

SCIENCE NEWS

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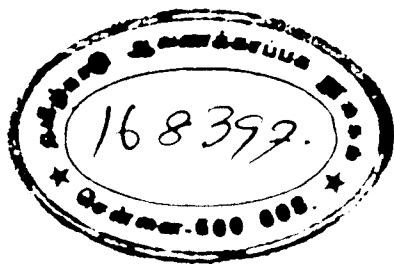
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PENGUIN BOOKS

Penguin Books Ltd, Harmondsworth, Middlesex
 U.S.A.: Penguin Books Inc., 3300 Clipper Mill Road, Baltimore 11, Md
 AUSTRALIA: Penguin Books Pty Ltd, 762 Whitehorse Road,
 Mitcham, Victoria

First published August 1957



72
 Apr 1, 1946
 NS7-45

Made and printed in Great Britain
 by The Campheld Press, St Albans

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THE INTERNATIONAL GEOPHYSICAL YEAR 1957-8

D. C. MARTIN

SINCE the dawn of man's existence on Earth the importance to him of the Sun can never have been in doubt. He had, however, been an inhabitant on the Earth for well over 100,000 years before he discovered the relationship of the motion of his planet to the sun, and only since the scientific revolution of comparatively recent times has he begun to measure the significance of this parent of the solar system on his daily existence.

It is the source of many forces. It not only provides light but, by heating the air and evaporating water, it generates energy which is converted into the air movements that determine our weather. Winds distribute heat from the tropics, transport moisture from the oceans, and cause rain to fall on the land areas. It has been calculated that the kinetic energy of this circulation of the atmosphere is almost equal to seven million atomic bombs. The general circulation of the earth's weather atmosphere is not yet fully understood. Likewise much remains to be discovered about the effect of the sun on the electrified layers in the upper atmosphere, so important in long-distance radio communication. The sun's behaviour is known to cause changes in the earth's magnetic field and to be connected with the appearance of the polar aurorae. What is the connexion between cosmic rays and the sun? What is the exact correlation between all these phenomena? How can we best seek the knowledge required to deal with questions such as these? Man's greatest co-operative scientific enterprise called the International Geophysical Year, which began on 1 July 1957, will be his latest attempt to find out more about the influence of the sun on his planet.

THE FIRST AND SECOND POLAR YEARS

The I.G.Y. is not the first such co-operative enterprise: indeed, it is the direct descendant of two earlier similar studies. Because the earth is a great magnet the polar regions are especially suited to studies of forces of solar origin. For instance, it is in the polar regions that disturbances of the earth's magnetic field are most frequent, and the displays of polar lights - aurora borealis or northern lights in the north, and the aurora australis in the south - are most frequent and vivid in roughly circular zones centred at the geomagnetic poles.

In 1875 an Austrian naval lieutenant called Karl Weyprecht, returning from a geographical expedition in the Arctic, suggested that money spent on such expeditions would yield far better results if they could take place at the *same* time and could make scientific observations at *different* places using the *same* kind of apparatus and following the *same* instructions. At first he received little support, but after five international meetings over a period of six years the force of his arguments prevailed, and in 1882-3 the First Polar Year took place. In that Polar Year twelve stations were occupied in the Arctic by Austria, Denmark, Finland, Germany, Great Britain in Canada, Holland, Norway, Russia, Sweden, and U.S.A. The British-Canadian station was at Fort Rae in Canada. The observations made over the period 1 August 1882 - 30 September 1883 by the scientists of the participating nations related to meteorology, geomagnetism, and the northern polar aurorae. It was a success and Weyprecht's faith was justified. These observations provided information that led to a very marked increase in our knowledge of the geophysical conditions of the north polar regions, and their relationship with similar phenomena at lower latitudes. When, therefore, it was proposed, fifty years later, to plan another Polar Year the idea was enthusiastically received.

Dr J. Georgi is said to have first formulated the proposal, at a meeting in Hamburg in 1927, and an International Commission for the Polar Year was set up by the International Meteorological Organization meeting in Copenhagen in 1929.

Dr D. la Cour was President of the Commission. The world economic crisis of the period created tremendous difficulties which were, however, overcome. This Second Polar Year began on 1 August 1932; 44 countries promised to participate and 22 of them undertook to organize special expeditions. In the Arctic there were 94 meteorological stations. The number of geomagnetic stations north of 60° N. increased from 7 to 30. Again meteorology, aurora, and geomagnetism were the chief subjects for study, but with the addition of scientific radio. Again Britain and Canada established a station at Fort Rae in Canada, but in addition Professor (now Sir Edward) Appleton led a small party of scientific radio investigators at Tromsø in Norway and made important pioneering observations there.

In meteorology the radio-sonde was then a recently designed instrument still in the experimental stage. This is the balloon-borne instrument that measures temperature, pressure, and humidity: it carries a radio transmitter which sends radio messages enabling the observations to be recorded at the earth's surface. It was greatly developed during World War II and nowadays usually carries a reflector for radar pulses enabling wind speeds to be measured. A result of the Second Polar Year was that, for the first time, really reliable information about the Arctic weather régime was obtained. The influence of the Polar Belt on the weather in lower latitudes became better understood.

An indication of the magnitude of the Second Polar Year may perhaps be given by the number of scientific papers listed in the *Bibliography for the Second International Polar Year 1932-33*, issued in 1951: Meteorology (104 papers), Radiation (47), Ozone (9), Aerology (112), Geomagnetism (216), Earth Currents (29), Atmospheric Electricity (48), Radioelectricity (80), Aurorae (77), Cosmic Rays (25), Hydrography (18). The classification is that by authors in the Bibliography, and where there is more than one author the same paper is listed more than once. Even so it represents a large volume of work.

Proposal for a Third Polar Year

Fifty years separated the first and second polar years but, as

mentioned when speaking of radio-sondes in meteorology, techniques still in their infancy in 1932-3 have been greatly developed since then. Ionospheric studies have greatly advanced and have been extended throughout the world; the new science of radio astronomy has appeared and provides new methods of studying the universe around us; that engine of destruction of World War II - the V-2 rocket - was transformed by American research workers into a scientific probe to enter the upper atmosphere and has given rise to the new technique of direct sampling by rocket exploration. The improvements in balloons and the elegant method of recording the cosmic ray incidence by balloon-borne photographic plates with special emulsions and the development of other techniques have placed scientists in a much more favourable position for geophysical studies since the Second Polar Year of twenty-five years ago.

When, in April 1950, according to Professor Sydney Chapman, Dr Lloyd Berkner suggested that it might be worth while having a Third Polar Year at half the time interval between the first two, this was thought to be a good idea, especially by the radio scientists who study the ionosphere.

During this quarter-century, too, the international organization of scientific effort had been strengthened. Some international scientific unions had been in existence in 1932/3, but others had been formed, and after World War II all the international unions had grown in strength, due in part to financial encouragement from Unesco. Their parent, the International Council of Scientific Unions, likewise had much more support and exerted a greater influence in the world of science. Membership of the International Council of Scientific Unions is in two categories: the Unions themselves (scientific members), and participating nations (national members). As a co-operative study would involve a number of different disciplines served by a number of unions, the parent organization was asked to consider a proposal for a Third Polar Year. It possessed the essential elements for the enterprise: the scientific unions to provide specialists and their co-ordinated international opinion, and the nations that would have to finance and carry out the observa-

tional operations. In examining the proposal the International Council of Scientific Unions came to the conclusion that many of the problems to be tackled were essentially of a global character, and that a world-wide network of stations would be necessary for their full investigation. It was therefore decided that the co-operative enterprise should be called The International Geophysical Year, and that it should take place over a period of eighteen months from 1 July 1957 to 31 December 1958, at a time when the sun would be in the phase when it displays a sun-spot maximum. These maxima occur at intervals of eleven years and many of the phenomena to be studied occur more frequently, and more intensely, at sun-spot maximum. The Second Polar Year took place at a time of sun-spot minimum.

In October 1952 the International Council of Scientific Unions set up a Special Committee for the International Geophysical Year consisting of representatives of the Unions concerned with geophysics and geodesy, radio science, astronomy, physics, and geography, together with representatives of the World Meteorological Organization. The Committee was charged with the preparation of a plan and a small bureau of officers was appointed consisting of Professor Sydney Chapman as President, Dr Lloyd Berkner as Vice-President, and Professor Marcel Nicolet as General Secretary. The Special Committee held its first full meeting in Brussels in July 1953 and has held annual meetings in Rome (1954), Brussels (1955), and Barcelona (1956). The Committee's plan for the International Geophysical Year is briefly described later.

THE FORCES TO BE MEASURED

As we have seen, the sun is the principal performer in the study to be made. It will therefore be kept under constant watch by daily visual, photographic, and radio observations. Associated with sun-spots are outbursts on the sun called solar flares which emit radiation of two types, waves and particles, both of which produce several terrestrial effects. The waves, travelling at the speed of light, are of different wavelengths, but all reach the earth after the same time interval of 8.5 minutes, and give rise

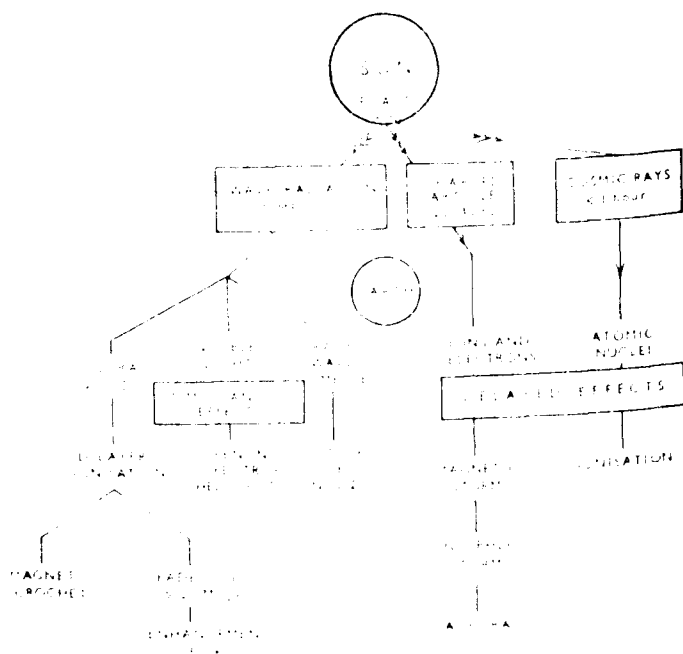


Fig. 1. Diagram of the effects produced by a solar flare when the emitted radiation and particles reach the terrestrial atmosphere. (After M. A. Ellison: *The Sun and Its Influence*, published by Routledge and Kegan Paul.)

to simultaneous effects. The particles have an average speed of 1,000 miles/sec. and the effects of the solar flare, due to particulate bombardment, begin 20 to 30 hours after its appearance. (Inset 11.)

The waves in the visible part of the spectrum (4,000-7,000 ångstrom units) enable the visual astronomer to make their measurements. Those in the ultra-violet and radio wave bands greatly disturb the electrified layers of the upper atmosphere, or ionosphere, and give rise to a number of interesting phenomena that will be studied by the radio scientist. The principal terrestrial

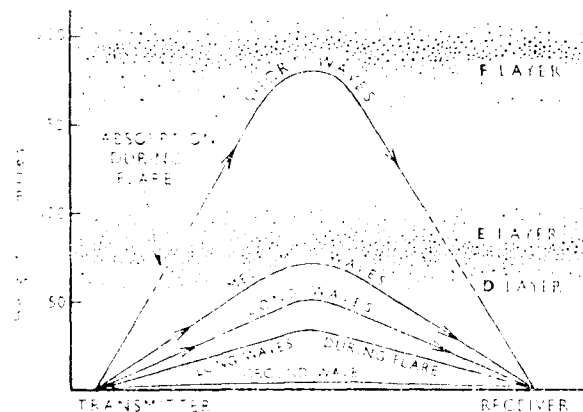


Fig. 2. Diagram showing reflexion of radio waves of various frequencies by the ionized layers in the upper atmosphere. (After M. A. Ellison: *The Sun and Its Influence*, published by Routledge and Kegan Paul.)

effect is manifest through radio—the electrified layers reflecting radio waves and thereby making long-distance radio possible. The sun's emission can give rise to a disturbance that interferes with this reflection and can cause a radio fade-out. Because of the ionizing effect of the solar flare emission on the electrified layers, that part of the earth's magnetism contributed by the ionosphere suffers a sudden change, detectable on the records of magnetic stations and called a crotchet.

Provided the earth is in their pathway, the arrival of the particles from the solar flare cause more marked effects in the form of ionospheric and magnetic storms and brilliant displays of the polar aurorae. The earth being a magnet, the poles exert an attraction on the charged particle jets and the aurora is a visible manifestation, a sort of electric poster sign, declaring to the observer of the night sky that a solar flare had taken place some 24 hours beforehand. The ionospheric scientists are anxious to know more about these ionospheric storms and, like the

geomagneticians, during the International Geophysical Year will observe from a great world-wide network of stations on a scale never attempted before. The incidence and morphology of the auroral displays and their spectrographic analysis can yield important information on solar-terrestrial relationships. Visual observers have been enlisted, especially in the northern hemisphere, not only from professional meteorologists but also from air crews, sailors, and volunteer amateurs. Their observations will be collected in accordance with a carefully pre-arranged plan. In addition photometric, spectrographic, and colorimetric observations will be made, and a recently developed camera, which takes pictures automatically of the whole sky at regular intervals of five minutes or less, will be extensively used. Such methods can only be used in darkness but in high latitudes there are long periods of continuous daylight, so radar methods will supplement visual and photographic methods. Radio pulses are transmitted and the radio echo from the aurora recorded.

Auroral displays occur at irregular intervals usually associated with a solar flare, but each night there is also a continuous very faint atmospheric luminosity called the 'night airglow' which can be detected instrumentally (by photoelectric photometers) all over the globe. It varies during the night and from place to place, and also with the sunspot cycle. Although the spectra of airglow and aurora here contain components in common, the former of much lower excitation energy, distinct differences have already been detected. Its spectrum contains hydroxyl bands and lines of atomic oxygen and sodium. The airglow will be studied on a world-wide scale for the first time.

Among the particles that come from the solar flare the fastest are similar to the primary cosmic rays. They are charged atomic particles which travel at a speed approaching that of light. In a recent solar flare, in February 1956, the cosmic ray intensity was very greatly increased. The origin of the cosmic radiation is still a mystery. Most cosmic rays are believed to come from interstellar space; the sun is not the only source, but an effort to understand more about the relationship will be made. A world-wide network of stations to map the intensity of the high

and low energy cosmic radiation reaching the earth's surface has been set up for the first time. The primary radiation is being studied at great heights by balloons, rockets, and artificial earth satellites.

Records of atmospheric movements in the upper and lower atmosphere will be made. Ionospheric drift is the phenomenon in which horizontal movements take place in the various ionized layers. Among the methods being used for its measurement are radar reflections from ionized meteor trails and also suitably spaced receivers 'listening' to radio star emissions coming through the ionosphere to stations on the earth's surface.

The general circulation of the lower, or weather, atmosphere is the domain of the meteorologist, and a better understanding of this circulation is his chief aim during the International Geophysical Year, when he will make a very extensive study over a greater area of the earth's surface, and send his airborne instruments to higher levels, than ever before. He will seek more information about the jet streams that occur in regions used by modern high-flying aircraft. The influence of mountain masses, the oceans, and the continents, including Antarctica, on the general circulation is being examined. World-wide records will be made of the solar radiation each day. The distribution of the atmospheric layer of ozone, which shuts off from the earth the short-wave or ultra-violet radiation from the sun, will be measured and its variation with latitude and seasons recorded. Thunderstorms, which occur at all hours of the day and night somewhere or other in the world, will be recorded by radio reception of the radio waves from lightning flashes. Cloud cover will be recorded photographically. A late addition to the programme was the suggestion to measure the nuclear radiation of the atmosphere and of precipitation, with possible extensions to oceans and glaciers.

Glaciers cover about ten per cent of the earth's surface (nearly sixty million square miles). They are present in every continent and it is intended to prepare a comprehensive world survey of glaciers. An attempt to measure the total ice content of the Antarctic ice cover is to be made. Present estimates show

that it represents fully eighty per cent of the entire glacial area of the world. Other glacial studies relate to the wastage and accretion of glaciers and the influence of varying meteorological conditions on them. Further evidence from the melting of glaciers of the gradual warming up already detected in certain northern hemisphere regions will be sought. Comparison with measurements of glaciers made now and in the future will enable slow climatic changes to be measured. Such changes could have very important economic consequences not only on agriculture but also through the raising of oceanic levels bringing danger to low-lying coastal towns. (Inset 15.)

The circulation of ocean currents is to be the main study of the oceanographers. The interaction between the atmosphere and the sea is important for the circulation of both. Although good charts of monthly average surface currents in ocean areas on regular sea routes are available, little is known of day-to-day changes. Even less is known about deep-water movements. Some fifty ships will help to study a variety of oceanographic problems, including a more intensive study of the balance between arctic and temperate currents in the Atlantic and Pacific Oceans, and the changes in the physical and chemical properties of the water at all depths in the main ocean basins during the last twenty-five years. New deep current measuring techniques will be employed. Tide gauges and long-wave recorders have been installed, especially on seldom visited islands, to supplement existing installations. Changes in mean sea level have important consequences for engineering if only in relation to the cost of providing protection against the risk of coastal floods.

The measurement of electric earth currents is also part of the programme of the International Geophysical Year, and opportunities will arise for recording earthquakes and making gravity measurements at out-of-the-way places where temporary observatories have been set up.

Another section of the observations relates to a world programme of determination of longitudes and latitudes which will result in an improvement of mapping the world by relating more exactly the geodetic networks of the continents. This will

be done by photographing the moon against a background of stars and using it as a triangulation point. Uncertainties of inter-continental distances, which are now as much as 300 feet, will be considerably reduced. It has been found that the earth's rotation varies slightly owing to meteorological causes, and as the result of synoptic astronomical and meteorological information being obtained it may be possible to elucidate the relationship. Comparison with two earlier longitude and latitude surveys should determine whether the continents on opposite sides of the Atlantic are drifting apart. The advent of quartz crystal clocks provides improved accuracy in time keeping and accurately timed reception of radio time-signals at various observatories will provide much information about the speed of propagation of radio waves, and this will be linked with the studies on ionospheric conditions.

Throughout the whole range of the studies of these physical forces acting on the earth, its oceans, and its atmosphere, none can be isolated. As we have just seen, longitude and latitude determinations are linked to the ionosphere and to meteorology: meteorology is closely linked to oceanography and glaciology: the ionosphere with geomagnetism: magnetic storms with the aurora. All relate to the sun. The correlation of each set of studies called for a master plan from the Special I.G.Y. Committee.

THE PLAN

The first step was to have a series of selection principles for the preparation of a programme which would have due regard to available resources of techniques and personnel. These principles were such as to include only:

- (a) Problems requiring synoptic observations at the *same* time at many different places on the earth's surface: problems that could only be undertaken by the *co-ordinated* effort of many nations (e.g., meteorology and ionospheric studies).
- (b) Problems, the solution of which will be assisted by the availability of synoptic observations (e.g., variation of earth's rotation in the longitude and latitude programme).

(c) Problems to which a contribution is possible because temporary observatories will be located in seldom visited parts of the earth's surface (e.g., gravity and earthquake measurements in Antarctica).

(d) Problems that require measurements of slowly varying geophysical phenomena for comparison with similar future observations at later epochs (e.g., geodetic and glacier measurements).

Nations were each asked to prepare a programme complying with these selection principles and given a number of sectional headings, e.g., solar activity, certain aspects of meteorology, ionospheric measurements, geomagnetism, aurora and airglow, cosmic rays, etc. Tentative programmes were submitted after those concerned in the various countries had discussed the question in detail. In Britain it was done through the National Committees of the Royal Society in the subject divisions concerned. These were then co-ordinated at plenary meetings of the Special Committee and experts from participating nations. The plenary international meeting in Rome in 1954 revealed that enthusiasm was mounting for this enterprise which was being supported on a scale beyond the hopes of its originators. It was at Rome, too, that the U.S.S.R., which occupies a large area of the earth's surface, announced that it would take part, thus substantially extending the area of observation. At present the number of participating nations is fifty-seven.

Six principal zones have been selected for the network of observatories over the earth's surface: two polar regions, the Arctic and the Antarctic, the equator, and three north to south meridians at 70°-80°W. through the American continent, 10°E. through Europe and Africa, and 140°E. through part of U.S.S.R., Japan, and Australia. These will be regions of specially intensive study, but there will be observatories elsewhere as well. In meteorology, aerological cross-sections will be along the meridians mentioned above, but also along 20°W., 30°E., 75°E., and 180°E., as well as 5°S, the equator, 5°N. and 40°N. (in North America).

Many observations will be carried out daily. For example, aerological stations will make two radio-sonde ascents and four

radar wind soundings each day, but a more extensive programme is planned for certain selected days to be known as Regular World Days. The calendar for the I.G.Y. shows that these Regular World Days occur at the rate of about three per month. One will be at the time of the new moon and others at times of unusual geophysical interest, e.g., at times of solar eclipses and unusual meteoric activity. Again, special arrangements have been made for the meteorologist for whom it is important to have continuous periods of intensive activity. Thus in each of the six three-monthly periods of the Geophysical Year ten consecutive days to be known as World Meteorological Intervals have been designated in such a way as to come at the summer and winter solstices and at the two equinoxes.

This selection of special days takes care of the regular and predictable aspects of the Geophysical Year, but some of the studies will concern unpredictable events that are dependent on solar disturbances, especially solar flares. From the continuous watch of the sun, astronomers can usually indicate a few days in advance that a disturbance may happen. Based on this prediction a World Alert will be announced from a centre in the U.S.A. and be sent immediately to national centres throughout the world. Each national centre will then warn all its observers so that they will be in readiness to give their closest attention to phenomena such as ionospheric disturbances, magnetic storms, and auroral displays. If the disturbance does not come about in the following few days there will be an All-Clear. Usually the disturbance will take place and the All-Clear will be given after the disturbance has subsided or passed with the rotation of the sun. This is a very important feature of the programme and rehearsals of the warning were conducted during the first six months of 1957.

Table I gives an idea of the number of stations in each discipline in the various geographical zones.

For each principal subject division a member of the Special Committee for the International Geophysical Year acts as a Reporter; for example, Professor Sydney Chapman is Reporter for aurora and airglow, Dr W. J. G. Beynon of Swansea is

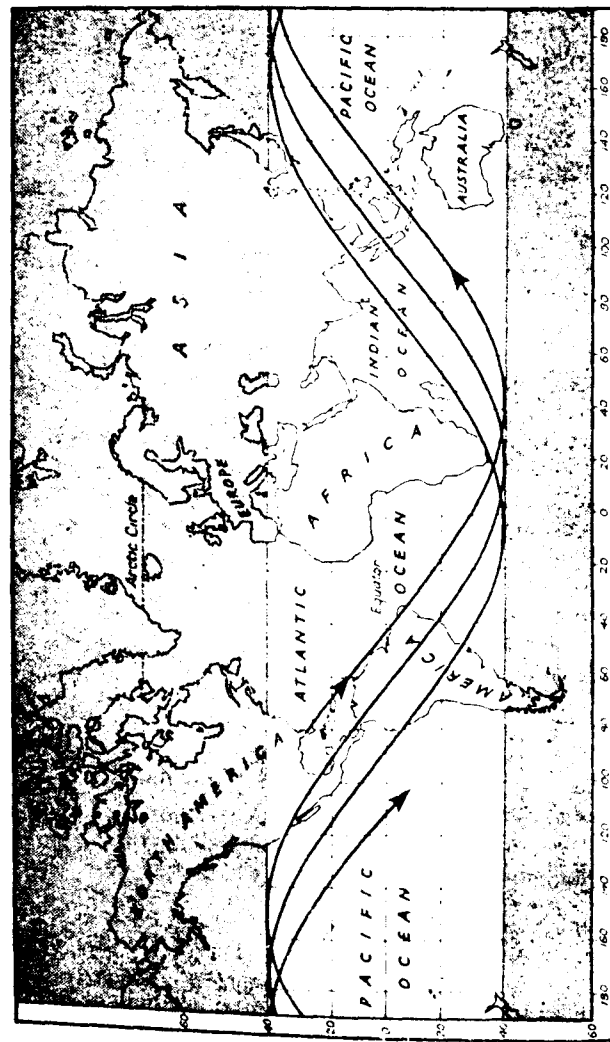


Fig. 3. Owing to the rotation of the earth the 90-minute revolution of the satellite brings it to a point about 25° W of its starting point. This map indicates countries over which the satellite is expected to travel on successive revolutions.

