourier series as in equation (2), we first find from the equation of continuity that the vector $\mathbf{u}(\mathbf{k})$ is normal to the wave vector **k**; thus,

$$\mathbf{u}(\mathbf{k})\ .\ \mathbf{k} = 0. \tag{6}$$

Next, the equation of motion gives

$$\frac{\partial \mathbf{u}(\mathbf{k})}{\partial t} = -\, i \sum_{\mathbf{k}'} \{\mathbf{u}(\mathbf{k}') \cdot \mathbf{k}\}\mathbf{u}(\mathbf{k}-\mathbf{k}') - i\, \tilde{\omega}(\mathbf{k})\mathbf{k} - \nu|\mathbf{k}|^2\mathbf{u}(\mathbf{k}) \tag{7}$$

where $\tilde{\omega}(\mathbf{k})$ is the coefficient of exp $(i\,\mathbf{k}\,.\,\mathbf{r})$ in the Fourier expansion of $\tilde{\omega}$:

$$\tilde{\omega} = \Sigma\ \tilde{\omega}\ (\mathbf{k})\ \exp\ (i\,\mathbf{k}\,.\,\mathbf{r}) \tag{8}$$

Multiplying equation (7) by $\mathbf{u}^*(\mathbf{k})$ and making use of the orthogonality of $\mathbf{u}^*(\mathbf{k})$ and **k**, we get

$$\tfrac{1}{2}\frac{d}{dt}\,|\mathbf{u}(\mathbf{k})|^2 = -\, i \sum_{\mathbf{k}'} \{\mathbf{u}(\mathbf{k}') \cdot \mathbf{k}\}\ \{\mathbf{u}(\mathbf{k}-\mathbf{k}')\ .\ \mathbf{u}(-\mathbf{k})\} - \nu|\mathbf{k}|^2|\mathbf{u}(\mathbf{k})|^2 \tag{9}$$

From equations (7) and (9) several important conclusions follow:

(1) Viscosity plays no role in the cascade process. Indeed, the only effect of viscosity is to reduce the amplitude of each Fourier component independently of the others. Thus,

$$\mathbf{u}(\mathbf{k};\ t) = \mathbf{u}(\mathbf{k};\ 0)\ \exp\ (-\nu|\mathbf{k}|^2 t) \tag{10}$$

Accordingly, the amplitude of the Fourier component with a wave number $|\mathbf{k}|$ decreases with a mean life $\tau_k = (\nu|\mathbf{k}|^2)^{-1}$. The smallest eddies are, therefore, the shortest lived.

(2) The pressure term does not also play any direct role in transferring energy between the different Fourier components. This is evident from the non-appearance of $\tilde{\omega}$ in equation (9). But the pressure term does play a role in exchanging energy between different directions belonging to the same $|\mathbf{k}|$. It thus operates in the direction of bringing about a *state of isotropy.*

(3) It is the inertial term which couples the different Fourier components belonging to different $|\mathbf{k}|$ and makes possible an exchange of energy between them. It is, therefore, the term which is responsible for the cascade process. The manner in which the inertial term operates to bring about a statistical distribution of energy among the different Fourier components is the central problem in the theory of turbulence.

IX

From our discussion up to the present, it would appear that the character of turbulence will depend on circumstances and in particular on the manner in which it is created and maintained. Certainly, no arguments have been advanced to indicate that this will not be the case. Nevertheless, we may ask: Are there aspects of the turbulence phenomenon which are universal? And by "universal" in this connection, we mean that the aspects in question are the same for all manner of ways of producing and maintaining turbulence. This question, whether there might not be universal aspects of the turbulence phenomenon is not unreasonable in view of the following circumstances:

We have stated that turbulence is mostly maintained by supplying energy to the largest eddies. The distribution of energy among these largest eddies will, of course, depend on the particular way energy is supplied and reflect among other things the anisotropy implicit in the whole process. Nevertheless, in virtue of the inertial term this energy cascades to smaller eddies; and moreover, the pressure term operates to efface the anisotropy of the larger eddies. Accordingly, we may expect that as we go down the hierarchy of eddies we will gradually lose correlation with the structure and distribution of the larger eddies. In other words, in the part of the volume away from the confining walls (in the model described in § IV, for example) we may expect to find a high degree of homogeneity and isotropy. The prevalance of homogeneity and isotropy among these smaller eddies is clearly necessary before we can contemplate on whether or not universal characteristics exist.

X

Now it is one of the surprising facts about turbulence that isotropy is the most common and most readily realized. For example, in a wind tunnel conditions of isotropy have been shown to prevail already near the grid through which the air is flowing. Similarly, isotropy has been established in atmospheric turbulence. In view of the importance of this prevalence of homogeneity and isotropy for our whole discussion, we shall define precisely what we mean by these terms and how their occurrence has been established.

XI

In isotropic turbulence it is clear that the mean square energy associated with a component of the velocity in some direction must be independent of the direction. However, for our purposes we shall need a more exacting criterion. We shall state the requirements as follows:

Consider the velocities $\mathbf{u}_a\ (P)$ and $\mathbf{u}_b\ (P')$ at a given instant of time at two points P and P' and in the directions of two unit vectors **a** and **b** (see Fig. 1); and consider the average value* of $< u_a\ (P)\ u_b\ (P') >$. Let **e** denote the vector joining P and P'. We shall define isotropy and homogeneity to imply that *in this case the quantity* $< u_a\ (P)\ u_b\ (P') >$ *is invariant to all rotations and translations of the vector configuration* (**a**, **e**, **b**) *as a rigid*

* Averages here and elsewhere are to be understood as ensemble averages in the sense of Gibbs. Also, angular brackets will be used to denote such averages.

body. The extension of this condition for the correlations between several components of the velocity at P and at P' is evident and need not be formally stated.

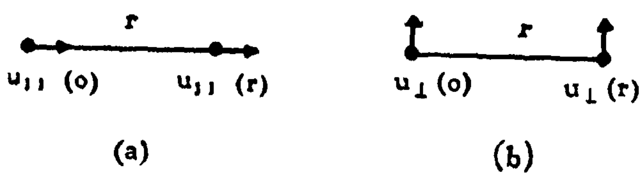

FIG. 1. The longitudinal (a) and the transverse (b) velocity correlations.

XII

We shall now state the kind of deductions that can be made from the equations of motion and continuity and the requirements of isotropy and homogeneity. For this purpose, we shall consider first the fundamental covariance

$$Q_{ij} = < u_i(P,\ t)\ u_j(P',\ t) >. \tag{11}$$

It can be shown (cf. von Karman and Howarth, 1938; Robertson, 1940; for an account of these and related developments, see Chandrasekhar, 1953) that the equation of continuity together with the conditions of isotropy and homogeneity require that this tensor be of the form

$$Q_{ij} = \left(\frac{1}{r}\ \frac{\partial Q}{\partial r}\right)\ e_i\, e_j - \left(r\, \frac{\partial Q}{\partial r} + 2\, Q\right)\ \delta_{ij} \tag{12}$$

where Q is a scalar function which depends (apart from t) only on the distance r $(= |e|)$ between the two points P and P'. The implication of this particular form Q_{ij} can be most readily seen by considering the longitudinal and the transverse correlations (see Fig. 2)

$$<u_{\parallel}(0)\ u_{\parallel}\ (r) > = f(r)$$
$$\text{and } < u_{\perp}\ (0)\ u_{\perp}\ (r) > = g\ (r). \tag{13}$$

From equation (12) it follows that

$$f(r) = -\, 2\, Q \text{ and } g\ (r) = -\ \left(r\, \frac{\partial Q}{\partial r} + 2\, Q\right). \tag{14}$$

Accordingly, these two correlations are related by

$$g = f + \tfrac{1}{2}\, r\, \frac{\partial f}{\partial r}. \tag{15}$$

This relation between the two correlations is a definite prediction and it has been directly verified by experiments in a wind tunnel. This verification is a strong confirmation that under the conditions of the experiments isotropy in the precise sense did prevail.

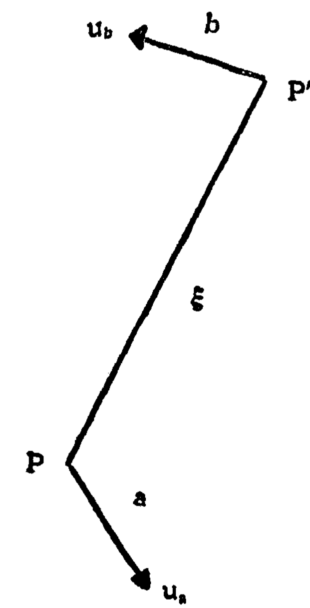

FIG. 2. For illustrating the requirements of homogeneity and isotropy.

A further confirmation of the prevalance of isotropy is provided by measurements on the rate of dissipation of the kinetic energy per unit mass ε. By combining the equations of motion with the requirements of isotropy it can be shown (cf. Taylor, 1935) that

$$\varepsilon = -\ 15\ \nu\ \left(\frac{\partial^2 f}{\partial r^2}\right)_{r=0} \tag{16}$$

i.e., the rate of dissipation is simply related to the curvature of the longitudinal correlation function at the origin. Again, this relation has been verified by G. I. Taylor who was the first to introduce the concept of isotropy in turbulence which we have described.

XIII

We now return to the question of § IX whether there might not be some aspects of the turbulence phenomenon which are truly universal. There is no assurance that such aspects exist. The prevalence of homogeneity and isotropy in turbulence as it occurs in nature and in the laboratory, suggests that there might be such aspects. And if such aspects exist, then what can one say about them from entirely general considerations; in particular, on what parameters can such universal aspects depend? Clearly, it is necessary that they do not depend on the linear dimensions of the system and on the manner in which energy is supplied; a dependence on these would be contrary to the assumption that the aspects under discussion are common features of all manner of turbulence. Universal aspects, if such exist, can describe only processes taking place in the medium far from the boundaries and which are, in a limit, independent of what is taking place there. To describe such processes, again assuming that they exist, we have at our disposal only the two parameters ε and ν, the constant rate of dissipation of energy by each gram of the fluid and the kinematic viscosity. *Thus, any aspect of the turbulence phenomenon which might have a universal character can depend only on these two parameters.* A further requirement which we may impose is that *the dependence of such universal aspects on ε and ν be such that the limit $\nu \to 0$ exists; and that in this limit the entire description of the aspects depends only on ε.* This latter requirement appears entirely reasonable since in the limit $\nu \to 0$, the sizes of the energy dissipating eddies also tend to zero. These statements concerning the universal aspects are the essential physical content of the principles which Kolmogoroff has enunciated. However, we have left open the question whether or not universal aspects exist; in particular, we have left open the possibility that Kolmogoroff's principles may not be applicable to *every* aspect of the turbulence phenomenon. Indeed, one of the questions which we shall have to settle concerns exactly the selection of the function to which we may apply the principles.

XIV

We shall now illustrate the ideas outlined in § XIII by considering the quantity

$$\psi(r,\ t) = \tfrac{1}{2} < (u_1' - u_1'')^2 >, \tag{17}$$

where u_1' and u_1'' are the x-components of the velocity at two points on the x-axis separated by a distance r and at two times, an interval t apart. (In this and in the subsequent sections, t will always signify the difference of the times at which the respective field quantities are measured at two points). If (cf. Fig. 2)

$$< u_1(0,\ 0,\ 0;\ 0)\ u_1(r,\ 0,\ 0;\ t) > = f(r,\ t), \tag{18}$$

then the quantity we are considering is related to this longitudinal correlation function (cf. equation (13)) by

$$\psi(r,\ t) = < u_1^2 > - f(r,\ t). \tag{19}$$

We now ask: Can we suppose that the specification of $\psi(r,\ t)$ lies within the framework of a universal theory? A decision on this can be reached only by applying Kolmogoroff's principles to this quantity and seeing whether we are led to any contradictions.

Consider first $\psi\ (r,\ 0)$ which is directly related to the longitudinal correlation function considered in § XII. Now this is a quantity of the dimensions of a square of a velocity. Since $(\nu^3/\varepsilon)^{1/4}$ and $(\varepsilon\nu)^{1/4}$ are the only combinations of ε and ν which are of the dimensions of a length and a velocity, respectively, Kolmogoroff's principles, if applicable to $\psi\ (r,\ 0)$ would require that

$$\psi(r,\ 0) \equiv (\varepsilon\,\nu)^{1/2}\ \Psi_1\ (r\,\varepsilon^{1/4}/\nu^{3/4}) \tag{20}$$

where $\Psi_1(x)$ is a universal function of the argument. If in the limit $\nu \to 0$, $\psi(r,\ 0)$ should cease to depend on ν, then the condition on $\Psi_1\ (x)$ is:

$$\Psi_1(x) \to C_1\ x^{2/3} \text{ as } x \to \infty, \tag{21}$$

where C_1 is a constant: for we can then conclude from equations (20) and (21) that

$$\psi\ (r,\ 0) \to C_1\ \ (\varepsilon\ r\ )^{2/3} \text{ as } \nu \to 0; \tag{22}$$

and this is independent of ν as required. But this last result throws doubt on whether Kolmogoroff's principles can be applied to $\psi(r,\ 0)$. For it is a strict consequence of the definition of ψ that

$$\psi(r,\ 0)\ \leqslant\ < u_1^2 >, \tag{23}$$

which follows from Schwarz' inequality:

$$< u_1' \; u_1'' > \; \leqslant \; < u_1^2 >. \tag{24}$$

This doubt on the applicability of Kolmogoroff's principles to $\psi(r, 0)$ is further strengthened when we consider

$$\psi(0, t) = \tfrac{1}{2} < \{ u_1 \; (0, 0, 0; 0) \; - \; u_1 \; (0, 0, 0; t) \}^2 >, \tag{25}$$

which is related to the correlation of the velocities at the same point at two different times. Since $(\nu/\varepsilon)^{\frac{1}{2}}$ is the only combination of ε and ν which is of the dimensions of a time, Kolmogoroff's principles applied to $\psi \; (0, t)$ would require that

$$\psi(0, t) \equiv (\varepsilon \, \nu)^{\frac{1}{2}} \, \Psi_2(t \, \varepsilon^{1/2}/\nu^{1/2}), \tag{26}$$

where $\Psi_2(x)$ is a universal function of the argument. If $\psi(0, t)$ should be independent of ν as $\nu \to 0$, then

$$\Psi_2(x) \to C_2 \, x \text{ as } x \to \infty, \tag{27}$$

where C_2 is a constant; for, we can then conclude from equations (26) and (27) that

$$\psi(0, t) \to C_2 \; \varepsilon \; t \text{ as } t \to \infty; \tag{28}$$

and this is independent of ν as required.

The unboundedness of $\psi(r, 0)$ as $r \to \infty$ and $\psi(0, t)$ as $t \to \infty$ implies that the function $\psi(r, t)$ cannot be specified without reference to the size, r_0, of the largest eddies present i.e., of the linear dimension of the system. Thus, one might say (as is customary in the literature) that the applicability of (22) is limited by $r \ll r_0$ and that this limitation will guarantee that

$$C_1 \;\; (\varepsilon \; r)^{2/3} \ll \; < u_1^2 >; \tag{29}$$

and similarly that (28) cannot be applied for $t > r_0/\{ < u_1^2 > \}^{1/2}$. But it is difficult to see how in the framework of a universal theory (assuming that such a theory exists) we can restrict the consequences of that theory in terms of parameters such as r_0 and $< u_1^2 >$ which are not related to ε and ν in any way.

XV

Arguments similar to those advanced in § XIV apply also to the spectrum of turbulence, $F(k)$. The definition of $F(k)$ is contained in

$$< | \mathbf{u} |^2 > = \int_0^\infty F \; (k) \, dk; \tag{30}$$

$F(k)$ is accordingly of dimensions $[L^3/T^2]$ and Kolmogoroff's principles would require that

$$F(k) \equiv (\nu^5 \varepsilon)^{1/4} \, \Phi \;\; (k \nu^{3/4}/\varepsilon^{1/4}) \tag{31}$$

where $\Phi \; (x)$ is a universal function of the argument. From the requirement that $F \;\; (k)$ becomes independent of ν as $\nu \to 0$, it readily follows that

$$F(k) \to \text{constant} \;\; \varepsilon^{2/3} \;\; k^{-5/3}. \tag{32}$$

This is the Kolmogoroff spectrum. But it makes the integral defining $F(k)$ diverge. It cannot, therefore, be valid for $k \to 0$; the description of the largest energy containing eddies cannot be within the scope of the universal theory.

That neither $f(r)$ nor $F(k)$ can be uniquely defined in the framework of a universal theory is further supported by the fact that the relation (cf. Heisenberg, 1948; equation (50) in this paper)

$$f(r, \, 0) = (\tfrac{1}{2}\pi)^{1/2} \int_0^\infty dk \, F(k) \, J_{3/2}(kr) \, / \, (kr)^{3/2} \tag{33}$$

between them, where $J_{3/2}$ denotes the Bessel function of order 3/2 is not meaningful when $F(k)$ is given by Kolmogoroff's spectrum: the Hankel-transfer on the right-hand side of equation (33) does not exist.

XVI

If the spectrum $F(k)$ and the fundamental correlation function $f(r, t)$ are both outside the framework of a universal theory, then the question arises as to what the function is for which we may seek a universal characterization.

It appears that it is meaningful to consider the space derivative

$$\chi(r, t) = -\frac{\partial f(r,t)}{\partial r}, \tag{34}$$

of the longitudinal correlation function and that in the framework of stationary homogeneous and isotropic turbulence it can be specified uniquely without reference to $< u_1^2 >$ or r_0. Several arguments in support of this can be advanced.

(1) Kolmogoroff's principles applied to χ $(r, 0)$ would require that

$$\chi(r, 0) \equiv \left(\frac{\varepsilon^3}{\nu} \right)^{1/4} \quad X_1 \; (r\varepsilon^{1/4}/\nu^{3/4}) \tag{35}$$

where X_1 is a universal function of the argument and that

$$\chi(r, 0) \rightarrow \text{Constant} \;\; \varepsilon^{2/3} \; r^{-1/3} \;\; \text{as} \;\; \nu \rightarrow 0; \tag{36}$$

and this does not diverge as $r \rightarrow \infty$. The divergence of the function at $r = 0$ need not concern us: it is due to the neglect of viscosity. [Also this divergence at $r = 0$, precludes us from considering χ $(0, t)$ at this point.]

(2) In contrast to equation (33) the relation (cf. Chamberlain and Roberts, 1955).

$$r^2 \frac{\partial^3 f}{\partial r^3} + 7r \frac{\partial^2 f}{\partial r^2} + 8 \frac{\partial f}{\partial r} = - \int_0^\infty k \, F(k) \; \sin \, kr \; dk, \tag{37}$$

represents a mathematically meaningful relation: The sine transform of k F (k) for the Kolmogoroff spectrum does exist; and it is clear that multiplication by k in the Fourier space is equivalent to differentiation with respect to r in ordinary space.

(3) The restriction to χ in the framework of a universal theory is in agreement with certain general ideas which have been advanced by Heisenberg and Schlüter that it is physically more significant to think of turbulence in terms of the vorticity field rather than in terms of the velocity field. If ω (= curl **u**) denotes the vorticity then it can be shown that the longitudinal vorticity

correlation $< \omega_1' \; \omega_1'' >$ defined analogously to $< u_1' \; u_1'' >$) is related to χ in the manner

$$< \omega_1' \, \omega_1'' > = \frac{\partial \chi}{\partial r} + \frac{4}{r} \; \chi; \tag{38}$$

and this correlation as we observe depends only on χ.

XVII

Suppose then that χ (r, t) is a function which can be determined in the framework of a universal theory. Then what should be required of a physical theory of stationary homogeneous and isotropic turbulence? We should hope that the theory starting from the equations of motion and continuity and some clearly defined physical postulates leads to a differential equation for χ (r, t) which satisfies the following conditions:

(1) The equation for χ allows a Kolmogoroff transformation i.e., if we measure

$$\begin{aligned} &\chi \text{ in the unit } (\varepsilon^3/\nu)^{1/4}, \\ &r \text{ in the unit } (\nu^3/\varepsilon)^{1/4}, \\ &t \text{ in the unit } (\nu/\varepsilon)^{1/2}, \end{aligned} \tag{39}$$

the equation for χ becomes dimensionless. This would prove that, consistent with Kolmogoroff's principles, χ is of the form

$$\chi \equiv (\varepsilon^3/\nu)^{1/4} \;\; X \, (r \, \varepsilon^{1/4}/\nu^{3/4}, \;\; t\varepsilon^{1/2}/\nu^{1/2}), \tag{40}$$

where X (x, y) is a universal function of the arguments.

Now in the limit of zero viscosity the function X (x, y) should have the behaviour

$$X(x, y) \rightarrow x^{-1/3} \; \sigma(y/x^{2/3}). \tag{41}$$

This behaviour of $X(x, y)$ for $\nu \rightarrow 0$ can be deduced as follows: Noting that $y/x^{2/3}$ is the only combination of the arguments $x = r \; (\varepsilon/\nu^3)^{1/4}$ and $y = t \; (\varepsilon/\nu)^{1/2}$ which is independent of ν, and expressing X (x, y) in the equivalent form

$$\chi(r, t) \equiv (\varepsilon^3/\nu)^{1/4} \;\; Y(r\varepsilon^{1/4}/\nu^{3/4}, \; \varepsilon^{1/3}t/r^{2/3}), \tag{42}$$

we observe that the condition that the right-hand side become independent of ν as $\nu \to 0$ is

$$Y(x, y/x^{2/3}) \to x^{-1/3}\, \sigma(y/x^{2/3}) \text{ as } x \to \infty, \tag{43}$$
$$y/x^{2/3} \text{ remaining fixed.}$$

These consequences of Kolmogoroff's principles will require of a differential equation for χ the following additional properties:

(2) The equation for χ when ν has been set equal to zero admits a solution of the form

$$\chi = r^{-1/3}\, \sigma(t/r^{2/3}), \tag{44}$$

where σ satisfies the boundary conditions enumerated below.

(2a) σ is an even function of the argument. This follows from the basic requirement that in stationary turbulence the tensor $< u_i' u_j'' >$ depends on the times at which the velocity components are measured at the two points, only through the absolute value of their difference. We must, therefore, require that

$$\frac{d\sigma}{dx} = 0 \text{ at } x = 0 \quad (x = t/r^{2/3}). \tag{45}$$

(2b) A second condition on σ is that it be bounded at the origin. Actually, it can be shown that σ should tend to a *positive constant* σ_0 as $x \to 0$:

$$\sigma \to \sigma_0 > 0 \text{ as } x \to 0. \tag{46}$$

The reasons for requiring $\sigma_0 > 0$ are somewhat involved and we shall not go into them. (The interested reader might refer to Chandrasekhar, 1956).

(2c) A final condition is that

$$\sigma \to 0 \text{ as } x \to \infty. \tag{47}$$

This condition is necessary: otherwise χ would not be meaningful in a universal theory.

We now return to the boundary conditions on $\chi(r, t)$. Clearly the evenness of $\chi(r, t)$ in t requires that

$$\frac{\partial \chi}{\partial t} = 0 \text{ for } t = 0 \text{ for all } r. \tag{48}$$

Further, we must also require that

$$\chi(r, t) \to C r^{-1/3}\, \sigma(t/r^{2/3}) \text{ as } r \to \infty \text{ for any finite } t, \tag{49}$$

where C is a numerical constant to be determined.

It remains to consider how we are to introduce in the theory the fact we have hitherto not considered namely, that we are dealing with a system in which there is a continuing dissipation of energy at the rate ε. At first sight it may seem difficult to introduce ε in a universal theory since this is also the rate at which energy is supplied to the system and we wish specifically to avoid any reference, direct or indirect, to the manner in which it is supplied. However, we can introduce ε without violating the framework of a universal theory by making use of Taylor's relation (cf. equation (16))

$$\left(\frac{\partial^2 f}{\partial r^2}\right)_{r=0,\ t=0} = -\frac{\varepsilon}{15\nu}. \tag{50}$$

as a further boundary condition. For χ expressed in Kolmogoroff's units (39) this condition implies that

$$\left(\frac{\partial \chi}{\partial r}\right)_{r=0,\ t=0} = \frac{1}{15}. \tag{51}$$

This last condition together with the earlier conditions (48) and (49) should determine C and make the solution for χ unique.

Let it be stated once again that if χ should be the quantity which it is meaningful to consider in a universal theory and if a deductive physical theory should lead to a differential equation for χ then it should be compatible with all the conditions we have enumerated. There is certainly no assurance that it will be possible to satisfy all these many conditions. Conversely, if a theory should lead to a differential equation for χ and it satisfies all these conditions then we may regard these facts as providing an *a posteriori* justification for the ideas we have set forth.

XVIII

We shall now describe a theory (Chandrasekhar 1955, 56) which leads to a differential equation for χ and which satisfies all the requirements of the preceding paragraph.

Various correlations between the velocity components at two different points ($\mathbf{r}'$ and $\mathbf{r}''$ say) and at two different times (t' and t'' say) are first defined under conditions of stationary homogeneous and isotropic turbulence. These correlations depend only on the vector joining P and P' and on the difference in the times t' and t''. Thus,

$$Q_{ij} = \langle u_i (\mathbf{r}', t') \; u_j (\mathbf{r}'', t'') \rangle,$$

$$T_{ij;\,k} = \langle u_i (\mathbf{r}', t') \; u_j (\mathbf{r}', t') \; u_k (\mathbf{r}'', t'') \rangle,$$

and $$Q_{ij,\,kl} = \langle u_i (\mathbf{r}', t') \; u_j (\mathbf{r}', t') \; u_k (\mathbf{r}'', t'') \; u_l (\mathbf{r}'', t'') \rangle, \tag{52}$$

are isotropic tensors depending only on $\mathbf{e} = \mathbf{r}' - \mathbf{r}''$ and $\mathbf{t} = t' - t''$.