TABLE I: *International Geophysical Year Stations*¹

Subject Division of I.G.Y.	NA	NB	NC	CE	SC	SB	SA	Total
Meteorology	81	123	126	73	107	16	33	559
Geomagnetism	50	44	37	23	10	7	25	196
Aurora and Airglow	58	74	20	9	4	9	26	200
Ionosphere	48	64	39	40	21	7	17	236
Solar Activity	3	39	29	6	4	1	—	82
Cosmic Rays	19	28	20	15	5	7	6	100
Latitude and Longitude	—	27	14	3	7	1	5	57
Glaciology	7	1	3	1	2	—	31	45
Oceanography	9	7	21	34	24	4	16	115
Rockets	3	2	4	—	1	—	—	10
Seismology	6	6	18	15	12	1	12	70
Gravimetry	3	12	11	17	12	4	7	66

¹The figures are taken from CSAGI 'Geographical Distribution of the I.G.Y. Stations' issued in 1956. There have been many additions since then but the table indicates the distribution of effort in the various sections of the programme.

NA - Arctic region

NB - Northern Subauroral zone

NC - Northern Minauroral zone

CE - Equatorial belt

SC - Southern Minauroral zone

SB - Southern Subauroral zone

SA - Antarctic region

Reporter for the ionospheric section, and Sir James Wordie for glaciology. Reporters are responsible for important co-ordinating measures especially with national correspondents and national committees in each country participating in their respective sectors of the programme. Besides simultaneity of observation it is highly important that, at all the different stations, observations should be made by the same kind of instrument in the same way, and that they be recorded in the same manner so that the records can be easily compared and analysed. This has involved careful standardization of instruments and the preparation of instruction manuals setting out precisely the methods of observation and the form of recording them. The Reporters are responsible for preparing these manuals, the first of which were issued in a preliminary edition in the early autumn of 1956 for the Antarctic expeditions.

A definitive edition of the manuals is being issued as part of the publication programme of the Special Committee in their publication *The Annals of the International Geophysical Year*. The programme also includes the publication of an introductory volume giving the history of the two Polar Years and the genesis of the International Geophysical Year. The *Annals* will also contain the official proceedings of conferences and a special volume of data about basic solar activity.

Adjoint secretaries have been appointed by the Special Committee to assist in regional co-ordination. The first and a very important region that called for co-ordination was the Antarctic. M. Georges Laclavere, Secretary-General of the International Union of Geodesy and Geophysics, was appointed adjoint secretary for Antarctica and he has presided over four Antarctic Conferences that have given a coherence to the Geophysical Year programme in that remote and inaccessible continent, in and around which there are now over fifty temporary stations ready to make a concerted attack on the geophysics of the region. Apart from the selection of sites to provide the desired coverage from the scientific standpoint there are three main activities for which co-ordination is essential, namely, radio communication, weather forecasting, and mutual support

(by sharing facilities such as aircraft and medical services in any rescue activities). In these polar regions radio communication is in itself very difficult, but the situation is aggravated by the claims of ionosphere, radio-sonde, radio astronomical, and other studies on the available radio wavelengths. Mr A. H. Sheffield of the British Colonial Office has been chairman of the group asked to sort out this very difficult situation and he has rendered outstanding service in doing so. Each expedition has been furnished with a special Radio Communications Manual which should be of great service to these Antarctic geophysicists.

Regional conferences have also been held in Stockholm for the Arctic Region, in South America for the Western Hemisphere, in Tokyo for the 140° E. meridian and Pacific, and in Moscow. To assist further in the co-ordination of operations Vice-Admiral Sir Archibald Day has been appointed as a member of the central secretariat in Brussels.

Treatment of Observations

It is clear that a vast amount of observational information will be collected. It has been agreed that all the results are to be deposited where they will be freely available to all scientists who desire to have them. This will be done in World Data Centres. One will be in the U.S.A., another in the U.S.S.R., and a third in another part of the world where there are traditional reasons for so doing, and where usually there are experts who are specially experienced in dealing with the information. In some subject sections, such as ionospheric observations, there will be regional centres sharing the collection in, say, Europe, U.S.A., U.S.S.R., and South East Asia and Australasia, but each region can exchange with the other collecting centres. A working group has been charged with sorting out the many problems which tend to be different in each subject section of the programme. In meteorology each participating nation will send copies of its observations on special forms to the World Meteorological Organization in Geneva, where they will be photographed and reproduced in micro-card form which can then be purchased by institutions desiring to have them.

In Britain there will be a World Data Centre for glaciological reports (British Glaciological Society), a regional centre for Europe for visual auroral information (University of Edinburgh), and a regional centre for ionospheric observations (the Radio Research Station at Slough).

Some discussions have taken place about the use of machines for analysing the results and as far as possible this will be done.

ROCKETS AND ARTIFICIAL SATELLITES

By indirect methods, such as the use of radio waves, we can learn a great deal about the upper atmosphere, but direct sampling is another and in some ways a better method. We can, for instance, go through the screening layer of ozone and measure the whole of the sun's radiation and not only that part which penetrates the layer. If we can carry a magnetometer into the upper atmosphere we can make a direct measurement of the magnetic field there. The state of ionization in the ionosphere can be directly measured and the behaviour of winds at great heights can be determined by injecting into the high atmosphere metal foil (the 'window' of World War II) and following its path by radar from the ground. By carrying a microphone aloft the number of micro-meteorites falling through the atmosphere can be estimated. By making suitable ground measurements of the sounds made by bursting grenades at high altitudes we can measure temperature, atmospheric pressure, and wind distribution. All these things can be done by sending rockets into the upper atmosphere to heights of 100 miles or more. As already mentioned the Americans have pioneered rocket exploration, starting with the V-2 rocket, and going on from there to make truly remarkable progress. During the International Geophysical Year, U.S.A., U.S.S.R., Australia, France, Japan, and Britain, intend to launch rockets from various parts of the earth's surface. Two American adaptations for rocket work will come into action, the 'rockoon', which is a rocket carried on the first part of its journey by a balloon and then fired, and the 'rockair', the rocket launched from an aircraft. Rockets will also be launched from ships at sea. (Insets 19 to 23.)



Fig. 4. Orbit of the U.S.A. artificial earth satellite. It will travel in an elliptical orbit round the earth in an apparent latitude range of about 40° on either side of the equator.

The British research programme is only in the second year of its development. It is carried out jointly by the Royal Aircraft Establishment, which will provide the rocket vehicle, and, on an Air Ministry vote of funds, by the Gassiot Committee of the Royal Society, which is co-ordinating the various university research efforts to provide the instruments that go into the rockets. The first trial firings took place in February 1957 at the Woomera rocket range in Australia. The rocket vehicle has been given the name 'Skylark' and it has been aptly described as looking like a dart with a motor. Power is supplied by the Raven solid fuel motor which burns for 30 seconds. The 1,800 lb of fuel is a plastic mixture of ammonium perchlorate, ammonium picrate, and a polymeric hydrocarbon. The total weight of the vehicle is 2,500 lb and it will carry 150 lb of instruments including a telemetering installation to radio back messages

of its instrumental observations. When properly developed it is expected to reach a height of 130 miles. It will be launched from an 80-ft-high launching tower. (Inset 24.)

There are, of course, serious limitations to rocket exploration of the upper atmosphere. The sampling and measuring are very localized and last only for a very short time. As our American colleagues say, we need a 'long-playing rocket' and if we could send up an artificial moon which would circle the earth we could overcome these shortcomings of the rocket. This is just what they plan to attempt. The U.S.S.R. has also announced an intention to launch artificial earth satellites. Under the aegis of the I.G.Y. both countries have agreed to use the same radio transmission arrangements to enable the satellites to be tracked by the same equipment. The Americans plan to launch about 12 artificial satellites from Cape Canaveral on the east coast of Florida. There will be a three-stage rocket assembly to put the satellite in its orbit. The first stage will take the vehicle 40 miles up and give it a terminal speed of 3-4,000 m.p.h., the second 130 miles high and a terminal speed of 11,000 m.p.h., and finally the third stage about 300 miles high for the ejection of the satellite itself into its orbit at a speed of 18,000 m.p.h. The satellite, which is a sphere about 20 inches in diameter and weighing 18.5 lb will then circle the earth in an elliptical path between 200 and 1,500 miles from the earth's surface. For some time it will make its circuit in ninety minutes, but the resistance of the atmosphere will tend to drag it. It will move towards the earth where eventually it will burn up owing to the friction of the earth's denser atmosphere. Tracking will be by radio and visual means. If this exciting and ambitious project is brought to a successful conclusion before the end of I.G.Y. it will be a tremendous technical achievement.

Apart from launching satellites, Britain will be participating in each section of the International Geophysical Year programme. The new giant radio telescope at Jodrell Bank now under construction will make a unique British contribution. The British programme is being co-ordinated by the Royal Society. Much has been written elsewhere about the Royal Society's

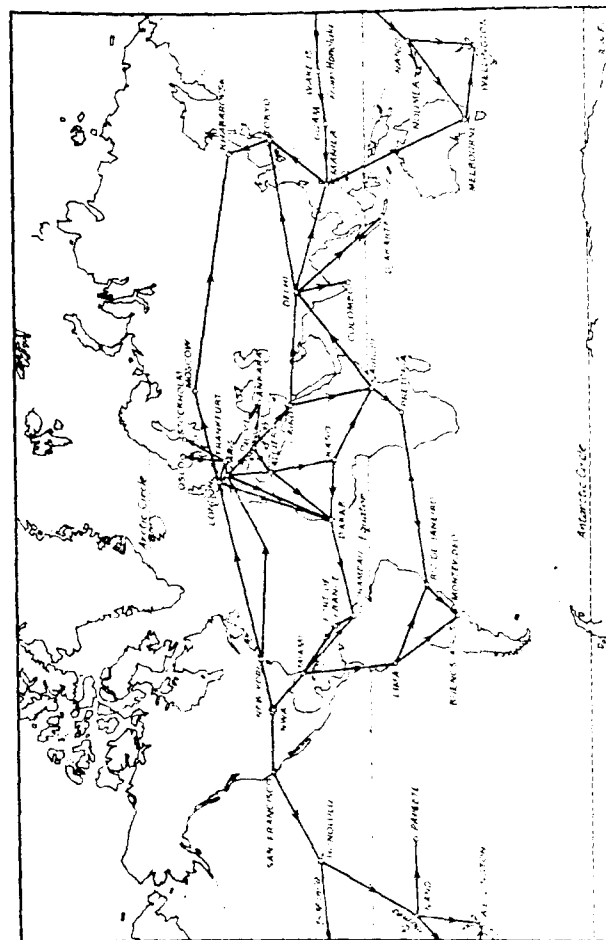


Fig. 5. I.G.Y. Special World Intervals are declared at times of unusual geophysical activity. The alert is communicated to observers throughout the world at high speed using the Meteorological Telecommunications networks shown here.

successful establishment of its Antarctic base at Halley Bay. Because of difficulty of access, the base had to be put in hand in good time to prepare for the full programme of observations which will be made from 1 July 1957. This is only the overture to the great work that lies ahead. As in a symphony the orchestration of the many instrumental contributions will produce results that none alone can achieve. (Insets 12 and 13.)

Primarily we seek new knowledge, but practical results will undoubtedly follow in the shape of improved weather forecasting, improved long-distance radio communication, and a better understanding of the conditions future high-flying aircraft will encounter.

The great co-operative enterprise in science has caught the imagination of many who are not scientists. Perhaps its successful completion will provide a hopeful example of peaceful international co-operation that will have results beyond science and be of benefit to the world community at large.

NUCLEAR COLLISIONS

P. E. HODGSON

PART I

ONE of the best ways of finding out about the properties of atoms and their nuclei is by studying what happens when two of them collide. If the collision takes place at a low energy only the outer electrons are affected. At higher energies the central nuclei themselves come to play a more and more important part in the collision, while at the highest energies the interaction between the nuclei is alone important. Indeed, at the highest energies a fast-moving nucleus cannot hold on to its retinue of electrons; they are torn away by the medium through which the nucleus is moving and are soon left behind. Collisions at lower energies are called atomic collisions; those at high energies, when the effects of the electrons may be neglected, are called nuclear collisions.

A collision between two nuclei is similar in many ways to that between two billiard balls, and, while recognizing its limitations, it is useful to keep this analogy in mind. When one billiard ball hits another its direction of motion is, in general, changed, and it moves on with diminished velocity. The energy it loses is transferred to the struck ball, which moves off in another direction. The same happens with nuclei, although now the collision takes place in three dimensions while in billiards (unless we are immoderately vigorous) it is confined to the surface of the table.

Newton's laws of conservation of energy and momentum can be applied to both types of collision; they give a simple relation between the energies and directions of motion of the particles before and after the collision. In the special case when the masses of the two colliding particles are equal this gives the simple result that the directions of motion of the particles after

the collision are at right angles to one another, irrespective of the other characteristics of the collision. Billiard balls behave in this way to a high degree of accuracy, with only slight divergences from theory owing to small effects like air resistance, friction, and the internal vibrations of the balls. Nuclear collisions obey the law even more accurately as there is no friction or air resistance for them; there can only be internal vibrations if one or other of the colliding particles is composite, and even this only occurs if the energy of collision is rather high.

A photograph of the collision between two protons (nuclei of hydrogen atoms) inside a photographic emulsion is shown in Inset 7. These emulsions are specially made so that, after processing, the path of any charged particle that has passed through it is revealed as a line of black grains of silver halide, rather like the vapour trail of an aeroplane flying at a very great height in the sky. The tracks formed in this way by nuclear particles are very small, but, using a powerful microscope, they can be seen clearly and also photographed. In the collision shown, one proton has entered the emulsion from the left and hit a stationary proton, perhaps one forming part of a water or organic molecule in the gelatin. After the collision, the incident proton was deflected and the stationary one knocked on. The angle between their directions of motion after the collision is seen to be close to a right angle, the slight divergence resulting from the plane of the collision not being exactly parallel to the plane of the emulsion. In the photograph we therefore see the projection of the angles between the three tracks on the plane of the emulsion. Accurate measurements of the real angle can be made with a microscope and these show that, within the uncertainties of measurement, the angle is ninety degrees. Furthermore, the energies of the two protons immediately after the collision can be found from the distance they travel through the emulsion before stopping. The ratio of these energies agrees with that calculated from Newton's laws. If the experiment were done in a cyclotron, with a particle accelerated to a known energy, this energy would be found to equal the sum of the energies of the two protons after the collision.

There is one important respect in which a nuclear collision differs from one between billiard balls. In the latter case, we can see which of the balls after the collision was the stationary one before it. And even if we could not see the collision directly it would not be difficult to mark one ball so that we would know which was which after the collision. But there is no way of marking protons; as far as we know they are all indistinguishable. So we have no means of knowing which of the two tracks after the collision belongs to the proton that was originally at rest, and which belongs to the one that struck it. This is illustrated in Figure 1. Indeed, it may not even make sense to ask this question. It is likely that during the collision the two protons

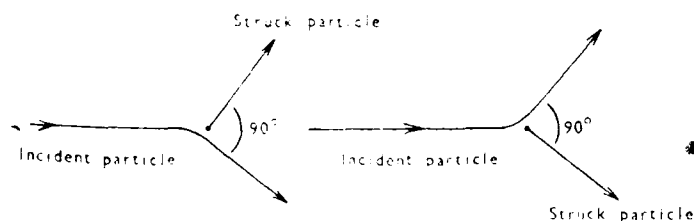


Fig. 1. Diagram showing two possible interpretations of the collision between two protons shown in Inset 7. There is no way of distinguishing between these interpretations.

interact strongly with one another, and are momentarily merged into a 'two-protonhood' which then separates into individual protons once more. Newtonian mechanics is unable to cope with this aspect of the collision but quantum mechanics can, and it gives results in agreement with a wide range of experiments.

It should also be added that at very high energies when relativistic effects become significant the angle between the directions of the particles after collision becomes rather less than ninety degrees. This effect can be accurately accounted for by relativistic quantum mechanics.

Another important characteristic of the collision is the probability of it happening at all. In billiards you can aim carefully

and be almost sure of scoring a hit. But nuclear particles are so small they cannot be seen to aim at; and even if they could be seen there would be no way of aiming our moving proton at one of them. So all that we can do is shoot lots of nuclear particles at a target and hope that some of them hit the nuclei of the material constituting it. This is often called a scattering experiment, from the way the incident particles are scattered in all directions by the collisions they make. In a particular experiment of this sort the probable number of hits is given by the product of the number of incident particles, the number of nuclei per unit volume of the target, and the cross-section of each nucleus for the type of projectile used. Other things being equal, the cross-section determines the probability of collision.

With billiard balls, the collision cross-section is simply the area of any section through the centre of the ball; it equals πR^2 , where R is its radius. It can be measured by a pair of callipers, is sharply defined, remains constant, and does not depend on the type of collision undergone by the ball.

• For nuclear particles the situation is much more complicated. In the first place they do not have sharp edges like billiard balls, but instead are quite fuzzy like a little ball of mist. With billiard balls you either have a collision or you have not; but with nuclear particles you just have less or more violent ones.

To describe collisions it is convenient to introduce a quantity called the 'impact parameter'. It is the perpendicular distance between the centre of the target particle and the direction of motion of the projectile. This is shown in Figure 2. If the impact

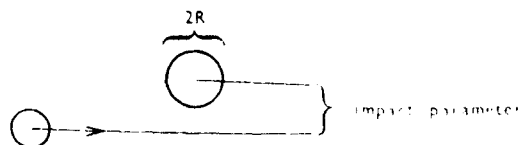


Fig. 2. The impact parameter in a collision is the perpendicular distance between the centre of the target nucleus and the initial direction of motion of the centre of the projectile.

parameter is zero, the collision is head-on; if it is nearly equal to the sum of the radii of the incident and target particles the collision is glancing. With billiard balls, if the impact parameter is greater than the sum of the radii, there is no collision at all; the projectile misses the target. This is not so for nuclear particles, because there is no sharply defined radius. An equivalent R can, however, usefully be defined by the relation $\sigma = \pi R^2$, where σ is the cross-section that can be deduced from the attenuation of a beam of particles passing through a target of known nuclear constitution.

If both colliding particles are charged, as in a proton-proton collision, there is the usual Coulomb or electrical interaction between them. Like the gravitational interaction, this can be represented by a force directly proportional to the product of the charges of the two nuclei, and inversely proportional to the square of their separation. (The gravitational force still acts in nuclear collisions, but it is quite negligible compared with the Coulomb forces.) Using classical electromagnetic theory the scattering due to this Coulomb force can be calculated. It is found to be inadequate to account for all the scattering that is observed, particularly at the higher energies. In addition, there is a strong interaction between neutrons and protons which cannot be Coulomb because one of the particles is uncharged. To account for these effects nuclear forces have to be postulated. Whether they are the same between two protons as between a proton and a neutron is a matter for further study. It turns out that nuclear forces are very strong near the centre of the nuclear particle, but their strength falls off much more rapidly with distance than that of the Coulomb forces. We can therefore think of the range of the nuclear forces as roughly defining the size of the nucleus, while the Coulomb field of force extends out far beyond its fuzzy edge. Particles with impact parameters considerably greater than the sum of their radii are thus still noticeably deflected by the collision.

Unlike billiard balls, nuclear particles have a collision cross-section that varies with the energy of the collision, sometimes by very large amounts. The cross-section also differs for various

types of nuclei. Some have abnormally high cross-sections, like the metal cadmium for low-energy neutrons. Rods of cadmium are therefore used as safety rods in nuclear reactors. If in an emergency we want to stop the reactor it is sufficient to slide in cadmium rods. These rapidly absorb the neutrons and the reaction dies down.

In general, the neutron cross-section decreases with increasing energy. At higher energies, when relativistic effects become significant, the cross-section levels off, becomes constant, and then slowly rises again as meson production begins to take place.

The angle through which a billiard ball is deflected by a collision is determined by the impact parameter. But with nuclei there is no means of knowing what the impact parameter is, so it is more convenient to describe the probability that a projectile will be deflected through a given angle by what is known as the 'differential cross-section'. This is a function of the angle of deflection, and its integral over all possible directions is the total cross-section.

Mathematically it is most convenient to consider any collision process in that system of co-ordinates in which the centre of mass (or gravity) of the colliding particles is at rest; this is called the centre-of-mass (or gravity) system. There are simple formulae that give the energy and angle and cross-section in this system in terms of the corresponding quantities that are measured in the laboratory system of co-ordinates.

Some typical graphs of the differential cross-sections in the centre-of-mass co-ordinates are shown in Figures 3 and 4 for proton-proton and proton-neutron scattering at several different energies. Those for proton-proton collisions are symmetrical about ninety degrees because of the indistinguishability of the colliding particles. Owing to the Coulomb repulsion between the particles the differential cross-section becomes very large for angles near 0° and 180° . At intermediate angles this Coulomb contribution rapidly becomes negligible, and in this region the cross-section is mainly due to nuclear forces. As these alone contribute to neutron-proton scattering, the differential cross-section does not attain such large values at 0° and 180° .

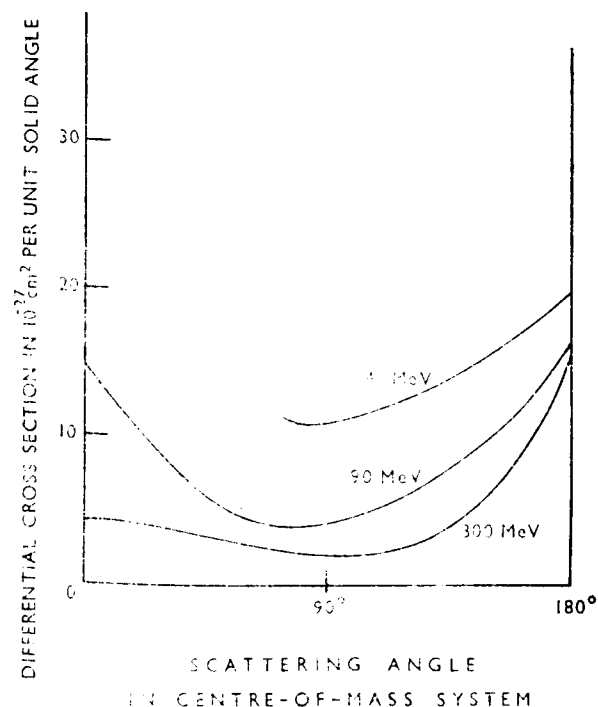


Fig. 3. The differential cross-section for neutron-proton collisions as a function of energy and scattering angles. The energies on the separate curves are those of the incident neutrons in the laboratory system of co-ordinates.

The cross-sections for the two processes in the central (nuclear force) region are very roughly of the same order of magnitude, but show considerable differences of detail. This does not, however, suffice by itself to prove that the proton-proton nuclear force is not the same as the neutron-proton nuclear force because of special effects arising from the indistinguishability of the particles in the proton-proton case. At energies up to about 100 MeV the differential cross-sections can be shown to be not inconsistent with the equality of the two

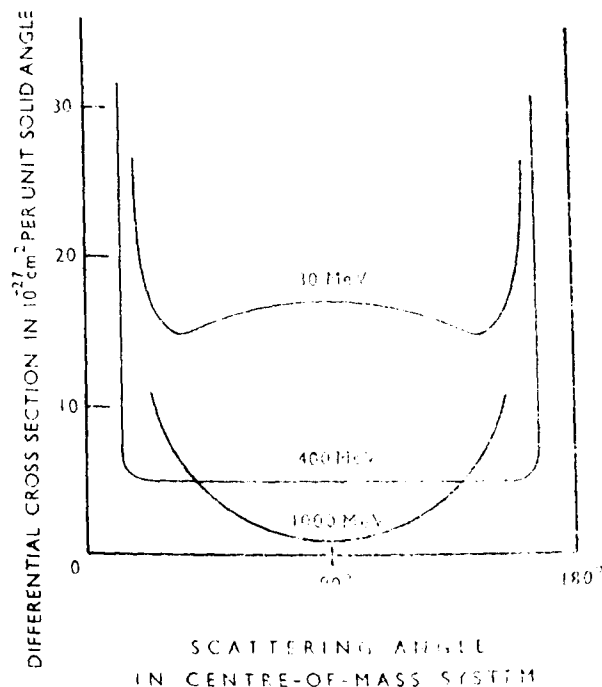


Fig. 4. The differential cross-section for proton-proton collisions as a function of energy and scattering angles. The energies on the separate curves are those of the incident protons in the laboratory system of co-ordinates.

types of force. At higher energies, it is more difficult to say whether the nuclear forces are charge-independent or not.

In each case, as the energy increases, the cross-section becomes steadily less. This may be roughly understood if it is assumed that the disturbance of the incident particle depends on the time it spends within reach of the nuclear field. Then the higher its energy the less time it will spend near the nucleus and so the less its average deflection and cross-section.

The differential cross-section has been measured for very

many different types of collisions as a function of energy. The apparatus used is shown in the schematic diagram of Figure 5. The scattered particles can be detected either by electronic counters, cloud chambers, or photographic emulsions.

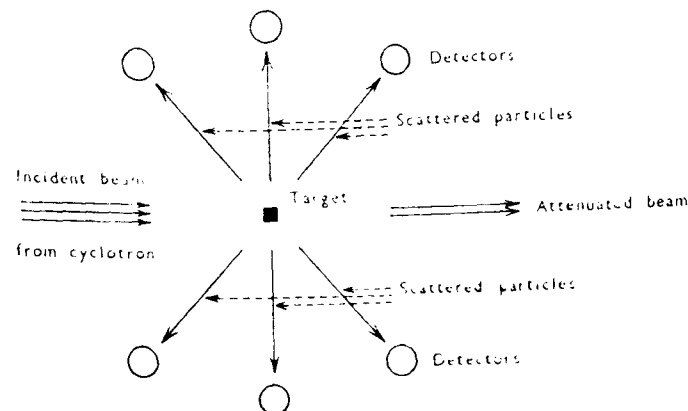


Fig. 5. Schematic diagram showing the arrangement of a typical scattering experiment.

The physicist is not content, however, to stop at the measurement of the differential cross-section for a number of collision processes; he wants to use these data to gain insight into the structure of the nucleus and the forces that hold it together. He does this by making guesses about the probable character of the nuclear forces, and then deducing from his guesses what the collision phenomena would be like if his guesses were correct. If the calculations do not quite correspond to what has been observed by the experimentalist, he alters his guesses and tries again. This activity is called theoretical nuclear physics.

The man who really put theoretical physics on the map was Newton. He was faced with the problem of explaining and understanding the observations of Galileo and others on the motions of bodies on the surface of the earth, balls rolling down planes, projectiles, etc., as well as astronomical observations

on the motions of the planets. Neither the type of interaction between the particles nor the mechanics they obeyed was known at that time. Newton suggested his inverse square law of gravitation and also formulated his mechanics. On this basis he calculated both the motions of bodies on the surface of the earth and those of the planets. Both agreed with observation to a high degree of accuracy; for the first time in history terrestrial and celestial motions had been united by a single explanation.

Newton's laws received one of their first setbacks in the atomic domain. To explain atomic spectra Niels Bohr suggested that electrons rotate in orbits around the nucleus, but he was unable to say why they remained in these orbits and did not continuously radiate energy and so spiral into the nucleus, as would be expected on classical electromagnetic theory. The law of force, the inverse square law of Coulomb, between the nucleus and the electrons was known, but the type of mechanics they obeyed was not. During the 1920s this difficulty was overcome by the development of quantum mechanics which proved able to account to a high degree of accuracy for a vast range of atomic and electronic phenomena. In practice, the chief limitation is the difficulty of solving the complicated differential equations that arise, but whenever they are soluble even by an approximate method prediction agrees with experiment.

A new situation arises when nuclear phenomena are considered because here we know neither the law of force between nucleons (a general term covering both protons and neutrons) nor the type of mechanics they obey. Rutherford used Newtonian mechanics and the Coulomb law of force to get a general idea of nuclear scattering, and some scattering processes (at low energies and when a light particle is scattered by a heavy nucleus) obey the Rutherford formula very well. But this approach cannot give more than a crude picture of most collision phenomena, and it is quite inadequate to account for many of the finer details. So what has been done so far is to assume that quantum mechanics remains valid in the nuclear domain and then to try to find, by a process of trial and error, a good representation of the nuclear interaction.

This approach has achieved some measure of success, although it has become clear that in its present form quantum mechanics is unable to cope successfully with collisions at very high energies or with much of meson physics. When a satisfactory theory of mesons has been developed, it should also cover nuclear phenomena and reveal the form of the interaction between nucleons and the mechanics accounting for their behaviour. But until this has been done there is no alternative but to use the more empirical phenomenological approach.

In the quantum-mechanical treatment of nuclear collisions the behaviour of the system is described by a wave function that satisfies Schrödinger's equation. This wave function can be expressed in terms of the spatial and temporal co-ordinates of all the particles of the system, together with the parameters specifying their internal motion. It is possible to find a solution of Schrödinger's equation that comprises the sum of an incident wave describing the motion of the projectile, and a scattered wave describing its motion after the collision. This gives the differential cross-section as a function of the angle of scattering, and this can be compared with experiments.

In order to find this solution it is usually necessary to solve a complicated differential equation containing explicit expressions for the nuclear interaction.

Mathematically it is convenient to express nuclear interaction between two particles by a potential such that the rate of change of the potential with the distance between the two particles equals the nuclear force between them. The main considerations governing the choice of these potentials are that they should be as simple as possible mathematically, should fall off with distance more rapidly than the potential corresponding to the inverse square law, and should agree well with other nuclear phenomena.

Some of the forms of nuclear force potential in common use include the square, triangular, parabolic, exponential, Gaussian, and Yukawa potentials. These are illustrated in Figure 6. In each case it is the radial variation of the potential that is shown, and this is the same in all directions.

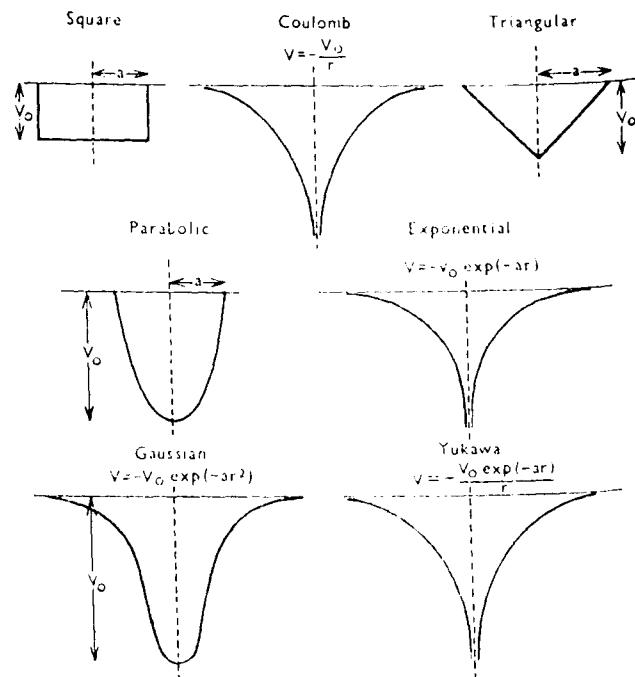


Fig. 6. The radial variations of some forms of potential wells frequently used in nuclear collision calculations.

These potentials have two adjustable parameters a and V_0 . In the square potential, for example, the depth of the well V_0 determines the strength of the nuclear force, and the width a its range or the distance over which it acts, and these parameters enter in a similar way into the other types of potential.

Using nuclear force potentials like these, the characteristic behaviour of some simple nuclear systems at low energies has been calculated. From the mathematical point of view the simplest are the deuteron, a stable combination of a neutron and a proton, and the neutron-proton and proton-proton systems that can only be studied by scattering processes. It was found

that most of the experimental data on these systems could be accounted for quite satisfactorily by any of these types of potential well. In other words, low-energy nuclear phenomena do not depend sufficiently critically on the precise radial dependence of the nuclear interaction for a choice between the various possibilities to be made.

In all these calculations it is assumed that nuclear forces act between pairs of particles. Thus, in more complicated systems, for example, the scattering of protons by deuterons or alpha-particles, the total interaction is found by adding up the interactions due to all possible pairs of particles. But there is no *a priori* reason to exclude the so-called many-body forces which depend on the positions of three or more particles. They have not been considered so far except in a general way because of the great mathematical difficulties created by introducing them. For a similar reason forces depending on the relative velocities of the colliding particles are usually excluded.

One discrepancy manifested itself quite soon. It was found that the wave function and potential that was fitted to give the correct characteristics of the deuteron failed to give the right cross-section for neutron-proton scattering. It was Wigner who pointed out that the likely reason for this was that the directions of the spins of the nucleons had not been taken into account. Most nuclear particles have a spin in addition to their other properties: in pictorial language they are not just little balls but little balls with arrows sticking through them. This spin can be compared with the spin that billiard balls can have, although, as the phenomena become more characteristic of the nuclear domain, these analogies get progressively weaker.

It might be thought that in a two-particle system the spins could have any relative orientation, and that in making calculations it would be necessary to average over all these directions. But in quantum mechanics only a few spin orientations are possible; in this case the spins either point in the same direction or they point in opposite directions, often referred to as the parallel and anti-parallel cases respectively. In a deuteron it happens that they are parallel, so our knowledge of it only

enables us to calculate what happens in a collision between a neutron and a proton in which their spins are in the same direction. But there is also the possibility that they may collide with their spins in opposite directions. These possibilities are shown in Figure 7. When both were taken into account, the discrepancy between theory and observation was cleared up.

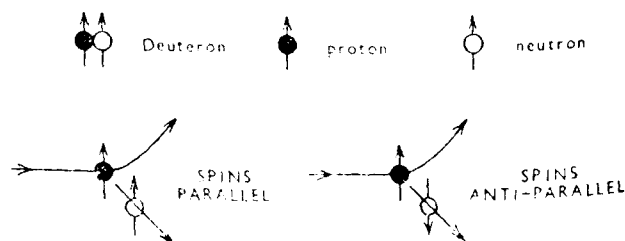


Fig. 7. Schematic diagram showing the spin orientations in the deuteron and in the two possible types of neutron-proton scattering.

These proposed nuclear forces can also be compared with known properties of heavier nuclei. In particular, many experiments show that the nuclear radius is quite accurately proportional to the cube root of the number of nucleons in the nucleus, in other words, nuclear matter has the same density in all nuclei. But forces of the type discussed above would give heavier nuclei that are much denser than the lighter ones. This difficulty can be overcome by postulating exchange forces. These have the property that if the corresponding potential acts on the wave function of two particles, it exchanges either their positions or their spins or both their positions and their spins.

There is a simple consequence of these exchange forces in neutron-proton collisions. If a beam of neutrons hits a hydrogen target, a beam of protons emerges from the other side, going in roughly the same direction as the incident neutron beam. In other words, the cross-section in the forward direction appears abnormally high. This cannot be understood classically, but can be understood quantum-mechanically with the help of exchange forces that have the effect of swapping the particles during the interaction.

A very crude picture can be given of this exchange process. Classically, we might think of a deuteron as just a neutron and a proton stuck together, rather like a white and a red billiard ball. But quantum-mechanically we think of them as bound together by a charged meson field. In one state of the meson field one particle is momentarily a proton and the other a neutron, while in another state the opposite is the case. We can then imagine the redness, which represents the meson field, jumping backwards and forwards from one ball to the other during the interaction, so that each nucleon is, in turn, a proton and then a neutron. Then when a fast neutron collides with a proton, the charge of the proton may jump over to the neutron, which continues on its way as a proton, with little change in direction.

This theory has been superseded by a more general one interpreting exchange forces explicitly in terms of meson field theory. Already it is known that mesons play a major role in holding the nucleus together, but no completely satisfactory theory of how they do this has yet been formulated.

The converse exchange process also takes place. When a beam of fast protons collides with stationary neutrons, a fast neutron beam emerges on the other side. In this case, however, the target cannot be composed simply of free neutrons, since these are unstable, but the same effect is observed with a target of some light nucleus like beryllium, which contains neutrons as well as protons. For collisions at high energies, this is almost equivalent to a target of free neutrons and protons, since the energy of interaction is much greater than that binding them together in the nucleus. This charge-exchange reaction is often used as a way of producing a beam of neutrons since uncharged particles cannot, of course, be accelerated in cyclotrons and other machines. The beam of neutrons produced in this way has a considerably broader energy, and angular spread, than the initial beam of protons, but it is still useful in many experiments.

So far all the nuclear collisions have been interpreted in terms of central forces, that is, forces along the line joining the two nucleons. But in 1940 Ramsey and his colleagues made some observations that indicated that not all nuclear forces are of this

type. They examined the hyperfine spectrum of deuterium and found that it could only be interpreted by supposing that the deuteron has a quadrupole moment. This in turn implies that the force between the neutron and the proton has a component that does not act along the line joining them. The direction of this component is determined by the ways the spins of neutron and proton are pointing. Some very general invariance and symmetry arguments enable the explicit form of the interaction to be expressed in terms of the spin and position vectors of the two nucleons. This non-central force is called the tensor force.

There are also reasons to indicate that the force between two nucleons also depends on the relation of their spins to their angular momenta; this is known as the spin-orbit force. A force of this type is also required by the shell model of the nucleus.

With the addition of tensor and spin-orbit forces, the theory of nuclear collisions becomes much more complicated mathematically than before. At the present time there is a great amount of research in progress to try to account quantitatively for various nuclear collision phenomena in terms of these various types of forces. Much of the numerical work is being handled by electronic computing machines, and already significant progress towards a general phenomenological understanding of nuclear forces has been made.

There are several other phenomena that are often associated with nuclear collisions. Very often after a collision the scattered particles have their spins pointing preferentially in one direction; this can be measured and linked up with other features of the collision. Again, if the energy of collision is high enough, one or more mesons may be produced and ejected from the point of collision. Finally, if one, or both, colliding particles are complex, it may be broken up by the force of the impact. These phenomena will be described in Part II.

(To be continued)

LOGIC AND BEHAVIOUR

F. H. GEORGE

THE scientific study of behaviour has now reached a stage at which more and more attention is being given to the internal workings of the organism, and its relation to outward behaviour. This matter can be put quite simply. There is a need for a predictive theory of the individual organism, as well as for groups of organisms, and this cannot be catered for by a psychological theory that lacks the physiological details.

Behaviourists have carried out investigations of the human being, in terms of external stimuli and responses. This, supplemented by introspective statements, gave us our first scientific theories of behaviour.

This *molar* type of behaviour, as it is sometimes called, is like the study of boxes that cannot be opened. One can see all the overt stimulus conditions and see also the overt responses, and from that, some measure of prediction can be achieved. The next step, following a long period of data-collecting, is to formulate a rigorous theory. This means that some sort of a guess has to be made about the internal mechanism that makes the wide variety of responses of the box possible. In short, by the use of theoretical terms linked by logic to the observable stimulus and response, theories are created.

Such theories make appeal to hypothetical processes, assumed to be going on inside the organism. They are of a postulational character and have the following general form. A model is constructed along symbolic lines – this model can be a mechanical one – and it is constructed in such a way that it can be given an interpretation as a human being, or part of a human being. The process is one of guessing how a mechanism works – from its external appearance alone. A person, having been shown a lock working, might be asked to guess how the internal mechanism

of the lock works. He will guess and then try and show by a series of tests that his model has all the characteristics that a lock requires, and *only* those characteristics. Scientific theories are constructed in just this way.

This form of construction is widely accepted, and we are suggesting only that this method should be supplied with models, built from logic, that are in keeping with the physiological facts. It seems necessary to open the box, or, to drop the metaphor, give our theoretical terms an interpretation based on the latest physiological information. This will still involve theoretical terms, but at least they will cover smaller gaps in our observable information, and this represents scientific progress.

The predictive power of a theory of behaviour that has a sound physiological foundation is bound to be increased, and a step is being taken, at the same time, towards the desirable end of the integration of scientific knowledge.

This takes us a great deal nearer to our goal of being able to give an account of human behaviour, and of understanding it. Our experimental methods, used on both animals and humans, as well as our knowledge of mathematics, philosophy, and logic, all contribute towards this ultimate aim.

In Canada, at McGill University, Professor D. O. Hebb has gone a lot further than most psychologists in trying to develop what he calls a neuro-psychological theory. The task is a formidable one. And even when we are able to state the neurological occurrences that accompany our overt behavioural changes, we have not finished. We must still go ahead and explain these in terms of chemistry and physics, and these in turn can be expressed in terms of the sort of energy changes that are dealt with in thermodynamics. These statements do not imply the classical thesis of reductionism; rather they are meant to suggest that there are various levels of language on which theories should be capable of being stated. These problems Professor Hebb has been aware of, and he has gone a long way to build a bridge from molar behaviourism to a new physiological behaviourism.

Cortical localization is one of the first problems that the neuro-psychologist and the neurologist have to tackle. Already

it is known that it is not merely a matter of finding more and more detailed information about sets of fixed connexions. The picture is very much more dynamic and more complicated.

It is certainly true that there is some measure of cortical localization; an area of the occipital lobe at the back of the head is clearly concerned with vision, and there are other areas of the brain explicitly connected with speech. There is also a great deal of overlapping of cortical function in different cortical areas. Thus repeated stimulation of the same point of the cortex will not necessarily produce the same response.

No doubt the problem of overlap is to be solved by assuming the presence of a wide variety of different cortical thresholds in any area at any time. This will facilitate the firing of many different circuits that lie closely adjacent to each other, possibly even having certain neurons in common.

The best example of the common interests of psychologists and physiologists is perhaps in the special senses. In vision, for example, there are many properties of the eye that one seeks to explain by appeal to physiological facts. Contrariwise, there are many visual problems that we can only understand in terms of the whole organism, drawing on its full power of storing memories and making logical inferences.

Let me illustrate the point with one example. The problem of seeing surfaces of differing, or similar, colours in varying illuminations is one that combines both points of view. The ability to discriminate brightness differences is something that we seek to explain by appeal to the firing of retinal elements that transmit information along the visual tracts via the lateral geniculate body to the occipital lobe of the cortex. From this occipital lobe it doubtless spreads to the rest of the cortex and also to much subcortical tissue.

If a subject looks through two peepholes at two coloured patches, he will record two colours, and this is a relatively simple (even though not altogether understood) physiological matter. If now the screen with the peepholes is removed, revealing the whole context of the objects, then the subject may be able to see that they are not really two different colours, or even two

different shades of the same colour, because the objects themselves are now recognized, and what we call their actual colour identified. Thus if through the peephole you saw two grey patches, and when the screen was removed you saw that what was actually there was two pieces of coal you would *know*, of course, that they were black. The person who is the victim of this illusion then makes the assumption (perhaps unconsciously) that the greyish phenomenal appearance is caused by the illumination, the difference between the two greys (or blacks) being due to differences of brightness. Under these conditions it is noteworthy that it is difficult, or perhaps impossible, for the person to see the phenomenal colour again, because of his knowledge of the actual colour. This experiment illustrates the interlocking of the process of perceiving with that both of the visual system and the higher cortical centres, which impose on the visual recording apparatus their prior knowledge and expectations. There are many problems of this sort that psychologists and physiologists are trying to unravel, and for this purpose we turn to a new quarter for help.

Logic

The development of informal logic has been a painstaking and lengthy process which goes back as far as human thought. The development of mathematical logic, on the other hand, has been recent and has been largely associated with the name of George Boole. The main body of its development has been towards an understanding of the foundations of mathematics. There has also, however, been a very considerable push towards an unravelling of the linguistic problems that have always been associated with informal logic and semantics.

The use of logic at this level has been of the utmost value to science in general. It has helped us to investigate the foundations of our subject, and to understand what the nature of theory construction is. Indeed our earlier remarks about the use of theoretical terms have been greatly clarified by logical analysis. Psychology has itself been greatly aided by such work, and has also often suffered as a result of ignorance of these very prin-

ciples of logic and philosophy of science. In fact, on the part of psychologists, there is, or has been until relatively recently, a considerable naïvety about logical and linguistic matters. This is partly because they still feel that their main work should be directed towards the task of collecting data, rather than towards formulating theories and testing them systematically.

In practice, this determination to avoid anything even remotely like armchair psychology has led to an enormous mass of experimentation, often of poor quality, and often based on a complete philosophical muddle. There are some signs that this unfortunate phase is passing, and it is becoming recognized that psychologists are, as scientists, as much in need of theory as of experiment; indeed it makes no sense to separate the two. Our concern with logic is not, however, mainly on the lines of rigorous thought, or directed towards keeping the scientist's nose to the logical thinking block. Rather it has a more practical value, and to understand this it is necessary to say a little more about mathematical logic.

One of the problems that beset mathematical logicians was to clarify the foundations of mathematics. So effectively has this been done that, although there are still doubts about these foundations, we have discovered other very important things about the nature of postulational systems. A group of theorems due to Gödel, Church, and Turing can be summarized together. They tell us that no postulational system sufficiently rich to incorporate all classical mathematics can at the same time be both consistent and complete. Furthermore there is no decision procedure for such a system as this. At the same time, many lesser systems were shown to have decision procedures. Let me remark briefly on the nature of a decision procedure or decision method as it is sometimes called.

Professor Tarski, the logician, has described it as follows:

A decision method must be a recipe, which tells one what to do at each step so that no intelligence is required to follow it; and the method can be applied by anyone so long as he is able to read and follow directions.

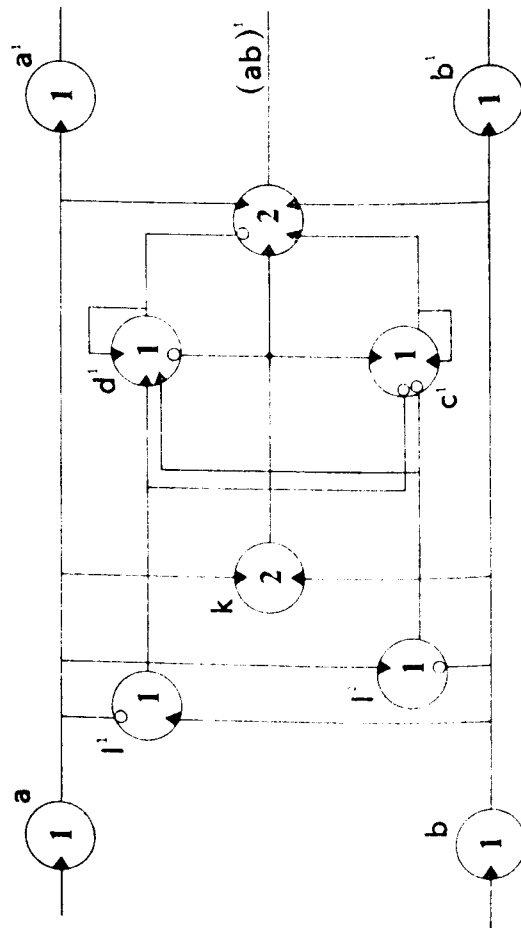


Fig. 1. Diagram of simple idealized nervous system. (For details see opposite.)