We have already seen that the equation of continuity and the conditions of homogeneity and isotropy restrict Q_{ij} to the form (12) and define it in terms of a single scalar function $Q\ (r, t)$. Similarly, it can be shown that the tensor $T_{ij;\,k}$ (symmetrical in i and j and solenoidal in k) is also uniquely expressible in terms of a single scalar function $T\ (r, t)$ in the form

$$T_{ij;\,k}\ (\mathbf{e}, t) = \frac{2}{r}\frac{\partial T}{\partial r}\ e_i\, e_j\, e_k - \left(r\,\frac{\partial T}{\partial r} + 3\,T\right)\ (e_i\,\delta_{jk} + e_j\,\delta_{ik})$$
$$+ 2\,T\,e_k\,\delta_{ij}. \tag{53}$$

With regard to quadruple moment $Q_{ij;\,kl}$ the assumption is made that it is related to the second-order moments Q_{ij} as in a normal distribution i.e.,

$$Q_{ij;\,kl} = Q_{ik}\,Q_{jl} + Q_{il}\,Q_{jk} + Q_{ij}\ (0,\ 0)\ Q_{kl}\ (0,\ 0). \tag{54}$$

This is the basic statistical hypothesis of the theory; and it is the only one that is made.

XIX

A basic assumption such as (54) requires some justification; at least the motivation for making it should be explained.

First, let it be stated that the use of quasi-Gaussian hypotheses, (similar to (54)) in the solution of physical problems is by no means novel. It underlies, for example, a systematic solution of the Boltzmann equation in the theory of gases; and it underlies theories of the liquid state as that developed by Kirkwood (to whom we owe the descriptive phrase "breaking the bars"). But what are the physical grounds for making such an assumption? We might answer this as follows:

Whenever a physical system exhibits a property which is the result of many different, apparently unrelated causes acting simultaneously, then the assumption that a Gaussian distribution underlies the property is a normal and a natural one. Thus, in the dynamical theory of gases and in the theory of Brownian motion such an assumption (even, if not in so undefended a form!) is made; and the resulting theories provide a description adequate for most purposes. In these instances when one wishes a description of higher accuracy (as in the theory of non-uniform gases) one finds that the quasi-Gaussian hypothesis generally leads to the desired next approximation.

In the phenomenon of turbulence the statistical element is provided by the inertial coupling between the different Fourier components of the velocity field. However, in a theory of turbulence we cannot assume, even as a first approximation, that the relevant distributions are Gaussian. For, in a Gaussian distribution the triple correlation $T_{ij;\,k}$ (like all odd moments) will vanish. But to make $T_{ij;\,k} = 0$ is to abolish turbulence! For, turbulence owes its origin to the phase relationships between the different Fourier components; and the vanishing of the odd moments is equivalent to asserting that no such relationships exist. Thus, by multiplying the equation of motion

$$\frac{\partial u_i'}{\partial t'} + \frac{\partial}{\partial x_k'}\ (u_i'\,u_k') = -\frac{\partial \bar{\omega}'}{\partial x_i'} + \nu\,\nabla^2 u_i' \tag{55*}$$

* The primes distinguish that the values of the variables at $\mathbf{r}'$ and t' are meant.

by u_j'' at ($\mathbf{r}''$, t'') and averaging we obtain an equation relating the double (Q_{ij}) and the triple correlations ($T_{ik;\,j}$). The term in the triple correlation arises from the inertial term in the equation of motion. If $T_{ij;\,k}=0$, then in the equation for Q_{ij} the role of the inertial term would have been eliminated. But as we have already emphasized in § VIII, it is the inertial term which holds the key to the turbulence phenomenon. Consequently, in a theory of turbulence we cannot make the customary Gaussian assumption.

If the Gaussian assumption cannot be made, then the quasi-Gaussian assumption appears as the next simplest one to make. But can we justify the assumption on any other grounds besides those of simplicity? And, when indeed can such an assumption be justified?

Consider the latter question first: For a one-dimensional Gaussian distribution,

$$f(x)=\frac{1}{\sqrt{\pi}}\,e^{-x^2} \tag{56}$$

we have

$$\langle x^2\rangle = 0\cdot 5,\ \langle x^3\rangle = 0 \ \text{and}\ \langle x^4\rangle = 0\cdot 75. \tag{57}$$

Suppose that in some instance these three moments are

$$\langle x^2\rangle = 0\cdot 45,\ \langle x^3\rangle = -\,0\cdot 05 \ \text{and}\ \langle x^4\rangle = 0\cdot 70. \tag{58}$$

It is possible that these moments are realized in a problem in which the non-vanishing of the third moment is of primary interest. Nevertheless, if the third moment is small (relative to the second and the fourth moments, as in the example) the skewness of the distribution required by the non-vanishing of the third moment may not be so great that the 2 : 3 Gaussian ratio between the second and the fourth moments is seriously in error. If this should be the case, then the quasi-Gaussian hypothesis may be adequate to determine the fourth moments (in a first approximation) in terms of the second. Clearly it should not be used for any direct evaluation of the third moments.

In using the quasi-Gaussian approximation in a theory of turbulence we are implicitly supposing that the relevant distributions,

even though skew, are not so skew that the fourth moments cannot be estimated (in a first approximation) in terms of the second moments by the Gaussian relation between them. We naturally ask if there is any empirical evidence for such a supposition. Without going into any detail it may be stated that the available evidence is not unfavourable. Thus, the triple correlations are indeed, small compared with the double correlations: the maximum value of $h=\langle u_1'^2\, u_1''\rangle/\langle u_1^2\rangle^{3/2}$ is $-\,0\cdot 05$ while $\langle u_1'\, u_1''\rangle\,/\,\langle u_1^2\rangle$ varies from 1 to 0 and is about 0·4 when h attains its maximum. Moreover, there have been attempts to verify the relation (54) directly and these attempts have in general confirmed it.

Quite apart from the empirical evidence which supports the use of the quasi-Gaussian approximation, we can perhaps justify its use in the theoretical development of a physical theory of turbulence as follows: We have indicated how from the equations of motion we can derive an equation relating the second and the third moments. We can similarly derive an equation relating the third and the fourth moments; an equation relating the fourth and the fifth moments, and quite generally an equation relating the nth and $(n+1)$th moments. The solution of the turbulence problem is formally equivalent to the solution of the infinite set of moment equations which can thus be derived from the Navier-Stokes equation. When any physical problem leads to such an infinite set of equations, a standard procedure for solving them is to consider the finite system formed by the first n equations and let n increase indefinitely (in principle, that is!). (This method of treating the moment equations is analogous to expanding a desired function in a complete set of orthogonal functions and retaining an increasing number of terms in the expansion.) In considering the infinite system of moment equations to which the Navier-Stokes equation leads, we have seen that breaking the system at the first equation leads to a trivial solution. Consequently, it is reasonable to ask: Do we obtain a physically significant solution by considering the first two equations? The quasi-Gaussian approximation is precisely the assumption which is needed to answer this question. Depending on the results which follow from the solution of the first pair of moment equations coupled through the quasi-Gaussian approximation, we may judge the usefulness of the approach. Similar methods have proved successful in many problems of mathematical physics; there is no *a priori* reason why it should not also prove useful in the solution of the turbulence problem.

XX

As we have explained in § XIX, we can derive from the Navier-Stokes equation an infinite set of moment equations. The quasi-Gaussian approximation (54) couples the first two of these equations and enables us to consider them independently of the others. We shall conclude our discussion of the turbulence problem by a brief summary of the analysis based on these two equations. It is, however, beyond the scope of the present essay to describe any aspect of the mathematical content of the theory. The interested reader might refer to the original papers (Chandrasekhar, 1955, 56 and Backus, 1957).

After suitable transformations and eliminations the theory developed on the premises outlined in §§ XVIII and XIX, leads to the following differential equation for χ:

$$\frac{\partial}{\partial r}\left[\left(\frac{\partial^2}{\partial t^2} - \nu^2 \frac{\partial}{\partial r} D_5 \mathbf{D}\right)\chi \Big/ \frac{\partial}{\partial r}\mathbf{D}\chi\right] = -\chi, \qquad (59)$$

where we have used the abbreviations

$$\mathbf{D} = \frac{\partial}{\partial r} + \frac{4}{r} \quad \text{and} \quad D_5 = \mathbf{D}\frac{\partial}{\partial r} = \frac{\partial^2}{\partial r^2} + \frac{4}{r}\frac{\partial}{\partial r}. \qquad (60)$$

It can be readily verified that equation (59) is compatible with Kolmogoroff's principles; for, if in accordance with these principles we measure χ, r and t in the units (39), we find that the equation becomes non-dimensional and that

$$\frac{\partial}{\partial r}\left[\left(\frac{\partial^2}{\partial t^2} - \frac{\partial}{\partial r} D_5 \mathbf{D}\right)\chi \Big/ \frac{\partial}{\partial r}\mathbf{D}\chi\right] = -\chi. \qquad (61)$$

Next consider the equation

$$\frac{\partial}{\partial r}\left[\frac{\partial^2 \chi}{\partial t^2} \Big/ \frac{\partial}{\partial r}\mathbf{D}\chi\right] = -\chi. \qquad (62)$$

obtained from equation (59) by setting $\nu = 0$. As we have seen in § XVII the similarity principles require that in this limit the solution for χ be of the form

$$\chi = r^{-1/3}\,\sigma(t/r^{2/3}), \qquad (63)$$

where $\sigma(x)$ satisfies the boundary conditions (45), (46) and (47). By mathematical processes which are too technical to outline here, it can be shown that equation (62) does allow a solution of the form (63) and further, that $\sigma(x)$ is uniquely determined (apart from adjustable scale factors) by the boundary conditions. Figure 3 illustrates the resulting solution for σ; and in Figure 4 the evolution of χ with t is illustrated.

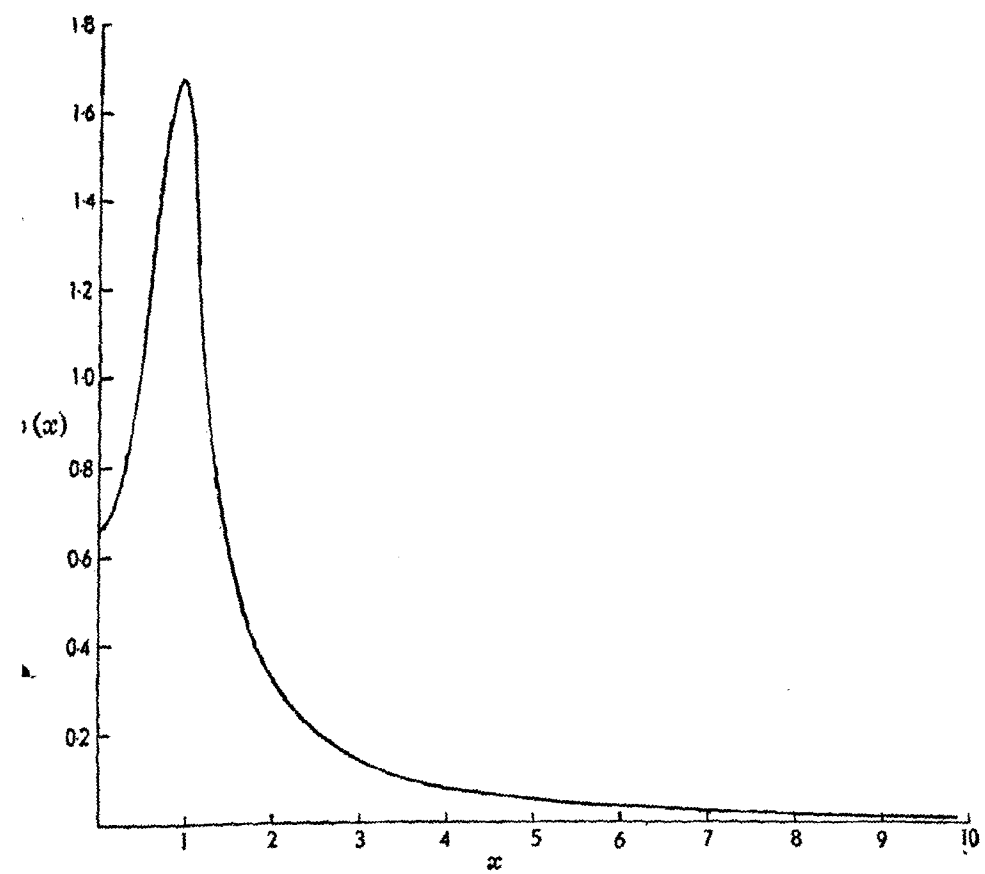

FIG. 3. Illustrating the dependence of the function σ on x.

Finally, it has to be shown that the conditions (48), (49) and (51) uniquely determine a solution of equation (61). While a rigorous proof has not been given to establish the existence of such a solution, it has been possible to demonstrate by numerical methods that a solution satisfying all the conditions of the problem can, in fact, be found.

XXI

The present essay has been devoted to a general discussion of what the central problem of turbulence really is and what the guiding principles are on which one may seek a solution of the problem. It has seemed to the writer that the formulation of the

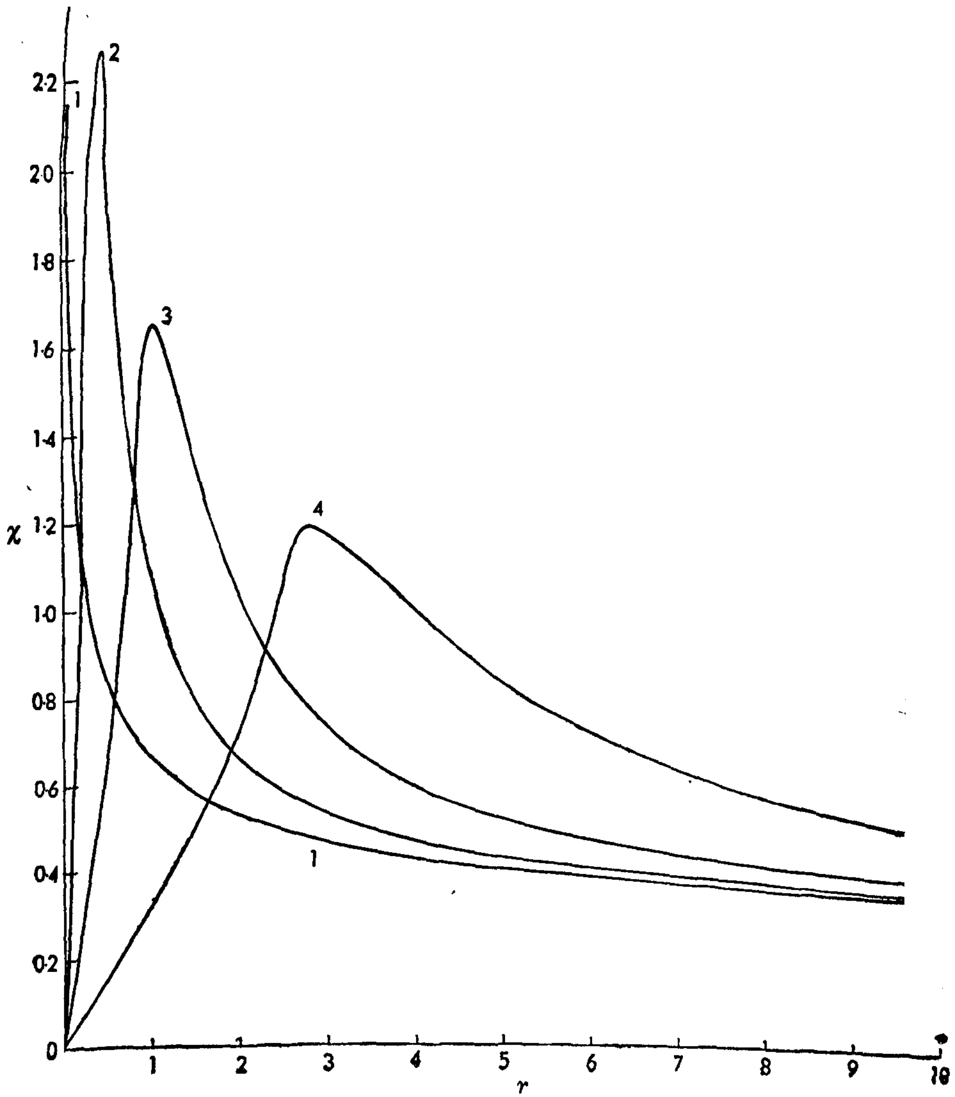

FIG. 4. The evolution of $\chi(r, t) = r^{-1/3}\sigma(t/r^{2/3})$ for various values of t. The curves labelled 1, 2, 3 and 4 are for $t = 0$, $0{\cdot}5$, $1{\cdot}0$ and $2{\cdot}0$, respectively.

problem and the clarification of the principles are of some value. While the ideas expressed are not all new, the point of view presented is a personal one: it is the point of view which led the writer to the theory of turbulence he has recently developed. The mathematical theory itself (except for the brief summary in § XX) *is not* described in this essay.

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Le Theoreme de Convergence en Theorie du Potentiel

PAR

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I. Introduction

1 — Un des théorèmes fondamentaux de la théorie classique du potentiel établit, selon H. Cartan, que l'enveloppe inférieure d'une famille de fonctions surharmoniques $\geqslant 0$ (dans un ouvert) est égale à une fonction surharmonique sur le complémentaire d'un ensemble exceptionnel qui est localement "polaire" ou "de capacité extérieure nulle". Une forme équivalente est que l'enveloppe inférieure d'une famille de potentiels de mesures $\geqslant 0$ pris avec la fonction de Green comme noyau dans un domaine ω, vaut un potentiel de ce type sauf aux points d'un ensemble du type exceptionnel précédent (il est même équivalent de traiter lecas particulier où ω est sphérique et où les masses ne chargent qu'un compact de ω).

Voici un bref historique de ce théorème: RADO [8] considérant des suites décroissantes montra d'abord grâce aux fonctions presque sousharmoniques de SZPILRAJN que l'ensemble exceptionnel est de mesure de Lebesgue nulle; BRELOT [1]prouva ensuite qu'il est de capacité intérieure nulle. Enfin H. CARTAN [4], utilisant essentiellement la notion d'énergie, montra que la capacité extérieure est nulle et que le théorème, considéré à l'origine pour des suites, s'étend à un ordonné filtrant décroissant donc à l'enveloppe inférieure d'une famille quelconque de fonctions surharmoniques positives. Récemment BRELOT [2] y parvint sans l'énergie en reprenant sa démonstration initiale, remarquant que pour les suites les résultats récents sur la capacitabilité de CHOQUET [5] permettent de passer de la capacité intérieure nulle à la capacité extérieure nulle, et ramenant à une suite le cas d'une famille quelconque.

Nous nous proposons ici non seulement de simplifier encore, sans usage de l'énergie, mais, par un effort axiomatique, de donner dans le cas d'espaces et de noyaux beaucoup plus généraux un énoncé qui fournira aussitôt les résultats maintenant classiques. On énoncera d'ailleurs certains résultats préliminaires avec une généralité plus grande qu'il ne serait nécessaire ici.

II. Preliminaires

2—*Définition* 1. Soit E un espace localement compact. On appelle *noyau* toute application G de $E \times E$ dans $\bar{R}_+$ (c.à.d. $[O, +\infty]$) telle que pour tout $x \varepsilon E$, $G(x, y)$ soit une fonction mesurable de y pour toute mesure $\mu \geqslant O$ de Radon sur E.

Pour une telle mesure $\mu \geqslant O$ sur E (qui peut être définie comme fonctionnelle $\mu(f)$ de f finie continue et nulle hors d'un compact), l'application $G\mu$ de E dans $\bar{R}_+$ définie par $G\mu(x) = \int G(x, y) d\mu(y)$ s'appelle le *potentiel* de la mesure μ pour le noyau G.

On notera M_+ l'espace des mesures de Radon $\geqslant O$ sur E (brièvement *mesures*), muni de la topologie faible bien connue (dite vague selon Cartan et Bourbaki).

On dira qu'une mesure $\mu \geqslant O$ est portée par un fermé F de E si le complémentaire de E est de μ-mesure nulle; le support $S\mu$ de μ est le plus petit des fermés portant μ.

Lemme 1: Pour que l'application Γ: $(x, \mu) \rightarrow G\mu(x)$ de $E \times M_+$ dans $\bar{R}_+$ soit semi-continue *inférieurement* (brièvement s.c.i.), *il faut et il suffit* que G soit s.c.i. dans $E \times E$.

Démonstration: Si E′ est la partie de M_+ formée par les mesures ponctuelles ε_x de masse-unité en x, l'application $x \rightarrow \varepsilon_x$ de E sur E′ est une homéomorphie qui identifie $E \times E$ avec la partie $E \times E'$ de $E \times M_+$. Donc si Γ est s.c.i, sa restriction à $E \times E'$ l'est aussi. C'est dire que $G\, \varepsilon_y(x)$ ou $G(x, y)$ est s.c.i, dans $E \times E$.

Inversement supposons que G soit s.c.i dans $E \times E$. C'est l'enveloppe supérieure d'une famille ordonnée filtrante croissante (G_i) d'applications de $E \times E$ dans R_+, finies continues et nulles hors d'un compact. Pour tout i, l'application $(x, \mu) \rightarrow G_i\mu(x)$ est continue dans $E \times M_+$; en effet elle s'écrit aussi $(x, \mu) \rightarrow \mu(G_{i,x})$ où $G_{i,x}$ est l'application $y \rightarrow G_i(x, y)$. On voit que c'est la composée de l'application continue $x \rightarrow G_{i,x}$ de E dans C(E)[1] et de l'application continue $(\mu, f) \rightarrow \mu(f)$ de $M_+ \times C(E)$ dans R.

1. **C(E) est l'espace vectoriel des fonctions finies continues nulles en dehors d'un compact de E, un voisinage de l'origine étant défini comme devant contenir toutes les fonctions de module $< \varepsilon$ nulles hors d'un même compact.**

Mais alors, comme $G\mu(x) = \text{Sup } G_i\mu(x)$, l'application $(x, \mu) \rightarrow G\mu(x)$ est s.c.i.

Corollaire: Si G est s.c.i. dans $E \times E$,

(a) Pour toute mesure μ, $G\mu$ est s.c.i dans E,
(b) Soit μ_n une suite de mesures convergeant faiblement vers μ; si pour *tout* $x \varepsilon E$ la suite $G\mu_n(x)$ est convergente, on a $\lim G\mu_n \geqslant G\mu$.

Définition 2. On dit qu'un *compact* K de E est de *G-capacité nulle* (G étant un noyau sur E) si, pour chaque mesure $\mu \neq O$ portée par K, la restriction de $G\mu$ à K est non bornée.

On dit qu'un ensemble A de E est de *G-capacité intérieure nulle* si tout compact contenu dans E est de G-capacité nulle.

Ces notions offrent peu d'intérêt pour un noyau quelconque car un sous-compact d'un compact de capacité nulle peut alors ne pas être de capacité nulle. Pour éviter de telles singularités, on se restreint aux noyaux "réguliers":

Définition 3: On dit qu'un noyau G est *régulier* si pour toute mesure μ de support compact, la propriété que la restriction de $G\mu$ au support de μ soit finie continue entraîne que $G\mu$ soit finie continue dans E.

On sait d'après EVANS [6], p. 238-241, ou VASILESCO [9], que c'est le cas du noyau classique newtonien ou logarithmique en espace euclidien, donc de la fonction de Green. On étudiera ailleurs des critères généraux de régularité.

Lemme 2: Soit G un noyau s.c.i. sur E et soit μ une mesure non-nulle portée par un compact K de E et telle que la restriction de $G\mu$ à K soit bornée. Alors pour tout $\varepsilon > O$ il existe un compact $K' \subset K$ tel que

(1) si μ' est la restriction de μ à K′, la restriction de $G\mu'$ à K′ soit continue
(2) on ait $\int d\mu - \int d\mu' < \varepsilon$

Démonstration: En effet d'après un théorème de Lusin généralisé, comme $G\mu$ est mesurable (puisque s.c.i) il existe $K' \subset K$ tel que $\int d\mu - \int d\mu' < \varepsilon$ et tel que la restriction de $G\mu$ à K′ soit continue. Posons $\mu'' = \mu - \mu'$, mesure $\geqslant O$. Le potentiel $G\mu$ est somme des fonctions s.c.i. $G\mu'$ et $G\mu''$; sa restriction à K' ètant continue, il en est de même de celles des autres fonctions, en particulier de $G\mu'$.

Corollaire : Si G est s.c.i. régulier et si K est un compact de capacité non nulle, il existe μ (non nulle) sur K, de potentiel fini continu dans E.

C'est dans les cas classiques un résultat de DE LA VALLEE POUSSIN [7], p. 84.

Notons encore que la régularité de G entraine que si K est de G-capacité nulle, tout sous-compact de K l'est aussi.

3 —Enfin arrivons à la partie la plus nouvelle de cette étude, au lemme-clef:

Lemme 3 : Soit E un espace topologique à base dénombrable d'ouverts. Soit $(f_i)_{i\varepsilon I}$ une famille d'applications s.c.i. de E dans $\overline{R}$ (c.à.d. $[-\infty, +\infty]$). Pour tout $J \subset I$, posons $f_J = \underline{\inf}_{i\varepsilon J}(f_i)$.

Alors il existe une partie dénombrable I_0 de I telle que si g est une application s.c.i. quelconque de E dans R, la relation $g \leqslant f_{I_0}$ entraîne $g \leqslant f_I$.

Démonstration : L'application $\mu \rightarrow \dfrac{\mu}{1+|\mu|}$ est une homéomorphie croissante de $\overline{R}$ sur $[-1, +1]$ et ramène le théorème au cas où les fonctions considérées prennent leurs valeurs dans un intervalle compact fini.

Soit alors $(\omega_n)_{n=1,2,\ldots}$ une base d'ouverts de E. Il existe dans I un élément i_n tel que :

$$(1) \quad \inf_{y\varepsilon\omega_n} f_{i_n}(y) - \inf_{y\varepsilon\omega_n} f_I(y) < \frac{1}{n}$$

Soit I_0 l'ensemble des ces i_n. Considérons $x \varepsilon E$. On va établir le lemme en montrant que

$$(2) \quad g \leqslant f_{i_n} \text{ quel que soit n entraîne } (3) \quad g(x) \leqslant f_I(x)$$

En effet pour tout $\varepsilon > 0$, il existe dans la suite (ω_n) un ω_p contenant x, tel que $\dfrac{1}{p} \leqslant \varepsilon$ et que

$$(4) \quad g(y) \geqslant g(x) - \varepsilon \text{ pour tout } y\varepsilon\omega_p.$$

Alors (1), (2) et (4) donnent

$$(1') \quad \inf_{y\varepsilon\omega_p} f_{i_p}(y) - \inf_{y\varepsilon\omega_p} f_I(y) < \varepsilon$$

$$(2') \quad \inf_{y\varepsilon\omega_p} g(y) - \inf_{y\varepsilon\omega_p} f_{i_p}(y) \leqslant 0$$

$$(4') \quad g(x) - \inf_{y\varepsilon\omega_p} g(y) \leqslant \varepsilon$$

d'où par addition membre à membre

$$g(x) - \inf_{y\varepsilon\omega_p} f_I(y) \leqslant 2\varepsilon \text{ et a-fortiori}$$

$$g(x) \leqslant f_I(x) + 2\varepsilon$$

Il s'ensuit (3) puisque ε est arbitraire.