There are various examples of such methods. For example, there is an algorithm (yet another name for a decision procedure) called Euclid's algorithm which will tell us whether or not in the elementary theory of integers two numbers are relatively prime or not. If we are presented with a statement to the effect that any two numbers p and q are relatively prime, then the algorithm tells us whether this is so or not.

The use of decision procedures is important because it allows us to know what is effectively constructible in terms of the models that we use to help the development of our scientific ideas. Thus, in particular, a certain use of logic as a system for building machines is known to have such a decision procedure and we know that if we construct a machine – even with a pencil and paper – in terms of the formulae of a certain limited system that is used, it can be effectively constructed.

The formulae we shall discuss are derived from the propositional calculus, and part of what is called the lower functional calculus, and such combinations can be represented in machine form. The great advantage of such decision procedures is that they allow us to study the properties of machines without going to all the expense and trouble of building them, though the building should be done whenever possible.

Logical Networks

It was the insight of Professors Warren McCulloch and Walter Pitts that led to the application of mathematical logic to the study of the central nervous system. They applied the principles of Boolean algebra directly to simple idealized nervous systems. We need not discuss the logical side of the matter here, in so far that we can see even better what the rather lengthy formulae tell us by using diagrams. Let us describe the system of drawing the diagrams (see Figure 1).

The circles will represent cells or elements. These elements can be in one of two states – live or dead. Associated with these two-way, or flip-flop, switches is a threshold number that is written inside the circle. This threshold number tells us that the number of excitatory inputs, symbolized by filled-in triangles

at their endings that are live at any instant, must exceed the inhibitory inputs by at least the threshold number for the element to fire.

In Figure 1, which illustrates all these simple conventions, the k -element's output fires if and only if both the excitatory inputs fire. If the threshold number had been one instead of two, then this condition would have involved the firing of either of the inputs. Either of the l -elements is fired by its excitation input firing and its inhibition input not firing. Figure 2, which shows a network that remembers the occurrence of a and b firing together, or the occurrence of either a and b firing alone, has also got elements – the counters – that fire their output into themselves, so that once fired they will go on firing themselves indefinitely until they are stopped, and they can only be stopped, of course, by the firing of an input of an inhibitory kind.

Let us consider Figure 1 a little more closely. The input elements of the whole net are a and b . When a and b fire together the k -element fires an instant later. The time of the firing of all elements is assumed to be the same, so that exactly one instant after a and b fire, a' , b' , $(ab)'$, and k fire, and an instant after that the c -element fires. If then a fires alone, or b alone, the element $(ab)'$ will still be fired, because of the c -element which has remained live and has been providing one of the two excitatory inputs necessary to fire $(ab)'$.

If a fired alone again $(ab)'$ would not be fired, because the last time it fired alone, an instant later the l -element l^2 fired, and this removed the count from the c -element, or, more precisely, it fired an instant later (two instants after a fired alone) an inhibitor into c^1 and stopped it.

If a had fired alone before it had fired with b , then the opposite sort of picture would have resulted. The element d^1 would have become live, and this 'remembers' that last time a fired it did so without b . This stops the $(ab)'$ element firing, if either a and b occur alone, and even now if a and b occur together. One occurrence of a and b together will overcome this inhibition and the machine will be back at the beginning again.

Now let us explain this logical net another way, by giving it

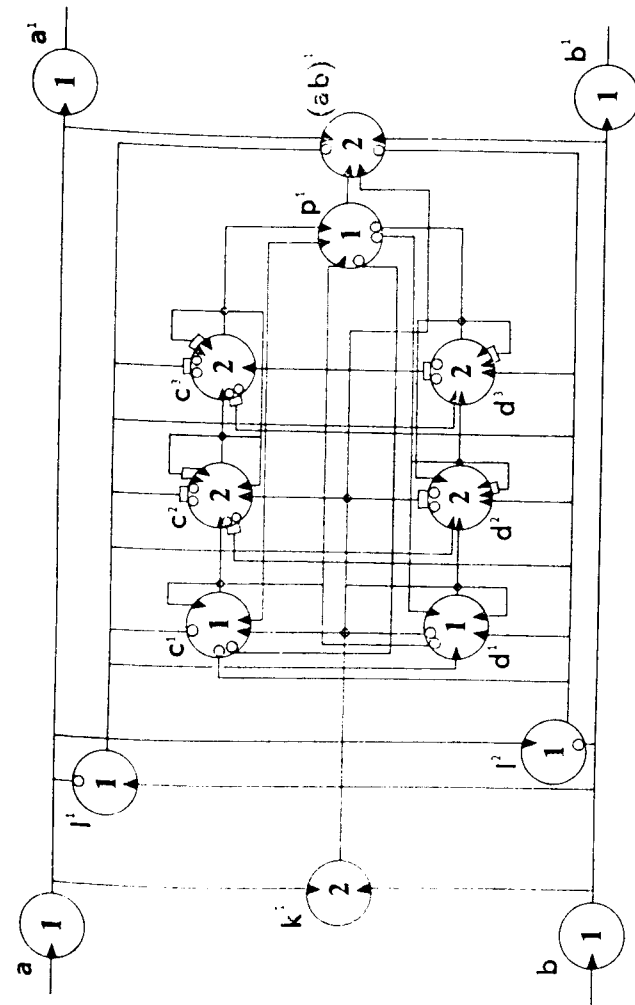


Fig. 2. Learning system with a longer memory than that in Fig. 1. (See p. 54.)

an interpretation in terms of Pavlov's classical conditional reflex theory. Think of a as being a sign for b . This can be made more realistic if we make a fire the instant before b . They will still be counted as firing 'together' because the only change in either Figure 1 or Figure 2 is the inclusion of a delay element which holds up the firing of b for one instant.

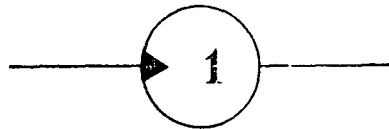


Fig. 3. Diagrammatic representation of delay element.

Now let us think of a as being the flashing of a light and b the presentation of a bone. If a fires together with b the light is followed immediately by the bone. So the appropriate response to a is $(ab)'$, which is a combination of the unconditioned response to light – say curiosity and slight startle – and the conditioned response, which is the salivation, and is b' . We distinguish b' from $(ab)'$ because it is generally felt that the conditioned response is not identical with the unconditional response to the second stimulus – the sight of food. They could, of course, easily be identified, i.e., $(ab)'$ could be made into b' .

Thus if the net in Figure 2 were presented with the food immediately after the light (a delay element is assumed to be included), then it will remember, by virtue of its c -element, and will have acquired a conditioned response. This will be strengthened by a continuing to be followed by b , and weakened if a fires without being followed by b . In this interpretation the case of b occurring without a ceases to be of interest and we can therefore dispense with the l -element.

In short, Figures 1 and 2 represent simple learning systems whose only difference is in the length of their memories. The first can remember up to one conjunction and disjunction of a and b , the latter can remember three such events of each type.

Another way of regarding the same nets would be to think of

them as probability machines. These would respond if the value of the number of times a and b occur together over the total number of times a or b or both fired is greater than some constant value, or critical ratio. This is the same as a Laplacian probability, where the critical ratio is taken to be $1/2$.

The reader may notice however that unless the number of counters available (the number of c - and d -elements) is large compared with the number of occurrences of a and b , the weighting of the machine will be in terms of the recent events only. This means that the distant past will be forgotten. If, on the other hand, there are more counters than events, then the nets will give a straight Laplacian probability. The system can, of course, be wired to give any sort of probability estimate.

If the machine is, as it were, supplied with food after lights it will learn the trick of realizing that the light has come to stand for the food that is to follow. It is also important to notice that the mechanism is a contingent one, in the sense that food will only be presented if the correct response is made. If the wrong response is made to the correct sign, and this could happen for bigger systems where every possible combination of the inputs was counted, then far from food being presented the machine will be punished. The result of punishment will be to score a disjunction to ensure that a particular combination does not fire again. This means that stimulus-response connexions that lead to a satisfying state of affairs for the organism are retained, whereas those that lead to pain are stamped out. This means that there must be a motivational system. Clearly the use of the words 'pain' and 'satisfaction' are interpretations of the system. More realistically, we might say, the correct response is one that stops the firing of some elements – these are not shown in the figures – that continually stimulates the net, and thus allows it to rest. With 'pain' the opposite happens.

The organism must have the motivational system built in, and this system represents certain 'basic needs'. The activity of need-reduction is then the essential mainspring of behaviour. Indeed we shall make the condition that the c -elements will not fire unless need-reduction has taken place, and similarly the

d-elements will not fire unless some unsatisfactory state such as pain follows the organism's response.

Of course there will, almost certainly, in the living organism, be a permanent memory store, apart from the looped-elements, and this could be added to the nets if it were needed. But there is a lot to be said for merely considering the organism's activity in terms of these loops as the only stores. One other fact should be noticed; if it were not for motivation, the organism would not be able to distinguish the use of different words, if say the correct response to two different words both led to satisfaction.

Computers

All that has been said about these logical nets has a considerable bearing on computer design. Indeed we have been giving the design of a computer in the form of a logical net. This is part of the process known as 'cybernetics'.

When one sets out a theory of organism, a theory about how the organism is constructed, one is, in effect, giving a blueprint for the construction of a computer. This means that the whole literature on the design of computers comes within our purview. Methods of storage, long term and short term stores, effective controls, and input and output systems, are all of the utmost interest. The fact that Boolean algebra, too, is of the greatest value to computer design further emphasizes the use of Boolean algebra that we already mentioned in connexion with logical nets.

As with the logical nets, we have an effective method for translating logical formulae into electronic gadgetry. There are components called *gates* utilized in the design of computers that realize the various basic logical operations. The use of triodes, or diodes, with simple components like resistances, is sufficient to mirror the logical operations of 'and', 'or', and 'not'. and the rest of Boolean algebra can be realized in terms of such components. We can translate our theoretical, or paper, machines into electronic form without any difficulty, although in practice there may be many short cuts and conveniences that it would be wise to use.

When we realize the full implications of the fact that logical nets are computing machines, then we see the close relationship that exists between computing machine design and theories of behaviour. For the mathematician it is worth remembering that a Universal Turing Machine – another form of paper machine – is equivalent to a general purpose digital computer, with an infinite number of punched cards, and the possibility of indefinite selection in the re-use of cards already punched. Of rather special interest to the behaviour theorist is the process of programming a computer, because this is equivalent to the business of teaching a human organism.

The Conceptual Nervous System

Now we come to the last aspect of the problems to be dealt with here. What has been said about computers and their design will have led to the realization that we are concerned with the development of effective methods of machine design. Thus, even if the designs discussed and suggested were quite different in their construction from the human nervous system, they would still have their uses. Their principal use under these circumstances would be as machine designs.

The student of behaviour is especially interested in the interpretation of the model that can perform what the human organism can perform. Of course lower level organisms may well form an intermediate step in this process.

Let us remember that our methods of theory construction were such that we used theoretical terms to bridge the gap between the observables in our system. We could at the same time formulate many of the properties that the organism must necessarily have if it is to behave in the way that it does – for example, the need for some sort of storage system is clearly absolutely vital. Thus what we were doing was constructing models that could be given an interpretation that would make them equivalent to a human organism. We agreed that any model might serve our purpose, thus different scientists have used models from hydraulic pumps to particle statistics. We are suggesting now that a logical model, in the form of computers and logical

nets, is especially suitable. This is, essentially, the underlying belief of cybernetics.

Now the next step is to examine our knowledge of human behaviour, as we know it from common observation and from the molar theory of behaviour, and our model of logical nets, and we are now in a position to say something about the nature of the central nervous system. To be on the safe side, let us say rather that such studies lead to what some writers have called a Conceptual Nervous System, and this system should then be matched against the picture of the Central Nervous System we have derived from our neurological studies. In other words what we have to do is to place a neurological interpretation on our molar theory. This is what logical nets enable us to do, while knowing that we bask within logical security. We also know that by the same token we are opening up the way to the general application of mathematics to the biological sciences.

The problem is largely one of to what extent we can make predictions on the basis of these idealized nets. This also raises the real problem of handling large-scale mathematical systems in a predictive manner. But of more immediate importance is the fact that in our logical net model we have made assumptions that are not in keeping with the known facts. Thus the absolute refractory period of every nerve cell is not the same, and of course there is the possibility of neural growth in practice which we are not directly catering for by the methods so far outlined. These omissions are in keeping with the developments of science in its oversimplified initial stages, defects that can later be brought into closer relation with the facts.

In our conceptual nervous systems we have a fairly well-defined system of connexions, but no mention has been made of their initial growth, which is of obvious importance. It may be that the growth of fibres in central nervous tissue is, within certain limits, a random process. These limits are set by use in organisms over thousands of years, and are transmitted genetically from generation to generation. The exact manner of genetic transmission is of course not understood.

Whatever the methods, there is little doubt that distinguish-

able organic characteristics are transmitted, and the structure, potential and otherwise, will largely determine the function of the organism. The higher up the evolutionary scale we go, the more we seem to dispense with the fixed patterns of behaviour that we call instinctive. This fact is well catered for by our conceptual nervous system, because a system of any size can be built upon the smallest nucleus of fixed or built-in activities.

The central nervous system takes on definite structural forms that determine the functions performable by organisms. The well-known swimming reflexes of the salamander depend only on the maturation of the nervous system. This is also in keeping with the design, or could easily be made to be.

Well-localized structures exist in the form of spinal tracts and the controlling areas of the medulla, pons, cerebellum, caudate nucleus, and the cortex itself, which are probably mediating and controlling centres for the whole organism. It seems likely that these important centres are best thought of as large aggregates of elements that are clustered together for the purposes of compactness. We should thus think in part of how we would arrange the elements of logical nets when the number of inputs was of the same order as would be necessary to emulate human activities. At the same time we must bear in mind the dimensions of nervous tissue – Warren McCulloch, for example, has estimated that there are 10,000,000,000 neurons in the human nervous system. Would a logical net containing the same number of elements have the same sort of functional capacities? It seems probable, in fact, that some sort of duplication or other economies are both possible and necessary.

If the neurologist were to set to work to reconstruct all he knows of the workings of the human cortex, using only the well-known properties of nervous tissue, using only the facts of inhibition and excitation, and the all-or-nothing law, the standard knowledge of refractory periods, facilitations, and so on, then he might provide the right sort of picture to compare with the logical nets described in this article. In this connexion it is unimportant that we do not know, for example, the exact nature of inhibition, since all that matters is that inhibition takes place.

As one particular instance of the agreement between our conceptual nervous system and the facts, we might mention the reverberatory circuits that certain physiologists have claimed to observe in the central nervous system; more evidence such as this is greatly to be desired.

Further Developments

The imminent paths of integration in science suggested by this work is of the utmost interest to the development of the whole of science. It is clear that in this article we have not by any means exhausted the possible uses of logic. Other work is already afoot to try to state the nature of the inductive systems used by humans under all circumstances. Thus the *Theory of Games* suggests that the different strategies operated by people – from the extremely pessimistic one of always being prepared to cut one's losses, to the extremely optimistic one of assuming that the best will happen, can all be mirrored in logical nets.

The other big step forward that has been recently taken is the realization that what philosophers of science tell us is the proper procedure for a scientist to go through to confirm his hypotheses, and indeed formulate those hypotheses in the first place, is the same procedure as for a rational machine, and can be pictured by a model capable of showing behaviour closely akin to that of human beings.

We are thus heading towards a complicated model of human behaviour from which we shall ultimately be able, or so we hope, to make predictive statements about individuals as well as groups. During this process of formulating the beginnings of the blueprint, we should devote some part of our time to the construction of some of the models in electronic gadgetry. In this respect the models built by Drs Ross Ashby, Grey Walter, and Uttley have been of the greatest interest, and have had the greatest heuristic value. The integration of the whole of science may be the long term aim, but the short term aim is to interest more and yet more people in the new and exciting prospects that confront the young science of cybernetics.

THE HISTORY OF THE MOON

D. W. ALLAN

As the Earth's nearest astronomical neighbour, the Moon has long been a peculiarly fascinating, if not tantalizing, subject for scientific study. The surpassing strangeness of the surface features revealed in great detail by good telescopes have excited the curiosity of scientists of every age since Galileo's, and speculations on the origin of lunar structures continue to be both numerous and diverse. Seeing that the physical causes of such large-scale surface features of the Earth itself as the great mountain ranges are by no means known certainly, it is not surprising that one cannot make an unequivocal choice among theories concerning the Moon. This does not prevent these theories from being debated with considerable vigour.

Our knowledge of the Moon has advanced considerably since the seventeenth century, when Samuel Butler depicted the 'virtuosi' of the Royal Society as discussing

'Whether the Moon be Sea, or Land,
Or Charcoal, or a quenched Firebrand;
Or if the dark Holes that appear,
Are only Pores, not Cities there.'

but the tone of their argument is not unfamiliar.

The visible surface of the Moon has by now been mapped in more detail than vast areas of the Earth (the Antarctic, for example), and its orbital motion is known with an accuracy perhaps unequalled among determinations of physical constants. Nevertheless, the Moon is still a subject of intense scientific controversy. The manner of its origin is intimately connected with the origin of the entire Solar System, and hence the many unsettled questions concerning the latter are reflected in difficulties in discussing the origin of the Moon. But it is in the interpretation of the surface features that the greatest conflict of opinion

arises. The most striking features, the so-called craters, are now widely believed to be the results of meteoritic impacts, but there are still distinguished scientists who support other hypotheses. Even the largest features of all, the great dark plains called *maria*, which are visible as grey patches to the naked eye, are a source of disagreement. It has lately been argued that they actually consist of rock powder or dust that has settled into flat plains in the low portions of the Moon; the older view is that they are great lava flows. Several types of smaller features, such as clefts and ridges, are still less satisfactorily explained. Altogether, then, although selenography, the charting of the Moon's surface, has reached a fairly high state of development, selenology, the elucidation of the origin and history of the lunar surface structures in terms of reasoned physical processes, remains as yet in a very speculative stage.

HISTORY OF LUNAR STUDIES

Like astronomy as a whole, the study of the Moon reached a peak among the Greeks, then lay largely dormant in medieval times, and has flourished since the fifteenth century, although in modern times progress in knowledge of the Moon has not always been as rapid as astronomical progress generally. It was Galileo's work that truly marked the beginning of modern astronomy. In 1609 he heard that a telescope had been made in Holland, and immediately reinvented it. His genius recognized the suitability of the instrument for exploring the heavens, and the Moon was the first body he studied. The *Sid reus Nuncius* of 1610 produced a sensation by the many new discoveries it contained, including the rough, mountainous appearance of the lunar surface, alike in nature to that of the Earth. England may take some pride in the fact that, in 1609, Thomas Harriot and his pupil Sir William Lower also examined the Moon telescopically though without much benefit to science; Lower gave a unique description: 'In the full she appears to me like a tart that my cooke made me last weeke; here a vaine of bright stuff, and there of darke, and so confusellie all over.'

The other great advance in the seventeenth century was, of

course, Newton's gravitational theory, which he first verified by considering the motion of the Moon. The *Principia* of 1687 also discussed the form of the Moon, explained some of the inequalities in its motion, and gave a theory of the tides. The subsequent development of lunar studies provides an interesting example of the interrelation of theory and observation, with an almost cyclical alternation of refinements of observations produced by improved instruments and advances of the theory to match the accuracy of the observations.

Progress in selenography, on the other hand, seems to have followed a practically independent course. In 1647 Hevelius of Danzig issued the first reasonably good map of the Moon, in which he named over 250 formations after terrestrial objects. The system of nomenclature that has prevailed, however, is not his, but that used on a map of 1651 by Riccioli, a Spanish Jesuit. He named formations after great men (not neglecting himself). Cassini, at the Paris Observatory, also produced a map, this time with positions obtained by measurement, but his main contribution was to enunciate three empirical laws of the Moon's rotation, completely explaining libration.

In the second half of the eighteenth century lunar theory was brought to a new stage of accuracy by Lagrange and Laplace. Among other things, they calculated what the shape of the Moon should be if it were in equilibrium under the forces acting on it, and Laplace, by a marvellous piece of analysis, discovered a secular acceleration in the Moon's motion which Halley (1693), from a comparison of contemporary tables with ancient eclipses, had suspected must exist.

J. H. Schröter published two volumes on the lunar surface details in 1791 and 1802. He introduced the method of measuring heights by the lengths of shadows, and made numerous measurements of crater forms from which he deduced the rule that the volume of rim material generally would just fill the crater depression. The outstanding selenographers of the nineteenth century were Beer and Mädler, who in 1837 published a map based on a painstaking survey of the Moon's surface, and an accompanying book *Der Mond* which gave a full description

of the surface features. They concluded that the Moon was an airless, waterless, unchangeable desert, with its surface broken by vast extinct volcanoes, and their work was considered so authoritative that it had the remarkable effect of suppressing interest in the subject for many years. Interest was to some extent revived in 1866 when W. Schmidt, who observed the Moon at Athens for many years and later published a very large lunar map, announced that there had been an important change on the surface: Linné, formerly described as a distinct and deep crater, was, he said, now merely a white patch. Though this matter can still raise debate, it is very doubtful whether a change did occur.

The nineteenth century saw tremendous advances in celestial mechanics, and such theoreticians as Hansen, Delaunay, Adams, and Newcomb studied the Moon in great detail. Adams again took up the question of the secular acceleration, and found that Laplace's theoretical value was too large, so that there still remained an observed acceleration that was not accounted for; the importance of this is discussed in the next section. At the turn of the century E. W. Brown's exhaustive researches completed the theory of the Moon's motion, and his tables are not likely to be improved upon for many years.

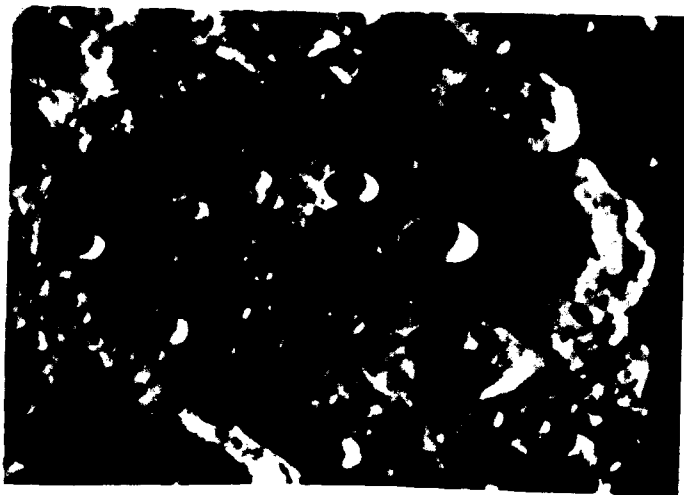
In this century, selenography has remained largely in the hands of amateurs, who have been especially active in Britain. Professional astronomers have not completely neglected the Moon; most of the great telescopes are used occasionally for lunar photography; several of the finest examples are reproduced here. (See Inset.) The recent increased interest in theories of the surface features may presage another period of advance in lunar studies, and it is encouraging to note that one of the most eminent modern astronomers, G. P. Kuiper, has undertaken an extensive observational programme with the 82-inch McDonald telescope, the third largest in the world.

WHAT WE KNOW ABOUT THE MOON

The previous section reviewed the gradual growth of the body of knowledge we now possess concerning the Moon; in many ways this is impressive, but it is still inadequate when one wishes



1. The Moon, age seven days; taken 6 May 1938 with 36-inch refractor. (Courtesy of Lick Observatory.)



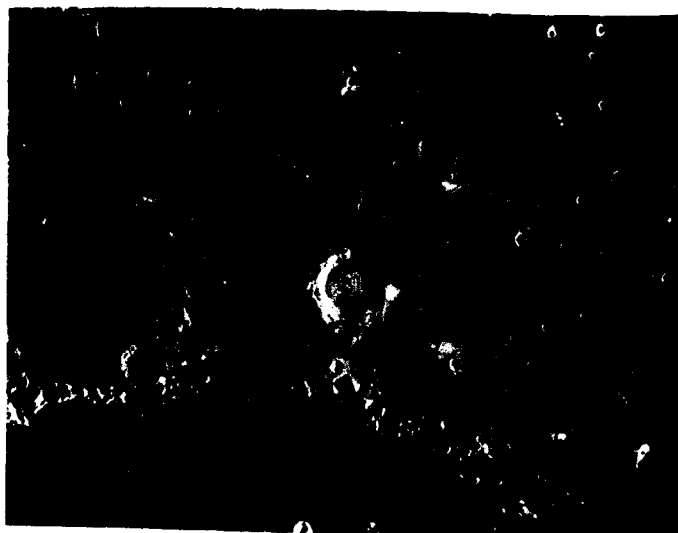
2. Clavius; 200-inch Hale reflector. (*Courtesy of Mt Wilson and Palomar Observatories.*)



3. Wargentín; photograph of a model by J. Nasmyth.



4. Mare Imbrium Region, Archimedes and Plato; taken 15 September 1919 with 100-inch reflector. (*Courtesy of Mt Wilson and Palomar Observatories.*)

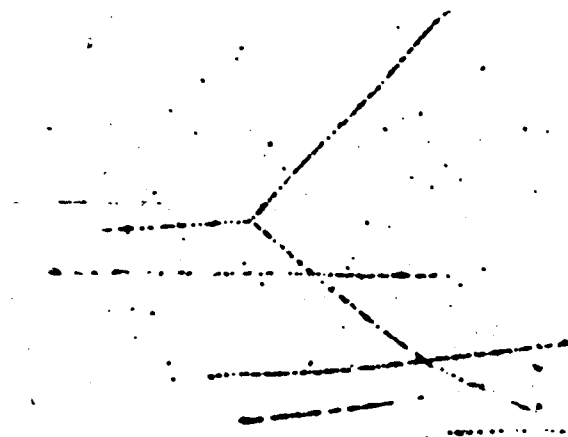


5. Region around Copernicus; taken 15 September 1919 with 100-inch reflector. (Courtesy of Mt Wilson and Palomar Observatories.)

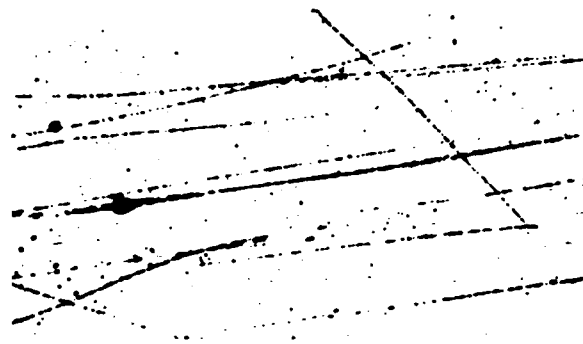


6. Ptolemaeus; taken 21 March 1945 at the Pic-du-Midi Observatory by H. Camichel, 23.5-inch refractor. (Courtesy of The Paris Observatory.)

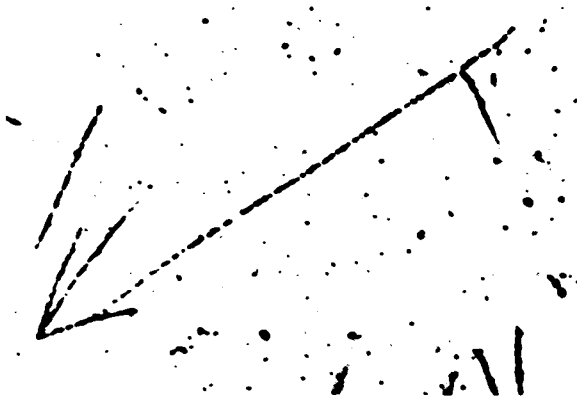
NUCLEAR COLLISIONS



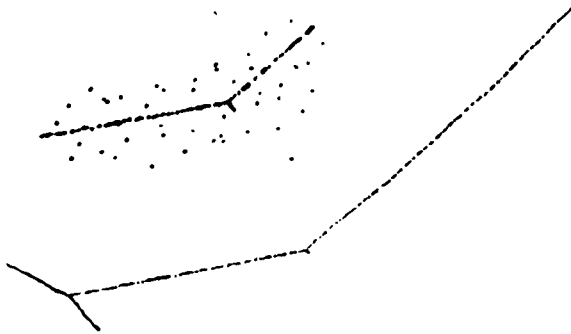
7. Photomicrograph of the interior of a nuclear research emulsion exposed to a beam of protons from a cyclotron. The tracks of four protons that entered from the left are visible. One of them collided with a stationary proton in the emulsion and knocked it on, producing a characteristic forked track. (Courtesy of Prof. C. F. Powell, F.R.S.)



8. Another photomicrograph of proton tracks. In this picture one of the protons has collided almost head-on with a nucleus of carbon, oxygen, or nitrogen (the constituents of gelatine) in the emulsion. It has bounced back in the direction from which it came, and the struck nucleus has moved forward a little way to make the short, thick track. (Courtesy of Prof. C. F. Powell, F.R.S.)



9. Photomicrograph of three-pronged 'star' formed by radio-active disintegration. Each of the three alpha particles emitted from the radioactive nucleus has made a short, thick track before coming to rest in the emulsion. One of them has collided with a proton in the emulsion, knocking it on to form the long, lighter track. (Courtesy of Prof. C. F. Powell, F.R.S.)



10. Facsimile projection drawing of a nuclear disintegration (on the left of the picture) from which an energetic alpha particle was emitted. Before coming to rest, this alpha particle collided with a carbon, oxygen, or nitrogen nucleus in the emulsion, knocking it on slightly to form the short, thick track. An enlarged drawing of the collision is shown in the top left-hand corner. (Observer: D. H. Perkins.)



11. The Sun: Chromosphere and Great Flare; taken 25 July 1946 in hydrogen ($H\alpha$) light. (Reproduced from M. A. Ellison: *The Sun and Its Influence* (Routledge and Kegan Paul, London, 1955) from M. L. d'Azambuja.)



12. The M.V. *Magga Dan* at Halley Bay. The main party of the Royal Society I.G.Y. Expedition, under the leadership of Col. Robin Smart, arrived at Halley Bay in January 1957 in the *Magga Dan*. She then went on to take members of the British Commonwealth Trans-Antarctic Expedition to their base at Shackleton. (Copyright, *The Royal Society*.)



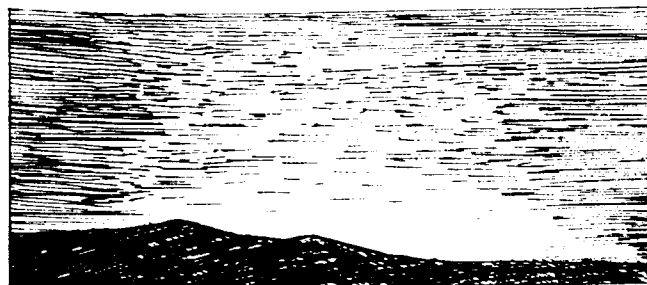
13. General view of the Royal Society Antarctic Expedition Base at Halley Bay, showing the main base hut and stores in the background. (Copyright, *The Royal Society*.)



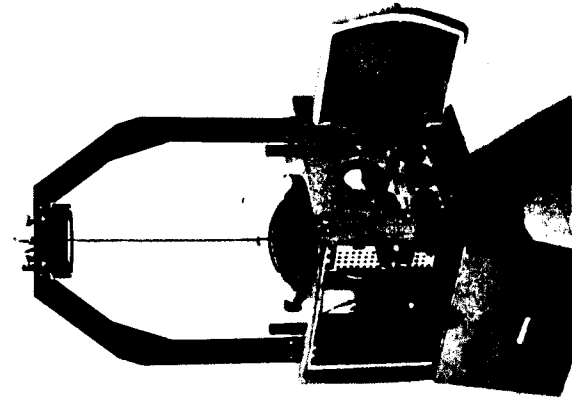
14. Two views of the Tottan Mountain Range 230 miles east of Halley Bay, taken by members of the Royal Society advance party on 11 January 1957, while flying in a Trans-Atlantic Expedition aeroplane. (Copyright, *The Royal Society*.)



15. Evidence of climatic change in twenty-six years. (*Above*) The Saskatchewan Glacier in the province of Alberta photographed in 1922. (*Below*) The same, taken in 1948 showing a recession of the terminus of the glacier of some 2,600 feet. (Courtesy of *The American Geographical Society*.)



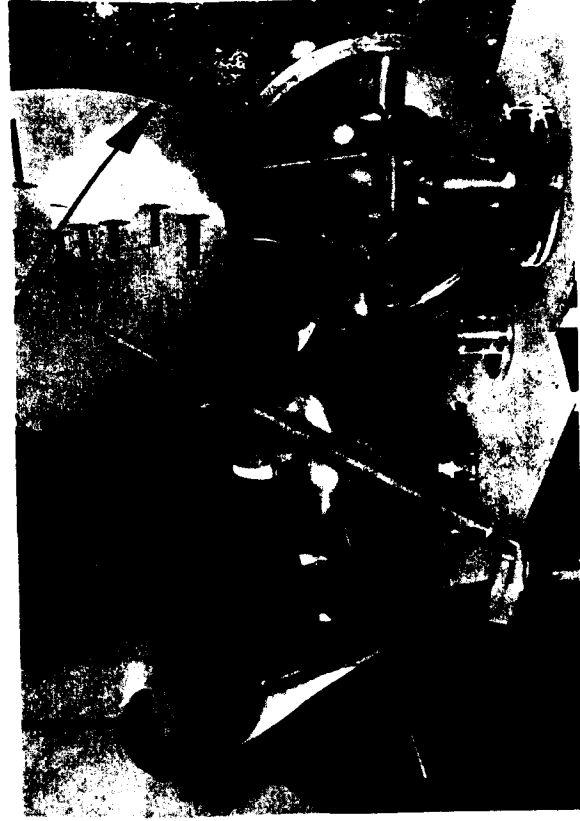
16. Three examples of the drawings of auroral forms which, with descriptions, are being distributed among European observers in preparation for recording during the International Geophysical Year. (Courtesy of *James Paton, Edinburgh*.)



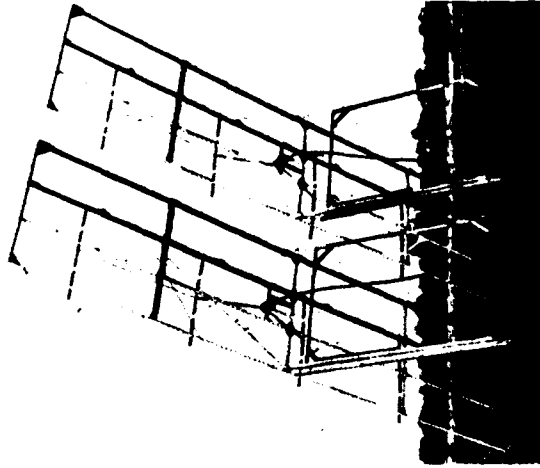
17. All-Sky Camera, St Andrews University, February 1957. An image of the whole sky is produced in the large convex mirror.
(Courtesy of James Paton, Edinburgh.)



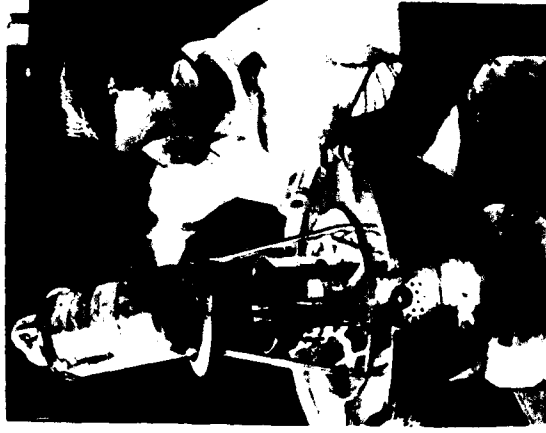
18. Photograph of the *Aurora Australis* at Halley Bay taken with an all-sky camera of somewhat different design.



19. Dr John P. Hagen, director of the satellite project, with a model of a three-stage rocket due to be launched from Cape Canaveral, Florida, during the International Geophysical Year. Models of the satellite, a 20-inch metal sphere full of instruments, are seen on the table behind.



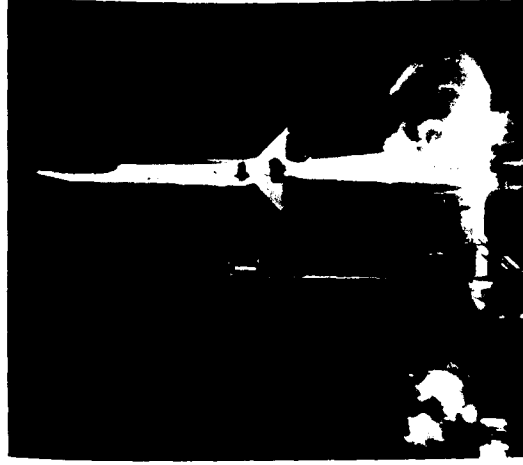
20. Interferometric aerial system at Cambridge similar to that being used to make continuous observations of solar radio emission during the I.G.Y. (Courtesy of J. A. Ratcliffe, F.R.S., The Cavendish Laboratory.)



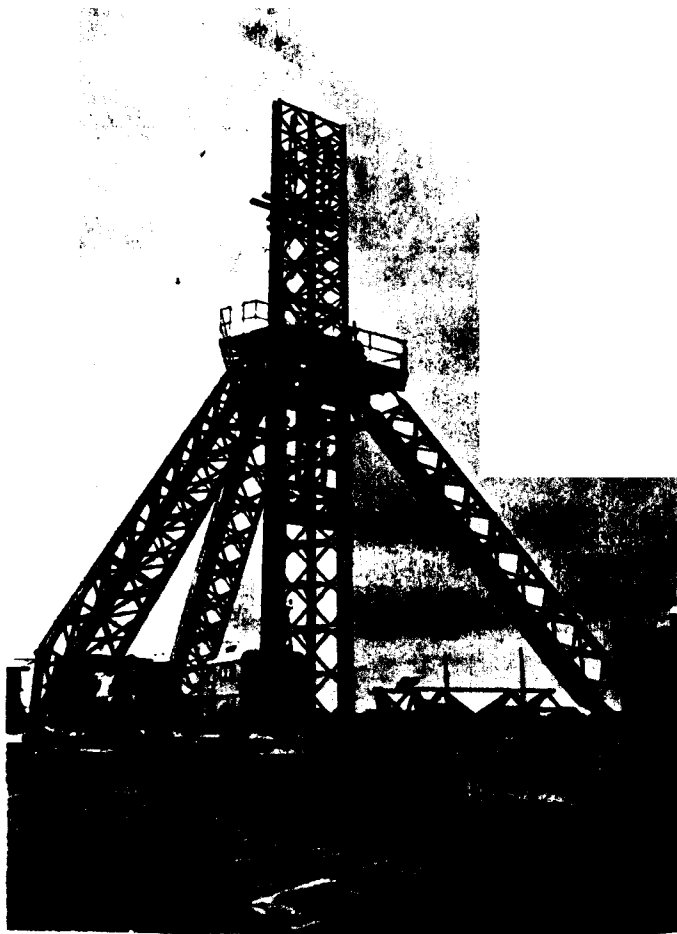
21. Member of the U.S.A. Naval Research Laboratory, Washington, D.C., placing an electronic circuit package in the earth satellite. The satellite is planned to make a complete circuit of the earth in 90 minutes.



22. Viking-13 Rocket in the gantry before being fired to test the first stage of the three-stage rocket to be used to propel the earth satellite. The scene is at the Patrick Air Base, the United States Air Force Missile Centre in Florida, U.S.A.



23. Photograph taken just after the first test rocket of the earth satellite programme had left the launching tower. The propelling vehicle for the satellite will be a three-stage rocket, the first stage of which will be a Viking Guided Missile.



24. The 80 foot launching tower for the British Skylark rocket. The rocket rides in three guide rails; the gimbals allow movement of the tower about the vertical. (Crown Copyright Reserved: reproduced by permission of the Controller, H.M. Stationery Office.)

to consider the lunar history of thousands of millions of years. Thus, the dynamical theory of the Moon's motions can give results of high accuracy for periods of hundreds of years, and results of a sort for intervals of thousands of years, but the theory breaks down for times of the order of thousands of millions of years. However, Sir George Darwin's researches on the effects of tidal dissipation of energy showed that a transfer of angular momentum from the rotating Earth to the Moon rotating about the Earth should result. This would produce the previously unexplained secular acceleration and also cause a recession of the Moon from the Earth. Sir Harold Jeffreys, from his revision of this theory, has given the time since the Moon was fairly close to the Earth as very roughly 4,000 million years. This is close to recent estimates that the Earth is 4,500 million years old,¹ but the uncertainty of the lunar theory is shown by the fact that H. Gerstenkorn, in a more recent treatment on the same lines, obtains 2,500 million years for the Moon's age.

The study of the lunar surface affords more insight into the Moon's history, because it is highly likely that we see there very ancient structures indeed. Measurements by Franz and Saunders of the positions of surface features have demonstrated that the Moon possesses a bulge towards the Earth which is much in excess of the bulge that would result if it were a figure of equilibrium. Independent estimates of the shape of the Moon, from comparison of dynamical theory with details of its motion, confirm the existence of this bulge, and suggest (though with less certainty) that its shape is not such as a completely liquid body would ever have assumed. So the bulge cannot be explained as a 'fossil tide' formed when the Moon was close to the Earth and in a plastic condition. This non-equilibrium shape could not be maintained unless the Moon possessed considerable strength to great depths, an important fact in considering possible temperatures within the Moon.

The assumed antiquity of the lunar surface is a consequence of the almost complete absence of an atmosphere there, which

¹ See 'Cosmic Ages' by P. Reasbeck in *Science News* 39.

prevents erosion similar to that on the Earth from taking place. Because of its low surface gravity, the Moon would, according to the kinetic theory of gases, lose most gases completely within a few thousand years. Measurements of the refraction of stars as they are occulted by the Moon have shown that the surface density of its atmosphere must be less than $1/2,000$ of that at sea-level on the Earth, while B. Lyot has suggested an even lower limit, less than $1/10,000$, by examining the Moon for a twilight effect. Even a very slight atmosphere could cause visible meteors, but none have been observed for certain. In fact, although the number of meteorite falls on the Earth suggests that about one hundred of mass ten pounds or more should fall on the Moon each year, the bright flashes which L. Lapaz has estimated such collisions should produce have certainly not been observed in such numbers. The explanation probably is that they are actually much fainter than estimated, but, considering their probable importance in its history, it is unfortunate that we have no direct evidence on the number of meteorites striking the Moon.

The lack of a substantial atmosphere allows the Moon's surface to be subjected to intense fluctuations of temperature, ranging from over 100°C in the full sun to less than -100°C out of it, according to measurements made by Pettit and Nicholson, using a thermocouple on the 100-inch Mount Wilson telescope. They also made detailed observations of temperature changes during an eclipse of the Moon, and these have been intensively studied in attempts to determine the thermal constants of the surface material. Jaeger and Harper's very thorough analysis, which also made use of observations of microwave radiation by Piddington and Minnet, showed that the surface behaves thermally like granular matter comparable to pumice or gravel interspersed with dust which lies on top of it to a depth of about two millimetres. The only other evidence on the nature of the lunar surface material is due to Lyot: he found from measurements of the proportion of the Moon's light that was polarized that the surface was covered by a substance whose characteristics resemble those of volcanic ash.

THE ORIGIN OF THE MOON AND THE EARTH

Because erosive processes are largely absent on the Moon, many or most of the structures to be seen there quite possibly date from times so remote that no similar geological record of any sort is left on the Earth. Thus the study of the Moon has an immediate bearing on the question of the origin of the Earth and of the entire solar system. A thorough review of theories of the origin of the solar system was given by Sir Harold Spencer Jones in *Science News* 14. It will suffice to say here that scientists no longer favour the 'catastrophic' theories current some years ago, according to which a collision with some other star, or some similarly violent event, left hot gases in the neighbourhood of the Sun, from which the planets condensed. Instead, the planets are thought to have accreted by a slow 'evolutionary' process from a dust or gas nebula of some sort, perhaps at the same time as the Sun was forming. The initial temperatures of the various planets and satellites would depend both upon the size they reached and how fast they accumulated, since the heat released by infalling material would increase as an accreting body became more massive, while the temperature of the interior would be further increased by compression. The major planets and the Earth may have been heated to melting point by the time they reached their present sizes, but the Moon and smaller bodies such as the asteroids probably formed at lower temperatures. Other processes, such as chemical heating or heating due to short-lived radioactive substances, now vanished, could have occurred, and one has to consider a number of possible initial conditions in studying how temperatures in the Moon might have changed throughout its history.

When Darwin put forward the tidal recession theory mentioned earlier, it was believed that all the planets had formed at high temperatures, and so had passed through a liquid stage. He therefore suggested that the Moon had once been part of the Earth, having been separated from it as a result of enormous resonance tides set up by the Sun in the liquid globe, the period of the solar tides then being close to the natural period

of oscillation of the Earth. This attractive idea was exploded by Jeffreys, who showed that tides of the required magnitude could not build up. It is now believed that the Moon and the Earth formed separately, but perhaps quite close together; it should be realized in this connexion that in a way they are quite unique in the solar system, in that the mass of the Moon relative to the Earth is much greater than for any other satellite. As Kuiper states: 'The Earth-Moon system is a double planet, resembling on a small scale the formation of a binary star, not a planetary system. Its history is entirely abnormal in the solar system.'

Once the system had formed, Darwin's tidal friction mechanism would come into operation, and the Moon would recede from the Earth. It has been mentioned that this process must have begun some thousands of millions of years ago and that the age of the Earth, 4,500 million years, may also be the age of the Moon. Certainly many meteorites appear to be about this age as well. However, the age of the Earth refers to the time since the mantle became stable, i.e., the whole Earth cannot have been molten since then, but there may have been a long interval prior to this date, during which radioactivity caused melting of a great part of the Earth. A similar history may hold for the Moon, and hence it is possible that it is as old as 5-6,000 million years. It is relevant to these considerations that the oldest rocks so far known are about 3,000 million years old, and there was therefore an interval of some 1,500 million years between the solidification of the mantle and the formation of the oldest surface rocks still extant. Since there is no geological record left from this period, there could for all we know have been structures like those on the Moon present on the Earth then. One explanation of this gap in the record is that radioactivity heated up the top fifty or so kilometres of the Earth, inducing tremendous volcanic and tectonic activity which left none of the original crust intact.

If similar processes took place on the Moon, they would be very important in interpreting the lunar surface features. With this in mind, the author has been studying the thermal history of the Moon in some detail; Figure 1 gives some of the results.

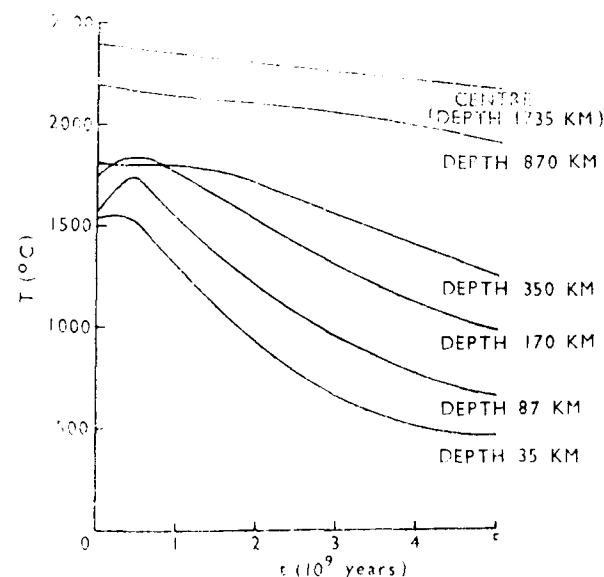


Fig. 1. Thermal History of the Moon: temperatures at various depths are shown, assuming that the temperature throughout was near the melting point 4,500 million years ago and that radioactivity has been concentrated near the surface.