Définition 4 : On appelle *adjoint* d'un noyau G sur E, le noyau G^* sur E défini par $G^*(x, y) = G(y, x)$. Il est s.c.i. si G l'est.

III. Le Theoreme de Convergence

4 —*Théorème* : Soit E un espace localement compact à base dénombrable d'ouverts[2] et soit G un noyau s.c.i. sur E dont l'adjoint soit régulier.

Soit $(\mu_i)_{i\varepsilon I}$ une famille de mesures sur E, $i_0 \varepsilon I$, et J l'ensemble des i tels que $G\mu_i \leqslant G\mu_{i_0}$. On suppose que :

(a) Les potentiels $G\mu_i$ forment une famille ordonnée filtrante décroissante.

2. c.à.d. que E est homéomorphe à un ouvert d'un espace métrique compact.

(b) Pour tout compact K, les masses $\mu_i(K)$ $(i \varepsilon J)$ sont majorées indépendamment de $i\varepsilon J$.

(c) Pour toute mesure fixe ν de support compact et de potentiel $G^*\nu$ fini continu, $\int G^*\nu d\mu_i^{CK} \to O$ selon l'ordonné filtrant croissant des compacts K[3], indépendamment des $i\varepsilon J$ (μ_i^{CK} désignant la restriction de μ_i au complémentaire de K) (la condition (c) est vérifiée si E est compact).

Alors (A) Il existe une mesure μ telle que $G\mu$ vaille Inf $G\mu_i$ sauf sur un ensemble de G^*-capacité intérieure nulle.

(B) De facon plus précise, il existe une suite α_n d'éléments de I tels que

(1) μ_{α_n} converge faiblement vers une mesure μ.

(2) la suite $G\mu_{\alpha_n}$ est décroissante.

(3) $G\mu \leqslant \inf G\mu_i \leqslant \lim G\mu_{\alpha_n}$

ces trois fonctions étant égales sauf sur un ensemble de G^*-capacité intérieure nulle.

Démonstration: Comme $(\inf G\mu_i) = (\inf G\mu_i)_{i\varepsilon J}$, on se ramène au cas $J = I$. Alors $\int G^*\nu d\mu_i$ ou $\int G\mu_i d\nu$ est borné indépendamment de i; car cela est majoré par $\int G\mu_{i_o} d\nu$ ou $\int G^*\nu d\mu_{i_o}$ qui d'après (c) est fini.

La famille $G\mu_i$ répond aux conditions du lemme 3. On considérera une suite (i_n) formant la partie I_o de I qu'introduit ce lemme. On en déduit grâce à (a) une suite $\mu_{i'_n}$ telle que la suite $G\mu_{i'_n}$ soit décroissante, avec $G\mu_{i'_n} \leqslant G\mu_{i_n}$. Grâce à (b) on en tire une suite μ_{α_n} convergeant faiblement vers une mesure μ.[4] Posons $\lim G\mu_{\alpha_n} = \Phi$. D'après le corollaire du lemme 1, $G\mu \leqslant \Phi$ donc grâce

3. c.à.d. que pour ν et ε donnés on a $\int G^*\nu d\mu_i^{CK} < \varepsilon$ pour un compact K convenable, indépendamment de $i\varepsilon J$.

4. Cela résulte de ce que C(E) (considéré note 1) contient ici un ensemble dénombrable partout dense de fonctions φ pour chacune desquelles on pourra, grâce au procédé diagonal, faire converger $\mu_{\alpha_n}(\varphi)$ pour une suite α_n convenable extraite de la suite (i'_n).

au lemme 3, $G\mu \leqslant \inf G\mu_i$ pour tout i. Ainsi (μ_{α_n}) satisfait à (1), (2), et aux inégalités de (3).

Montrons enfin que l'ensemble A des x où $G\mu(x) \neq \Phi$ est de G^*-capacité intérieure nulle: Sinon A contiendrait un compact K de G^*-capacité non nulle. D'après le corollaire du lemme 2 il existerait une mesure $\nu \neq O$ portée par K, de potentiel $G^*\nu$ fini continu dans E. Or

$\int G\mu_{\alpha_n} d\nu = \int G^*\nu d\mu_{\alpha_n}$, quantité bornée indépendamment de n, par une constante k finie. Le premier membre tend vers $\int \Phi d\nu$ fini. On aura la contradiction cherchée en montrant que le second membre tend vers $\int G^*\nu d\mu$ ou $\int G\mu d\nu$. Cette limite est évidente si E est compact. Sinon, soit K un compact de E et φ_k une fonction continue $\geqslant O$ majorée par $G^*\nu$, égale à $G^*\nu$ dans K et nulle hors d'un compact. D'abord

$\int \varphi_k d\mu_{\alpha_n} \leqslant k$ donc $\int \varphi_k d\mu \leqslant k$ et enfin $\int G^*\nu d\mu \leqslant k$. Puis $\left| \int G^*\nu d\mu_{\alpha_n} - \int G^*\nu d\mu \right| \leqslant \int (G^*\nu - \varphi_k) d\mu_{\alpha_n} + \left| \int \varphi_k d\mu_{\alpha_n} - \int \varphi_k d\mu \right| + \int (G^*\nu - \varphi_k) d\mu$. Le premier et le troisième terme sont majorés par $\int_{CK} G^*\nu d\mu_{\alpha_n}$ et $\int_{CK} G^*\nu d\mu$; donc en vertu de la condition (c), ε étant donné, ils sont majorés par ε pour un choix convenable de K indépendamment n. Si K est fixé le second terme est $< \varepsilon$ pour n assez grand. Il s'ensuit que le premier membre tend vers O pour $n \to \infty$.

5 — *Applications.* D'autres énoncés voisins résultent immédiatement des remarques suivantes:

(1) Si G est strictement positif, (b) est conséquence de (c);

(2) Si les $\mu_i(E)$ sont bornés, (b) est satisfait, et (c) l'est sous l'une des hypothèses suivantes:

(α) les μ_i ne chargent qu'un même compact,

(β) pour toute ν de support compact dans E non compact, $G^*\nu$ tend vers O au point d'Alexandroff de E.

(3) Supposons G tel que, quelles que soient μ et μ', Inf $(G\mu, G\mu')$ soit un potentiel et que $G\mu \leqslant G\mu'$ entraîne $\mu(E) \leqslant \mu'(E)$.

Alors, si pour un indice $i_0 \varepsilon I$, $\mu_{i_0}(E)$ est fini, on a la propriété (A) sans les hypothèses (a), (b), (c), mais avec (β).

En effet considérons les enveloppes inférieures d'un nombre fini quelconque des $G\mu_i$, puis leurs enveloppes inférieures ave $G\mu_{i_0}$. On obtient des potentiels de certaines mesures μ_i'. L'enveloppe inférieure des $G\mu_i'$ vaut celle des $G\mu_i$ et les μ_i' satisfont, sous les conditions ci-dessus, à (a), (b), (c).

(4) Appelons G-capacité d'un compact K la borne supérieure des charges $\mu(K)$ des mesures de support dans K telles que $G\mu \leqslant 1$ sur K. La G-capacité intérieure d'un ensemble A est la borne supérieure des G-capacités des compacts contenus dans A; la G-capacité extérieure de A est la borne inférieure des capacités intérieures des ouverts contenant A. Un ensemble A est dit G-capacitable si ses deux capacités précédentes coïncident (Voir [5]).

Supposons que les boréliens soient G-capacitables, comme c'est le cas d'après [5] pour le noyau newtonien dans R^n ($n \geqslant 3$) ou de la fonction de Green dans un domaine euclidien ou même un *espace de Green* (Voir [3]). Alors l'ensemble exceptionnel du théorème, où $G\mu \neq \lim G\mu_{a_n}$ étant borélien, est de G-capacité *extérieure* nulle.

6 — *Cas des potentiels de Green dans un espace de Green* Ω.[5]

On prendra pour G la fonction de Green de Ω; on a ici $G^* = G$.

Proposition: Soit μ_i une famille de mesures dans Ω, admettant chacune un potentiel de Green $G\mu_i$ non partout infini. Il existe une mesure μ telle que $G\mu = \inf G\mu_i$ sauf sur un ensemble de capacité extérieure nulle.

Démonstration: On se ramène d'abord immédiatement au cas où il existe un $G\mu_{i_0}$ qui majore tous les $G\mu_i$, et où la famille est filtrante décroissante. D'aprés (5, 1), il suffit alors de montrer que les (μ_i) satisfont à (c).

5. Dans le cas particulier d'un domaine euclidien borné par exemple, on peut, au lieu du lemme topologique 3, utiliser la propriété suivante: soit (v_i) une famille filtrante décroissante de fonctions surharmoniques $\geqslant 0$, sommables dans un domaine euclidien. Si une suite extraite décroissante v_{i_n} satisfait à $\int v_{i_n} d\omega \to \inf \int v_i d\omega$, toute fonction semi-continue inférieurement minorant $\inf v_{i_n}$ minore $\inf v_i$; autrement dit la régularisée de $\lim v_{i_n}$ minore $\inf v_i$.

Or $G\mu_i^{CK}$ est, dans $\overset{\circ}{K}$, (intérieur du compact variable K), une fonction harmonique majorée par la plus grande minorante harmonique de $G\mu_{i_0}$ dans $\overset{\circ}{K}$. Comme celle-ci tend vers 0[6], d'ailleurs uniformément sur tout compact, selon le filtre des K, il en est de même de $G\mu_i^{CK}$ indépendamment de *i*. De sorte que $\int G\mu_i^{CK} dv$ ou $\int G v d\mu_i^{CK}$ tend vers O pour toute v du théorème, indépendamment de *i*.

Remarque: La démonstration est particulièrement simple dans le cas où Ω est l'intérieur d'une boule (ou l'extérieur de cette boule complété par le point à l'infini) et où les supports des μ_i sont dans un même compact de Ω. De ce cas particulier on pourrait passer aussi au cas général.

Corollaire: On peut déduire de là, comme on le sait (Voir par example Cartan [4]) qu'une famille de fonctions surharmoniques $\geqslant 0$ dans un espace de Green admet comme enveloppe inférieùre une fonction égale à une fonction surharmonique, sauf aux points d'un énsemble de capacité extérieure nulle, ou ce qui est équivalent, polaire.[7]

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6. Cette propriètė d'un potentiel quelconque se démontre en se ramenant au cas où μ_{i_0} est une masse ponctuelle unité; et dans ce cas ce n'est autre qu'une des propriétés fondamentales de la fonction de Green.

7. Un ensemble est polaire s'il est localement une partie de l'ensemble des infinis d'une fonction surharmoniqu.

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Resume of Research activities of the Departments of Science, University of Madras since their inception

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EDITORIAL NOTE

Despite the fact that this University is completing its hundredth year since its inception, the older of the Science Departments are very much younger, having been in existence only for a quarter of a century. In presenting this résumé of the highlights of the investigations of the Science Departments of this University, we have much pleasure in dedicating this as our humble contribution to the progress of science and learning in the various Universities all over the world.

कर्मण्येवाधिकारस्ते मा फलेषु कदाचन ।
मा कर्मफलहेतुर्भूर्मा ते सङ्गोऽस्त्वकर्मणि ॥

Thy business is with action only, never with its fruits; so let not the fruit of action be thy motive, nor be thou to inaction attached.

—The immortal *Bhagavad Gita*, 2nd discourse, sloka 47.

CONTENTS

Department of Botany

1930 — 1956

The first Honorary Director, Professor T. Ekambaram initiated some amount of work in Botany and during the short period of his tenure of office, three theses and some publications appeared.

It was only in 1933 that Professor M. O. P. Iyengar took over as the first permanent Director and established a school of research in the field of Algae. The work initiated was broad based and covered limnological observations of fresh, estuarine and marine algal forms, systematics, life-histories, morphology and cytology. Much of this was pioneering work in so far as this country was concerned. In the field of limnology much of the work has been reviewed critically by Iyengar (1939) under the heads: lakes and larger pieces of water; algal flora of temporary waters and their succession; pieces of water with permanent water blooms caused by species of *Microcystis;* paddy field algae; algae of estuarine regions; algae in relation to aquatic animals; and algae and mosquito larvae.

In the field of systematics the major work has been on living and fossil diatoms (Venkataraman, 1939; Subrahmanyan, 1946; Iyengar and Subrahmanyan, 1943), desmids (Iyengar and Vimala Bai, 1941) and Cyanophyceae (Iyengar and Desikachary, 1944). Several new genera belonging to various groups of algae were also described: *Cladospongia* Iyengar and Ramanathan (1940) in the Craspedomonadaceae; *Characiosiphon* Iyengar (1936), *Pseudovalonia* Iyengar (1938), *Triplastrum* Iyengar and Ramanathan (1942), *Hormidiella* Iyengar and Kanthamma (1940), *Heterothricopsis* Iyengar and Kanthamma (1941) and *Gloeotilopsis* Iyengar and Philipose (1956) in the Chlorophyceae; *Chrysodictyon* Ramanathan (1946) in the Chrysophyceae; and *Mastigocladopsis* Iyengar and Desikachary (1946b), *Camptylonemopsis* Desikachary (1948) and *Iyengariella* Desikachary (1953) in the Cyanophyceae. Many new species and forms belonging to different groups were also described.

Life-history studies were carried out on a number of forms, notably in *Eudorina elegans* (Iyengar, 1937), *Pseudovalonia forbesii* (Iyengar, 1938), *Cylindrocapsa geminella* (Iyengar, 1939), *Caulerpa* (Iyengar, 1940), *Characiosiphon rivularis* (Iyengar, 1954), *Anadyomene stellata* (Iyengar and Ramanathan, 1940), *Microdictyon tenuius* (Iyengar and Ramanathan, 1941), *Cyclotella meneghiniana* (Iyengar and Subrahmanyan, 1942), *Characium terrestris* (Kanthamma, 1940), *Enteromorpha* (Ramanathan, 1936, 1939b), *Carteria* (Ramanathan, 1942), *Bacteriastrum* (Subrahmanyan, 1945a), *Navicula halophila* (Subrahmanyan, 1946b), etc. Life-history studies have also been carried out on several of the new genera already mentioned.

Another aspect on which much attention has been focussed is the developmental morphology and cytology of many tropical forms. Particular mention may be made here of the work on *Melobesia farinosa* (Balakrishnan, 1946), *Grateloupia lithophila* (Balakrishnan, 1949), *Eudorina indica* (Doraiswami, 1940), *Spirogyra* (Doraiswami, 1946), *Polysiphonia platycarpa* (Iyengar and Balakrishnan, 1950), *Enteromorpha compressa* var. *ligulata* (Ramanathan, 1939b), *Micrasterias denticulata* var. *notata* (Saraswathi, 1946), various species of diatoms (Subrahmanyan, 1945b, 1946b) and *Chara zeylanica* (Sundaralingam, 1946, 1954).

The outcome of all these carefully planned and precise scientific investigations has been one of enriching our knowledge of algae, and tropical algae in particular, in all its aspects: morphological, cytological, ecological, developmental and taxonomical. Indeed, much of this work on the green algae has been summarised by Professor Iyengar (1951) in a chapter on Chlorophyceae in the *Manual of Phycology* edited by Prof. G. M. Smith of the Stanford University and published by the Chronica Botanica Co.

In 1944 there was a re-orientation of the work from Algae to Mycology and Plant Pathology in the Department with the appointment of Professor T. S. Sadasivan as Director in succession to Professor M. O. P. Iyengar. Broadly speaking, the following investigations have been undertaken during the past twelve years: soil-borne diseases of plants (including micro-ecology of soil fungi and other microorganisms), the physiology of fungi and the physiology of host-parasite relationships, particularly Fusariose wilts in plants, techniques in bioassay and chromatography, spectrochemical studies on uptake of ions by plants, work on vivotoxins and fungal enzymes, respiration and electrophoretic studies in plant tissues, and systematics and taxonomy of fungi.

The work on soil conditions and root diseases, particularly those of cotton and pigeon pea, has been one of detailed studies

of survival of fungal pathogens in soils on the face of amendments and as affected by soil microfloras (Subramanian, 1946 a, b, 1950; Sarojini, 1950; Sulochana, 1952 a-d; Kovoor, 1954; Ramakrishnan, 1955a). It has been shown that *Fusarium vasinfectum,* the cotton wilt organism, is a *soil inhabitant* and *Fusarium udum,* the pigeon pea wilt fungus, is a *root inhabitant* and that the heavy metal zinc in pure culture controls the toxin (Fusaric acid) output of the former organism (Kalyanasundaram and Saraswathi-Devi, 1955a). This finding has found practical application in that the zinc content (as determined by bioassay using *Aspergillus niger*) of the major *Fusarium* wilt-sick cotton soils of Southern India is optimum for toxin production *in situ,* whereas a high concentration of zinc acts as a limiting factor in certain other areas where the fungus is present but is innocuous. The role of trace elements in the control of plant wilts, for which considerable evidence has accumulated, has been reviewed in detail (Sadasivan, 1950, 1951, 1952; Sadasivan and Subramanian, 1954a). Microbial antagonism in soils as another factor in the delimitation of the saprophytic phase of soil-borne fungal pathogens in the presence of many heavy metals such as Al, B, Co, Li, Mn, Mo and Zn together with a statistical interpretation of the triple interaction: micro-elements, concentrations and incubation periods was indicated by Sulochana (1952 a-d).

The symptomatology of Fusariose wilt of cotton has been studied in detail particularly in relation to internal changes such as ascorbic acid, chlorophyll and reducing sugar contents; histological changes in the diseased vein-cleared leaves were mainly elongation and shrivelling of the palisade cells and a reduction in the number of chloroplastids. During the progress of the disease, starch synthesis was inhibited during light periods, but normal translocation continued during dark periods indicating no serious derangement of phloem function (Kalyanasundaram, 1954b). Similarly, work on non-protein and protein nitrogen (NPN and PN respectively) indicated that the result of pathogenesis appeared to be a decrease in the available NPN constituents of the host which is suggestive of the operation of the enzyme systems of *Fusarium vasinfectum* (Sadasivan and Subramanian, 1954a; Lakshminarayanan, 1955a). External vein-clearing symptoms with onset of disease was completely described for the first time (Satyanarayana and Kalyanasundaram, 1952). The screening of toxin-invaded plants under ultra-violet illumination was described by Subba Rao (1954).

Much evidence has been presented by many workers in this laboratory in the elucidation of the mechanism of Fusariose wilts (Sadasivan, 1955; Kalyanasundaram, 1955b; Lakshminarayanan, 1955a; Subramanian, 1955c). The highlights of these investigations may briefly be summarised as follows: There is overwhelming evidence to show that the disease syndrome is the result of toxaemia rather than one solely of mechanical vessel plugging induced by pectic enzymes or polysaccharides, etc. The demonstration of the production of Fusaric acid *in vivo* in cotton plants infected by the fungus was made by using an elegant chromatographic technique, chelating the Fusaric acid from internal tissues of the host with copper which gave specific R_f values (Lakshminarayanan and Subramanian, 1955). This has been confirmed further by using a bioassay cum chromatographic technique (Kalyanasundaram and Venkataram, 1956). It has also been shown that *Fusarium vasinfectum* produces antibiotics in the unsterilized soil which is a finding of considerable significance (Kalyanasundaram, 1955c).

Study of enzyme systems both of the cotton plant and *Fusarium vasinfectum* has yielded fruitous results. For instance, sizeable quantities of cysteine along with other major amino acids like asparagine and glutamine were present in the resistant varieties of cotton examined but were absent in a susceptible cotton variety tested and it is suggestive of this cysteine of the resistant variety of cotton chelating with Fe''' available in the host and rendering this quantum of iron unavailable for chelation with the toxin which appears to be a pre-requisite for toxigenic wilting of cotton (Lakshminarayanan, 1955b). Pre-treatment with an optimum concentration of 5-10 ppm. of 8-quinolinol was found to give effective protection to cut shoots of cotton against toxaemia to dialysed culture filtrates of *Fusarium vasinfectum.* The chemotherapeutant was also effective *in vivo* in sand cultures (D. Subramanian, 1956). Further work on pectin methyl esterase and pectin galacturonase activity of Fusaria indicated that high root pectin content of cotton plants seems to be correlated with susceptibility and low levels with resistance and the main seat of pectin synthesis and storage in the susceptible variety is the root while it is the shoots and leaves that accumulate higher pectic reserves in the resistant cotton varieties studied. Therefore, the pathogen despite its ability to utilize pectin substrates is denied such a source from the roots of resistant varieties thereby rendering its pectic enzyme systems inoperative (Lakshminarayanan, 1956b). It is relevant to mention here that the emphasis in studying amino acid build-up in plants has now shifted to one of examining root exudates as exosmosis of these pectin fractions has come to be regarded as not only in the realm of theoretical possibility but one of practical importance and, indeed, does take place. Recent work in this field in this laboratory has thrown considerable light and indicates differences in the amino acid exudates from resistant and susceptible rice plants to the foot rot fungus, *Fusarium moniliforme* (Andal, Bhuvaneswari and Subba Rao, 1956; Andal and Subba Rao, 1956).

Growth factor studies have been carried out with many genera of tropical fungi such as *Pellicularia koleroga, Piricularia* spp., *Sclerotium oryzae, Corticium microsclerotia* and *Cercospora personata* (Mathew, 1952, 1953, 1954b; Sadasivan and Subramanian, 1954b; Apparao, Saraswathi-Devi and Suryanarayanan, 1954). Eleven isolates of *Pellicularia koleroga* were found to be heterotrophic to thiamine, but their capacity to synthesise this vitamin was not completely lost as they do well in a mixture of thiazole and pyrimidine or pyrimidine alone. *Piricularia oryzae*, however, was unable to do this in young cultures, but with advancing age utilizes an equimolar mixture of thiazole and pyrimidine or pyrimidine alone. Further work on growth requirements of *Piricularia oryzae* showed that thiamine, and iron and zinc, and possibly copper, are indispensable for growth but, nevertheless, interdependent in their action.

Work on other aspects of the physiology of fungi can be summarised as follows: the physiology of Fusaria has been studied in detail. Aeration stimulated mycelial growth but inhibited sporulation although it had no effect on pH of the medium (Sarojini and Yogeswari, 1947). Carbon, nitrogen and pH relationships to the growth of Fusaria showed that there were differences between species in so far as growth, their sugar and nitrogen utilization and shifts in the pH of the media are concerned (Srinivasa Pai, 1953). Sporulation varied with the source of nitrogen, urea being the best, followed by potassium nitrate and ammonium sources (Subramanian and Srinivasa Pai, 1953). Similar studies on *Piricularia oryzae* showed that the fungus failed to utilize the usual inorganic ammonium nitrogen sources such as ammonium chloride, ammonium sulphate and ammonium nitrate, whereas it readily utilised other nitrate sources. Organic acids such as fumaric, succinic, tartaric, citric, oxalic, acetic and lactic acids, or addition of calcium carbonate stimulated growth and aided utilization of inorganic ammonia. It was thus clear that utilization of different forms of nitrogen would depend on pH changes and in this process organic acids or calcium carbonate act as buffering agents and help in the maintenance of pH at an optimum level.

More recent work has indicated the essentiality of certain heavy metals to growth and sporulation of Fusaria using bioassay techniques (using *Aspergillus niger*, 'M' and 'M.U.B.L.1' strains). Work on different strains of *A. niger* has shown different degrees of sensitivity in the detection of heavy metals (Saraswathi-Devi, 1954a, 1955). The Madras strain (M.U.B.L.1) was found to be less sensitive to traces of manganese and more sensitive to copper, and perhaps molybdenum also, than the standard Mulder strain ('M' strain). Quite recently, spectrochemical studies have been initiated in studying uptake of metabolites by wilted plants and the consequent derangement thereof in the mobility of ions. It has been shown, using the standard Lundegårdh (spark-in-flame) technique that cotton plants infected by *Fusarium vasinfectum* showed an increased uptake of magnesium, calcium, iron and manganese and decreased accumulation of potassium over the healthy controls. It has been suggested that the derangement in the selective absorption of ions, seen in the infected plants, is more likely to have been caused by chemical agents (toxins) than physical causes such as plugging of vessels (Sadasivan and Kalyanasundaram, 1956). Confirmation of this was obtained from studies on the conductivity of roots, stems and leaves of infected cotton plants which showed a remarkable fluctuation in the ionic concentration of the tissues prior to the appearance of systemic symptoms; with the appearance of symptoms in the leaves, the conductivity of the tissues showed an increase over the healthy, indicating accumulation of electrolytes (Gnanam, 1956).

In the field of systematic mycology, detailed studies were made on the fungus floras of soils and the rhizosphere of crop plants. Soil Fusaria and Fusaria infecting crop plants were intensively investigated and systematic accounts have been published (Subramanian, 1951a, 1952a, 1952d, 1954b; Prasanna Varma, 1954; Venkataram, 1955b). The question of the "wild type" in the genus *Fusarium* has been considered in the light of work on a large number of fresh isolates of different species obtained from soils as well as from crop plants; it was concluded that species of *Fusarium* occur in nature in a multiplicity of forms and not as a single "wild type" (Subramanian, 1951b, 1955b). More recently, problems re-

lating to classification of Fusaria were also critically reviewed and discussed (Subramanian, 1955a).

Apart from studies on soil fungi, considerable work has also been carried out on other saprophytic and parasitic fungi which include many new records for India and many new taxa. The Fungi Imperfecti have received much attention and twenty-two new genera have been described, of which sixteen are hyphomycetes and six are coelomycetes. The new hyphomycete genera described are *Beltraniella* Subramanian (1952c), *Lacellinopsis* Subramanian (1953a), *Koorchaloma* Subramanian (1953c), *Lomaantha* Subramanian (1954a), *Lomachashaka* Subramanian (1956a), *Paathramaya* Subramanian (1956a), *Prathoda* Subramanian (1956a), *Tharoopama* Subramanian (1956a), *Phaeotrichoconis* Subramanian, (1956c), *Prathigada* Subramanian (Subramanian and Ramakrishnan, 1956d), *Dwayamala* Subramanian (1956e), *Kutilakesa* Subramanian (1956e), *Nalanthamala* Subramanian (1956e), *Bahusandhika* Subramanian (1956e), *Vakrabeeja* Subramanian (1956e) and *Starkeyomyces* Agnihothrudu (1956b); the six new coelomycete genera are *Plagionema* Subramanian & Ramakrishnan (1953c), *Rostrospora* Subramanian & Ramakrishnan (1952), *Petrakomyces* Subramanian & Ramakrishnan (1953a), *Anthasthoopa* Subramanian & Ramakrishnan (1956a), *Alpakesa* Subramanian & Ramakrishnan (1954) and *Shanoria* Subramanian & Ramakrishnan (1956e). In the ascomycetes one new genus of the Hemisphaeriales, *Sapucchaka* Ramakrishnan (1956a) was described. It will be noticed that we have made a departure in naming new genera: most of the names have been derived from our classical language, Sanskrit and not from Greek or Latin. We commend this to workers in countries familiar with this language, particularly because Greek and Latin root sources have been drawn upon rather intensively in the past. Taxonomic studies on hyphomycetes (Subramanian, 1956a, b, c, d, e), and on some genera of the Sphaeropsidales such as *Neottiospora* (Subramanian and Ramakrishnan, 1953b, 1954, 1956b), *Amphichaeta* (Subramanian and Ramakrishnan, 1956c) and *Ciliochorella* (Subramanian and Ramakrishnan, 1956e) have also been in progress. Systematic accounts of Indian species of *Curvularia* (Subramanian, 1953b), and *Periconia* (Subramanian, 1955d) and South Indian myxomycetes (Agnihothrudu, 1954a,b, 1955, 1956a) were published.

A mycological herbarium was started in 1951 and many of the observations and records made from periodical collections of fungi largely by Drs. Subramanian and Ramakrishnan have yet to be published.

Besides the original publications cited already, two lengthy and important compilations on Indian fungi were also brought out during the period. One is a list of fungi recorded in India during 1938-1952, intended as a successor to Mundkur's *Fungi of India—Supplement I* published in 1938 (Ramakrishnan and Subramanian, 1952). The second, is a similar list covering the period 1952-56 (Subramanian and Ramakrishnan, 1956d). A list of Indian soil fungi, including the larger fungi, was also published in 1952 (Subramanian, 1952f). These lists are largely intended as an aid to workers in systematic mycology and taxonomy of fungi in this country and indeed, contain a very complete bibliography of Indian systematic mycology during the period 1938-1956.

In concluding this brief résumé we feel it our duty to thank several institutions in India, particularly the Indian Academy of Sciences, the National Institute of Sciences, the Current Science Association and the Indian Botanical Society, for much encouragement by publishing our research papers. We also wish to record our deep appreciation of the generous grants-in-aid which have flowed from the Ministry of Education, Government of India and the University Grants Commission and have enabled us to put into operation many precision instruments so vital for modern research methodology in the study of botanical problems.

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Department of Biochemistry

The research work carried out in this department can be broadly divided into two sections, one dealing with investigations carried out between the years 1933 and 1948 when Dr. M. Damodaran developed a school of biochemical research with emphasis on studies of proteins, peptides and proteolytic enzymes and the second between the years 1949 and 1956 when Dr. P. S. Sarma developed a school of research with emphasis on water soluble vitamins and their inter-relationships and on biochemical investigations using radioactive isotopes.

Damodaran and Sivaswamy (1936) isolated 'anacardein' from cashew nut (*Anacardium occidentale*), in yields amounting to 18 per cent of the fat free seed. In analysing this protein according to the Van Slyke nitrogen distribution method, it was found that the precipitate obtained with phosphotungstic acid was completely free from sulphur, even though the presence of cystine in the protein has been established beyond doubt. Further studies showed that the extent of precipitation at any particular temperature is dependent on the concentration of cystine content and that below a certain minimum concentration of cystine, there was no precipitation. Hence, certain proteins may contain cystine and still show no cystine sulphur in the phosphotungstic acid precipitate.

Krishnan and Krishnaswamy (1939) investigated the proteins and other nitrogenous constituents of water melon seeds (*Citrullus vulgaris*) and isolated one globulin in a crystalline condition. Damodaran and Narayanan in the same year studied the seeds of *Canavalia obtusifolia*, and showed that they had high urease activity and that they were a good source of the amino acid 'canavanine'.

Damodaran and Ramachandran (1940, 1941) have isolated a trypsin resistant phosphopeptone of constant composition in the form of its barium salt by digesting 'para-nuclein' which separated as an insoluble complex when casein was digested with pepsin. From their results of analysis, the authors have concluded that the phosphopeptone is a polypeptide of ten amino acids made up of three molecules each of glutamic acid and isoleucine and four molecules of serine.

In the field of enzymes, Damodaran and Sivaramakrishnan (1937) showed that the seeds of the water melon (*Citrullus vulgaris*) were a potent source of urease, and that this urease preparation was better than those obtained from soya bean or jack bean for urea determinations. Later, Damodaran and Sivaramakrishnan (1946) have shown that for the estimation of urea in biological fluids, the water melon urease was far more satisfactory than the usual urease preparations from soya bean or jack bean.

Srinivasan (1936) obtained an enzyme preparation from the pressed juice of drumstick (*Moringa pterygosperma*). This enzyme which oxidised ascorbic acid and hence called ascorbic acid oxidase was studied in detail in regard to its properties and also the kinetics of enzymic reaction.

Damodaran and co-workers have also carried out studies on some of the basic problems of enzymic proteolysis. Thus a systematic study has been conducted on ammonia formation and on hydrolysis of peptide linkages during the action of pepsin, trypsin, erepsin and papain. Three typical proteins,casein, edestin and gliadin were used. It was found that the amide and peptide hydrolysis do not run parallel and that the ammonia formed was mainly due to the decomposition of the primary products of protein hydrolysis. The secondary decomposition was not due to enzymic action, but was the result of acidic or alkaline reaction of the digestion mixture. In a subsequent experiment, Damodaran and Narayanan (1938) have studied the action of these enzymes on various amides, and have established the specificity of the proteolytic enzymes in relation to the 'amide' nitrogen of proteins. Further, there has been considerable difference of opinion as to the formation of free amino acids, particularly tyrosine during the digestion of proteins by pepsin. It was generally held that pepsin splits proteins into higher peptides from which amino acids were liberated only by the further action of other specific enzymes called peptidases. Damodaran and Krishnan (1938) have obtained clear evidence to show that tyrosine was liberated during peptic digestion of casein.

The properties of glutamic acid dehydrogenase from germinating seeds have been investigated by Damodaran and Ramakrishnan Nair (1938). It was found that the enzyme was present in the seedlings of *Phaseolus mungo,* and the purified enzyme was found to oxidise naturally occurring l-glutamic acid thus differing from deaminase of animal origin. The properties of the purified enzyme have also been studied.

Damodaran and Ramaswamy (1940) have investigated the succinic dehydrogenase activity in germinating seeds with a view to study the mechanism of formation of asparagine. It was observed that all leguminosae seeds tested showed succinic dehydrogenase activity on germination. This enzyme was, however, absent in seedlings of the water melon and of rice. The authors have suggested that in the leguminoseae, the accumulation of asparagine during germination took place at the expense of glutamic acid, succinic acid being formed from the latter. The aspargine was then formed from succinic acid and ammonia

A comparative study of the enzymes arginase and canavanase from both animal and plant sources has been made by Damodaran and Ananthanarayanan (1940). Their findings have indicated a close parallelism between the activities of arginase and canavanase. The behaviour of the two enzymes on autolysis and in presence of cobalt ions indicated that the two enzymes may be identical.

Yeshoda (1941) worked out a method for obtaining the milk clotting enzyme of *Withania coagulans* in a highly concentrated form. This enzyme had no proteolytic activity, a point of interest throwing light on the mechanism of clot formation, which was considered by some to involve a proteolytic breakdown of the casein prior to coagulation.

Damodaran and Subramanian (1948) have investigated the amino acid changes and also urea formation during germination of seeds. The presence of the enzyme 'aspartase' which converts aspartic acid to fumaric acid and ammonia has been demonstrated in seedlings of *Phaseolus mungo, Cicer arietinum,* and *P. sativum.*

Studies on Ascorbic Acid :

Using uniformly C^{14} labelled radioactive glucose, the direct conversion of glucose to ascorbic acid has been shown to take place in germinated seedlings. The influence of ammonium sulphate on the biosynthesis of ascorbic acid has also been studied by Sivarama Sastry and Sarma (1956). Further, the percentage conversions of radioactive glucose, fructose and sucrose to radioactive ascorbic acid in germinating green gram seeds were determined. It was found that all the three sugars were converted to ascorbic acid to the same extent. The influence of vitamins of the 'B' group on the biosynthesis of ascorbic acid has been investigated by employing the corresponding anti-vitamins and it has been shown that thiamine, pyridoxine and pantothenic acid play a significant role in the various enzymic steps involved in this conversion (Thangamani and Sarma, 1956).

Studies on nicotinic acid and its inter-relationship with tryptophane:

The factors which affect the conversion of tryptophane to nicotinic acid in various systems as in *Neurospora crassa*, germinating seeds, rice moth larvae (*Corcyra cephalonica* st.), and the albino rat have been studied particularly from the point of view of the influence of (i) various 'B' vitamins, (ii) proteins and amino acids and (iii) various carbohydrates. Using anti-vitamins, it has been shown that pyridoxine, folic acid and biotin are involved in the biological synthesis of nicotinic acid from tryptophane (Shanmugasundaram and Sarma, 1953). As regards proteins and amino acids, it has been found that protein hydrolysate and certain amino acids inhibit the utilization of tryptophane, kynurenine and 3-hydroxy kynurenine but that they do not have any action on the utilization of 3-hydroxy anthranilic acid and nicotinic acid. It was also found that in the case of germinating seeds the presence of fructose lowers the biosynthesis of nicotinic acid whereas glucose had no such effect.

The metabolism of nicotinic acid and nicotinamide studied in the rice moth larvae has shown that it differed in certain important respects from that observed in higher animals. Thus, neither form of this vitamin is methylated prior to excretion and the main excretory metabolite is free nicotinic acid, irrespective of whether nicotinic acid or nicotinamide is given in the larval diet. Nicotinuric acid, the glycine conjugate of nicotinic acid has also been found to be excreted in significant amounts (Sundaram and Sarma, 1956). A system bringing about deamidation of nicotinamide has been investigated in the rice moth larvae and in *Neurospora crassa* and its locale in the cellular organisation of the organism was found to be the soluble cytoplasmic material.

Studies on Biotin and Inositol:

A deficiency of biotin was found to produce in the rat, a higher retention of nitrogen. The urea excretion and the per cent of ingested nitrogen converted into and excreted as urea, as also the ratio of urea nitrogen to urinary nitrogen were all found to decrease appreciably, when the animals developed an uncomplicated deficiency of this vitamin (Siva Sankar and Sarma, 1952). A similar accumulation of nitrogen was also found in the tissues of biotin deficient larvae. Ramachandran and Sarma (1955) have found that the gamma isomer of hexachlorocyclohexane the anti-vitamin of inositol inhibited the synthesis and secretion of amylase in pigeon pancreatic slices in the same manner as a dietary deficiency of inositol. Further, biotin was found to reverse the effect of the gamma isomer on amylase formation by obviously stimulating the synthesis of inositol.

Paper chromotagraphic Separation of 'B' group of Vitamins:

The separation and identification of all the members of the vitamin 'B' complex excepting folic acid have been achieved by ascending paper chromatography using a new solvent system consisting of n-butanol, methanol, benzene and water. Folic acid was detected as well as estimated by the same technique employing phenol saturated with water as the solvent system (Radhakrishnamurthy and Sarma, 1953). Further, a useful modification in the technique of ascending paper chromatography was devised to facilitate better separation of constituents which have close and low R_f values, by employing a pad of filter paper discs to provide extra capillary absorption.

Studies on Shark Liver residue as a rich source of 'B' vitamins:

Shark liver residue left over as waste material after extraction of liver oil was investigated for its possible utilization as a cheap source of nutritionally essential factors (Rajagopalan and Sarma, 1956). Proteolysed extracts prepared from liver residues were analyzed for the following 'B' vitamins, thiamine, riboflavin, nicotinic acid, pantothenic acid, vitamin B_6, folic acid, vitamin B_{12}, biotin, choline and inositol. It was found that the liver residue could be used as a very good source for the preparation of liver extracts of appreciable nutritional potency.

The Influence of 'B' Vitamins on nitrogen metabolism:

The role of 'B' vitamins, thiamine, biotin, p-amino benzoic acid, folic acid and pantothenic acid in amino acid metabolism in germinating green gram seeds (*Phaseolus radiatus*) has been investigated. It was found that during germination, there was a rapid fall in glutamic acid and a marked increase in the level of aspartic acid. Both the anti-vitamins of thiamine and biotin produced an accumulation of glutamic acid and a corresponding fall in aspartic acid. Sulphanilamide produced an accumulation of histidine and arginine and a fall in the level of methionine and serine. Using glutamic acid and glucose, both uniformly labelled with C^{14}, the biosynthesis of asparagine has been studied in three species of legume seeds and using C^{14} labelled glucose, evidence has been obtained for the rapid synthesis of glutamic acid during germination (Sivaramakrishnan and Sarma, 1955)

Studies on the nutritive value of reconstituted milk:

Reconstituted milk, as prepared by the Government Milk Factory, Teynampet, Madras, has been found to be inferior in nutritive value, to fresh cow's milk or to toned milk as shown by growth experiments with albino rats. Estimation of different vitamins by chemical, spectrophotometric and microbiological methods showed that reconstituted milk had a lower vitamin value in regard to most of the vitamins investigated than eiher cow's milk or toned milk.

The growth promoting value of reconstituted milk for rats was not improved by supplements of different amino acids and vitamins but was improved markedly on supplementation with casein showing that the lower growth promoting value of reconstituted milk was probably due to its low strepogenin content. Also evidence was obtained for the presence in skim milk powder stored at 37°C and 60°C of a substance toxic to *Lactobacillus bulgaricus* 09 This growth inhibitor was obtained in a concentrated form and its properties studied. The data obtained suggest that it is peptide in nature and possessed anti-strepogenin activity.

Studies on phosphatases and phosphoproteins:

Highly active preparations of French bean pyrophosphatase were obtained by the following methods (i) fractional precipitation with acetone, (ii) fractional precipitation with ammonium sulphate and (iii) adsorption on calcium phosphate gel and subsequent elution with five per cent sodium chloride and finally dialysis. The product thus obtained was about hundred times as active as the crúde extracts of the seeds. The purified pyrophosphatase did not show any activity towards sodium β-glycerophosphate, but it liberated orthophosphate phosphorus from sodium pyrophosphate, adenosine triphosphate and thiamine pyrophosphate. The optimum pH and the effect of various inhibitors and activators have been studied.

A phosphatase specific for the dephosphorylation of phosphoproteins was detected in the tissues of higher animals and in oil seeds (Sundararajan and Sarma, 1953). The purification and characterization of this relatively little known enzyme has been studied in detail. An enzymic method for the preparation of dephosphorised casein has also been developed as a result of these studies. Amino acid analysis and other studies carried out on the dephosphorylated protein have shown the superiority of the enzymic method over the existing chemical methods. Further, an investigation of the biosynthesis of casein in the lactating mammary gland of rat has been carried out and evidence has been obtained to indicate the presence in this tissue of an active enzyme needed for the phosphorylation of proteins.

Studies on the Biochemical role of Zinc:

The growth inhibition produced by excess dietary zinc in rice moth larvae was found to be counteracted by whole liver extract, the alkali stable fraction of liver extract and by desoxy ribonucleic acid. None of the 'B' vitamins was effective in this respect with the possible exception of vitamin B_{12}. The inhibition in catalase levels observed in zinc toxicosis was reversed by copper.

Cystine caused a specific growth inhibition and fat accumulation in rice moth larvae which was reversed by tryptophane and to a lesser extent by nicotinic acid. Zinc sulphate at physiological levels was partially effective in this condition.

In cholesterol fed rats, the *in vitro* uptake of radioactive zinc (Zn^{65}) by erythrocytes decreased, these values being very nearly normal when zinc was also added to the diet. The distribution of radioactive zinc in the livers of rats also followed the same pattern.

Biochemical studies on thyroid hormone:

The optimum conditions for maximum thyroxine formation on iodination of different proteins have been studied. Shark ray collagen, a scleroprotein has been shown to yield a high percentage of thyroxine when compared with other scleroproteins like silk fibroin. In the field of protein iodine interaction, it was observed that the hydroxy-amino acids (threonine, serine, and hydroxyproline) in the free as well as in the bound form in proteins, were completely oxidized by iodine. Further, cysteic acid, the oxidation product of cystine was shown to be formed on iodinating proteins. A new colorimetric method of determining diiodotyrosine has been developed using the metal chelating property of diiodotyrosine (Moudgal, Ramachandran and Sarma, 1954).

Investigations carried out on the goitregenic action of groundnut in albino rats have shown that the goitregenic factor is an anthocyanin, arachidoside, present in the red pigment of seed coats. This goitregenic action is overcome by additions of small amounts of iodine to the diet. Tracer technique involving the use of radioactive iodine (I^{131}) has conclusively proved that arachidoside is the goitregenic factor. On similar lines, an anthocyanin isolated from cashew nut red seed coat has been found to be goitregenic. Tracer studies with radioactive iodine have further shown that mode of action of these goitregenic agents consists in competing with tyrosine for elemental iodine in the thyroid tissue.

During the course of investigation on the metabolic role of thyroid hormone in the animal body the following interesting observations have been made. Thyroid hormone was found to influence biological methylation systems in the animal body. Thyroid imbalance was also found to affect glucuronide conjugation in the rat. Further, *in vivo* as well as *in vitro* experiments have shown that thyroxine can depress the activity of enzyme catalase. Feeding iodoamino acids to rice moth larvae was found to affect growth, metamorphosis and oxygen consumption (Srinivasan, Moudgal and Sarma, 1955).

Studies on the preservation of Neera :

Among the various substances tried for the preservation of 'Neera' the sweet palm juice, the anti-malarial substance 'Paludrine' has been found to be quite effective in keeping Neera in an unfermented state for a period of fifty four hours. The maximum concentration of 'Paludrine' needed was one in five thousand parts though generally, lower concentrations were found to be sufficient if weather conditions were favourable. Extensive field trials conducted at Udangudi in Tinnevelly District have shown that Neera preserved with 'Paludrine' gave higher yields of palm gur and sugar. Further, the gur prepared without 'Paludrine' got contaminated with various fungi and its keeping quality was very poor whereas the gur prepared from Neera preserved with 'Paludrine' was free from any contamination or mouldy growth on the surface. A patent has been obtained for this process by the Council of Scientific and Industrial Research. It may be stated that feeding trials with albino rats for over hundred days have shown that daily addition to the diet of 'Paludrine' at a concentration of thirty milligrams per cent did not produce any untoward symptoms or affect the rate of growth of young albino rats.

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REVIEWS

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Sivaramakrishnan, V. M. and Sarma, P. S. 1953. Inhibition Analysis: A Review with Reference to 'B' Vitamins. *J. Madras Univ.*, B, 23: 40.
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APPENDIX I

List of Research Students who were Awarded Research Degrees in Biochemistry, University of Madras

M.Sc. Degree

Sivaswamy, T. G. 1937. A New Globulin from Cashew Nut.
Devi, Miss P. 1937. Chemical Composition of the Fat from the Seeds of *Carcinia indica*.
Krishnan, P. S. 1938. The Globulin from the Seeds of Water Melon.
Krishnaswamy, T. K. 1938. A New Glutelin from the Seeds of Water Melon.
Ramaswamy, R. 1938 Isolation of 1'-3-4 Dehydroxy-phenylalanine from the Seeds of *Mucuna pruriens*.
Anantanarayanan, K. G. 1939. Isolation of Canavanine from the Seeds of *Canavalia obtusifolia*.

Narayanan, E. K. 1939. On the Specificity of Proteolytic Enzymes-amide Hydrolysis.

Sivaramakrishnan, P. M. 1939. Water Melon Urease.

Ramakrishnan Nair, K. 1940. (i) Glutamic Dehydrogenases from Germinating Seeds (ii) A tannin from Indian Gooseberry with a Protective Action on Ascorbic Acid.

Ramachandran, B. V. 1940. Amino Acids of Casein Phosphopeptone.

Venkatesan, T. R. 1941 Amino Acid Changes in Germinating Seeds.

Srinivasan, V. R. 1943. Nitrate Reduction in Plants.

Vijayaragavan, P. K. 1945. Biological Value of Proteins with Special Reference to Blood Regeneration.

Roberts, G. W. 1946. Blood Regeneration in Phenylhydrazine Anaemia with Special Reference to Changes that Take Place in the Bone Marrow and Blood and Iron Metabolism.

Kerala Varma, 1947. Mechanism of Symbiotic Nitrogen Fixation by Leguminosae.

Rangachari, P. N. 1947. Pectin Content of Indian Plant Materials with an Investigation on Tamarind Seed Mucilage.

Subramaniyam, S. 1948. Bacterial Oxidation of Sorbitol to Sorbose.

Ninan, Verghese, 1948. Kidney Proteins.

Visvanathan, R. 1949. Enzymic Hydrolysis of Starch.

Chandran, K. 1949. Isoleucine in Nutrition with Special Reference to Haemopoiesis.

Siva Sankar, D. V. 1949. Proteins and Other Nitrogenous Constituents of the Castor Seed.

Lakshminarayanan, K. 1950. Microbial Enzymes.

Friedmann. H. C. 1950. Enzyme Studies on Hepatic Adenosine Triphosphate Breakdown.

Ramachandran, L. K. 1951. Studies on the Hydroxyamino Acids, Hydroxylysine, Serine, and Threonine.

Sundararajan, T. A. 1952. Phosphoproteins.

Tirunarayanan, M. O. 1953. Studies on Biotin.

Ranganathan, G. 1953. Carbohydrate Metabolism: Studies on the Biosynthesis of Ascorbic Acid.

Ramachandran, S. 1954. Investigation on the Enzymic Role of Biotin and Inositol.

Rajagopalan, K. V. 1954. Investigations on Shark and other Fish Liver Residues.

Moudgal, N. R. 1954. Biochemistry of Iodoproteins.

Sivarama Sastry, K. 1955. Studies on Ascorbic Acid.

Ph. D. Degree

Narayanaswamy, A. 1948. Protein Structure-Studies on Shark Ray Collagen.

Ramachandran, M. 1950. Tryptophane in Proteins.

Siva Sankar, D. V. 1951. Unsaturated Fatty Acids and Their Vitamin Interrelationship.

Ramáchandràn, L. K. 1953. Some Studies on Protein, Protein Constituents and Other Iodinated Derivatives.

Shanmugasundaram, E. R. B. 1953. Inter-relationship among some Vitamins and Amino Acids.

Sivaramakrishnan, V. M. 1955. The Influence of Certain Vitamins on Nitrogen Metabolism.

Srinivasan, V. 1955. Biochemical Studies on Iodoproteins and Goitregenic Agents.

Sundaram, T. K. 1955. Influence of Vitamins on Excretory Pigments.

Radhakrishnamurthy, R. 1955. Studies on the Inter-relationship among Vitamins of the 'B' Group.

Sundarajan, T. A. 1955. Studies on the Dephosphorylation of Phosphoproteins.

D.Sc. Degree

Srinivasan, M. 1942. Ascorbic Acid Potency of the Indian Gooseberry (*Phyllanthus emblica*) and the Preparation, Properties, and Application of Ascorbic Acid Oxidase.

Department of Organic Chemistry

The Department of Organic Chemistry has in view the development of research along synthetic approaches to analogues of naturally occurring substances, and the isolation and structure determination of the active principles of vegetable drugs.

On the synthetic side work is in progress on nitrogen heterocyclic compounds. The quinazoline group has many attractive features about it and as a preliminary, the synthesis of a few 4-phenyl quinazolines was effected. This has been followed by the synthesis of 4-benzyl-quinazoline and in view of its close relationship to benzyl isoquinolines, the synthesis of alkyl and alkyloxy substituted 4-benzyl quinazolines is being persued. The synthesis of a number of 3-substituted-2-methyl-4-quinazolones, with halogen and alkyl substituents in the benzene ring has been carried out. The preparation of a few 3 : 4-quinozolonyl quinazolines, which are structurally analogous to the alkaloids Evodiamine and Rutaecarpine, was effected.

In the indole group, a convenient method for the preparation of indole-3-aldehyde has been developed, arising from studies on the mechanism of conversion of gramine to indole-3-aldehyde by reaction with hexamine. The method consists in adding a solution of an equimolecular mixture of indole or substituted indole and hexamine in dilute organic acids to a refluxing solution of another mole of hexamine in the same solvent. Indole-3-aldehyde and 2-phenylindole-3-aldehyde have thus been obtained in 60% and 99% yields respectively. The yields of aldehydes with alkylindoles are much lower and very from 15 to 40%.

Consequent to the finding that skatole participates in the Mannich reaction to give N-dialkylaminomethyl bases, a study has been undertaken to investigate if other 3-substituted indoles also react likewise. 3-Ethyl indole, 3-phenylindole, 2:3-dimethylindole, 2-methyl-3-ethylindole, 3-cyanoindole and also 2:5-dimethyl pyrrole have been found to give N-Mannich bases. 3-Benzylindole, 2-methyl-3-benzylindole and 2-phenyl-3-methylindole, while they do not give Mannich bases under the same conditions, have, however, afforded neutral products whose structures are under investigation. Most of the derivatives of indole that have been reported so far to give Mannich bases have the 3-position free, which gets substituted by the entering dialkylaminomethyl group. The orientation is probably on account of the activation of carbon-3 due to the lone pair of electrons on the nitrogen atom of the indole nucleus. Evidently, when position-3 is blocked by a substituent, the dialkylaminomethyl group gets linked to the relatively electron-rich N-atom itself. Electron releasing and electron attracting groups in position-3 may be expected to favour or hinder respectively the formation of N-Mannich bases. The yields of Mannich bases obtained with the substituted indoles seem to bear out this expectation.