If the Moon solidified 4,500 million years ago, and radioactive substances were concentrated near its surface, then the interior temperatures would change with time as shown in the figure. Evidently temperatures would have risen near the surface, perhaps even causing localized remelting, so that there could have been a source of lavas on the Moon for 1,000 million years or more after it had solidified as a whole. Present temperatures would be well below the melting point throughout, in accordance with the conclusions from the non-equilibrium shape given in the previous section. The importance of this criterion in placing limits on the amount and distribution of radioactivity in the Moon was first pointed out by H. C. Urey. Similar studies of

lunar thermal histories for different assumed initial conditions have shown that the Moon could not have been melted as a whole by its own radioactivity unless it was originally formed as long ago as 5,500 or 6,000 million years, and that it could have formed at low temperatures 4,500 million years ago and never melted since, but in this case there would be no temperature rise near the surface to account for lava flows.

THE MOON'S SURFACE FEATURES

Many of the characteristic lunar surface features can be seen in Inset 1, which shows the Moon at first quarter. As is customary with lunar maps and photographs, this is given inverted with north to the bottom and south to the top of the page; the photograph shows the western half of the disk. A black and white photograph represents the Moon's appearance very accurately, since any colours are but the faintest of tints, the only well-identified coloured region being a slightly yellowish patch near the crater Aristarchus. The striking difference in appearance between the maria and the uplands, or continental, regions results partly from the difference in brightness, partly from the much greater number of craters with which the latter are covered. Inset 1 also shows several of the lunar mountain ranges, and many finer features such as rills or clefts, ridges, and grooves are visible. Some of the bright rays from the crater Tycho (not itself visible) may be seen spreading out over the southern region, but these are not so prominent as at full Moon.

The maria occupy about half the Moon's disk, and predominate in its northern half. Some have quite irregular boundaries; others are bordered by chains of mountains, are roughly circular in shape, and have some similarity to the largest of the craters. An example of the latter type is Mare Serenitatis (the largest dark plain on the lower half of Inset 1). It is some 700 kilometres in diameter, and is connected on the east to the largest of the circular maria, Mare Imbrium, which is more like 1,300 kilometres across. Part of the latter is shown on Inset 4. It will be noticed that the floors of these maria are not featureless: only an occasional large crater is found, but there are many

small ones, and here and there can be seen the so-called 'ghost' craters, the buried remains of craters older than the maria. There are numerous variations in brightness, white patches, and dots (the most prominent white dot to the eastern side of Mare Serenitatis in Inset 1 is the famous Linné). Often the white dots are found under close inspection to be 'haloes' surrounding a small crater. The surfaces of the maria are not completely level, but contain many ridges that are often concentric with the boundaries of the maria: Inset 4 shows some of these. Many features beyond the maria themselves are evidently connected with them in origin, such as the mountains about the circular maria. At the end of the last century G. K. Gilbert pointed out that many ridges around Mare Imbrium point in its direction, and that hundreds of U-shaped valleys or grooves are also thus orientated. Some of this radial pattern can be seen in Inset 4.

The circular structures that have been given the generic name 'crater' vary greatly in size, from walled plains 300 kilometres in diameter to tiny pits at the limit of visibility. Inset 2 shows one of the largest, Clavius, 235 kilometres in diameter, 5,000 metres deep, and about 1,600 metres high on the exterior. This fine photograph shows a number of later smaller craters distributed over Clavius, and gives some idea of how the forms of the craters change with size. The floor of Clavius is rather flat, with but slight indications of a central peak, whereas the smaller craters have central peaks, smaller inner plains, and more extensive structures round the inner wall. The very smallest craters seem to be simple bowl-like structures. This is not to say that craters of the same size are always exactly alike. Some present the ruined or battered appearance of Clavius, while others are sharp-cut and fresh looking, such as Copernicus (Inset 5). Again, a number of craters have very flat floors, raised higher than normal, apparently having been 'flooded' with material similar to that forming the maria. Two such, Archimedes and Plato, show on Inset 4, and another, Ptolemaeus, is given as Inset 4. The most striking example, Wargentia, is a crater near the south-east limb which has been filled to the brim, creating a curious plateau. This is shown in Inset 3.

Inset 5 shows Copernicus, one of the most prominent craters on the Moon. It and Tycho are extremely conspicuous at full moon because of their ray systems, bright streaks extending radially from them for enormous distances (up to 1,500 kilometres). The photograph shows the rays, as well as several small craters surrounded by similarly whitish haloes. Copernicus is undoubtedly a late crater, as one can see from the fresh undamaged appearance of the buttresses, ridges, and terraces of the wall. The diameter of the crater is 90 kilometres, the depth 3,400 metres, and the height above the surrounding plain 1,000 metres. Other markings besides rays can be detected radiating from the crater, as is the case with several of the craters shown on Inset 3. Insets 4 and 5 show a number of craters with central peaks, a characteristic feature of craters other than the smallest and largest ones. One or two on these photographs reveal smaller craters in the peaks; this is not very common.

Inset 6 shows the crater Ptolemaeus, 180 kilometres across. It is one of the flat-bottomed craters that seem to have been filled in in some manner. This superb photograph shows that the floor is not completely flat but is dotted with numerous tiny craters, and several 'ghost' craters can be detected as well.

The lunar mountain ranges are, as already remarked, associated with the maria. They bear no resemblance to folded mountain-chains on the Earth, looking instead somewhat like great chunks of material which have been hurled there (Inset 4). Cracks in the Moon's surface known as clefts or rills are found by the hundred, many around the borders of the maria. They are up to two kilometres wide and often end at a small crater, or turn at one near the centre. Sometimes a row of small craters lies along the cleft, looking like the chain craters west of Copernicus. The wider clefts are occasionally seen to be filled nearly to the surface, and to have flat bottoms.

As to how well we can actually see the Moon in telescopes and on photographs may be in order. It has been estimated that the 200-inch Palomar telescope can show the Moon as if it were at a distance of 30 kilometres, but this supposes ideal 'seeing' (atmospheric conditions). A better estimate is that with

a large telescope magnifying powers of the order of 1,000 can generally be used to advantage (corresponding to seeing the Moon as if from a distance of several hundred kilometres). The important factor is the resolving power of the telescope, since beyond a certain point increased magnification merely enlarges a blurred image, and this increases in proportion to the size of the aperture. The best photographs show the Moon no better than a 10-inch or 15-inch telescope under good conditions. There is thus still room for a great deal more visual work to be done, especially if really large telescopes are available.

THE ORIGIN OF THE MOON'S SURFACE FEATURES

No process known on the Earth has been thought too unlikely to be put forward at one time or another to explain the Moon's surface features. The craters especially seem to have stimulated imaginations; to give only a few examples, it has been suggested that they mark the spots where enormous gas bubbles rose through congealing lava and burst; that they are coral reefs left stranded when a lunar ocean disappeared; and that the entire lunar surface is covered by deep ice in which former pools of water left the crater structures. The knowledge reviewed earlier on such matters as the lunar temperatures and atmosphere, though scanty, is at least sufficient to rule out many far-fetched hypotheses like these.

The so-called craters of course derive their name from their supposed volcanic origin, but it is certain, now that a great deal is known about their forms and dimensions, that if they did originate by some igneous process it must have been rather different from those that produced terrestrial volcanoes. For example, although the Moon's lesser gravity might have allowed much larger craters to have formed than on the Earth, it is hard to see how their interiors could be lower than the general surroundings, as with most lunar craters. Of course, since formations from the Earth's early history are lost to us, unfamiliar volcanic processes may have occurred. There are some lunar features whose igneous origin seems very probable: the chain craters are most easily explained as volcanic blowholes of some

kind. Certain low domes with minute orifices on their tops are not unlike small terrestrial volcanoes, and there are some features resembling dikes (vertical sheet-like intrusions of molten rock). Jeffreys has suggested that many of the craters were formed in the same way as ring-dikes on the Earth, while others were formed by the explosive release of gases. Many of the details mentioned in the previous section, such as the radiating grooves about craters and some of the maria, are most easily explained by some kind of explosive activity.

The most likely source of the tremendous number of intense explosions required to account for the hordes of craters seems to many scientists to be meteoritic collisions, not volcanic activity. That the Moon's surface had been shaped by meteorites was first suggested by Gruithuisen in the early nineteenth century, and Gilbert in 1892 pointed out how much evidence there was for an immense collision having taken place in Mare Imbrium. The fact that the craters are all circular in shape then seemed a great obstacle to the hypothesis, since many of the colliding objects would obviously not strike vertically. The key to understanding the collision process came in the 1920s when several people pointed out that a high-velocity meteorite would behave much as a high-explosive bomb does; so much heat would be released that high-pressure gases would be produced as in an ordinary explosion, and no matter what the angle of collision a circular crater would result.

R. B. Baldwin has marshalled the evidence in favour of the explosive origin of craters very convincingly in his book *The Face of the Moon*. Figure 2, taken from this, shows that there is a consistent relationship between the diameters and depths of terrestrial explosion pits, meteorite craters, and lunar craters (only 'fresh' lunar craters that do not appear to have been altered greatly are plotted). The few meteorite craters known on Earth correspond in size to relatively small lunar craters and are quite similar in form. A photograph of the Arizona crater, which is a little over a kilometre in diameter, is given in *Science News* 39. Practically every detail of the crater form is understandable in terms of the explosion hypothesis. Schröter's rule is

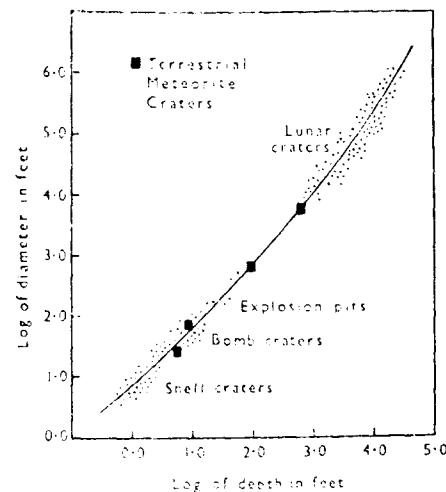


Fig. 2 Diameter-Depth Graph (after R. B. Baldwin): there appears to be a consistent relationship between diameter and depth for terrestrial explosion craters, terrestrial meteoritic craters, and 'fresh' lunar craters.

obviously explained. The radial ridges and grooves around many of the craters obviously fit the hypothesis, while the rays can be ascribed to rock powder thrown out in long trajectories. The central peaks can perhaps be explained by a rebound of material compressed during the collision, or simply as debris left by the explosion. T. Gold has lately examined the mechanism of a supersonic collision in detail, and he believes that both the existence of central peaks and even the occasional appearance of craters thereon are what would be expected. To explain the craters filled with material resembling that of the maria, as well as the implications of the fact that there are notably more craters on the continental regions than on the maria, requires a consideration of the origin of the maria.

Once it was realized that there could never have been enough water on the Moon for the maria to have formed as the beds of

actual seas, it became generally accepted that they are enormous lava flows. These must have occurred some time after most of the craters had formed, overwhelming the existing crater-covered surface, a few traces of which remain as 'ghost' craters. The buckling and crackling of these enormous lava sheets in cooling could have produced ridges and clefts such as are observed. However, now that it is no longer believed that the Moon was originally formed in the molten state, the origin of the lava flows is not immediately obvious. Radioactive heating is a possible answer, as the previous discussion of the Moon's thermal history has shown. A collision on the enormous scale of that which caused Mare Imbrium would release any lava available in the crust. Baldwin, indeed, believes that practically all the maria were filled with lava from the Imbrium explosion. G. P. Kuiper thinks that the maria were formed at the time of maximum melting of the Moon; thus so much lava was available when the Imbrium collision occurred that great quantities were splashed across the surrounding continents to form the mountain ranges. He believes that the craters with level floors are further evidence of the availability of reservoirs of lava, while the central peaks of many craters are also igneous in origin. The continental regions probably represent the original crust of the Moon, which consisted of loose rubble in the pre-melting stage but which was changed into hardened metamorphic material during the period of maximum melting. The differences in the sharpness of the features of the various craters result from their having been formed in different sorts of material, and a similar explanation holds for the fact that only the younger-looking craters have rays.

The variation in freshness of appearance of craters can be explained in quite a different way, in terms of the result of some erosion process, and T. Gold has lately made the interesting suggestion that such a process could account for the maria if it is assumed that they are great dust plains formed by the eroded material finding its way to the lowest regions on the Moon. There can be little doubt that there is a great deal of dust-like material on the Moon, both because of the evidence from

temperature variation and because estimates of the amount of meteoritic dust falling on the Earth show that a considerable amount must also fall on the Moon. Gold argues that intense ultra-violet and X-radiation from the Sun, playing on rock surfaces unprotected by any atmosphere, would, over periods of thousands of millions of years, cause significant erosion. It is a difficulty of the theory that, contrary to what usually happens when rock is pulverized, the darkest parts of the Moon are considered to be dust and the lightest rock. Gold suggests that the solar X-rays might cause the surface to darken, while the continually eroding highlands would present fresh, lighter rock. On these assumptions, the ray craters and white craters must have been formed comparatively recently, since otherwise the white markings would have been eroded, covered over, or darkened by radiation. Features like ridges and rills are explicable, since dust at a few metres depth would become compacted and behave like a solid, but the rills would have to be quite young. It is hard to see how an object like Wargentin could come about.

H. C. Urey has proposed a modification of the dust theory which removes some of the objections to it. He ascribes the origin of the dust to the explosions forming the lunar craters and maria. These produced great clouds of dust and water vapour, from which the dust settled out and the water fell as rain, washing the dust into low places. Perhaps a temporary atmosphere was maintained while collisions were frequent, and this kept rays from forming, since powdery material would not be thrown out in neat trajectories. Urey thinks there may also be some lava flows on the Moon, but sees their origin in the heating accompanying collisions rather than in internal heat. He believes that neither the Moon nor the Earth have ever been molten.

In weighing the merits of these various theories, the principal consideration must be how well they fit into a consistent history of the Moon from its origin up to the present. For example, it is evident that the process that formed the largest craters could not have extended much past the time when the maria were formed. Kuiper has the interesting theory that the Earth was once surrounded by a 'sediment ring' akin to the rings of Saturn:

as tidal friction caused the Moon's distance from the Earth to increase, it passed through this ring and experienced an intense bombardment (thus the Earth would never have suffered so heavy a fall). His theory would impose some restrictions on the time required to melt the Moon, its original distance from the Earth, and the rate of recession. It is by examining such interrelations that theories can be tested, and thus even the study of the lunar surface features alone requires a study of the entire history of the Moon.

CONCLUSION

Any (or none) of the theories just described may be true; this makes the study of the Moon all the more interesting, especially since definitive answers to some questions may be at hand; it is possible that rockets will, within a few decades, photograph the surface of the Moon from orbits around it. For the moment, however, the Moon's history can only be sketched very tentatively. The choice seems to lie between two general outlines of events, which may crudely be referred to as the 'cold' and 'hot' theories.

According to the 'cold' theory the Moon was formed between four and five thousand million years ago by accretion. The craters were caused by the explosive impacts of meteorites or planetesimals in the final stages of the accretion process, some irregularity of which left the bulge in the Moon. The maria were also caused by collisions, which may have involved some melting, but the theory that they are great dust plains fits better into this synthesis of events. If the dust has been produced by the erosion of surface rock, the craters and rills on the maria must be surprisingly young. It is more likely that the dust was produced as the craters formed, and the maria as well as the craters date from near the time of origin. The ray craters and some small craters (e.g., those on the maria) have been acquired since then, but otherwise the Moon has led a quiet existence. Nevertheless, it is not impossible that gradual heating by radioactivity may result in great changes on the surface in the distant future.

According to the 'hot' theory, the Moon is rather older,

having accreted between five and six thousand million years ago. For 500 or 1,000 million years it heated up because of its own radioactivity, meanwhile slowly receding from the Earth. Between 4-5,000 million years ago the Moon had become almost entirely molten, and then solidified again quite rapidly (once it was liquid, convection currents would transfer heat to the surface and away comparatively rapidly). The volcanic theory of crater origin would fit this history, if it is assumed that they and the maria formed at about this time, but a more acceptable view is that they were formed by impact, and several of the largest impacts happened to take place near the time of maximum melting, so that huge flows of lava were released to form the maria. There are difficulties in understanding the distribution of meteorite falls with time; it must be assumed either that the supply of large meteorites ran out just after the maria were formed or that by a coincidence the Moon passed through the 'sediment ring' near the time of melting. The lunar bulge can be explained either as having been produced in the original accretion, and not lost in the melting process, or as one of the effects of the terrific collisions that caused the maria. In either case it must be assumed that the Moon was still quite close to the Earth otherwise the bulge would have been lost, and one can deduce that the primitive Earth probably had no oceans (else the Moon would have receded much more rapidly). As remarked in the discussion of thermal history, there may have been heating effects and possible sources of lava for 1,000 million years after the Moon solidified as a whole: this may explain some of the lava-filled craters, and there is even a possibility that some of the maria were formed later than the time of complete melting. By now the Moon is quite devoid of internal heat sufficient to cause further surface changes.

That two such very different outlines of events in the Moon's history should both be well within the bounds of possibility may perhaps seem surprising. It is chastening to reflect that, despite its having been studied by all the means at the disposal of science, indeed, for as long as science has existed, the Moon retains much of its age-old mystery.

FURTHER READING

Baldwin's *The Face of the Moon* (Chicago, 1949) discusses the meteoritic theory at length, and contains a good bibliography of lunar studies.

Some more recent papers of importance are:

Kuiper, G. P.: *Proceedings National Academy of Sciences U.S.A.*, 1954 **40** 1096.

Urey, H. C.: *ibid.*, 1955 **41** 127, and *Sky and Telescope*, 1956 **15** 2.

Gold, T.: *Mon. Not. Roy. Astr. Soc.*, 1956 **115** 585; see also recent issues of *The Observatory*.

Publications of the British Astronomical Association contain much of interest on the Moon. A useful small-scale map of the Moon by Elger has recently been reissued (London, Phillip, 1955).

THE POLYSACCHARIDES OF HUMAN TISSUES

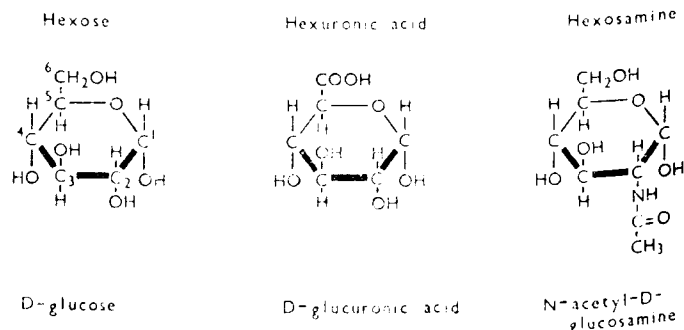
S. A. BARKER AND M. STACEY

POLYSACCHARIDES, together with nucleic acids, proteins, and lipids, are the most vital macromolecular constituents of human tissues. Often they are intimately associated with each other even to the extent of forming firmly bound complexes such as lipopolysaccharides, nucleoproteins, and mucoproteins. Each one performs a specific task. Polysaccharides act as energy reserves, as lubricants, as structural and connective materials, while others, as will be described, have a special physiological activity. Nucleic acids play a dominating role in cell division and, in combination with proteins, in determining hereditary characteristics. Proteins not only form the main structural material of all tissues: they can also be said to be the substances that make us 'tick' since they constitute the major portion of the structures of the enzymes that are the 'bio-catalysts' of all life processes. Lipids, which are fats or fat-like substances, include such physiologically active substances as the esters of vitamins A and D, besides the more prevalent glycerol esters of fatty acids that are deposited in the storage organs, such as adipose tissues, and serve as fuel for the body. In the nerve fibres lipids are believed to act as insulators.

Evidence from many laboratories shows that the polysaccharide constituents of body tissues are much more widely spread, and have more important biological functions, than was originally thought, and more attention must be paid to their behaviour in health and disease.

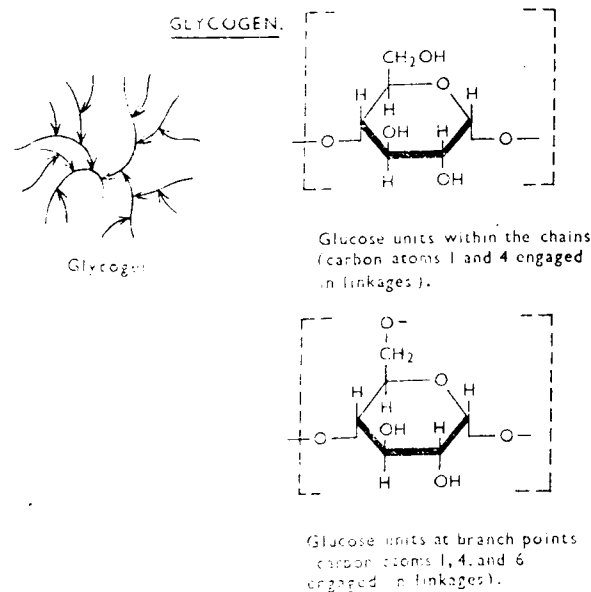
As the name implies, polysaccharides are long chains or polymers in which the repeating units or building bricks are 'monosaccharides' or sugars. Monosaccharides include hexoses such

as glucose, galactose, and mannose, each with the molecular formula $C_6H_{12}O_6$, hexuronic acids such as glucuronic acid and galacturonic acid with the molecular formula $C_6H_{10}O_7$, and hexosamines such as N-acetylglucosamine and N-acetylgalactosamine with the molecular formula $C_8H_{15}O_6N$. An example of each of this class of monosaccharide shown by Haworth-type formulae is given below. The numbers in the first formula indicate the position of the carbon atoms.



The polysaccharides are 'condensation' type polymers which can be regarded as being formed by elimination of water molecules between a series of monosaccharides; the 'glycosidic' —OH group on carbon atom No.1 is invariably involved in this elimination. Carbohydrate chemists have shown that any monosaccharide can exist in two forms, the so called α or β . In the example given D-glucose is written in the α -form in which the —OH group attached to carbon atom No.1 is below the plane of the ring system. The β -form has the —OH and —H groups attached to carbon atom No.1 interchanged. The linkages between carbon atom 1 of one saccharide can engage any one of carbon atoms 2, 3, 4, or 6 of the next saccharide. In this way many beautiful complex patterns are built up—added variation coming from the presence of α - or β -type linkages. When the linkages are of one kind only, e.g., '(1 $\rightarrow$ 4)- α ', we get a long straight-chain molecule as with the 'amylose' fraction of starch.

When the linkages are of mixed types as with '(1 $\rightarrow$ 4)- α ' and '(1 $\rightarrow$ 6)- α ' we get a branched-chain molecule such as the amylopectin component of starch or as glycogen the reserve carbohydrate of the body.



Glycogen is a polymer of glucose having the highly branched type of structure shown. All units are linked α -(1 $\rightarrow$ 4) and any unit involved in branching is additionally linked α -(1 $\rightarrow$ 6). The ratio of all the glucose units present to the number of chain ends is about 12. The molecular weight of human muscle glycogen is about 2.4×10^6 . Glycogens come from many sources and in many ways resemble starch, but they can easily be distinguished from starch because while the latter stains blue with iodine the corresponding colour obtained with glycogen is red or red-brown. Starch amylopectins and glycogens have closely similar molecular structures.

Glycogen occurs mainly in the liver and muscle. The normal glycogen content of human liver (dry weight) is about 4–5 per cent, while that of resting muscle is 0.5–1 per cent. Since, however, muscle constitutes 40 per cent of the tissues of a normal human being, the total glycogen content of resting-muscle is greater than that of liver. When the muscles are being used the glycogen rapidly decreases because it is converted to lactic acid which is transported by the blood to the liver where it is reconverted to glycogen. Later this glycogen can be broken down into glucose, some of which is transported by the blood back to the muscle where it is again stored as glycogen. To make up for the loss of energy incurred in this process the blood sugar is generally augmented from other sources, e.g., by direct absorption of glucose from the alimentary tract.