1-Dimethylaminomethyl skatole and its methiodide were employed as intermediates in the synthesis of 3-methyl-1-isotryptophane. 1-Methylgramine and its methiodide are good alkylating agents. It was of interest, therefore, to study alkylations with the skatole derivatives. Free 1-dimethylaminomethyl skatole displayed a pronounced tendency to reverse to skatole and proved to be a poor alkylating agent. Its methiodide, however, has alkylating properties comparable with those of 1-methyl-gramine methiodide. Sodium cyanide, ethyl malonate, nitroethane and phenyl magnesium bromide all undergo alkylation with 1-dimethylaminomethyl skatole methiodide to give satisfactory yields of N-substituted skatoles. Amine exchange reactions were also carried out, demonstrating parallelism in alkylating properties.

It has been established that a slight alteration in the structure of a compound involved in the chemical process, whereby living cells are produced and maintained, may give rise to a substance which interferes with or inhibits the activity of, the parent compound. Such compounds are of interest as potential antibacterial agents. Among the structural changes which have been effective in such conversions is the introduction of substituents like halogen, alkyl, hydroxyl, etc., or the replacement of one by the other of the isosteric groups –NH–, –O–, –S–, –CH : CH– in the structure of metabolites. Analogues of tryptophane are of interest in view of the important role that amino acid plays in metabolic processes. The synthesis of some analogues of tryptophane has been undertaken. The synthesis of dl-3-methyl-1-isotryptophane was achieved as follows:

Skatole ⟶ 1-Dimethylaminomethyl skatole ⟶ 1-dimethylaminomethyl skatole methiodide ⟶ Ethyl-β (1-skatyl) -α-cyano-α-acetamidopropionate ⟶ 3-methyl-1-iso-tryptophane.

The synthesis of 3-methyl-2-isotryptophane was carried out as follows:

Ethyl benzene ⟶ O-nitro ethyl benzene ⟶ O-amino ethyl benzene ⟶ O-chloracetamido ethyl benzene ⟶ O-dimethylamino acetamodoethyl benzene ⟶ 3-methyl-2-isogramine ⟶ 3-methyl-2-isogramine methiodide ⟶ ethyl-β (2-skatyl)-α -acetamidopropionate → 3-methyl-2-isotryptophane.

Work is in progress to synthesise 1-isotryptophane itself by a series of reactions starting from indole-3-aldehyde. One of the intermediates, ethyl-β (3-cyano-1-indolyl)–α–acetamido–α–cyanopropionate has been prepared.

With a view to preparing analogues of physiologically active compounds which contain the indole nucleus and for whose synthesis indole is employed, methods of synthesis of thiopheno-(2, 3 : 2′, 3′)-pyrrole are being studied.

Work is in progress to utilise tryptophane, which is fairly easily prepared by Mannich reaction, to synthesize members of the β–carboline group and then to take advantage of the presence of the carboxyl group to build up a fourth condensed ring structure. A few members of α-pyridyl-indoles have been synthesized. Closely allied to this is the synthesis of pyrido-pyrimidines. Methyl-2-amino-pyridines, with the exception of the 6-methyl base, reacted homogeneously with β–iodo-propionic acid to afford 3, 4-dihydro-2 H-pyrido-(1, 2a)-pyrimidine–2–ones. In the case of 6–methyl–2–amino–pyridine two products were obtained, the desired pyrimidine-2-one was obtained only in poor yield. There are only very few known representatives of pyrimidine derivatives carrying a heterocyclic ring in position-2. Of the various possible routes for the synthesis of members of this group, the reactivity of malondiamide to ring closure is under examination. The condensation of O-phenylene-diamine with quinoline-2, 3–, 4–, 5–, 6–, 7–, and 8-carboxylic acids have been carried out to obtain 2-quinolylbenzimidazoles.

In the isoquinoline series a convenient method has been worked out for the synthesis of 1-(2′, 5′-dimethoxybenzyl)-3-methyl-3 : 4-dihydro-6, 7-methylenedioxy isoquinoline. As a corollary to this, all the seven quinoline carboxylic acids have been condensed with α–methyl homopiperonyl amine and the amides cyclised to give 1-quinolyl-3-methyl-3: 4-dihydro-6, 7–methylenedioxy isoquinolines.

The condensation of lithium α-picoline with epichlorhydrin is being investigated. The reaction proceeds fairly smoothly and a homogeneous product has been obtained. A rigid proof of its constitution is being worked out.

A group of workers are engaged on the addition of thioglycolic acid to double bonds. Methyl thioglycolate very readily adds on to methyl cinnamate under the catalytic influence of piperidine in the absence of a solvent. When the reaction is carried out using dry sodium methoxide in benzene, cyclisation also seems to take place. With benzal azlactone in absolute methanol and a few drops of piperidine, addition, opening of the azlactone ring and esterification take place with facility. These products are preliminary steps in a projected synthesis of 2-phenyl-5-ketoimidazolidothiophane and 2-keto-4-phenyl-2, 3, 4, 6-tetrahydro-thieno- (3, 4)-imidazole. The addition of thioglycolic acid to Schiff-bases is also under study.

In the homocyclic series, one line of work is the synthesis of naphthaquinones with alkyl and alkyl-oxy substituents in the non-quinonoid nucleus. The interest in this group of compounds stems from the chemistry of Sea Urchin colouring matter, which is of great physiological and biochemical interest. Before entering into the synthesis of polysubstituted quinones, a start has been made with the synthesis of 6-methyl-7-methoxy tetralone. The condensation of this and similarly constituted tetralones with nitroso dimethylaniline followed by hydrolysis to naphthaquinones is the general procedure under experimental investigation.

Tetralone chemistry has received some attention in another direction. Methyl 4-keto-1, 2, 3, 4-tetrahydro-2-naphthoate gave the amide on shaking with ammonia, and the hydrazidehydrazone by treatment with hydrazine hydrate. The oxime also gave the oxime hydrazide. The Hofmann degradation of the amide and the Curtius degradation of the hydrazide gave interesting results. The only product that could be isolated was 1-naphthol. The degradation of the oxime hydrazide also gave the same result. The tetralone oxime afforded the p-toluene sulphonic ester in alkaline medium. The Neber rearrangement of this ester gave the amino ketone in very poor yield. Worse still the free base proved to be too unstable to be of use in synthetic work.

The preparation of certain compounds with structures less complicated than those of the steroid hormones, but having many

of their structural features has been undertaken. The intermediate required for the preparation of such compounds is 1, 5-dioxo-7a-methyl-2, 3, 5, 6, 7, 7a-hexahydro indene, which has been synthesized by an improved method involving the reaction of 2-methyl-1, 3-cyclopentanedione with 1-dimethylamino-3-butanone. Work is in progress to introduce the characteristic hydroxy acetone side chain of adrenal cortical hormones via the 1-oxo group. Similar analogues are also proposed to be prepared from 1, 6-dioxo-8a-methyl-1, 2, 3, 4, 6, 7, 8, 8a-octahydronaphthalene.

Experiments have been carried out to obtain direct chemical evidence for the non-planer structures of cyclohexanone, cycloheptanone and fluorenone. If these cyclonones exist in non-planar forms, it was considered likely that their carboxymethoximes might be capable of resolution. The carboxymethoximes of cyclohexanone and cycloheptanone formed only homogeneous double salts with L-brucine which could not be separated into diastereoisomeric forms. In the case of fluorenone carboxymethoxime, two crops of the brucine double salt, differing in rotation were obtained; these however regenerated the parent body of little rotation on decomposition with acid. Rapid interconversions of the non-planar forms are probably responsible for the failure of the attempts at resolution.

A few years back Dr. K. N. Menon and his collaborators worked out a method of estimating experimentally the glyceride composition of fats and oils. The method consists in acetone permanganate oxidation, fractional extraction of the azeloglycerides, finding the saponification value and computing the quantities. This method became essential as laboratories could not afford the cost involved in low temperature fractional crystallisation employed at Liverpool. The method evolved by Dr. K. N. Menon and collaborators found acceptance by workers in the field. One draw-back in the method is the uncertainty that no hydrolysis actually occurs during acetone-permanganate oxidation arising from the potassium salt formed. To lessen this possibility, periodical addition of small quantities of acetic acid was resorted to by Dr. A. R. S. Kartha, one of the collaborators of Dr. K. N. Menon. It is not certain that even this refinement is absolutely free from objection. A method has to be evolved, one which can be employed even in an ordinary college laboratory equipped only to teach to the B.Sc. level, which avoids the presence of alkali in any form during oxidation. Another great desirability is to have a cheap reagent to effect the cleavage of the glycol, formed as the first stage of the oxidation, in a neutral medium. In an investigation on petroselinic acid, oxidation with peracetic acid or performic acid was found to be very effective in obtaining 6 : 7-dihydroxy stearic acid. Preliminary examination of per-acid oxidation of natural fats is encouraging. Before pursuing the problem to a further stage of development, it became important to develop a suitable reagent to cleave the glycol formed, working in a neutral medium. This has now been accomplished.

Oxidation of erucic, petroselenic and oleic acids with silver iodide dibenzoate in dry benzene resulted in the corresponding lower melting threo dihydroxy acids, whereas the use of benzene containing a small quantity of water gave mainly the corresponding higher melting erythro dihydroxy acids. It has been established that even traces of water brought about the inversion. An entirely new method of 1 : 2-glycol cleavage by the use of silver iodide dibenzoate has been established, and to the best knowledge of this laboratory, this constitutes the first record of 1 : 2-glycol cleavage by silver iodide dibenzoate; and constitutes one more elegant tool for the step-wise degradation of ethylenic compounds. Among the compounds that were tried out for this type of cleavage were:—

(a) 9 : 10-Dihydroxystearic acid yielding pelargonic aldehyde and azelaic semialdehyde.
(b) 13 : 14-Dihydroxy dehenic acid yielding pelargonic aldehyde and brassylic semialdehyde.
(c) 9 : 10 : 12-Trihydroxy stearic acid yielding β-hydroxy pelargonic aldehyde and azelaic semialdehyde.
(d) 6 : 7-Dihydroxy stearic acid yielding lauric alhehyde and adipic semialdehyde.
(e) Hydrobenzoin yielding benzaldehyde.
(f) α-Benzoyl glycerol yielding benzoyl glycolic aldehyde.

Degradation of the sequiterpene, longifolene, has been engaging our attention. Chromic acid oxidation in acetic acid medium has yielded, besides the known acid, and neutral fractions, a body of m.p. 131-132°, which gets thrown out when the sodium hydroxide extract of the oxidation product is saturated with carbondioxide. It yields a methyl ether of b.p. 144-146°/3 mm. and an ethyl ether of b.p. 152-155°/3mm. when treated in acetone solution in presence of anhydrous potassium carbonate with methyl iodide and ethyl iodide respectively. The methyl ether, although it distilled within a short boiling range, has started separating into a solid fraction and a liquid fraction on standing. Since this spontaneous separation of the methyl ether does not seem to be complete, further work on that is kept suspended.

The neutral fraction gave the known dione of m.p. 93-94° and a new product of m.p. 158-160° when the fraction distilling over at 200-230°/3 m.m. is fractionally crystallised from light petrol. The dione of m.p. 93-94° yields a dibasic acid of m.p. 225-227° on hydrogen peroxide oxidation in acetic acid medium at room temperature.

On the synthetic side in the terpene field, work is in progress to synthesize the bicyclic monoketone formed by the aldolisation of the primary oxidation product of patchouly alcohol. Camphor has been condensed with cyanacetic ester to yield the substituted ester with the double bond in the desired endo-cyclic position. The condensation of this with α-methyl-β-bromo-propionic ester is under investigation.

Work on vegetable drugs is also engaging our attention. Preliminary investigation has shown that *Cyclea burmani* yields a mixture of alkaloids that is amenable to fractionation. *Cryptolepis buchanami* has yielded a colourless, neutral product in fairly large amounts. The semi-solid residue from the petrol extract, on tituration with acetone, yields the solid product of low solubility in cold acetone. Extraction of bulk quantities of the drug is in progress.

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Department of Physical Chemistry

I. *Photo-initiated free radical polymerization of vinyl Compounds in aqueous solution:—*

In the early thirties Haber and Weiss (1932, 1934) concluded that in the reaction between hydrogen peroxide and ferrous or ferric iron OH radicals were formed. Baxendale, Evans and Park (1946) have shown that OH radicals produced in the Haber-Weiss reaction lead to the initiation of polymerization of vinyl compounds in aqueous solution. Rabinowitch and Stockmayer (1942) interpreted the spectra of ferric ion-pair complexes in aqueous solutions as electron-transfer spectra. Evans and Uri (1949) have shown that atoms and free radicals produced by irradiation of ion-pair complexes lead to the polymerization of vinyl compounds in aqueous solution. Evans, Santappa and Uri (1951) have reported on the polymerization work using acrylonitrile, methyl methacrylate and methacrylic acid as monomers and ion-pair complexes of the type $Fe^{3+}X^-$ ($X^- = OH^-$, Cl^-, N_3^-, etc.) as photo-initiators. Santappa (1954) has extended this work and complete details of kinetics with azide, chloride and OH radicals and vinyl monomers have been reported. Subramanyan and Santappa (1956) have made use of ion-pair complexes $FeHctr^+$, $FeC_2O_4^+$ from ferric citrate and oxalate, aqueous solutions as photo-initiators in the polymerization of methyl methacrylate, methyl acrylate and acrylonitrile. Chaitanyan and Santappa (1956) have carried out similar investigations with methyl acrylate as the monomer and $Fe^{3+}OH^-$, $Fe^{3+}Cl^-$ as the initiators.

Light absorption fraction and electron transfer:—It is assumed that the absorption process is connected with the change.

$$Fe^{3+}X^- \xrightarrow[k_s I]{h\nu} Fe^{2+}X$$

The energy difference between the complex $Fe^{3+}OH^-$ and the fully dissociated and hydrated state can be calculated from the thermodynamic data to be $\sim$ 40KCal. The light absorption maximum on the other hand corresponds to $\sim$ 90KCal. The difference is understandable on the basis of the Franck-Condon principle since no change in the internal nuclear distance will occur during the optical transition. This means that the internal nuclear distance and the configuration of the solvated shell in $Fe^{2+}OH$ will be the same as that in the ion-pair $Fe^{3+}OH^-$. The system will, therefore, be in a non-equilibrium configuration and the difference of $\sim$ 50KCal is to be attributed to the repulsion energy between the nuclei in these states. A dissociation of the complex $Fe^{2+}OH$ might, therefore, be expected. OH radicals thus produced lead to subsequent reactions such as the polymerization of vinyl compounds. The light absorption process and electron transfer process hold good for other complexes $Fe^{3+}Cl^-$, $Fe^{3+}N_3^-$, $Fe^{3+}Hctr^{2-}$ and $Fe^{3+}C_2O_4^{2-}$.

The reaction scheme : The following reaction scheme includes those reactions which are likely to occur:

(1) Light absorption process k_ε is the fraction of light absorbed by $Fe^{3+}X^-$)

$$Fe^{3+}X^- \xrightarrow{k_\varepsilon I} Fe^{2+}X$$

(2) Primary dark back reaction

$$Fe^{2+}X \xrightarrow{k_d} Fe^{3+}X^-$$

(3) Initiation of polymerization of monomer, M, by the primary product $Fe^{2+}X$

$$M + Fe^{2+}X \xrightarrow{k'_i} Fe^{2+} + X - M -$$

(4) Separation of the primary product

$$Fe^{2+}X \xrightarrow{k_s} Fe^{2+} + X$$

(5) Secondary dark back reaction

$$Fe^{2+} + X \xrightarrow{k_o} Fe^{3+} + X^-$$

(6) Free radical initiation of polymerization

$$X + M \xrightarrow{k_i} X - M -$$

(7) Proporgation of polymerization

$$X - (M)_n - + M \xrightarrow{k_p} X - (M)_{n+1} -$$

(8) Termination of polymerization

(a) by disproportionation or by free radicals :

$$X - (M)_p - + X \xrightarrow{k'_t} X - (M)_p - X$$

(b) by recombination of active endings

$$X - (M)_p - + - (M)_q - X \xrightarrow{k_t} X - (M)_{p+q} - X$$

A 250-W high pressure mercury vapour lamp (BTH) was used as a light source which was rendered parallel by a quartz condenser lens and the parallel beam passed through a series of filters for purpose of isolation of monochromatic wavelengths 313, 365, 405, 435 mμ etc. A quartz reaction cell 46 mm. long, 50 mm. diameter) containing the deaerated system vinyl monomer-ion-pair in aqueous solution was placed in a thermostat at 25 to 30°C and irradiated by the monochromatic beam for an hour or two till *ca.* 10 to 15% conversion of the monomer took place. The variations in rate of monomer disappearance, -dm/dt (by weight of the polymer); the rate of ferrous ion production dFe^{2+}/dt (colorimetrically by o-o' phenanthroline) and the chain lengths of the polymers, n, (viscometrically) were studied as a result of changes in (1) light absorption by the ion-pair, k_ε (by change of pH or ferric ion concentration) (2) light intensity, I (actinometrically), (3) monomer concentration (M), (4) quantum yield for ferrous ion production (γ) and (5) initially added ferrous iron and ferrous iron formed during the course of the reaction. Using stationary-state kinetics the reaction scheme would lead to

$$dFe^{2+}/dt = \frac{k_\varepsilon I}{k_d + k_s + k'_i M} \left\{ (k'_i (M) + \frac{k_s k_i (M)}{k_o (Fe^{2+}) + k_i (M)} \right\} \qquad (1)$$

Had the initiation of polymerization occurred mainly by the primary product $Fe^{2+}X$ it would have meant that the quantum yield would rise with the monomer concentration and could not reach a constant value below unity. This was not borne out by our experimental results. On the contrary the quantum yields reached constant values below unity and were practically independent of the monomer concentrations for all the complexes studied. It was therefore assumed that $k'_i(M) \ll k_s$ and, therefore,

$$dFe^{2+}/dt = \frac{k_s k_\varepsilon I}{k_d + k_s}\left\{\frac{k_i[M]}{k_o[Fe^{2+}] + k_i[M]}\right\} \quad (2)$$

$$\text{and } \gamma_{Fe^{2+}} = \frac{k_s}{k_d + k_s}\left\{\frac{k_i[M]}{k_o[Fe^{2+}] + k_i[M]}\right\}$$

The maximum quantum yield would be $k_s/(k_s + k_d)$ (3)

The fact that the maximum values for quantum yields were reached even in the absence of monomers indicated that radicals interacted with impurities in the distilled water under those conditions. This aspect of the impurities in the system has been fully discussed by Santappa (1954) separately. The applicability of equation (2) to the experimental results has been tested. (1) dFe^{2+}/dt V_s k_ε yielded linear function in all cases. (2) dFe^{2+}/dt against ferrous produced in the reaction or initially added was shown by plotting $1/dFe^{2+}/dt$ Vs Fe^{2+} when linear plots were obtained and from the slopes of the plots ko/ki values have been evaluated. Plots of dFe^{2+}/dt against (M) were more or less flats for reasons cited above with all complexes except $Fe^{3+}N_3^-$ in which case $1/\gamma$ was plotted against [1/M] and k_o/k_i was evaluated from the slopes. From intercepts of plots under (2), $k_s/k_d + k_s$ values evaluated confirmed the values of maximum quantum yields in all respects. (3) The influence of light intensity was seen by plotting $dFe^{2+}/dt \ \{1 + k_o[Fe^{2+}]/k_i[M]\}$ against I using k_o/k_i obtained under (2).

The scheme also leads to the following expressions for rate of monomer disappearance:

$$-dM/dt = (k_p/k_t^{1/2}) \ (k_s k_\varepsilon I/k_d + k_s)^{1/2} [M] \quad (4)$$

and for the chain-length of the polymers:

$$n = 2(k_p/k_t^{1/2}) \ (k_d + k_s/k_s k_\varepsilon I)^{1/2} [M] \quad (5)$$

For many of the initiators used linear function of $-dm/dt$ against (a) $I^{1/2}$ (b) $k_\varepsilon^{\ 1/2}$ and (c) [M] were obtained. Had the termination occurred by disproportionation or by free radicals stationary state kinetics would have led to the dependence of $[M]^{1/2}$ and independence of $I^{1/2}$ on $-dm/dt$. From plots under (a), (b) and (c) values of $k_p/k_t^{1/2}$ have been evaluated for all the monomers with all the initiators. From plots of (n) against (a) $I^{-1/2}$ (b) $k_\varepsilon^{-1/2}$ and (c) [M] also $k_p/k_t^{1/2}$ values have been evaluated. The work conclusively proved that initiation of polymerization was by the free radicals and termination was by combination.

II. *A spectrophotometric investigation of the complexes of ferric iron with oxalic and citric acids*:—

This investigation is connected with I above because a knowledge of the instability constants, molar extinction coefficients, conditions for the stability of the ion-pairs $Fe^{3+}Hctr^{2-}$ and $Fe^{3+}C_2O_4^{2-}$ is necessary before they are used as photo-initiators of polymerization. A systematic spectrophotometric investigation of these complexes in aqueous solution was, therefore, undertaken by Subramanyan and Santappa (1955, 1956). It was found that equimolar proportions of ferric iron and oxalic acids formed a complex with a characteristic maximum absorption at 290 mμ. From measurements of optical densities of 1 : 1 mixture at 290 mμ at pH = 1 and 0·7 it was found that the peak at 290 mμ became sharp with lowering of pH. The existence of a single complex was confirmed by measuring the optical densities of ferric nitrate + oxalic acid solutions in which their mole fractions varied from 0·2 to 0·8 at a total molar concentration of 10^{-3}M. The difference between the observed extinction and that calculated on the basis of no reaction between the components was plotted against $[Fe^{3+}]/[Fe^{3+}] + [ox]$. The sharp maxima at the ratio 0·5 over the whole wavelength range studied (280 — 400 mμ) showed conclusively that the only complex formed under these condition was that in which ferric ion and oxalic acid combined in equimolar ratios:—

$$Fe^{3+} + H_2C_2O_4 \underset{}{\overset{K_1}{\rightleftharpoons}} Fe^{3+}(H_xC_2O_4)^- + (2-x)\,H^+ \quad (6)$$

whence

$$\log K_1 - \log \frac{(FeH_xC_2O_4)^{(1+x)+}}{[Fe^{3+}]\,[ox]} = (2-x)\ \log H^+$$

The value of x and, therefore, the ionic state of the complex was obtained from the slope of the plot

$$\log \{ [FeH_xC_2O_4]^{(1+x)+}/[Fe^{3+}] [ox] \}$$

against $-\log H^+$. The slope obtained was 2 and therefore the formula of the complex was $Fe^{3+}C_2O_4^{2-}$. The product $[FeH_xC_2O_4]^{(1+x)+}/[Fe^{3+}] [ox]$ was evaluated by using ferric thiocynate coloured complex as an indicator for ferric ions at equilibrium and measuring the optical density 1 : 1 M Fe^{3+} : oxalic acid at pH $= 0{\cdot}7$ and ionic strength (μ), 0·5 at 525 mμ at which all the species except $FeSCN^{++}$ have negligible absorption. Then K_1 at pH $= 0{\cdot}7$ and $\mu = 0{\cdot}2$ was evaluated as $5{\cdot}182 \times 10^2$. From the total absorption at each wavelength and with known $(FeC_2O_4)^+$ it was possible to evaluate the extinctions due to the complex and construct ε V_s λ curve for $\lambda = 2600$ to 4200 Å. Similar investigations were carried out in case of complex formation between ferric ions and citric acid. The formula of the complex established was $Fe^{3+}HCtr^+$ and the equilibrium constant k_2 for for the formation of the complex at pH $= 0{\cdot}7$ and $\mu = 0{\cdot}2$ was 2·16

$$Fe^{3+} + H_3Ctr \xrightarrow{K_2} Fe^{3+}HCtr^{2-} + 2H^+$$

and the extinction curve between $\lambda = 3200$ to 4200 Å was also drawn. The spectrophotometric study of ferric oxalate and citrate association complexes was necessary to calculate k_ε, the fraction of light absorbed by the complex required for our studies on vinyl polymerization with these association complexes as photo initiators.

III. *Chain transfer reactions and the nature of initiation in the polymerization of styrene* :—

Santappa and Vaidyanathan (1955) have studied transfer reactions between polystyrene radicals and solvents like acetic acid, propionic acid, n-butanol, iso-butanol, tertiary butanol, diethyl ketone, etc. all at 60 and 70°C under uncatalysed as well as catalysed (benzoyl peroxide) conditions. By a study of variation of the reciprocal degree polymerization against the ratio solvent : monomer or (S/M) it was possible according to the equation

$$1/P_n = 1/P_o + C_s [S/M] \qquad (7)$$

to evaluate the transfer rate coefficient C_s which is k_{fs}/k_p, k_{fs} and k_p representing the specific rate constants for transfer of polystyrene radical with the solvent and for propogation respectively. During the course of these investigations certain interesting observations not reported so far were made. The overall rate often decreased more rapidly with increasing [S/M] than that accounted for by the normal decrease of monomer concentrations. The existence of a critical ratio [S/M] for each solvent beyond which polymerization was retarded and sometimes completely inhibited was noticed. The slackness of secondary initiation by solvent radicals was concluded.

Another interesting aspect that was investigated was to determine the mode of initiation of polymerization by the catalyst. Conflicting opinions were expressed on the subject—some contending the formation of a complex between the monomer and catalyst and others opined that the initiation step was a unimolecular or bimolecular reaction between the catalyst and the monomer. If it is an unimolecular initiation one needs to keep the ratio $[Catalyst]^{1/2}/[Monomer]$ or $[Cat^{1/2}/M]$ constant in a study of variation of $1/P_n$ against [S/M]. For a bimolecular initiation it is $[Cat/M]^{1/2}$ that should be kept constant. It is now well recognized that the initiation process is quite different from the foregoing views and it is given by $2k_{df}$ [cat), k_d is the specific rate constant for spontaneous decomposition of the catalyst, having a catalyst efficiency, f, which is the ratio, $k_a[M]/k_a[M] + k_b \cdot k_a$ and k_b are the rate constants for the reaction of primary radicals with the monomer and with themselves respectively and the expression for P_n would be

$$1/P_n = k_t^{1/2} (k_{df})^{1/2} [Cat]^{1/2}/k_p[M] + C_s[S/M] \qquad (8)$$

If $k_a[M] \gg k_b$, f is unity and, therefore $[Cat^{1/2}/M]$ needs to be kept constant; on the other hand if $k_b \ll k_a[M]$, $[Cat/M]^{1/2}$ must be kept constant in a study of $1/P_n$ Vs [S/M]. In other words it is possible to evaluate the relative importance of the primary radicals from the catalyst for initiation or recombination between themselves. In a study of polymerization of styrene in toluene at 80—100°C by several catalysts, it was found that initiation reaction of primary radicals was important for the catalysts benzoyl peroxide, methyl ethyl ketone peroxide and tertiary butyl hydroperoxide while the initiation and recombination reactions had comparable rates with ditertiary butyl peroxide as the catalyst.