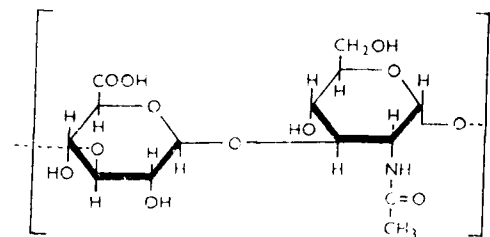
There are several types of disease that are associated with the storage of abnormal amounts of glycogen in various tissues. One of the best defined was first described by von Gierke: it involves abnormal deposition in the liver. In 1952, Cori and his collaborators showed that in several cases of the disease the glycogen content of the liver reached more than 10 per cent. The cause was traced to the almost complete absence of one of the enzymes (glucose 6-phosphatase) responsible for the conversion of glycogen into glucose. Glycogen deposition was therefore favoured and the polysaccharide was no longer available for blood sugar formation. The structure of the glycogen produced during von Gierke's disease was identical with that of normal glycogen. Other types of glycogen storage disease are much rarer, although in one of these abnormal quantities of glycogen are stored in all tissues especially in heart, diaphragm, and skeletal muscle. Here, the glycogen from many tissues was found to be abnormal in that the 'outer' chains in the molecules were shorter. This abnormality was again traced to an enzyme deficiency because in this case none of the enzyme responsible for breaking down the branch points (amylase: 6-glucosidase) in glycogen could be detected. The lack of enzyme explained the abnormal glycogen structure and the accumulation of glycogen in the tissues.

MUCOPOLYSACCHARIDES OF CONNECTIVE TISSUE

Mucopolysaccharides are complex polysaccharides combined with a small amount of protein and usually contain a hexosamine as one component. Connective tissue, which is a rich source of these mucopolysaccharides, consists of the connective tissue cells (or fibroblasts), fibres, and the so-called 'ground substance' or amorphous matrix that surrounds them. Karl Meyer and his collaborators have distinguished at least six acid mucopolysaccharides in connective tissue: hyaluronic acid, chondroitin sulphates A, B, and C, chondroitin, and keratosulphate.

Hyaluronic acid, or tissue ground substance

Hyaluronic acid is a very large macromolecule forming highly viscous solutions in water. It is composed of equal numbers of D-glucuronic acid and N-acetyl-D-glucosamine residues. It is known that some of them are linked as shown.

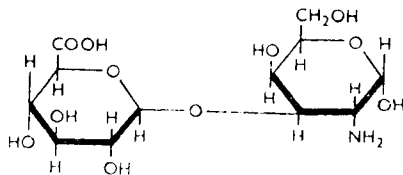


Hyaluronic acid has been isolated from human umbilical cords, synovial fluid (the 'lubricating' fluid secreted in the interior of the joints), skin, and the culture fluid of fibroblasts derived from human bone. Polysaccharides with similar properties have been isolated from a tumour (a liposarcoma) and from the pleural fluids of a patient with a lung tumour. Hyaluronic acid is rapidly broken down to small fragments by the 'spreading' enzyme hyaluronidase. This can be demonstrated by the remarkable loss of viscosity of its aqueous solutions so treated. *In vivo*, hyaluronic acid has the important function of offering resistance

to penetration by foreign matter, including agents of infectious disease. Some bacteria and spermatozoa contain large amounts of hyaluronidase.

Chondroitin sulphates A and C

Both these polysaccharides, which occur in connective tissue and are organic sulphates, are broken down by acid to equimolar quantities of galactosamine, glucuronic acid, acetic acid, and sulphate. The acetic acid is attached to the amino groups. On mild acid hydrolysis both give the same disaccharide, chondrosine, which has the structure shown.



The calcium salts of the two mucopolysaccharides differ in their solubility in aqueous alcohol, and in their optical rotations (A has $[\alpha]_D = -30^\circ$; C shows $[\alpha]_D = -19^\circ$).

Chondroitin sulphate A occurs in the rib cartilage of newborn babies while chondroitin sulphate C is a minor constituent of umbilical cord, cartilage, and tissue cultures of fibroblasts derived from human skin. Both polysaccharides have been isolated from tumours (chondrosarcomas).

Chondroitin sulphate C has been isolated from nucleus pulposus (a tissue derived from the intervertebral discs of the spinal column) and from a chordoma (a spinal tumour).

Chondroitin sulphate B

This mucopolysaccharide contains equal numbers of N-acetylgalactosamine and hexuronic acid residues, together with one sulphate group for every two monosaccharide units. The hexuronic acid, recently identified as L-iduronic acid, is extremely rare. It differs from D-glucuronic acid in that the positions of the $-H$ and $-CH_2OH$ groups on carbon atom 5 have

been interchanged. Chondroitin sulphate B has the lowest optical rotation of the three, i.e., $[\alpha]_D = -59^\circ$, and its calcium salt is the most insoluble in aqueous alcohol. It also differs from chondroitin sulphates A and C in showing weak anticoagulant activity, and being resistant to testicular hyaluronidase. No record has been found of its isolation from human sources but it is found in calf skin, pig skin, heart valves of pig and calf, and pig tendon.

Chondroitin

Chondroitin ($[\alpha]_D = -21^\circ$) is composed of equimolar quantities of N-acetylgalactosamine and glucuronic acid. Since, however, it contains little or no sulphate it is believed to be a precursor of chondroitin sulphate A or C. It has not yet been isolated from human tissue but has been found in bovine cornea.

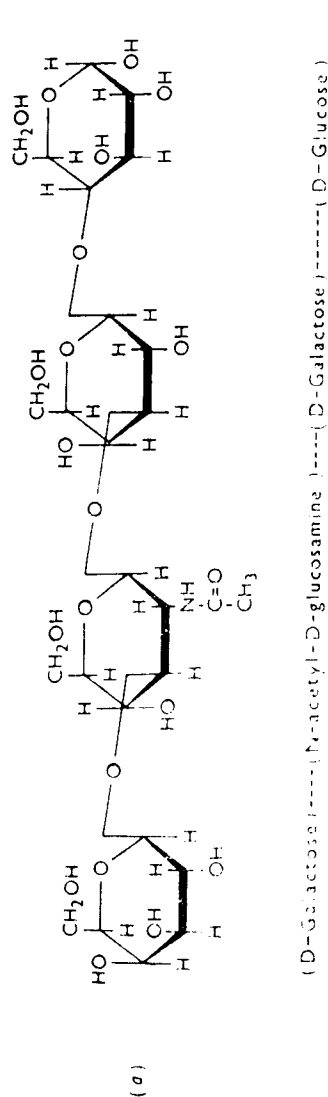
Kerato sulphate

This polymer is composed of residues of N-acetylglucosamine, galactose, and sulphate in equimolar proportions. It has also been isolated from bovine cornea and is probably identical with a similar compound in human abdominal subcutaneous tissue and human intervertebral discs.

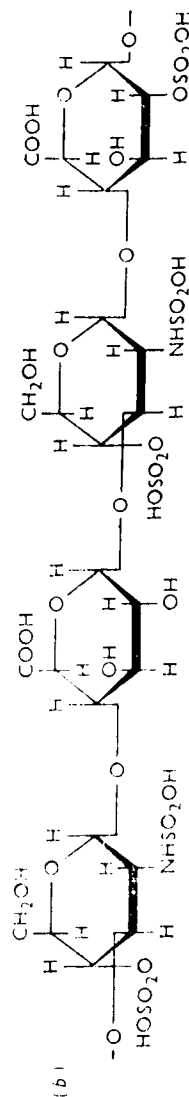
OLIGOSACCHARIDES OF HUMAN MILK

During the last few years scientists in Germany and America have discovered that human breast milk, and the secretion (colostrum) that precedes it, contains a number of oligosaccharides (substances containing from 2 to 8 monosaccharide units approximately) besides the normal milk sugar, the disaccharide lactose. The striking difference between these oligosaccharides and those found in cows' milk is that the former contains a rare sugar, L-fucose, which is absent from the latter. Three of the breast-milk oligosaccharides are α -L-fucosyl derivatives of a fourth which has the structure (a) on p. 88.

One may well ask, what is the purpose of these oligosaccharides? Investigation has shown that the most abundant bacterium occurring in the intestine of a normal breast-fed baby is



(D-Galactose)-----[N-acetyl-D-glucosamine]-----[D-Glucose]



Lactobacillus bifidus. A particular strain of this organism (var. Penn.) will not grow on a normal medium unless human milk or any one of the four breast-milk oligosaccharides described above is added. These oligosaccharides therefore play the role of growth factors. Cows' milk shows very little activity in this respect. Human blood group polysaccharides (described below), which have many structural features in common with the human milk oligosaccharides, also act as growth factors for *Lactobacillus bifidus* (var. Penn.). Both this organism and human saliva contain enzymes capable of breaking down both the blood group polysaccharides and breast-milk oligosaccharides and setting free N-acetyl D-glucosamine, L-fucose, and D-galactose. These then are the clues to what one feels is as yet an incomplete but fascinating story. The breast-fed baby can at least gurgle with delight over being fed with a rare sugar.

BLOOD GROUP POLYSACCHARIDES

In the years that have elapsed since Landsteiner first discovered the four major blood groups, research by Morgan, Stacey, Kabat, and others has revealed that the blood group substances, which furnish the basis of this classification, are polysaccharide-amino-acid complexes. Since the amount of blood group substances in the red blood cells is exceedingly small, to investigate them advantage has been taken of their presence in various human secretions such as saliva, gastric juice, tears, nasal mucus, bronchial mucus, semen, and urine. About 80 per cent of human beings of a particular blood group produce the corresponding blood group substance in their tissue fluids and secretions. Morgan and collaborators have in the main used human ovarian cyst fluids to get sufficient blood group polysaccharide for structural determination.

All the blood group substances (A, B, B', O, and Le^a) contain L-fucose, D-galactose, D-glucosamine, D-galactosamine and the same 11 amino acids (lysine, arginine, aspartic acid, glutamic acid, glycine, serine, threonine, alanine, proline, valine, and leucine (or isoleucine or both). However they differ quantitatively as shown in Table I.

TABLE I

Blood group substance	$[\alpha]_{546}$	Per cent Fucose	Per cent Hexosamine	Per cent reducing sugar after hydrolysis
A	$+15 \pm 5^\circ$	13.5	37	57
B	$0 \pm 5^\circ$	17.9	20	50
B'	$-20 \pm 5^\circ$	20.0	22	56
O	$-30 \pm 3^\circ$	14.0	31	54
Le ^a	$-40 \pm 4^\circ$	13.0	32	57

The following glucosamine-galactosamine ratios were found for the various blood group substances: A 1.6; B 2.8; O 2.5.

The rare deoxy sugar L-fucose in the blood group factors was first discovered at Birmingham University where some insight was given into parts of the structure of the blood group A factor from pepsin; D-mannose, D-galactose, and D-glucosamine were other constituents. Part of the D-glucosamine and L-fucose units were present as end-residues and the amino groups of the D-glucosamine units were acetylated.

Kabat has put forward the hypothesis that the blood group substances have skeletons 'made up of galactose, N-acetylglucosamine, and N-acetylgalactosamine in ratios of about 2:1:1. To this would be attached in some acid-labile arrangement, fucose and various oligosaccharide side chains consisting in part of N-acetylglucosamine and N-acetylgalactosamine in different ratios depending upon the various blood group specificities.' He also believes that a terminal non-reducing 1 $\rightarrow$ 6 α -galactosidic linkage is an important determinant of blood group B specificity.

Heparin

Heparin obtained from liver or lung tissue is a complex polysaccharide composed of alternate residues of D-glucosamine and D-glucuronic acid which carry five sulphate groups for every four monosaccharide units. The formula (b) on p. 88 has been postulated by Wolfrom.

Certain elements of this structure remain in doubt, and indeed Dische has reported that heparin behaves abnormally in certain colour reactions. He suggests the possibility that this may be due to the fact that heparin contains an analogue of glucuronic acid rather than glucuronic acid itself.

Heparin is the body's powerful blood anti-coagulant substance. The coagulation of blood is extremely complex but essentially it consists in the following conversions:

Formation of the enzyme thrombin

(i) Prothrombin $\xrightarrow{\text{enzyme precursor } \text{Ca}^{++} + \text{thrombokinase}}$ thrombin (active enzyme)

(ii) Blood coagulation proper

Fibrinogen $\xrightarrow{\text{thrombin}}$ fibrin
(a soluble plasma protein) (insoluble protein)

Heparin will not exert its anticoagulant activity and indeed has no effect on either of the isolated systems (i) and (ii) unless an additional factor, known to be present in blood, plasma, and serum, is also present. This factor is believed to be a lipoprotein.

Heparin is believed to originate in the mast cells of connective tissue. Such cells are found mainly in the vicinity of capillaries and in the walls of the blood-vessels. Heparin is usually isolated from the liver and lung, where the mast cells can readily be detected by staining with a basic dye, such as Toluidine Blue, which is known to interact with heparin and other sulphate containing polysaccharides.

The authors have isolated a sulphated polysaccharide, which showed some, but not all, of the structural features of heparin, from the liver of a young girl who died of a rare disease called gargoylism. The main acid hydrolysis product of heparin and this polysaccharide were apparently identical, but the latter did not show more than traces of blood anti-coagulant activity. The disease, which results in severe growth deformations of the skeleton and other supporting tissues, gave rise to deposition of large amounts of this particular polysaccharide in the liver, and

appeared to have completely knocked out the normal glycogen storage system.

Mucoproteins (or Glycoproteins)

These are carbohydrate-protein complexes of which the reaction for protein predominates. They are probably of two types: (a) mucoproteins in which polysaccharide is loosely bound by polar linkages to protein, and (b) mucoproteins in which the carbohydrate is firmly bound to the protein. Several mucoproteins of the latter type are found in human serum and rather drastic treatment with alkali is necessary to dissociate the protein and carbohydrate moieties. They are known to contain galactose, mannose, glucosamine, galactosamine, and fucose together with a complex acid called sialic acid. About 10 per cent of the total serum glycoprotein consists of orosomucoid, an acidic glycoprotein which contains 40 per cent of carbohydrate. Orosomucoid contains 12.4 per cent hexosamine (with glucosamine and galactosamine in the proportions of about 3 to 1) and 11 per cent sialic acid.

Research during the last few years has indicated that in patients suffering from a wide variety of diseases the concentration of the serum mucoproteins is markedly increased. Typical

TABLE II

Serum	Hexose	Hexosamine	Fucose	Sialic acid
Normal	121 ± 2.1	83.4 ± 4.1	8.9 ± 0.6	60 ± 3.1
Active tuberculosis	204 ± 15.6	211 ± 9	13.9 ± 1.9	178 ± 12.6
Subacute bacterial endocarditis	167 ± 19.3	144 ± 11	10.9 ± 1.2	102 ± 9.6
Advanced Cancer	195 ± 25.1	203 ± 12	14.2 ± 2.1	
Parenchymatous liver disease	141 ± 6.4	158 ± 9.5	15.7 ± 1.3	96 ± 3.2

examples are shown in Table II. The various monosaccharide constituents in normal and pathological sera are expressed as milligrams per 100 cubic centimetre of serum.

The reasons for these increases are not fully understood; some schools of thought believe they are due to breakdown of the ground substance of connective tissue and release of the products into the circulation while others suggest that the increased serum mucoprotein reflects processes associated with tissue proliferation. Urinary mucoproteins are important substances. We have found that when low molecular weight dextran is administered to patients as a blood plasma substitute and part of it is excreted the amount of urinary mucoprotein is doubled.

Cerebrosides

The cerebrosides are found chiefly in the human brain. Although present in the highest concentration in the white matter of the nervous tissues they also occur in the grey matter. When hydrolysed they give one molecule each of D-galactose or D-glucose, a fatty acid, and a nitrogenous base, sphingosine. Four cerebrosides that contain the galactose moiety are known and differ only in the nature of their fatty acid; one containing glucose has been reported. They break down as follows:

Cerastine	→ galactose, sphingosine, and lignoceric acid
Phrenosine	→ galactose, sphingosine, and α -hydroxy-lignoceric acid
Nervone	→ galactose, sphingosine, and nervonic acid
Oxynervone	→ galactose, sphingosine, and α -hydroxy-nervonic acid
Glucosidocerastine	→ glucose, sphingosine, and lignoceric acid.

Other tissues where cerebrosides have been reported are the kidney, spleen, liver, lung, retina, and red blood cells. In most cases of Gaucher's disease abnormal deposits of the glucose-containing cerebroside are found in the spleen. Compounds

called gangliosides, which are related to the cerebroside, have been detected in the cerebral cortex of the brain. The cortex of a patient suffering from Tay-Sachs disease (infantile amaurotic idiocy) was found to contain ten times the normal content of gangliosides. The gangliosides contain the complex acid, neuraminic acid in addition to a fatty acid, galactose, and sphingosine. Neuraminic acid appears to be closely related to the sialic acid found in mucoproteins.

*

In conclusion it can be said that polysaccharides and their complexes play a major role in the physiology of the human body. In many pathological conditions abnormal or greatly decreased amounts of polysaccharides, or their complexes, are present in the tissues, indicating that some marked change in metabolism has occurred. In several cases cited it appears that the changes are due to the lack of a specific enzyme.

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THE NOT-SO-RARE EARTHS

T. M. DUNN

IN the conventional periodic table, the chemist's filing cabinet of the hundred elements, the pigeon-hole allotted to the element lanthanum is really more crowded than it appears since it contains fourteen additional elements, formerly called the 'Rare Earths', but now usually called the 'Lanthanons' or 'Lanthanides'. These elements are still largely unfamiliar, although there are few who have never seen a 'flint' light a cigarette-lighter wick, or have never watched a dazzling white searchlight beam probing the blackness of the sky. Both of these common sights, however, owe much to the almost unknown group of elements. The aim of this article is to show that many of these elements, which even fifteen years ago were mere chemical curiosities, are already of considerable technological importance. The fact is that this group of elements was almost the Cinderella of the periodic table till, with the coming of nuclear fission, their potentialities began to be realized.

Reasons for Revival

The reasons for the present interest in this group can more readily be appreciated when the products of the fission of U^{235} by thermal neutrons are examined. The yield curve for these products is reproduced in Figure 1. It shows two well-defined maxima at atomic weights 95 and 139, and this second mass number is most common among the lanthanides. The yield curves for other heavy elements that undergo fission with thermal neutrons are similar to that for U^{235} , so it became important in the development of atomic piles to learn more about the chemical and physical properties of the lanthanide group. The investigations were undertaken for three main reasons.

First, very little was known about such nuclear properties of

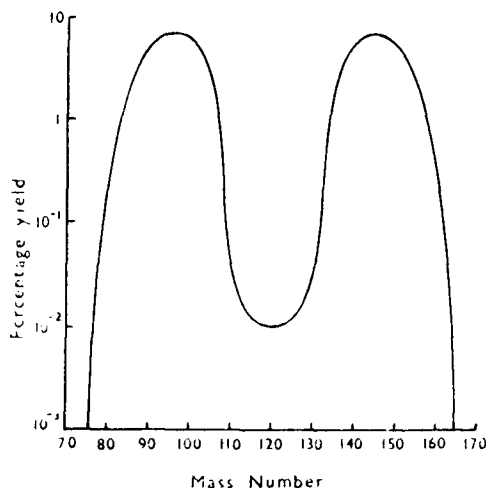


Fig. 1. U^{235} fission yield curve.

these elements as their cross sections for slow neutron capture, and if this proved to be very great for those species formed in large amounts during fission, then, obviously, this could result in very inefficient atomic piles because of neutron absorption by fission products instead of by uranium or other fissile material. Secondly, after a pile has been operating for a certain time the uranium slugs are removed for re-processing. It is thus necessary to know how best to remove the commonly occurring diluents and so recover the unchanged fissile metal as well as the new artificial elements, such as plutonium, that have been formed. And thirdly, before this separation could be carried out on the large scale required, even when the method was known, more had to be learned of the degree of hazard due to the radioactivity of the various possible lanthanide isotopes that are formed in the fission process. Some of these isotopes are not found in nature and their properties were not known.

These three reasons initiated research which covered all the conventional chemistry of extraction and reaction as well as the

radiochemistry of the whole group and within a relatively short space of time a great deal of new information has been obtained.

HISTORY OF THE LANTHANIDES

The history of the lanthanides began in 1750 when the first mineral bearing them was recognized as having some entirely new properties. The mineral was subsequently examined by Berzelius and Hisinger in 1803 and named cerite. Also around the turn of the 18th century, the Swedish chemist Gadolin examined a mineral found near Ytterby and concluded that it contained 'a new earth'. None of these workers, however, realized the complex nature of their respective minerals, and this did not become apparent until 1839, when Mosander re-examined Berzelius's cerite.

From then on successive members of the 'rare earth' family made their appearance until, about 1908, von Welsbach, of gas-mantle fame, and Urbain simultaneously isolated lutecium from ytterbium residues, and the whole family was complete except for element 61. For its debut it had to await the coming of the atomic age. Brauner predicted the existence of another element in the correct position in 1903 but, apart from what proved to be two false alarms in 1924 and 1926, when the missing element 61 was named florentinium and illinium respectively, it remained for Marinski and Glendenin in 1948 to detect the element in the fission products of U^{235} . They suggested the name prometheum (later changed to promethium) to indicate its birth in the fires of nuclear fission. This latter name is now adopted officially.

Since the discovery of promethium most of the work on the rare earths has been concentrated upon the important task of examining the chemistry, physics, and physical chemistry of the individual lanthanides.

Structure of Lanthanides

Having dealt with the history of their discovery and the reasons for their revival, let us now see what features the elements of the group have in common to cause them to be

TABLE I

Element	Symbol	At.No.	At.Wt.	Electronic Structure
Lanthanum	La	57	138.92	$4f^0 5s^2 5p^6 5d^1 6s^2$
Cerium	Ce	58	140.13	$4f^2 5s^2 5p^6 5d^0 6s^2$
Praseodymium	Pr	59	140.92	$4f^3 5s^2 5p^6 5d^0 6s^2$
Neodymium	Nd	60	144.27	$4f^4 5s^2 5p^6 5d^0 6s^2$
Promethium	Pm	61	(147)	$4f^5 5s^2 5p^6 5d^0 6s^2$
Samarium	Sm	62	150.43	$4f^6 5s^2 5p^6 5d^0 6s^2$
Europium	Eu	63	152.0	$4f^7 5s^2 5p^6 5d^0 6s^2$
Gadolinium	Gd	64	156.9	$4f^7 5s^2 5p^6 5d^1 6s^2$
Terbium	Tb	65	159.2	$4f^9 5s^2 5p^6 5d^0 6s^2$
Dysprosium	Dy	66	162.46	$4f^{10} 5s^2 5p^6 5d^0 6s^2$
Holmium	Ho	67	164.94	$4f^{11} 5s^2 5p^6 5d^0 6s^2$
Erbium	Er	68	167.2	$4f^{12} 5s^2 5p^6 5d^0 6s^2$
Thulium	Tm	69	169.4	$4f^{13} 5s^2 5p^6 5d^0 6s^2$
Ytterbium	Yb	70	173.04	$4f^{14} 5s^2 5p^6 5d^0 6s^2$
Lutecium	Lu	71	174.99	$4f^{14} 5s^2 5p^6 5d^1 6s^2$

assigned to only one pigeon-hole of the periodic table instead of 14 that would be required for other elements. Table I gives a list of the rare-earth elements, together with their symbols, atomic numbers, atomic weights, and, most important, their electronic structures. In many texts, and in the literature, it is common practice to include yttrium and scandium under the general heading of 'rare earths' since they usually co-occur in nature. This co-occurrence is connected with the fact that they belong to the same group or column in the periodic table and so, much as fluorine, chlorine, bromine, and iodine resemble one another chemically, yttrium and scandium resemble lanthanum and the rest of the lanthanides. It is an academic question, and of little moment, whether to include lanthanum in the group, but its tripositive ion resembles the similar ions of the rest of the group electronically and so it behaves similarly in chemical reactions.