IV. *Rates of Initiation and Chain Transfer Constants in the Polymerization of Methyl acrylate*:—

The liquid phase polymerization of methyl acrylate is of considerable interest in view of the fact that considerable differences were observed between the gas phase polymerization of this monomer and other acrylic monomers. The general nature of polymerization of methyl acrylate in bulk under a variety of conditions, evaluation of rates of initiation, the chain transfer constants for reactions between the growing polymer chain and monomer, catalyst, etc., have been studied by Mahadevan and Santappa (1955). An accurate study of bulk polymerization of methyl acrylate was rendered difficult by the setting in at the very early stages of polymerization, the phase of auto-acceleration which could, however, be considerably reduced by using a diluent like ethyl acetate and confining polymerizations to low conversions of c. ten per cent, 50 as well as 20 per cent of methyl acrylate (5.5 and 2.2 molar) in ethyl acetate were employed. With benozyl peroxide as a catalyst at 60°C it was found that the overall rate constant, $R_p/[Cat^{1/2} M]$ decreased nearly four fold when [M] decreased from 8.8 to 2.2 molar. By using 5.5 molar monomer in ethyl acetate and for conversions 1 to 10 per cent little variation in overall rate constant was observed and with 2.2 molar monomer, the variation was minimum which indicated that the phase of auto-acceleration was kept to the minimum. Catalysts, benzoyl peroxide, tertiary butylhydroperoxide, ditertiary butyl peroxide and methyl ethyl ketone peroxide have been used at temperatures 65-75°C. At sufficiently high concentrations of the catalysts, the catalysed polymerization was very much faster than pure thermal polymerizations so that the equation for the overall rate

$$R = k_p (k_d f \text{ cat})^{1/2}[M]/k_t^{1/2} = K[M][Cat]^{1/2} \tag{9}$$

was generally obeyed. In all cases a regular variation of overall rates with $[\text{catalyst}]^{1/2}$ were observed. The intercepts of these plots indicated the extent of thermal rate plus rate due to auto-acceleration. The intercepts which were 10 to 15 per cent of the total overall rates with 5.5 molar monomer disappeared with 2.2 molar monomer. From the slopes of R Vs$[Cat]^{1/2}$ plots the K values have been evaluated.

The relationship between degree of polymerization (P_n) and overall rate, R, in the absence of a chain transferring solvent is best represented by the equations:

$$1/P_n = (k_t R/k_p^2[M]^2) + k_{fm}/k_p + (k_{fc}[Cat]/k_p[M]) \tag{10}$$

$$= (AR/[M]^2) + C_M + (C_{cat}[Cat]/[M]) \tag{11}$$

[Cat/M] will be equivalent to R^2/K^2M^3. With very high concentrations of the catalysts or at high overall rates with low concentrations of the catalysts a curvature in the plots $1/P_n$ Vs. R was noticed. This was evidently due to pronounced transfer of the growing radical with the catalyst. At low catalyst concentrations and conversions transfer with catalyst was relatively so unimportant that a fairly good determination of A might be obtained. The plots were straight at values of catalysed rates far exceeding thermal rates that the determination of A was considered fairly accurate. The accuracy of these values, however, depended on the relationships between degrees of polymerization and intrinsic viscosities of polymer solutions and on the limitations imposed upon evaluation from the graphs with lot of scattered points. With known values of K and A rates of initiation (R) were evaluated,

$$2K^2A = 2k_d f(1+x) = R_i(1+x)/[Cat] = R_i'/[Cat] \tag{12}$$

Plots of $(1/P_n) - AR$ Vs R^2/K^2M^3 or

plots of $(1/P_n - AR)$ Vs [Cat/M]

With all the catalysts were all linera and C_{cat} and C_m were evaluated from the slopes and intercepts of these plots. A comparison of the values of rates of initiation at 70°C. indicated that benzoyl peroxide, methyl ethyl ketone peroxide and tertiary butyl hydroperoxide were of the same order of reactivity, R_i being equal to 5×10^{-5} sec^{-1}. Ditertiary butyl peroxide appeared, however, to be nearly fifteen times weaker than benzoyl peroxide for initiation. With regard to C_{cat} values all the catalysts except ditertiary butyl peroxide indicated the same order of reacivity ($\sim 10^{-2}$). The C_m values ($\sim 10^{-5}$ to $\sim 10^{-6}$) were of expected orders. Activation energies for R_i' C_{cat} and C_M were evaluated. With known k_d values for the catalyst it was possible to evaluate the catalyst efficiencies. In all cases it was nearly unity. The independence of catalyst efficiency on temperature was also realized.

V. Methyl ethyl ketone peroxide as an initiator in vinyl polymerization:—

Methyl ethyl ketone peroxide (MEKP) has not been extensively employed as an initiator in vinyl polymerizations. Gopalan and Santappa (1956) have carried out a systematic investigation of kinetics of polymerization of methyl methacrylate and styrene in bulk as well as solution with MEKP as an initiator at 65-80°C. The solvents used for the purpose were benzene, toluene, methyl, ethyl ketone and ethyl acetate. Per cent conversion against time curves both in bulk and in solution passed through the origin indicating the absence of period induction and suitability of the catalyst for further studies of polymerization. Employing a hundred fold variation of concentration of MEKP the order of reaction with respect to the catalyst was studied. Plots of Rates vs. $[Cat]^{1/2}$ were all linera both in bulk and in solution. From the slopes of these plots K values (equation 9) have been evaluated. From studies of 1/Pn. vs. Rates both in bulk and solution it was possible to evaluate A values (equation 11) also. The values of activation energies for K as well as A have also been evaluated. As described under Section IV, the C_{cat}, C_m and R'_i values for styrene and methyl methacrylate bulk polymerization with MEKP have also been evaluated. Evaluation of these constants in solution was also possible. The A values obtained by plotting 1/Pn. vs. R/M^2 in solution at different monomer concentrations was used to plot $(1/Pn) - (AR/M^2)$ against (S/M) at constant [Cat/M]. From the slope and intercept of the linear plots were evaluated transfer coefficients for the solvent, C_s and C_M respectively. For the R'_i values in solution polymerization for these monomers have also been evaluated. The order of the reaction, overall rate, with respect to monomer concentration was evaluated as 1·5 by plots of log R vs. log M in bulk as well as in solution. It could, therefore, be described that the reaction was of the first order with respect to monomer concentration and the other one half might be explained as the catalyst efficiency 'f' being dependent on monomer concentration. The decomposition of MEKP was also studied in ethyl acetate. It was found to have a spontaneous decomposition independent of the type of the solvent as well as an induced decomposition in the presence of the solvents.

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Department of Geology and Geophysics

The Department of Geology and Geophysics started with the appointment of a Reader in May 1952. The Reader appointed is Dr. P. R. Jagapathy Naidu, Ph.D. (Basel), who had worked previously for twenty years in the University of Mysore and is aged 53.

A hall and a room had been allotted to the Department in the Alagappa Chettiar College of Technology Buildings. During the first year these were fitted with electric, water and gas supply. Indents placed for furniture, optical and chemical equipment were being executed during the second year. A Research Assistant, Sri S. Ramanathan, M.A., was appointed in September 1953, and also a few students were admitted for research. With a partial equipment available in the Department at the beginning of 1954, research commenced and with the addition of apparatus in subsequent years, the Department was well-set for optical and chemical investigation of rocks, minerals, and ores. Thirty-four research papers have been published during the last two years (Ref. Appendix). The general scheme of research, as is current in the Western countries and in India, has been followed. An area in the Madras State was selected for detailed mapping of rock formations and structures. Various representatives of the rock formations are collected, these are brought to the laboratory and modern optical chemical techniques are applied to a study of these specimens.

According to the second Five Year Plan, submitted to the University, five districts were chosen in the Madras State for detailed mapping. These are Chingleput, Salem, Coimbatore, North Arcot, and Tirunelveli districts. Areas, roughly each of 200 sq. miles, were assigned to students for careful mapping and the specimens collected from them have been investigated on modern techniques of research. The results are embodied in five theses submitted for the M.Sc. and Ph.D. Degrees of the University, and in the thirty-four papers published from this Department. The results are summarised below.

Babu, has published six papers and has submitted a thesis for the Ph.D. Degree of the Madras University. In the paper entitled 'Migmatisation in Kattriguppe Quarry, Bangalore district, Mysore State' (J. Madras Univ., B, XXV, No. 2 129-146, 1955), he has given a map of the Kattriguppe Quarry and has reported analyses of rock specimens. He has applied the technique of Doris L. Reynolds (Mrs. Holmes) to the chemical transformation of the rock types. By observing the geochemical changes involved, he has established the culmination and depression of cafemic and minor constituents, and has shown that the trend of differentiation in this area has been from amphibolite to quartz-diorite. He holds that the effect of the geochemical changes has been to produce rocks of normal igneous series by the process of mechanical pulverisation and reciprocal reaction.

In the paper entitled 'A Calciferous Amphibole from a Xenolith in Granite' (J. Madras Univ., B, XXIV, No. 3, 307-313, 1954) he has reported the analysis of a hornblende from an amphibolite, occurring as a xenolith in granite of Kattriguppe, Bangalore district, and its optical characters. The Niggli values of the analysed mineral lie within the range of values given for common hornblendes. W,X,Y, and Z values of the analysed mineral are compared with Berman's classification of common hornblendes. These values of the analysed mineral lie between those of hornblende-edenite and Hastingsite. The values of (Na, k), Al, Fe^{111}, and ca are plotted on the miscibility diagram of Sundius. The plotted point lies midway between Pargasite and Edenite indicating that the amphibole is composed of the molecules of Pargasite and Edenite.

In the paper entitled 'Anorthite Content and the Twin-Laws of the Plagioclase Feldspars of Some Granites and Gneisses from the Mysore State' (Quartly. Jl. of G.M.M. Society of India, Vol. XXVII, No. 1, March 1955) he gives the anorthite content and twin-laws of the plagioclase feldspars of granites and gneisses collected from the southern parts of the Mysore state. Köhler values were determined for the Mysore feldspars. These are generally in agreement with low temperature values of Köhler. Cumulative diagrams are given for the anorthite content and for various complex and parallel laws observed in the series.

The Pericline twins occur as fine lamellae across the albite twins. The grains, therefore, show combined albite pericline twins. The maximum incidence is of albite and percline laws, and the least of the carlsbad and albite-carlsbad (2) albite-ala law is fairly abundant (49). Albite-ala is as much characteristic of granites and gneisses as the albite and pericline laws. The albite-ala law is more evident in the granites (29) than in the gneisses (14).

In the paper entitled "The Heavy Accessories of Chamundi Granites and Gneisses," Mysore, Mysore State (J. Madras Univ., B, XXV, No. 3, 291-300, 1955) he deals with the heavy accessories of 'Chamundi Granites and Gneisses', their distribution and variation. The frequencies are estimated and represented after Evans, Hayman, Majeed (1934), and also after the manner of Stark and Barnes (1935). An attempt has been made to correlate these rocks with granites and gneisses of Cuddapah. From the study and comparison of the heavy accessories of these two suites of rocks we find, that while the Cuddapah granites are essentially hornblende granites and are trondhjemitic in character (Naidu, 1954), the Chamundi granites are chiefly mica-granites. Though most of the other heavy minerals are common between the two areas, garnet is absent in the Cuddapahs. The association of biotite-garnet places the Chamundi granites at a higher grade of metamorphism than the Cuddapah granites.

In the paper entitled 'Tectonic and structural Study of Chamundi Granites and Gneissic Environs, Mysore' (J. Madras Univ., B, XXVI, No. 1, 31-50, 1956) he deals with the tectonic and structural study of the Chamundi granites and their gneissic environs. A map embodying structural features such as mineral orientation, foliation planes and joints is prepared along lines enunciated by Hans Cloos (described by Balk, 1937). The field relations of the different rock types found in the area are summarized. Mega-fabric as well as petrofabric diagrams have been prepared. Since it is seen from the fabric study, that there is preferred orientation in all the diagrams of granites, gneisses and migmatites the rocks are regarded as tectonites.

Balasubrahmanyan, has published three papers and has submitted a thesis for the M.Sc. Degree on the Sankaridrug and associated rocks.

In the paper entitled 'The Association and Genesis of Wollastonite and Scapolite-bearing Rocks of Sankaridrug, Salem District' (J. Madras Univ., B, XXV, No. 2, 153-185, 1955) he has studied the wollastonite and scapolite-bearing rocks of Sankaridrug, the contact metamorphic assemblages developed in calc-bands and discussed in the light of Eskola's facies. The geological and tectonic relationship of the anorthite-gneiss of Sittampundi to the calc-gneiss of Sankaridrug is suggested.

In the paper entitled 'Some Minerals from the Calc-Bands of Sankaridrug, Salem District' (J. Madras Univ., B, XXV, No. 3, 263-270) he deals with the chemistry of the minerals occurring in the main calc-band passing through Iveli, near Sankaridrug. The study includes the analyses of a pyroxene, a wollastonite and an amphibole.

In the paper entitled 'Tectonics of the Granites, Gneisses, and Migmatities of Sankaridrug' (J. Madras Univ., B, XXV, No. 3, 255-61, 1955) he has made a structural study of the Sankaridrug massifs, based on the field-technique originated by Hans Cloos.

The microfabric of the country rock and a migmatite is reported and it is held that the petrofabric diagrams are those of schistose and quartz-rich rocks.

Leelananda Rao has published six papers and submitted a thesis for the Ph.D. Degree on the 'Charnockite Series of the Type Area of Sir Thomas Holland'.

In the paper entitled 'Twins, Parallel Growths, Parting and Extinction Angles in Pyroxenes of Charnockites from the Type Area of Sir Thomas Holland' (J. Madras Univ., B, XXIV, No. 1, 53-60, 1954) he finds that optic axial plane is invariably parallel to the lamellae in orthopyroxenes and perpendicular to the lamellae in clinopyroxenes. The lamellae are parallel to (100) in both. Growths of the two pyroxenes parallel to (100) are also present. The so-called Herring-bone twins are really the result of the accidental growing together of two individuals. The composition face is irrational. The inclined extinction angles in orthopyroxenes are normal extinction angles theoretically possible in orthorhombic crystals.

In the paper entitled 'The Geology and Petrology of Pachaimalai' (J. Madras Univ., B, XXV, No. 1, 55-81, 1955) he has noted that the khondalitic suite of rocks are typically represented in Pachaimalai. Based on petro-chemical studies it is concluded that the parent rocks of the khondalite series are arkosic or micaceous-sandstones partly very rich in quartz. Hedenbergite-garnet-magnetite rock, occurring intimately associated with the khondalites, shows close similarity to the related rock types of Eulysites of Loch Duich, Rosshire described by Tilley (1936). Charnockites and

Enderbitic charnockites show intrusive relationship to the khondalites. Field characters suggest that garnetiferous granulite (Leptynite) is a reconstituted phase of khondalites. Dyke rocks show some interesting evidences of assimilation.

In the paper entitled 'Dyke Rocks of Pallavaram' (J. Madras Univ., B, XXIV, No. 2, 213-23, 1954), he finds that dolerite dykes intermediate in character between pyroxenites and augite-diorite dykes occur in Pallavaram. The average anorthite content of the plagioclase feldspars of the dykes is Ab_{45} An_{55} and all the types of twin-laws, normal, parallel and complex are displayed by them. Pyroxenes occur as both twinned and untwinned grains. The phenocryst pyroxenes show variation in 2V from $+ 50°$ to $+ 40°$ and the ground mass pyroxenes from $+40°$ to $+25°$. There is no break in the values of 2V from $+32°$ to $+40°$ as suggested by Hess (1941). The dolerite dykes of Pallavaram closely resemble the Cuddapah dykes in essential mineralogical and petrological characters.

In the paper entitled 'Further Studies on Dyke Rocks of Pallavaram' (J. Madras Univ., B, XXV, No. 3, 323-39, 1955) he describes the structural, petrographical and petrochemical characteristics of the dykes of Pallavaram. Following the petrographical methods of Niggli, the author is driven to the conclusion that these dykes belong to pacific suite and their parent magma is Eucrite. As the dykes show interaction along the contact zones, the possibility of contamination of magma in giving rise to tholeitic types is not altogether ruled out.

In the paper entitled 'Charnockites and Associated Rock Types of the type Area of Sir Thomas Holland: Part I' (J. Madras Univ., B, XXVI, 93-115, 1956) he presents a detailed map of the 'Charnockite series' of the type area of Sir Thomas Holland. The structural elements have been evaluated and the mutual field relationships of the rock types indicated. The area consists of Psammitic, pelitic, semi-pelitic, calcareous and igneous members which had attained earlier the sillimanite grade of metamorphism. These metamorphosed rocks have been later subjected to a regressive metamorphism by the intrusion of the Charnockites ('acid member of the Charnockite series' of Sir Thomas Holland).

Naganna, C., (J. Madras Univ., B, XXVI, No. 1, 1-9, 1956) reports that dyke rocks of composition of noritic olivine dolerites and olivine dolerites occur around Davangere, Mysore state. The plagioclases of these rocks are all twinned and the anorthite content in them ranges from 58 to 72 per cent. All types of twin-laws, normal, parallel, complex and interpenetration, are noticed. Of the mafic minerals olivine and both ortho- and clino-pyroxenes are found. Two specimens of these rocks, texturally different are chemically analysed and their petrochemistry discussed. The magma which has given rise to these two types is found to fit into 'Gabbroide magmen' of Niggli's magma types and lies in between 'eu-kritisch' and the next 'c-gabbroid' types, the difference in colour and texture in these rocks is found to be due to the different cooling history of these rocks. These rocks bear a close resemblance to the dyke rocks of Dodkanya (Mysore State) which have an ultrabasic and charnockitic geological setting.

Naidu, Reader of the Department has published four papers.

In Current Science, May 1955, No. 24, pages 154-155, he has outlined two methods of measurement of extinction angles in hornblendes which show strong absorption. In the first method he gives a stereographic procedure of locating the optic axial plane and therefrom the extinction angle. In the second method, he applies the Biot-Fresnel law.

In Current Science, Feb. 1955, No. 24, pages 47-48, he reports interference figures in reflected polarized light of rock forming minerals, and suggests that the interference figures are due to scattering of light in some cases and penetration into the media in other cases.

In Current Science, December 1954, No. 23, pages 387-389, he reports various types of twins in the cordierites from the burnt rocks of Jharia and Raniganj coal fields, and also the optical and chemical characters of the cordierites. He regards the complex patterns of twins as functions of temperature.

In the *Indian Mining Journal,* Vol. 2, No. 1, pages 12-17, January 1954, he gives the first of a series of studies on the granites of Southern India. In this, the first series, he describes granites occurring between Gulburga in the Hyderabad State, and Tiruttani in the Madras State, along a distance of 600 miles. The chemical characters of the rocks, and the optical characters of the minerals contained in them are given. The granites vary from Trondhjamites to granodiorites, through leucogranites, granites and quartz diorites.

Nehru,' has published four papers and has submitted a thesis for the M.Sc. Degree on 'The Tiruchengode Granites and Its Relationship to the Sittampundi Anorthosite'.

In the paper entitled 'Tectonics of the Granites and Gneisses of Tiruchengode' (J. Madras Univ., B, XXV, No. 3, 227-233, 1955) from a study of the poles of joints in stereographic projection he concludes that the Tiruchengode granite intruded as a dome. The petrofabric diagram of the C-axes of the quartzes of the granite and migmatite of this area correspond to Ia and IVi of the schematic diagrams of quartz axes as given by Fairbairn (1954). The conclusion is reached that the granites and migmatites have been once quartzites, which have been subjected to rheomorphism.

In the paper entitled 'A Pyroxene from Sittampundi, Salem Dt.' (J. Madras Univ., B, XXV, No. 2, 167-172, 1955) he has analysed a clino-pyroxene from Sittampundi and has determined its optical characters. Its characters are compared with the pyroxenes of Adirondack Anorthosite Series and he holds that the pyroxene crystallized from a magma rich in aluminium and calcium.

In the paper entitled 'Geology and Petrochemistry of the Anorthite-Gneiss and Associated Rocks of Sittampundi, Salem Dist.' (J. Madras Univ., B, XXV, No. 2, 173-188, 1955) he has given analyses of the anorthite-gneiss and the associated rocks of Sittampundi (Salem Dist.), and has compared them to similar rocks occurring in calc-bands of Sankaridrug. These two bands together form an anticline warped up by the intrusion of the granites of the area. The origin of the Anorthite gneiss is considered not similar to those of Anorthosites occurring elsewhere. The view is put forward that the Anorthosite complex of Sittampundi represents a metamorphic facies of the Eclogite, and pyroxene-hornfels (sub-facies—spinel-Diopside-Anorthite—Grossularite sub-facies) grades. Original impure calcareous (non-magnesian) sediments and pyroxenite peridotite intrusions are the units metamorphosed.

In the paper entitled 'Two Amphiboles from the Anorthite and Biotite Gneisses of Sittampundi, Salem Dist.' (J. Madras Univ., B, XXV, No. 1, 19-28, 1955) he gives the analyses of an amphibole from Anorthite gneiss and another from an adjoining Biotite-gneiss and has determined their optical characters. Their chemical and optical relationships to other analysed amphiboles are discussed, and the amphiboles are calciferous aluminous amphiboles. The nomenclature of calciferous amphiboles is reviewed.

Raghavan, has published three papers on the Jalarpet granite. In the first paper 'Heavy Mineral Suites in the Granite Rocks of Jalarpet' (J. Madras Univ., B, XXV, No. 2, pages 147-152, 1955) he records the heavy mineral residue of the granitic rocks of Jalarpet. The index figure of the heavy residue has been determined. It has been observed that the minerals are distributed uniformly with no striking change in colour or form. Apatite, sphene and epidote, however, are more abundant in the hornblende-bearing granite than in the Biotite-bearing types.

In the second paper 'Plagioclase Feldspars of Granites, Gneisses and Associated Rocks of Jalarpet' (J. Madras Univ., B. XXIV, No. 3, pages 341-346, 1954) he deals with the anorthite content and twin-laws of the plagioclase feldspars of granites and gneisses, collected from the Yelagari Hills, near Jalarpet Railway Station. From Tertsch's stereograms, the feldspars of the Jalarpet series, are inferred to belong to the low temperature series. Cumulative diagrams are given for the anorthite content and various twin laws, observed in the series.

The Pericline twin occurs as fine lamellae across the albite twins—the grains show the combined albite-pericline twins. Albite-ala and albite law are of the largest incidence (53) and (52) respectively. Manebach-ala and Manebach-akline are the least (3). Albite-ala is more evident in granites (54% of the total) than in gneisses (34% of the total).

In the third paper 'Bluish-green Hornblende from an Amphibolite of Jalarpet' (J. Madras Univ., B, XXIV, No. 2, pages 245-250, 1954) he reports that a hornblende was separated from an amphibolite in Bromoform and various dilutions of Clerici's solution. Its chemical composition and optical characters were determined. Therefrom it is concluded that it corresponds to amphiboles occurring in gabbros.

Ramanathan, the Research Assistant of the Department, has published six papers, and has submitted a thesis for the Ph.D. Degree 'On the Ultrabasic Rocks of Salem and Dodkanya and Their Relationship to the Charnockites Series.'

In the paper entitled 'Plagioclase Feldspars from Charnockites of Salem' (J. Madras Univ., B, XXIV, No. 2, pages 225-236, 1954) he has determined the twin-laws of the plagioclase feldspars of the Charnockites of Salem. The more abundant twin laws are compared in a histogram. The abundance of albite and Pericline twin-laws and

the greater representation of untwinned grains are factors in favour of assigning a metamorphic character to these charnockites (cf. Turner and Gorai). A check on the laws is afforded by Nikitin's and Berek's constructions and also by calculating Köhler and Tertsch values, which correspond mostly to the low temperature values of the Austrian authors. Cumulative diagrams of all the poles of association planes and of the poles of twinning planes of complex twins are presented, the former shows a large dispersion.

In the paper entitled 'Shonkinites from the Ultrabasic Areas of Salem' (J. Madras Univ., B, XXV, No. 3, pages 315-333, 1954), he reports the occurrence of potassic rocks, Shonkinites rather rare rock types in the world from the ultrabasic areas of Salem. Their chemical analyses and optical characters are reported. The petrogenesis of the rocks is discussed.

In the paper entitled 'Vogesites and Noritic Olivine Dolerites from Salem and Dodkanya' (J. Madras Univ., B, XXV, No. 1, pages 29-54, 1955) he has studied five dyke rocks, two from Salem and the rest from Dodkanya, Mysore. He has analysed the rocks and determined the optical characters of their minerals.

The dykes of Salem (Vogesites) seem to be related to a Shonkinitic magma while those of Mysore (Noritic olivine dolerites) are related to a gabbroid magma.

In the paper entitled 'On the Hypersthene-bearing Rocks of Salem—Part I' (J. Madras Univ., B, XXVI, No. 1, pages 117-159, 1956) he gives a geological map of the ultrabasics and hypersthene-bearing rocks of Salem and a brief account of the texture, mineralogy, and chemistry of the hypersthene-bearing rocks. The hypersthene-bearing rocks are found to be of more than one age. The petrogenesis of these rock types is indicated.

Researches on the geology of Chingleput District the Charnockites and basalts of Vellore, metamorphism in Gangavarpet (Madurai Dist.), the geology of Western Ghats near Nagercoil, the granitic rocks between Madras and Palghat and basalts of Chindawara and Gulburga are under progress.

APPENDIX

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Department of Mathematics

The history of this department, in a sense, also marks the history of a new era of mathematical study and research in our country. While vast new fields were being opened up and a better and deeper understanding of the older fields of the subject gained by such investigations in Europe during the last hundred years, it is only in the last two or three decades that a just appreciation of these new trends and methods came to be among mathematicians in our country. And in this process of expanding the horizons of Indian mathematics this department of Mathematics under the able and far-sighted guidance of Dr. R. Vaidanathaswamy has played a considerable role.

After doing distinguished work in geometry and theories of algebraic forms during his stay at Edinburgh and London, R. Vaidyanathaswamy returned with a Ph.D. from London and a D.Sc. from Edinburgh to occupy the post of Reader and Head of the newly formed department of Mathematics from 1927. But in the course of his twenty five years of service in the University Dr. Vaidyanthaswamy continuously extended his domain of interest and initiated a whole generation of students to the intricacies and beauties of many branches of mathematics. Subjects of current research in the West, like modern algebra, set-theory, theory of partial order, symbolic logic, and topology were introduced perhaps for the first time in any Indian University by Dr. Vaidyanathaswamy. Quite a few of the younger mathematicians of promise who have started their research career under the guidance of Dr. Vaidyanathaswamy will remember his enthusiasm and energy for the development of mathematics in our country. To him this department owes a considerable debt of gratitude for having raised it to a centre of active research and study in many fundamental branches of Mathematics.

It is, therefore, only fitting that in this year of the Centenary of the University, the University should be bringing out a volume of 'collected papers' published by Professor Vaidyanathaswamy.

The first three years Dr. Vaidyanathaswamy was engaged in preparing and publishing various papers on algebraic geometry and algebra, continuing his work in Scotland. The first ten or eleven papers (of those listed under his name in the bibliography attached) were prepared during this period. From 1930 the Department was made permanent and Dr. Vaidyanathswamy confirmed as Reader. Among the earliest students in the department were Messrs. Audinarayanan, Nagabushnam and Krishnamurthy Rao. From even 1932 onwards Dr. Vaidyanathaswamy began arranging courses of lectures on various modern topics for the benefit of the research students.

S. S. Pillai, another great number theorist got the first D.Sc., degree from this University. Following him, B. Ramamurthy got his D.Sc., with a thesis on the 'Binary geometry of the rational norm curve.' V. Ganapathy Iyer got his D.Sc., with a thesis on 'Properties of integral functions with bounded values at a prescribed sequence of points'; A. Narasinga Rao with his thesis on 'Circle geometry' and S. Meenakshisundaram with a thesis on 'Fourier Ansatz and non-linear parabolic equations' followed, and P. Kesava Menon was the last to get his D.Sc. from this University with a thesis on 'Contributions to the Theory of Numbers.'

So geometry and function theory were the first fields of interest in the Department. Modern algebra came after this. Mr. T. Venkatarayudu, Miss. S. Pankajam, worked on groups and Boolean algebra for their M.Sc.; logic was also studied by Miss Pankajam and Mr. K. Chandrasekharan. In course of lectures during the years 1940 to 1945 Dr. Vaidyanathaswamy dealt with various current topics like symbolic logic, algebra of partial order, topology, set theory and so on. The work of the students of this time reflect these interests. K. Chandrasekharan with his work on Bessel summability, V. S. Krishnan with work on partially ordered sets and congruences for these, M. V. Subba Rao with studies of linear operators on function spaces and K. G. Ramanathan with his studies on finite Abelian groups got their M.Sc. degree then.

Ph.D. degrees were awarded by the University on the basis of theses to Mr. K. Chandrasekharan, Miss Suseela, Miss Padma, Mr. V. K. Balachandran, and Mr. M. V. Subba Rao. Messrs. V. S. Krishnan and K. G. Ramanathan took their doctorate degrees from external Universities (from Paris and Princeton respectively). Messrs. K. Chandrasekharan and S. Meenakshisundaram also went to the Princeton Institute for advanced study for post doctoral work.

Based on many courses of lectures that he had delivered in the Department, Dr. Vaidyanathaswamy published in 1947 his treatise on set topology, wherein a special fature was the extensive use of lattice properties in topology, and a large collection of examples.

Geometry came back with Miss Suseela's work on Non-Desarguesian geometry and Miss Padma's work on Tensors and region complexes. Lattice theory was continued in the work of Mr. V. K. Balachandran, and linear spaces were studied by Messrs. M. V. Subba Rao and S. Sankaran. The former finished his Ph.D. thesis and submitted it to our University, while the latter went to complete his studies in Columbia University. Miss Padmavally did considerable work in set theory, in the study of cardinals, ordinals etc. C. S. Venkataraman followed Dr. P. Kesava Menon in the study of multiplicative functions and took a Ph.D., for this work.

From 1949 Dr. Vaidyanathaswamy was promoted Professor, and a lecturer, Dr. M. Venkataraman was also appointed. This helped to launch a new M.Sc. course of one year for post Honours candidates. Lectures were also kindly undertaken by the Professors of some of the neighbouring colleges. This M.Sc. course was organised in such a way as to make it easier for students coming from their Honours to gain the necessary extra background in modern branches of Mathematics to take up a research career. The first syllabus includes topology, function spaces, probability and quantum mechanics, the second comprises modern algebra, topology, group representations and quantum mechanics and the third treats of groups, lattices, rings, fields, set-topology and representation theory for various combinations of these basic structures. Syllabus 1 was used for three years, syllabus 2 for one year and the third syllabus has been used for the last four years.

The M.Sc. course has given many of the aspiring research workers a necessary background in basic branches of the subject, and has also provided the Department a ready source of trained students for research. The scholarships provided by the University, and more recently also by the Government of India have given the opportunity for research students to complete their studies effectively; for some to prepare their doctoral thesis for others to complete post-doctoral studies.

After the retirement of Professor Vaidyanathaswamy in 1952, the programme of work generally followed by him has been continued by his successor, Dr. V. S. Krishnan, who joined as Reader and Head of the Department from July 1952. The M.Sc. courses are continued and provide trained candidates to take up research; and courses of lectures of two months or so each are given by the Reader and the Senior lecturer on various topics for the benefit of research students. Some of the topics so covered are: topics in topology, dimension theory, combinatorial topology, linear spaces, integration, number theory, measure theory and probability, uniformity, semi-uniform spaces, convergence and écart, homology theory, topological algebras, Lie groups, structure theory of semi-groups and other algebraic structures, etc.

These last years have seen the beginnings of a study of algebraic topology which in recent years has been expanding considerably in power and scope. The study of structural features of composite mathematical structures involving algebraic, topological and partial order structures has also been taken up.

A further welcome feature during these last few years has been the visit by eminent western Mathmaticians to our University; most of them had come as guest Professors to the Tata Institute of fundamental research at Bombay, and paid a visit to our University. Lectures by such visiting Professors were given by Prof. Maass from Heidelberg, Prof. Schwarz from Paris, Prof. Siegel and Prof. Deuring from Göttingen, Prof. Eichler from Germany, Prof. Ambrose from Massachusetts, etc.

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Department of Physics

The department of Physics was set up at the beginning of the academic year 1952-53. The department is engaged in research, both in experimental and theoretical physics, and conducts in addition a one year post-graduate (post B.Sc. Honours) course leading up to the master's degree in two subjects (a) X-ray and Crystallography and (b) Statistical Mechanics. The department has now grown very nearly to its full strength, as may be seen from Table I. The staff at present consists of the following:—

Professor: Dr. G. N. Ramachandran, M.A., M.Sc., Ph.D. (Cantab.), D.Sc., A.I.I.Sc., F.A.Sc.

Reader: Dr. Alladi Ramakrishnan, M.A., Ph.D. (Manch.), F.A.Sc.

Research Assistant: Sri S. Raman, B.Sc. (Hons.), M.Sc.

TABLE I

Number of students in the department of Physics during the period 1952-1956

Years	1952-53	53-54	54-55	55-56	56-57
Research					
for M.Sc. ..	1	3	4	1	1
for Ph.D. ..	2	2	5	9	11
Post-doctoral ..	—	1	1	—	—
Course					
X-rays and Cryst. ..	—	—	4	4	5
Stat. Mech. ..	—	—	4	—	4

The laboratory has been equipped mainly for X-ray and optical work, particularly for the study of biological structures by physical methods. This is being extended to include other physical and physico-chemical methods, so that the department may be in a position to undertake researches in all branches of biophysics in due course.

A summary of the main lines of research work being undertaken in the department and the important results obtained are given below:

BIOPHYSICS

1. *Structure of Proteins:*

A programme of research has been initiated on the structure of proteins, in particular on the Collagen group, which form a main sub-division of the fibrous proteins. Collagen is widely distributed, being the main component of skin and hide and of connective tissue, besides forming the main organic part of the skeletal system. The work on the structure of collagen was started in 1953. X-ray diffraction patterns of collagen fibres from various sources were obtained and a structure was proposed on their basis, which consisted of triple helical chains of amino acid residues stabilized by interchain hydrogen bonds (Ramachandran and Kartha, 1954). These are linked together to form cylindrical rods, which occur in a hexagonal array. Although the structure explains the features of infrared spectrum and chemical composition of collagen, it did not completely agree with the X-ray data for stretched collagen.

So a modified structure was proposed which was topologically very similar to the previous one (Ramachandran and Kartha, 1955a) and agreed with the essential requirements of the X-ray pattern (Ramachandran and Ambady, 1954). The three helical chains are now wound into a superhelix in the form of inter-twined coiled coils. Two hydrogen bonds could be satisfactorily formed for every three residues. The third carbonyl oxygen could be hydrogen bonded to the hydroxyl group of the hydroxyproline in the neighbouring rod. This explains, in a satisfactory way, the relationship between the stability of the collagen fibre and its hydroxyproline content. The Fourier transforms of this model was found to be in good agreement with X-ray diffraction data (Ramachandran and Kartha, 1955b). However, the structure was found to be sterically not very satisfactory involving a few short contacts. It could not also explain the naturally occurring sequence of the amino acid residues. The structure was, therefore, further revised, however, retaining the broad features of the previous structure. Insistence on the formation of more than one hydrogen bond in three residues was abandoned. An additional hydrogen bond was introduced through a water molecule (Ramachandran 1956).

The Fourier transform calculations showed that this gave better agreement with X-ray diffraction data. The spherical transform of this model has also been computed. This should theoretically correspond to the diffraction pattern of thermally shrunk collagen or gelatin. For in these cases the protofibrils remain intact, although they take a folded configuration and the X-ray diffraction can be expected to be a highly disoriented representation of the pattern of the normal state. The agreement between the spherical transform and the diffraction pattern of gelatin was found to be fairly satisfactory.

The absence of reflections like 110 in collagen is difficult to be explained when the coiled coil rods are arranged in a hexagonal array. This led to the proposal of a cylindrical lattice structure which explains in a natural way the absence of all reflections of the type *hko,* with both *h* and *k* non-zero. (Ramachandran and Sasisekharan, 1956). This model also naturally explained the equatorial long spacings observed in natural wet tendon by Cowan, North and Randall (1955).

On the experimental side, X-ray diffraction photographs were recorded for collagen fibres from various sources and under different conditions, wet and dry, stretched and unstretched, and treated with various reagents. Often it was found necessary to use inclined beam rotation technique, because this gave a greater angular range along the meridian and varying resolution along the layers. Charts and tables have been recently prepared to determine the ξ and ζ values from the film coordinates for the various tilts of the beam with respect to the oscillation axis.

The X-ray pattern of collagen, contrary to statements made by previous workers, has been found to exhibit significant changes when the fibres were chromium tanned. On the basis of the experimental results, some ideas have been developed regarding the mechanism of the fixation of chromium salts in collagen.

The influence of various lyotropic agents on collagen fibres has also been studied. It has been observed that a progressive alteration of the structure is brought about by the lyotropic agents although the original structure is regained by washing away the salts with distilled water. Some of the stages in the alterations mentioned above gave an X-ray pattern closely similar to elastin. The structure of elastin has also been studied and its structure is also found to be based on a triple chain helical configuration closely similar to collagen.

Very recently, studies have been initiated on the keratin group of proteins, in particular on feather keratin.

2. *Crystallisation of Salts in Proteins:*

An interesting phenomenon, namely, the oriented crystallisation of inorganic salts has been observed with collagen fibres kept in suitable salt solutions and dried (Ramachandran and Ambady 1955). An important fact noticed with regard to the various salts which crystallised in collagen is that the unit cell dimension along the fibre axis is always very nearly a submultiple of 28·6 A or 2 × 28·6A. In continuation of these observations, a detailed study of the calcification of collagen has been carried out. Collagen fibres when kept in a suspension of precipitated calcium phosphate gave an X-ray diffraction pattern closely similar to the pattern given by a section of normal bone (Ramachandran and Santhanam, 1956). The influence of the presence of other ions and pH on the deposition of apatite crystallites has also been investigated.

3. *X-ray Studies on Cuticles:*

As a result of X-ray studies made on the cuticles of arthropods, it was found that the epicuticle of scorpion contains chitin, a constituent which was formerly considered to be absent in the epicuticles of all arthropods (Krishnan, Ramachandran and Santhanan, 1955). The epicuticle in the case of scorpion and centipede was found to be composed of a protein-chitin complex, containing a large percentage of chitin. In other cases, no chitin was present in the epicuticle in agreement with the current ideas of the constitution of the epicuticle (Santhanam 1955).

CRYSTALLOGRAPHY AND CRYSTAL PHYSICS

1. *Crystal Structure Analysis:*

A new method called the Difference-Patterson method has been developed to solve crystal structures. The method was shown at first to work with simple crystals such as phthalocyanines and the isomorphous pair barium chlorate and barium bromate (Kartha and Ramachandran 1955). The method was also applied to a more complicated example and was shown to work well (Sasisekharan 1956). This method is being applied systematically to solve unknown structures of crystals in this laboratory.

As an adjunct to the structure determination of fibrous proteins, the crystal structures of some amino acids have been worked out. The crystal structure of DL-aspartic acid has been worked out (Amirthalingam and Ramachandran 1955) by a combination of trial and error methods making use of models with Patterson-projections along two axes.

The crystal structure of tyrosine hydrochloride and hydrobromide are being worked out by the D-P method. These are in the final stage of refinement. The structure determination of lysine hydrochloride is also in progress.

The crystal structure of some inorganic compounds such as potassium tellurate dihydrate and a new form of titanium carbide have also been determined.

During the course of the structure analysis, space group, unit cell and molecular weight determinations of various compounds have been undertaken (Kartha, 1954; Sundara Rao *et al.*, 1954; Srinivasan, 1956).

To save much of the labour of computing structure factors and Fourier transforms in the initial stages of structure determination, an apparatus was constructed for obtaining them optically. The apparatus is simpler than previous designs in that only one lens is used (Aravindakshan 1957).

Measuring the intensities of various reflections from crystals by a Geiger Counter, the absolute configuration of the atoms in sodium chlorate and glucosamine hydrochloride, have been determined, using the anomalous dispersion of the chlorine atoms for the CuKα radiation (Ramachandran and Chandrasekharan 1957).

The main features of the structure of the high temperature form of $KClO_3$ were worked out from the powder photograph. The structure was found to be a sort of mixture of the two twins of low $KClO_3$ (Lonappan and Ramachandran 1956).

2. *Thermal Expansion Studies:*

The work arose out of an attempt to determine the thermal expansion of the monoclinic crystal, potassium chlorate, with the idea of throwing some light on the interesting transformation that occurs after the transition point. As the experimental technique developed in this connection turned out to be very convenient and accurate, the method was used for determining the thermal expansion of other crystals having anionic groups of the type BO_3, viz., othorhombic KNO_3 and triclinic HBO_3.

From the transformation studies on $KClO_3$ it was observed that there occurs a change of symmetry from monoclinic to orthorhombic system above 250°C, and that the structures of the two modifications namely high $KClO_3$ and low $KClO_3$ must be closely related (Lonappan 1955a; Ramachandran and Lonappan 1957). The study of thermal expansion of KNO_3 for various ranges of temperature was made and the ellipsoid of expansion was determined (Lonappan 1955b). The measurements of thermal expansion showed in the case of orthoboric acid the occurrence of a negative expansion, the direction of which was found to be parallel to the shortest hydrogen bonds (Lonappan 1955c). Incidentally, this is the first time that the complete expansion tensor of a triclinic crystal has been determined by the X-ray methods.

3. *Perfection of Crystals*:

A Geiger Counter for counting X-rays together with the associated electronic equipment were constructed to study the texture of crystals. Using the Geiger Counter spectrometer and a polarising monochromator the degree of perfection of a number of crystals such as calcite, rock salt, quartz and lithium fluoride have been measured (Chandrasekharan, 1955a,b). The relative intensities of various reflections and also the variation of the intensities of a particular reflection with the degree of perfection are broadly in agreement with the expectations from the theory developed by Hirsch and Ramachandran (1950) (Chandrasekharan 1955b).

The theory of anti-reflections (Ramachandran and Kartha 1952) has been extended and the integrated values of the reflected and anti-reflected intensities have been obtained analytically for an internal reflection (Ramachandran 1954).

A paper has been published on the representation of any state of polarisation of a light beam (including partial polarisation). The Poincaré representation is used to discuss the theory of monochromatic depolariser (Ramachandran 1952).

THEORETICAL PHYSICS

1. *The Cascade Theory of Cosmic Ray Showers*:

Since the first formulation of the cascade theory of Bhabha and Heitler, considerable work has been done in this field which forms one of the principal branches of the cosmic ray theory. The group here has been mainly concerned with the stochastic implications of cascade problems and seven papers have been published on this subject. Very recently, a new approach to the cascade theory has been suggested.

2. *Theory of Random Functions*:

Random functions have attracted the attention of pure mathematicians for a considerable time. But there seems to be a necessity for a physical approach which is more useful in the application of actual problems. In collaboration with the students, Ramakrishnan has developed a physical approach to stochastic processes and a phenomenological interpretation of integrals of random functions. Over fifteen papers have been published on this subject.

3. *Statistical Problems in Astrophysics*:

With the publication of five papers by Chandrasekhar and Munch on stellar statistics, a new field of application of stochastic methods has arisen in astrophysics. The methods developed in the department are quite suitable for the extension of stochastic ideas to such astrophysical problems. Seven papers have been published in the Astrophysical Journal on this subject.

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Department of Statistics

The work of the Department of Statistics in the University of Madras falls under three broad categories, namely, (i) teaching, (ii) conducting and guiding research and (iii) assisting in the designing of scientific experiments and planning investigations and in the analysis of collected data and interpretation of the results. The following pages contain a short historical account of the development of these functions and a review of the work that has been so far undertaken together with an appraisal of the aspects of study that are in progress. A list of publications prepared by the teachers and research scholars of this department, including the titles of theses accepted for research degrees, are appended to this account.

Historical Background :

The history associated with the origin and development of the Department of Statistics has influenced, to a great extent, the nature and content of the work undertaken in this Department. While Statistics was introduced as a subject for special study for the Honours degree course in Mathematics, even as early as 1920, it was introduced at the University level first only a decade later in the Department of Economics. In 1929 the Diploma Course in Economics, that was being conducted by the University, was revised and Statistical Methods was introduced as a subject for study. The new regulations that were brought into force from 1930 led to the creation of the post of Lecturer in Statistics in the Department of Economics from 1st July 1930. He was appointed to work under the direction of the Head of the Department and deliver lectures, conduct classes, and engage in research and assist in any other academic work relating to the Department of Economics. Thus Statistics was given a place first in the Department of Economics and this position was retained without any change for a decade.

It was decided in 1940 to institute a Diploma Course in Statistics at the University and also provide for the study of Statistics in B.A. and B.Sc. (Pass and Honours) courses from the next academic year. These changes presented the administrative difficulty of fixing the department of study to which Statistics should be assigned and this situation led to the creation of a separate department of study and research in Statistics in the faculty of Science. Thus, in 1941 the post of the Lecturer in Statistics was separated from the Department of Economics and the lecturer constituted the new Department of Statistics. The Department of Statistics, thus constituted with a single lecturer, remained without any change till the end of 1952. In January 1953, the Lecturer, under the scheme of rotating Readerships, was promoted as Reader and as Professor from 1st January 1957. From July 1953 a post of Lecturer has been added, so that the Department at present has a Professor and a Lecturer. During this total period, three times the lecturer was either on leave or on deputation and in his absence part-time lecturers were appointed for the conduct of the Diploma classes. The details of the occupants of these posts are as follows:—

1. Mr. N. K. Adyanthayya, B.Sc. (Hons.), B.Sc. (Lond.), Lecturer in Statistics, Department of Economics (1-7-1930 to 1-7-1933).
2. Sri N. Sundararama Sastry, M.A., M.Sc., Ph.D. (Lond.), F.S.S., Lecturer in Statistics, Department of Economics (22-8-1934 to 31-10-1941), Lecturer and Head of the Department of Statistics (1-11-1941 to November 1943).
3. Sri D. V. Rajalakshman, M.A., M.Sc., Ph.D. (Manch.), F.S.S., Dip. Econ., Lecturer and Head of the Department of Statistics (18-7-1944 to 31-12-1952), Reader and Head of the Department of Statistics from 1-1-1953 to 31-12-1956, Professor from 1-1-1957 onwards; also Hon. Librarian, Departmental Libraries, 1953-54.
4. Sri G. S. Lingappaiah, M.Sc. (Mysore), Lecturer in Statistics (11-7-1953 onwards).

During the quinquennium, commencing from 1951, the facilities for research and teaching in the Department have been considerably improved by providing equipment, like calculators and tables, and by strengthening the library. Besides one University studentship the Government of India have allotted four scholarships for research and this year a research fellow on exchange from France has also been admitted. On the whole, seventeen research scholars worked in the Department and nine of them were awarded research degrees and two are awaiting the result of the theses submitted by them, while three others are continuing work in the Department.

Review of Work :

Ever since the creation of the post of Lecturer, emphasis has been placed on the teaching aspect of his duties. This was the

natural consequence of the circumstances under which the post was originally sanctioned. During the first decade, the teaching work was mainly for the Diploma Course in Economics. With the institution of the Diploma Course in Statistics and the formation of the Department of Statistics in 1941, the Lecturer was entrusted with the responsibility of conducting this course in addition to his usual teaching work in the Department of Economics. This change also added considerable amount of administrative work to him. In the same year, the Lecturer also commenced inter-collegiate lectures for students taking Mathematics Honours course with Statistics as a subject for special study. These lectures gradually became a part of the work of the Department and have been extended in recent years for the Statistics and Economics Honours courses also. During 1948-50, the Lecturer taught Statistical Methods applied to industry for the B.Sc. (Tech.) students. In 1952 he assisted in organizing a course in Statistical Quality Control under the U.N.T.A.A. scheme and also received the training. In addition to this the Reader also organized special lectures in Statistical Methods for scientific research for all research scholars. The addition of a Lecturer to the Department since July 1953 provided some relief in the teaching work of the Head of the Department for the Diploma Course in Statistics. Thus the teaching work of the Reader comprises of giving different inter-collegiate lectures and special lectures for the research scholars, besides the teaching work for the Diploma Courses in Statistics and Economics.

The second aspect of the work that was given prominence from the beginning was that of providing assistance in the academic work of the Department of Economics. This statistical assistance, which usually took the shape of analysis of collected data and interpretation of the results, was confined mainly to Economics during the early period. But, with the separate formation of the Department of Statistics, this assistance was gradually sought by workers in other departments of study and research. In this context, Statistics as a branch of scientific knowledge stands rather unique. The applications of the subject are found in every branch of experimental work that depends on quantitative measurements. This gradual recognition of the need for using Statistics in various branches of scientific study resulted in a phenomenal increase in the work of the Head of the Department. He has been giving assistance in designing experiments and planning investigations and in the analysis of collected data including interpretation of the results for research workers in various branches of studies. Though this aspect forms a significant part of the work of the Head of the Department, this cannot take the shape of publication of this Department.

The third category of work, namely, conducting and guiding research, formed always an integral part of the activities of the Head of the Department. Research workers were being admitted ever since the post of Lecturer was created and these scholars from July 1953 have all been working under the guidance of the Reader. All of them possess normally good qualifications in Mathematics and in Statistical Methods. The list appended to this review contains most of the published articles and titles of theses accepted for research degrees arranged according to the alphabetical order by authors and relate to the studies undertaken by the staff members, Mr. Adyanthayya, Dr. Sastry, Dr. Rajalakshman, and the research students who worked under their guidance. Unpublished reports and papers awaiting publication are not included in the list. Mr. Lingappaiah who joined the Department as Lecturer in July 1953, has been mainly taking some of the classes for the Diploma Course in Statistics.

Various aspects of studies that have been undertaken by the Department can be broadly classified into two categories, methodological and applied. The close association of Statistics as a part of the Department of Economics for over a decade influenced considerably the choice of topics for research work. Applied problems that require collection and analysis of data and the interpretation of these results, particularly selected from the field of Economics, received greater emphasis. Even here the early investigations were based on data collected from the sector of Agricultural Economics. Besides a number of articles included in the appendix, the two booklets prepared by Dr. Sastry in collaboration with Dr. Thomas and the thesis of Dr. Rajalakshman accepted for the 'Gokhale Prize' belong to this branch of studies. Though emphasis continued to be on the applied work even after the formation of a separate Department of Statistics, there was a steady shift in the choice of subjects. Topics were selected from aspects of trade, industry, and prices. Number of papers published during the forties, including the thesis of Dr. Sastry accepted for the doctorate degree, were based on these studies. Equally important has been the gradual widening of the scope in the choice of topics for study to include various branches of knowledge, like Biology, Education and Demography, besides Economics. This expansion of work that resulted in a number of publications has been accentuated by the steady increase in the statistical assistance given to research workers in various branches of studies.

During the last decade these applied studies gradually shaped into two distinct branches of work. Current problems that involve statistical analysis of data and interpretation of the results form one branch. Under this category, choice of the topic for study can be from any branch of knowledge and the investigations usually lead to the preparation of a paper. This continues to be one of the aspects of work of the Department.

The other category of applied work related to empirical studies on observational data with the specific purpose of illustrating or providing verification of the results obtained on methodological problems. These studies often also help fundamental work on methodology. One important branch of studies undertaken in this category has been analysis of time-series. Commencing with the analysis of observational time-series, a number of investigations have been undertaken on the methodological aspects of the analysis and published as papers. This branch of theoretical work has been further pursued considering time-series as a particular aspect of stochastic processes. Some of the results in this branch of methodology have been included in the thesis of Dr. Rajalakshman. The study of some aspects of stochastsic processes is one of the important branches of methodological work that is being undertaken by the Department. In this emphasis is laid on the problems of specification and inference of suitable stochastic models along with the necessary empirical analysis of real or artificial data.

Work based on problems on methodology selected from the general branch of sampling distributions formed a part of the studies undertaken by the Department from the very beginning. Problems on correlation were taken first and later these studies extended to distributions associated with different test criteria. Study of samples drawn from normal and non-normal universes including some aspects of testing of statistical hypotheses continues to be a fundamental aspect on which work is in progress. Most of the results have been included as parts of theses submitted for research degrees and published as papers.

Another aspect of work recently introduced as a part of the activities of the Department is that of planning and conducting sample investigations. These have been designed to provide adequate practical experience and also serve as applied work on sampling techniques for research workers. The data collected will be analysed and published as applied work. With the growing importance of applications of Statistics, considerable expansion of all the activities detailed above can be expected in the Department.

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Department of Technology

The growth and development of the Alagappa Chettiar College of Technology is a fascinating history by itself. The question of instituting technological courses had been under consideration of the University of Madras ever since 1933, since it was *conscious* that there were needed researches in science that would have a more direct relation to human *welfare which* might also advance our *basic knowledge of technology* and that the trained technological personnel should be available to the industry in the Southern Region served generally by the University. This question was considered at several meetings of the Syndicate, *but* had to lie over for better days, for lack of *proper* finance. The department of Chemical Engineering was started in the year 1944 thanks to a generous donation of Dr. Alagappa Chettiar and subsequent State and *Government* of India aids to the College. In the year 1945, courses in Leather Technology and Textile Technology were also started. The scope and functions of the *laboratories* are concerned towards the achievement of the following aims:

1. To train personnel in the *professions* of Chemical Engineering, Textile Technology and Leather Technology.
2. To build up a centre of research for higher *technological* education and training.
3. To initiate research on problems connected with industrial needs of the region.
4. To build up a liaison relationship with existing chemical industry of the region and to help them in *their* expansion.

To fulfil the above duties the College has well equipped laboratories for analytical work and for instruction in the operation of pilot plants connected with *specialized technologies*. The departments have given technical advice to firms and industries on industrial projects and have carried out research investigations at bench and pilot plant level on fundamental and applied aspects of Chemical Technology. The years up *to* 1950 *were* mainly devoted to equipping the laboratories and integrating the courses. Since then, however, more emphasis has been given to undertake research projects. The various phases of the research and development activities of the laboratories are described below.

Synthetics from Fats and Oils

A comprehensive review of the production of synthetic detergents from vegetable oil origin was prepared (Janardhan 1950a). Fractional crystallizations of commercial stearic acid from acetone and methyl alcohol, acetone and rectified spirit, and benzene and methyl alcohol binary mixtures were attempted with good results (Janardhan 1950b). Optimum conditions for ammoniation process for converting fatty acids into their corresponding nitriles were investigated (Janardhan 1950c). The nitriles thus prepared were converted into the corresponding amines by reduction at copper cathode (Janardhan 1953a) and the process was awarded a patent (44230 Indian Patent). Various conditions for dehydrating castor oil were tried in the presence of different catalysts like $NaHSO_4$, Silica gel, etc., and under reduced pressure (Kannayya & Janardhan 1950). Attempts were made to increase the unsaturation of dehydrated castor oil by halogenation and dehalogenation and the properties of the resulting resinous products were studied (Kannayya & Janardhan 1951).

Analytical Research

In a programme of development of analytical methods, various new techniques have been reported by the laboratory. The colorimetric method for the determination of copper employing rubeanic acid has been critically examined (Janardhan 1953). The colorimetric estimation of tin using phosphomolybdic acid has been developed (Subrahmanyan & Janardhan 1955). A summary of work carried out on estimation of tin by electrodeposition at controlled cathode potential from acid and alkaline solution has been done (Subrahmanyan & Janardhan 1955). A new and accurate method for estimation of germanium has been developed (Hamsath Ibrahim & Madhavan Nair 1956). The coulometric technique has been extended to a number of nonaqueous solvents and to mixtures of such solvents with water.

South Arcot Lignite Utilization

Investigations on the nature and properties of South Arcot Lignite included proximate analysis and determination of calorific

value, sulphur and nitrogen contents. The low temperature carbonisation assay was performed at different temperatures. The proximate analysis of the chars and the determination of their calorific value were also carried out (Subrahmanyan & Madhavan Nair 1954). A complete study of the low temperature tar, obtained from the lignite at 600°C, has been made. Besides a determination of the physical characteristics of the tar, the work comprised of distillation of tar into several fractions, alkali extraction of the phenols, followed by the fractionation of phenols and of the washed oil, and estimation of naphthalene, anthracene, phenol and pyridine bases (Subrahmanyan & Madhavan Nair 1954). The germanium content of the lignite ash has been determined by gravimetric and polarographic methods (Subrahmanyan & Madhavan Nair 1955). Montan wax was extracted with solvents at different pressures. Preparation of high quality active carbons from lignite has also been studied under the influence of activating agents such as steam, zinc chloride, phosphoric acid, calcium chloride, etc., at temperatures varying from 500°C to 800°C. The adsorptive properties of the carbons obtained were quantitatively studied on different adsorbents like iodine, oxalic acid, methylene blue, malachite green, etc., and suitability of these carbons has been demonstrated for decolorising molasses, palm ghur and cane jaggery (Jagannadhaswamy & Madhavan Nair 1955). Aerial oxidation of lignite was done with fixed as well as fluidised beds and the best conditions for the maximum yield of humic acid have been worked out. The importance of humic acid as a soil conditioner in increasing the uptake of fertilizer has been established by an extensive series of pot culture experiments (Jagannadhaswamy & Madhavan Nair 1956).

Unit Operations and Process Research

Investigations on the kinetics of absorption of CO_2 by alkalis were completed (Chandrasekhar 1950). A study for developing a basic correlation between the power required for the transport of slurry was undertaken and design data were obtained (Poonen 1954). An investigation into the sedimentation of fine particles in a centrifugal field has given interesting results. The size analysis of ultrafine particles in the 1 to 5 micron range by the usual methods is a highly time consuming operation. A method of effecting this analysis using a super centrifuge has been developed in the laboratory (Raman 1955). A study of the nature of filtration, structure of filter cakes and the role of filter-aids in filtration was made for evaluation of filtration technique (Subba Rau 1955). An investigation of the vapour liquid equilibria over ternary system involving acetic acid, water and salts has indicated that the vapour-equilibria for acetic acid-water system are highly influenced in the presence of salts (Venkataraman 1954). The design and fabrication of a direct fired firebrick lined rotary kiln was studied to evaluate the various factors influencing them (Jayaraman 1949). A design for a cylinder cap for use with leaky gas cylinders was developed (Jayaraman 1950). Description and operation of an experimental refrigeration unit as a heat pump has been discussed (Subba Rau & Govinda Rau 1955).

Potentialities of the development of cotton seed oil industry in India was stressed and economics of cotton seed crushing have been discussed (Laddha 1954). The various ginning processes used in India have also been discussed (Mohanty 1954). Vegetable oils of commerce have to be refined free from fatty acids before further processing. The usual method of effecting this is by adding alkali in sufficient quantity to neutralise the acids and removing the soap formed. Investigations were carried out to apply solvent extraction process to effect this separation and to discover suitable solvents to separate the fatty acids for the oils. In this connection, complete equilibrium and phase distribution data were obtained for peanut oil—oleic acid—acetic acid and peanut oil—oleic acid—furfural at 40°C (Venkataraman & Laddha 1955). Further investigations indicated that ethyl alcohol can be used as a selective solvent for extraction of oleic acid from groundnut oil—oleic acid solution (Venkataraman & Laddha 1955). The methyl esters obtained by methylation of castor oil were fractionated by means of liquid—liquid extraction technique to get a fraction richer in pure methyl ricinoleate. The study indicated that the solvents furfural and hexane can be used for such fractionation (Kasturirangan & Laddha 1955). In a study of the extraction of glycol from aqueous solution the ternary systems Glycol—n Butyl alcohol—water and Glycol—isobutyl alcohol—water were studied and equilibrium and tie line data have been obtained (Lakshminarasimhan, Gopalan & Laddha 1956).

The laboratories of the college are at present engaged with the problems of heat transfer in packed beds, extractive distillation techniques, liquid—liquid extraction studies and beneficiation of the naturally occurring ores in South India.

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Department of Zoology

The University Zoological Research Laboratory was started in 1927, largely due to the initiative and foresight of Sri K. Rammuni Menon, who was its first Director. The laboratory was accommodated in a single room in "Marine Villa" which was later demolished to give place to the present building. This was completed and occupied in 1933 when Prof. R. Gopala Iyer was appointed full time Director. From the inception of the laboratory, the main lines of research, have been of a marine biological character. In 1944, on the retirement of Prof. Gopala Iyer, Dr. N. K. Panikkar succeeded as Director. In November 1946 the present Director Dr. C. P. Gnanamuthu, took charge. In 1950 the staff of the Laboratory was added to by the sanction of the post of a reader and later the post of a lecturer. To these posts Dr. G. Krishnan and Dr. S. Krishnaswamy were appointed.

In 1948, a scheme for continuous supply of sea water in the laboratory was placed before the Government of India and was sanctioned in 1950 at a cost of Rs. 75,000/- this is nearing completion. Further generous grants obtained through the University Grants Commission enabled the equipment of the laboratory with more modern apparatus suitable for the pursuit of researches in animal physiology.

Contributions to Indian Zoology from the Department of Zoology University of Madras

I. *Plankton studies*: Though the *"Investigator"* had collected data regarding the physico-chemical and biological conditions of the Indian ocean and the Bay of Bengal, yet detailed observations regarding the plankton of the western part of the bay were first presented for the Madras waters in the form of a plankton calendar in 1932 (24, 167). In the subsequent years, plankton was collected nearly every day and data were collected from qualitative and quantitative analysis of plankton and from estimations of pH and salinity. During the last six years, sea water samples were estimated for silicates, phosphates, nitrates and oxygen concentration; and records of temperature, pH and salinity were maintained (168, 216, 217). Correlations between the fluctuations in the quantity of phytoplankton collected and the fluctuations in the amounts of the different plant nutrients were sought. The hydrographical data gathered during last six years, showed that this area of the bay is as rich as any other sea; that the phytoplankton blooms do not show such marked seasons as in the temperate waters but nevertheless show marked peaks following the concentrations of nutrients; and that the numbers of copepods—which may be taken as the animal index of organic productivity—also show maxima, occurring close behind the diatom pulses. The seasonal fluctuations in temperature, oxygen content and concentrations of plant nutrients, shed light not only on the occurrence of coastal currents of a northerly and southerly character in September-February and March-August periods respectively but also the incidence of upwelling of bottom waters during May-July.

The organic productivity of temperate waters has been studied by several. But in India the rate of organic production was estimated for the first time at Madras and was found to be limited rather by a ceiling intensity of sunlight and the composition of phytoplankton than by the uniformly high temperature and the never-depleted-amounts of plant nutrients. It was found to range from 0·048 to 0·547 mg. of carbon per litre per day—which compares favourably with 0·02-0·41 and 0·00 to 0·88 mg. per litre per day obtained at Long Island sound and Georges Bank in the higher latitudes.

In the course of the plankton studies, the life histories of several coelenterates (174, 190, 192, 197, 201), polychaets (2, 4, 10, 116) molluscs (222), crustacea (27, 29, 163, 165), echinoids (8, 12), balanoglossids (184, 186, 189) and different species of fish have been described (7, 41, 176, 177, 179, 180). Several forms like *Sagitta bedoti* (264), *Cestum amphitrite* (15) and *Ctenoplana bengalensis* sp. (96A) were recorded for the first time in Indian waters or were new to science.

II. *Study of copepods:* Of the different groups of organisms which maintain the food cycle in the sea, the copepods which form 80% of the total surface plankton at Madras are rightly treated as "the animal pasturage of the sea". This group was singled out for intensive study since it has been exhaustively studied in other countries. In India, Sewell began this investigation as early as 1912 and has been followed up at Madras by Krishnaswamy who has identified and described over 132, 137, 138, 139) species of which seven are new to science. The life histories of 17 have been sketched (128, 129, 134). Their physiology is being studied. Of the weed-clinging Harpacticoid copepods, 90 species belonging to 43 different

genera have been idenitfied and described, 9 being new to science. About five families of Harpacticoids and Cyclopoids were found to have invaded and colonized the sandy beach at Madras. Of these minute, extremely modified copepods confined to the microscopic interstices between particles of sand, 19 species were described (141, 145, 147). All were established as new species since it was found that very litttle work has been done on the microfauna of this newly discovered environment and that these peculiar copepods are extremely limited in their dispersal and are specialized in their adaptations.

Several families of this extremely plastic order—the copepoda—have taken to a parasitic mode of life. Forms were collected from widely different hosts like sea anemones, prawns, crabs and fishes. About 24 new species were described (67, 69 to 71, 73 to 76, 78, to 85, 87, 88, 91, 93, 94) with notes on morphology, physiology and life histories.

Thus, this extremely diversified order of Crustacea has been studied intensively in relation to their different habitats and the papers published represent a definite contribution to our knowledge of the Crustacea so important from the point of view of fisheries.

III. *Study of helminth parasites*: The cestodes parasitic in the guts of different market fishes of other countries have been studied extensively. Of the Madras fishes, 74 species which act as hosts to larval and adult cestodes were listed (242, 243, 244, 265) and the parasites collected from these have been identified and described. The encysted and pleurocercoid stages of the larvae of nearly 23 species and the adults of over 54 species have been dealt with fully. A new family Monoporophyllidae and 17 new species have been described. 66 species of the trematodes, especially the Monogenea which damage the gills of their fish hosts, have been described. Of these nearly 23 are new to science (214, 215). Thus, it may be claimed that the taxonomic survey, which is a necessary prelude to experimental studies of their nutrition, respiration, their effect on the hosts, the factors responsible for their specificity, etc, has been completed.

Three species of Acanthocephala infesting Madras fishes were described and the life history of *Moniliformis moniliformis* whose larval life is spent in the cockroach and adult period in the domestic rat, was studied in detail by experimental infections of laboratory bred hosts.

IV. *Ecological studies*: The relation of animals to the different habitats in a tropical area marked by higher temperature average, absence of marked seasons, higher rate of bacterial decomposition, rapid depletion of oxygen and nutrients, is another field in which important contributions have been made. The brackish water areas of Adyar and Cooum have been studied with respect to the marine elements like the Actinians (190, 191, 193, 199) polychaets (1, 5), molluscs (221, 203, 204), Crustacea (169, 170) and fishes which breed there after the mouths of these rivers have been sand-barred and conditions of salinity, oxygen content and pH change. Notes on the breeding of the different groups of animals represented have been made and it was found that in common with other tropical fauna there is evidence of continuous and discontinuous reproductive activity probably accentuated by slight fluctuations in hydrographical conditions and in a few cases by lunar periodicity as well. Preliminary observations on the osmoregulatory powers of polychaets (125) and gastropods of these brackish waters have been made.

The microfauna, inhabiting the capillary waters of the twelve-feet wide intertidal zone of the sandy beach, have been studied intensively with reference to the ecology of this interstitial habitat. Like other well defined environments this is self-sufficient so far as food is concerned through the organic production by the diatoms, the derivation of particulate organic matter from the decay of forms cast ashore and rotation of nutrients maintained by bacterial agency. The compensation depth being only two inches from the surface and the oxygen content decreasing to 1.5 c.c. per litre at a depth of 10 inches, limit the biotope to this depth. The fact that this depth is not less than is found in sandy beaches of higher latitudes suggests that in spite of higher temperature and more rapid bacterial decomposition, increased oxygenation is maintained through active photosynthesis and by capillary currents sustained by more rapid evaporation. The specialized forms of copepods and nematodes — the major groups studied so far — their localized distribution and their being confined to particular levels of the different zones and their differing from other genera and species recorded from temperate areas are features of the department's contribution.

The community of sessile forms growing on harbour structures is of ecological interest. The growth of these tropical species appears to be continuous while their breeding varies from being limited to once or twice a year, to being continuous with a few

peaks of intensity or being uniformly continuous (205, 206). Within the harbour, the composition of the community differs at different stations though the numbers at all stations vary uniformly, being lowest in October-November. Studies on the settlement of sessile organisms showed that there is a regular succession of different communities (48) on the same test panels in the different months of the year and that salinity, depth of water, currents and the nature of substratum, influence the settlement of the larvae. The growth of *Modiolus striatulus, Bowerbankia* sp., *Cynthia* sp., and *Dasychone* sp. studied very closely in the different stations, and in the laboratory, revealed that the tropical rapidity of growth was associated with not temperature alone but also affected by other factors such as salinity, turbidity and the early incidence of sexual activity.

The factors responsible for the settlement of barnacle cyprids were studied experimentally in the field and in the laboratory. It was found that the formation of a primary film (51) of bacteria and algae is a prerequisite and that the gregarious attraction (50) of previously settled cyprids of same or related species favours settlement. The intensity of illumination, the speed of currents, the height of tide, the colour of substratum (52), the composition of the animal community in the area also influence the cyprids of different species (50), in a way clearly suggestive of the narrow zones of the natural habitat to which the adults are confined.

The study of the ecology of sedentary ascidians, crustacea and bivalves which foul and damage wooden craft and timber structures, was started eight years ago, earlier than anywhere else in India. 82 species of cirripedia which foul timber were collected and described (43-45, 53) 11 being new to science. Of the animals which bore into timber, 20 species of Teredines (33, 37), 6 species of pholads (54) and three species of amphipods and Isopods (241) were listed and described. Of these 17 were new to science. The life histories of several typical forms have been studied in detail and the data, accumulated regarding their capacity to digest cellulose, will aid in formulating measures to protect timber against these marine pests. During the last three years, the department has conducted extensive tests on different species of Indian timber in collaboration with the Forest Research Institute, Dehra Dun.

V. *Physiological and Histochemical Studies.*

It is well-known that tropical conditions favour an inward migration from the sea to the estuaries and backwaters. Such migration involves special physiological adaptations, the most obvious being the development of osmoregulatory powers which condition their survival in media less saline than the sea. Naturally attention was directed to a study of the organs involved in osmoregulation. In the polycheats belonging to the family Nereidae, it was found that marked variations occur in the relative size and amount of blood supply of the nephridia in closely allied species inhabiting the sea, brackish and fresh water (117). In the stenohaline form *Perineris nuntia* the nephridia are small relative to the body size while in *Nereis chilkensis* which is able to withstand dilution of the external medium so as to enable them to thrive in brackish water, the size of the nephridium is comparatively larger and the blood supply to it more pronounced. These features are even more prominently seen in *Lycastis indica* which occur in fresh water. Similar studies were undertaken on the kidney of gastropods *Thais rudolphi, Murex tribulus, Cerethidia cingulatus, Vivipara varieta, Melania elegans* which have been taken from habitats of varied salinity conditions. Although the kidney shows similar structural features in all the above mentioned forms, in those living in brackish and freshwater, like *Vivipara* and *Cerithidia* special modifications occur in the form of extensions to the kidney containing renal filaments. These appear to be related to the habitat and the necessity for greater osmotic work in an external medium of low concentration. Another feature characteristic of these species is the variation in the musculature of the renal pore enabling a wider opening of the renal cavity. The significance of this feature of the forms living in media of low salinity conditions, may be to facilitate an increased outflow of water.

Detailed experimental studies on the relation between energy requirements as measured by the rate of oxygen consumption and the ability to survive in low salinity conditions involving osmotic work, have been carried out with reference to the prawn *Metapeneus monoceros*. The rate of oxygen consumption which increases when the animal is in hypotonic media attains a constancy after about a stay of sixteen hours in the medium. A study of the oxygen consumption in relation to temperature, pH, and oxygen content of the external medium showed that the rise of temperature increases the oxygen consumption but no direct effect was observable in regard to pH and oxygen content of the water within certain limits, but a marked decrease in the oxygen tension lessens the rate considerably.

Studies on the respiration of the common frog with reference to the mechanism of breathing and the role and significance of cutaneous respiration revealed interesting results. Contrary to the prevailing conception, it is shown that in addition to the movements of the buccal floor, the flanks play an important part in the respiratory movements recalling the respiratory mechanism of the reptiles. The above studies also showed that hitherto the importance of cutaneous respiration in frog has been somewhat exaggerated. The cutaneous respiration in frog appears to be only subsidiary to pulmonary respiration and is by itself inadequate to meet the respiratory needs of the animal.

A series of studies have been devoted to a study of the physiology of digestion in crustaceans and molluscs. In the prawn *Metapeneus monoceros* it was found that all the digestive enzymes are produced by the hepato pancreas capable of digesting carbohydrates, proteins and fats. The lipolytic enzyme digests lecithin, methyl acetate and olive oil, the proteolytic enzyme, fibrin, peptone and gelatine. Carbohydrates such as insulin, pentosans, raffinose are digested by the enzymes present. The ranges of pH and temperature within which the activity of these enzymes are maximum have also been determined. The importance of the digestive enzymes of the wood boring molluscs have been recognized and detailed studies on the sources and nature of these enzymes, their property and the factors influencing their activity have been made out with reference to the common wood boring teredinid of Madras, *Bankia indica* (32, 34). The digestive equipment of this species is peculiar in that it includes cellulose enabling it to live on wood. This obviously is an adaptation for their mode of life and habitat. An interesting feature is that in addition to cellulose, all the other enzymes for the digestion of fats, proteins and carbohydrates are present as in the allied groups like *Pecten* and *Ostrea*. The cellulose digesting enzymes are produced by the crystalline style and the digestive diverticula. The role of the enzymes of the crystalline style appears to be a preparatory one acting on large molecules reducing them to a simpler state. The cellulose in digestion is split up first into cellobiose which is further acted on by a cellobiase to complete the digestion.

Experimental studies were conducted on the influence of physical factors of the environment in the development of the ascidian *Polyclinum indicum*. An interesting result obtained is that the metamorphosis of the larvae of *P. indicum* is accelerated by mechanical disturbances under laboratory conditions and it is suggested that this factor may have an influence in their natural habitat also.

In the last few years, histochemical studies have received much emphasis as the chemical constitution of an organ enables an understanding of its functional behaviour. The insect cuticle has been studied in considerable detail from the above point of view and some workers extended such studies to a few groups of arthropods suggesting a uniformity in all arthropods. It was, therefore, of interest to find that from studies carried out in the laboratory on the arachnid *Palamneus swammerdami,* the structure and composition of the cuticle differ very markedly from the conditions reported in insects and is unique among arthropods in containing sulphur containing amino acids and in the absence of tyrosine and phenolic substances (118, 120), These features are reflected in the mode of hardening of the cuticle. Although the similarity in this respect is suggested in the vertebrate keratin, it is clear that this is different from it for the X-ray diffraction pattern obtained with the epicuticle is very unlike that given by keratin. These features noted above have been recorded for the first time. It is considered that the arthropod epicuticle is a non-chitinous, lipoprotein layer. But in *Palamneous* it is found, from both histochemical tests and X-ray diffraction studies, to contain a proportion of chitin. Further studies revealed a similar occurrence of chitin in the epicuticle of the myriopod *Scolopendra subspinipes* which resembles *Palamneus* in the nature of the proteins and the mode of hardening. In the aberrant group Pycnogonida, the epicuticle presents features recalling those found in *Palamneus* but it is devoid of chitin. Along side of the above studies, attention was directed to strucure and mode of formation of the cuticle of crustaceans in which only few groups have hitherto been studied in detail. In the stomatopod *Squilla* the cuticular organization is similar to that of the decapod crustacea. From studies on the cuticle of *Penaeus* and *Squilla* it is noted that although the crustacean cuticle is fundamentally similar to that of insects, there is wide range of quantitative differences especially in regard to tanning, which appears to be unimportant in crustacea in which the prime cause of hardening is by calcification. The hardening of the cuticle at each moult is regulated and controlled by harmones produced by the neurosecretory centres in the eye stalk. These centres of secretion are the X organ and the sinus gland. A study of the histology and histogenesis of these organs has been made in the crab *Ocypode quadichaudii* and *Squilla holochista.* Other

neurosecretory centres in the central nervous system, are being investigated.

VI. *Anatomical and life history studies.*

From the very inception of the laboratory attention was directed to a study of the habitats, anatomy and life history of the more common organisms characteristic of the fauna of Madras. The anatomical studies include most of the invertebrate groups and fishes. Polychaets like *Marphysa* (5), *Glycera, Armandia, Dasychone,* crustacean *Neptunus* and *Emerita,* molluscs *Kalinga* (221), *Stiliger* (222), *Meretrix, Modiolus,* Echinoderms such as *Salmacis* (12), *Chondrocloea* (175), *Pentaceros,* and the teleost *Otolithus* (56) have been studied in detail. The anatomy of these types not only serve to fill a gap in our knowledge of Indian animals, but also showed by comparison with their allies in the temperate and colder regions, in what respects life under tropical conditions and the adaptations necessitated by such conditions, bring about modifications in anatomical features. This feature is more prominently seen in the life history studies of the animals of Madras. The study of the brackish water polychaetes like *Marphysa* (1) and *Diopatra* (116) revealed a marked alteration of the free-swimming phase in the life history and increased provision for the developing young. In *Marphysa,* the eggs are protected in gelatinous egg cases in which various stages of development are passed. The jelly serves for both protection against draught and as nutrient to the developing young. In *Diopatra* the eggs are of large size and richly laden with yolk. These are laid inside the tubes of the parent animals and the whole course of development is passed within the shelter of the tubes, and a free swimming larval phase is completely lost—similarly in the gastropod *Stiliger* (222), an abbreviated larval phase and rapid metamorphosis have been noted. An interesting observation in regard to the life history of the brackish water anemone *Phytocoetus gangeticus* is the occurrence of neoteny (194).

Life history studies of a number of marine types, whose larval stages are found in the plankton, have been made. The larvae of crustaceans, gastropods and coelenterates have been studied and the life history of principal species are now known. In this respect, detailed studies have been made of the fish eggs and larvae of Madras. Some of these have been successfully reared in the laboratory tanks and valuable information of the sequence of larval stages, the food and food habits of the young fish have been gathered with reference to a number of species of common edible fish of Madras.

The life history studies have a special importance with reference to the fouling organisms which damage floating timber and the underwater structures. The life histories of molluscs and crustaceans which foul timber have been studied. Detailed knowledge is gained especially of the cirripedes of Madras harbour, their early larval stages, the metamorphosis, mode and conditions favouring settlement (46, 50, 51, 52).

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