The reason for the uniqueness of the lanthanide group is made clear by reference to Table I where the electronic structures of the elements are given. The lower energy shells that

have been filled in forming the lower elements of the periodic table are not included in the table so it must be understood that the symbols $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10}$ precede the structures given. These symbols refer to the different types of energy levels that electrons occupy in atoms: their order is shown in Figure 2.

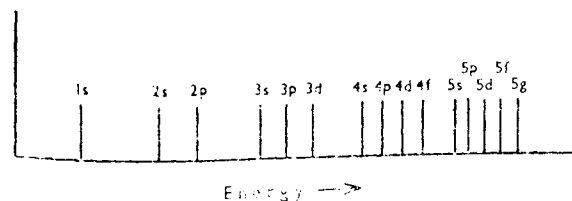


Fig. 2. Order of atomic energy levels.

These 'shells' of electrons can be thought of as something like the layers of an onion with the nucleus at the centre. They have, however, more complex shapes, but they do tend to get larger as their principal quantum numbers (1, 2, 3, 4, ...) increase, and so can accommodate more electrons. Thus the shell having principal quantum number 1 can hold only 2 electrons, whereas when the quantum number is 3, the shell can take 18 electrons in all, these being distributed among sub-shells called, for reasons that need not trouble us here, *s*, *p*, *d*, *f*, etc. It has been shown that an *s* sub-shell can hold only 2 electrons at any time, whereas a *p* sub-shell can hold 6, a *d* sub-shell 10, and an *f* sub-shell 14 in all.

In general, shells have higher energies the higher their principal quantum number, and then in the order $s < p < d < f$, as shown in Figure 2, so that for example a $3p$ shell will fill before a $3d$, and the $3d$ will fill before any other shell of principal quantum number 4, such as $4s$, $4p$, $4d$, $4f$.

The reason for the group-like characteristic of the lanthanides is that this order is not always strictly preserved, and, in fact, the $4f$ sub-shell lies higher in energy than $5s$, $5p$, $5d$, and $6s$, and so they fill before it. Reference to the structures make this clear.

Lanthanum has the full structure $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 4f^0 5s^2 5p^6 5d^1 6s^2$, the $5d$ shell also being 'out of order' and being higher than $6s$. Thus it will be seen that lanthanum has no $4f$ electrons and this distinguishes it from the rest of the lanthanides. Cerium is the next element and its structure is either $\dots 4f^1 5s^2 5p^6 5d^1 6s^2$ or $\dots 4f^2 5s^2 5p^6 5d^0 6s^2$ with the electron that was previously in the $5d$ shell going into the $4f$ shell as well as the additional electron required in moving from lanthanum to the next element. This type of behaviour is fairly common: the cause is that electrons, being negative charges, repel one another strongly and upset the simple order of levels that is well known for helium, where the order followed is strictly according to the rules given above.

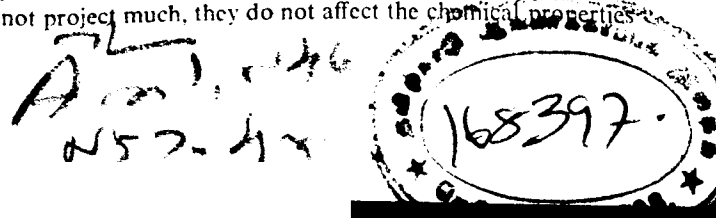
To understand most of the features of lanthanide chemistry it is necessary to appreciate in detail what happens in moving from lanthanum to the next element cerium. Chemically the thing that distinguishes one atom from another is atomic number, i.e., the number of positive charges on its nucleus. Since lanthanum has an atomic number of 57 and cerium 58, to transform the former to the latter one proton, i.e., a positive charge, must be added to the lanthanum nucleus. If this is done without as yet adding the extra electron required to maintain electrical neutrality, then the monopositive cerium ion Ce^+ results. The electronic structure of this is known: it is $\dots 4f^1 5s^2 5p^6 5d^1 6s^1$. Comparison with the structure of lanthanum shows that what has happened is that by adding a positive charge to the nucleus, one of the electrons has gone out of the $6s$ sub-shell to the $4f$ sub-shell, showing that the $4f$ sub-shell is starting to become lower in energy relative to the $6s$ sub-shell. This process goes even further if another positive charge is added to the nucleus to give the dipositive praseodymium ion Pr^{++} which has the structure $\dots 4f^2 5s^2 5p^6 5d^1 6s^0$, and if still another proton is added to the nucleus to give the neodymium tripositive ion Nd^{+++} , then the structure is $\dots 4f^3 5s^2 5p^6 5d^0 6s^0$. We could now add three electrons to Nd^{+++} to give the neutral neodymium atom which might be expected to be $\dots 4f^3 5s^2 5p^6 5d^1 6s^2$. In fact, as reference to Table I shows, the actual structure is

$\dots 4f^4 5s^2 5p^6 5d^0 6s^2$. This could not have been predicted: it is an experimental fact, it being impossible to predict whether the first electron will go into the $5d$ or the $4f$ sub-shell.

The group behaves regularly during the addition of three more protons and electrons to form the next elements down to europium, which has the structure $\dots 4f^7 5s^2 5p^6 5d^0 6s^2$. There is a change in behaviour at this point, however, and the next electron goes into the $5d$ sub-shell to give the element gadolinium the structure $\dots 4f^7 5s^2 5p^6 5d^1 6s^2$. The $4f$ sub-shell has room for 14 electrons so in the elements europium and gadolinium the sub-shell is exactly half full. This half-filled sub-shell has particularly stable properties connected with its symmetry, and, in the same way, $4f^0$ and $4f^{14}$ are both very stable. These completely full, half filled, and unfilled sub-shells play an important part in the chemistry of elements in general and the same is true for the lanthanides.

The reason why the rare-earth elements occupy only one space in the conventional periodic table is that they all have a tripositive ion as their most stable species in solution. Normally, valency changes as one goes from one element of the periodic table to the next, but the reason why this does not happen for the lanthanides is that the $4f$ electrons are not simple 'valency' electrons as is usually the case. They are, in fact, what are usually called 'inner electrons'. This refers to the shape of the space they occupy in the atom, and even though normally electrons with the highest energy tend to be furthest out, this is not so for the $4f$ electrons. It is relatively easy to show that they do not project out very much but lie more or less inside the $5s$, $5p$, $5d$ and $6s$ electron sub-shells. Since it is the outer electrons that determine chemical reactivity, it is the $5d$ and $6s$ electrons that matter, and most of the lanthanide elements are similar in their complement of these.

Since one seldom deals with reactions involving uncharged metal atoms, for most reactions then it is ions that are compared. The lanthanides all have structures $\dots 4f^n 5s^2 5p^6$, i.e., they differ only in the number of $4f$ electrons, and since these do not project much, they do not affect the chemical properties



of the ions which are thus all triply positive and so react very similarly, provided they are all about the same size. (To a first order, size is determined only by the number of positive charges on the ion, so that all lanthanide ions are about the same size.)

The question may pertinently be posed as to why the ions are most stable when triply charged, but this is not easy to answer. The number of positive charges required for an ion to be stable in solution is, broadly speaking, determined by two factors. First, there is the amount of energy required to remove the electrons. This will obviously increase rapidly for each electron that is taken off. Secondly, the amount of stabilization energy (heat of hydration) that will result from the loss of these electrons. This stabilization occurs because the positive ions polarize the solvent molecules around them and attract them so that they form a solvent shell around the ion. The attraction is obviously greater the greater the number of positive charges on the ion, but to create each of these charges requires a large amount of work to be expended in removing an electron, so that the final most stable state is a compromise between the two factors.

We have seen that it is usually the 5*d* and 6*s* electrons that are removed to form the ions, and since this is true for all the lanthanides it means that the same ionic species will probably be the most stable for them all. Here, too, we see the reason for lanthanum itself being included in the group since its tripositive ion will have the same outer structure as all the rest and so it will resemble the others chemically, even though neither neutral La nor La³⁺ has any 4*f* electrons.

OCCURRENCE AND SEPARATION

The above discussion has endeavoured to show why the fifteen rare-earth elements have very similar properties chemically and why they are thus dealt with as a group in much the same way as, for example, lithium, sodium, potassium, etc. Before proceeding to look at their very interesting properties, it is worth while considering how they are found in nature, with what abundance, and how they are separated.

Contrary to their customary name, the 'rare earths' are not

really rare: rather, they are widely distributed and this gives an illusion of rarity. Figure 3 shows the known abundances, and it is a remarkable fact that the elements of even atomic number are much more abundant than those with odd atomic number. At first sight the percentages of the earth's crust may appear small, but they come into perspective when we consider that as a group the rare earths are more abundant than copper, lead,

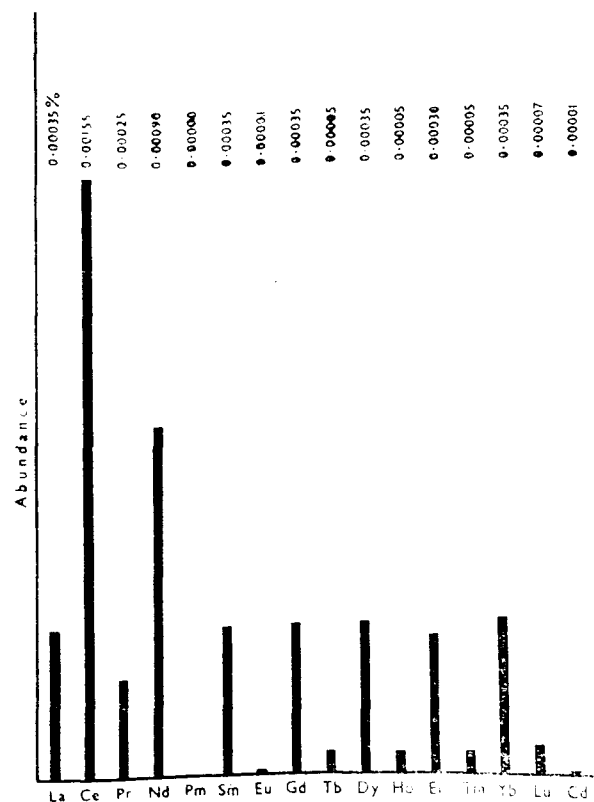


Fig. 3. Relative abundance of rare earths.

zinc, uranium, tungsten, cobalt, tin, mercury, iodine, platinum, gold, cadmium, arsenic, and many others.

There are now known to be about 200 different rare-earth-bearing minerals: these are found mainly in the United States, Russia, India, Brazil, Norway, and Australia. The main minerals are monazite (which also contains much thorium), polycrase, samarskite, gadolinite, cerite, fergusonite, euxerite, and allanite. Many of them contain yttrium for reasons already mentioned.

The ores are usually ground and passed through a magnetic separator which attracts the strongly paramagnetic lanthanides towards the strong part of the magnetic field, while the diamagnetic silica, etc., goes to the weak part of the field. The concentrated ore is then finely ground and, in general, either digested with hot concentrated sulphuric or hydrofluoric acid, or fused with caustic soda. Any undissolved material is filtered off; the base metals are precipitated as sulphides and these are also removed. The addition of oxalic acid then precipitates the rare earths plus thorium and zirconium. This is then digested in ammonium oxalate which dissolves the lanthanides but leaves the rest. It is from this source that the thorium used in breeder reactors is mainly derived.

Previous to 1943, the lanthanides were then separated from one another by a series of tedious crystallizations which depended upon slight differences of solubility between various salts of the members of the group. Many thousands of operations were necessary and even then the final amounts obtained were very small for most of the less abundant elements. Nowadays, the final separation is carried out by ion exchange columns. Usually some chemical method is employed to divide the group into two parts called the yttrium and cerium sub-groups, although the division is not a sharp one. These sub-groups are called the 'heavies' and 'lights' respectively, since the former sub-group contains mainly Y, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu, and the latter the lighter La, Ce, Pr, Nd, Sm, and Eu.

The elements Ce and Eu can be prepared relatively easily due to the stability of the configuration $4f^0$ and $4f^7$ as discussed above. Thus cerium forms an ion Ce^{+4} with structure $4f^0 5s^2 5p^6$,

and europium forms Eu^{+3} with structure $4f^7 5s^2 5p^6$. These ions have chemical properties somewhat different from the usual tri-positive ones so chemical methods can be used to remove them from the mixture. The other elements of the group are separated on ion exchange columns. The present process uses an 'Amberlite' exchange resin upon which the lights or heavies are first adsorbed in a narrow band at the top of the column. This column is then 'eluted' or washed through with some chemical that forms a complex with the adsorbed ions. Since the complex forming powers of the ions differ slightly among themselves preferential elution will occur, in which those most strongly complexed will be washed out first. In practice an ammonium citrate solution has been found to be very suitable provided the pH is controlled by additions of citric acid. Many different variants of exchange resin, eluent solution, concentration of eluent and adsorbed ions, etc., are in fact used for different separations in the final stages, but in all cases the general procedure is as outlined.

If radioactive material is available from a pile then 'tracers' can be inserted into the column and the progress of elution followed by measuring the radioactivity with a Geiger counter or other appropriate instrument. In this way either one ion or several may be 'tagged', depending upon the radioactive material available. Experimentally, the activity is plotted against the total volume eluted at that time and curves are obtained of the type shown in Figure 4, provided, of course, that there are tracers present for the elements represented. It was by an examination of such peaks that promethium, element 61, was first discovered. It will be observed that the elution order is in exactly the reverse to that of atomic numbers, so it was expected that promethium would lie between neodymium and samarium, as in fact it did.

PHYSICAL AND CHEMICAL PROPERTIES

From the point of view of atomic energy one of the most important properties of the group is their very large cross section of capture for thermal neutrons. The cross sections of gadolinium,

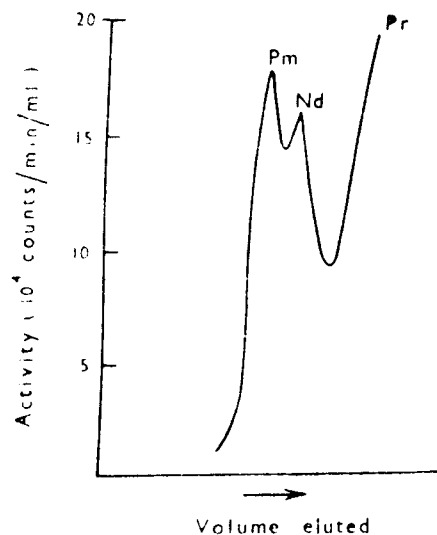


Fig. 4. Curve showing the elution order of the elements in fission products as determined by their activity when tracer material is added.

samarium, and europium are 30,000, 4,250, and 2,500 barns* respectively, and by way of illustration these values may be compared with the cross section of capture of cadmium, which is the usual material used to regulate the neutron flux in atomic piles, where the value is 2,600.

From these figures it is evident that gadolinium metal would act as an exceedingly efficient nuclear fission 'fire extinguisher' in cases where a pile was getting out of control. This also means that even small amounts of gadolinium or its salts formed during

*The unit 'barn' refers to 10^{-24} cm² and has an amusing origin. It is reported that the late Enrico Fermi was discussing the cross sections of neutron capture with some students who remarked upon how small the unit 10^{-24} cm² was. Enrico Fermi is reputed to have looked up in some surprise and retorted, 'Small! It's as big as a bloody barn', and from that instant the name of the unit had been decided.

the fission process will result in a large decrease in pile efficiency.

The radioactivity of the lanthanides is also of interest. Most of them are only electron emitters of fairly low energy so that few radiotoxicological hazards arise although γ -ray emission sometimes accompanies the β emission and, in one or two cases, α particles having energies 4-5 MeV are emitted.

One feature of the production of the lanthanides group during U^{235} fission has been the production of element 61, promethium, Pm. This element does not occur in nature in any of its isotopic forms, but during the fission process an isotope having a mass number of 147 is produced with a 2.6 per cent yield. The isotope decays by electron emission with a half life of 3.7 years and this is easily long enough for its chemical and physical characteristics to be determined. Thus it is that this renaissance of interest in the rare earths has resulted in the discovery of a previously unknown element, and since that time about half a dozen less stable isotopes of the element have also been identified. The metals themselves are highly electropositive, i.e., they tend to form positive ions easily in solution, so it is only with the greatest difficulty that they can be prepared in the pure metallic state although most of them have now been isolated in macro amounts. One of the difficulties encountered in their preparation is that they form an almost infinite series of solid solutions one with the other and also with most other metals. These alloys, annoying as they are in the preparative stage, are proving to be very useful in the correlation of the theory of metals with the practical side of the subject, simply because of the large number of possible combinations that form alloys. It has also been reported that lanthanum metal is a superconductor of electricity.

All the metals and their compounds display a strong paramagnetism (i.e., they move towards the strong part of a magnetic field) and gadolinium itself is ferromagnetic* below 16° C.

*The temperature at which the behaviour changes from ferromagnetic to paramagnetic is known as the Curie point. It is the temperature below which the individual metal atom magnets start to interact with one another strongly, and instead of behaving as a collection of individuals act co-operatively.

Gadolinium metal may thus be picked up by a magnet in the normal way provided that the temperature is less than 16°C ; above this temperature, even though attracted to the magnet, the attraction is not nearly enough to support its own weight.

The paramagnetic properties of the lanthanides (actually of their ions) played a very important part, even as early as 1932, in the development of the quantum theory of the magnetic properties of matter. Their paramagnetism is due almost entirely to the presence of the $4f$ electrons which, being well inside the outer electron shells, are not disturbed by the electric fields of neighbouring ions. This allowed direct comparison of their experimental magnetic moments with the theoretical values calculated by Van Vleck for the tripositive ions, and Figure 5 shows how well these theoretical values agree with the experimental.

Still connected with magnetic effects is the role played by

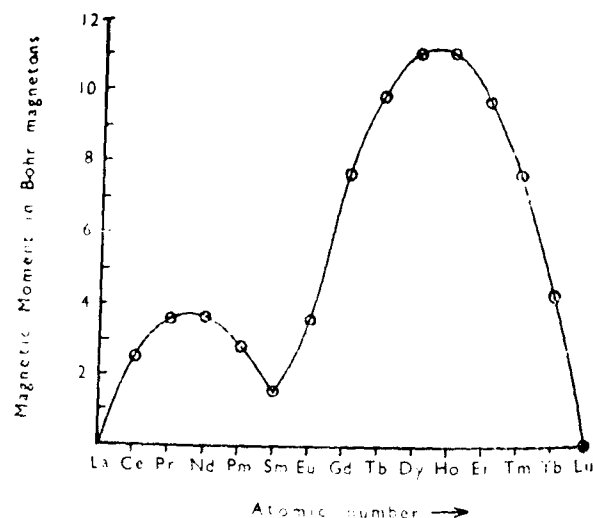


Fig. 5. Curve showing change in magnetic moment throughout the rare earth series. On this scale experimental and calculated values are indistinguishable.

gadolinium sulphate octahydrate in attaining temperatures as low as only 0.0002°K above absolute zero (about -273.14°C), which is the lowest temperature so far reported. In this process the salt is cooled down to the temperature of liquid helium (about 4°K) in the presence of a very strong magnetic field, and when temperature equilibrium has been obtained the magnetic field is suddenly switched off. The removal of the field causes the salt to absorb heat from its surroundings since the individual ion magnets can now take up random orientations, and to do this requires energy which they take from their surroundings. This causes the temperature to drop to the value given.

Some of the lanthanide ions have rather characteristic pastel colours. When the tripositive ions are arranged in order of their atomic numbers, regularities, which were first noticed by Main Smith in 1927, appear. These regularities can be summarized as 'the first seven ions have colours similar to the last seven placed in the reverse order'. This feature is brought out in the way in which the ions are listed in Table II, which gives the colours of the various cations, these being almost completely independent of the nature of the anion.

TABLE II

M^{+3}	Colour		M^{+3}
La	colourless	colourless	Lu
Ce	colourless	colourless	Yb
Pr	green	pale green	Tm
Nd	red	red	Er
Pm	pink	brown-yellow	Ho
Sm	pale yellow	pale yellow-green	Dy
Eu	pale pink	pale pink	Tb
Gd	colourless		

The reason for this colour regularity is related to the fact that an atom with a configuration $4f^n$ has the same types of energy levels as one with $4f^{14-n}$, e.g., if $n=2$, then $4f^2$ would be similar

to $4f^{12}$ and these correspond to praeodymium and thulium tri-positive ions which, the table shows, both have the same colour. Since this rule holds so well it means that the absorption of light in the visible region, which is what gives rise to the visible colours, is restricted to transitions involving the $4f$ electrons only and no others. This has not been confirmed experimentally in all cases, but the spectra that have been analysed show this to be true. There are other absorption bands in the ultraviolet which are due to the excitation of other electrons, but these do not affect the visible colour.

APPLICATIONS

Chemically, the lanthanides have not up till now been very important, although one compound at least has been in use for a considerable time. This compound is ceric sulphate, which is a very powerful oxidizing agent, and is used extensively in volumetric analysis. Its use as an oxidizing agent depends upon the ease with which the ceric ion, Ce^{+4} , will accept an additional electron and so revert to the oxidation state of three which was shown above to be characteristic of the whole group. The ceric ion has no $4f$ electrons whereas the cerous ion has one electron in its $4f$ shell, so that it is this electron that is removed when cerous ion is oxidized to ceric ion.

Probably the earliest known use of the group was in the Welsbach gas mantles where the small ceria content improved the quality of the light. Ceria has now found a very important use as an optical polishing agent in place of jeweller's rouge. Its utilization for this purpose rests on the fact that it is much easier to clean off the surface properly and so does not give rise to after-corrosion of the polished surface. It is also claimed that a much higher polish results from its use.

The group has been found to be increasingly useful in the optical and enamel industries. The former depends mainly upon the large range of sharp colour absorptions that can be found in the various salts and in their strong ultraviolet absorption. Thus many scientific filter glasses for the visible region are made with glass incorporating one or other lanthanide, as also are the

protective glasses used by workers in glassblowing and welding industries. The Crookes lenses in sun-glasses depend upon the strong absorption of long wavelength ultraviolet light by the lanthanide oxides, and similar glasses are also much used scientifically.

In synthetic jewellery the colours of the lanthanides also find a useful place. Artificial rubies depend for their colour upon a mixture of cobalt and neodymium salts, and green praseodymium salts are used for artificial emeralds. Even bright purple 'gems' can be fabricated by use of neodymium salts alone.

The oxides themselves have been increasingly investigated as possible additives for special glasses. One example is the use of lanthanum oxide, which is colourless, in conjunction with other non-silica bases to make a glass having a very high refractive index and yet low dispersive power. Such glass is very useful for the wide-angle lenses used in high-altitude aerial cameras.

In any discussion of the uses of lanthanides the widely known *misch metal* and its associated *Auer metal* must be mentioned. The former contains mainly cerium (about 70 per cent) with smaller amounts of lanthanum, praseodymium, neodymium, and very much smaller amounts of the other lanthanide metals. *Auer metal* is 35 per cent iron and 65 per cent *misch metal*. The importance of both these alloys is in their pyrophoric nature, i.e., they emit showers of hot sparks when struck or scratched and so are useful as 'flints' in lighters. These alloys are also included in tracer bullets and other pyrotechnic devices.

Finally, the lanthanides, particularly dysprosium and holmium, are by far the most paramagnetic substances of all the elements and they are coming into use as catalysts wherever their paramagnetism is of importance. Now that these elements are being produced on a much larger scale it would not be surprising to see a rapid expansion in the uses to which they may be put, and with the coming of really large-scale production the metals and their alloys may become of great service.

*

The purpose of this article has been to endeavour to show how many of these elements have now become accepted media

of rapid technological advance. In addition, with the new demands placed upon the chemist and the metallurgist by modern high-speed engineering, it is comforting to have grounds for hope that somewhere in one of the hundred pigeon-holes of the periodic table, or by a combination of them, may be found the right elements for any job.

RESEARCH REPORT

A. W. HASLETT

X-RAYS FROM SOLAR FLARES

Preparations for the International Geophysical Year have led to the discovery that solar flares, in addition to previously known effects, are accompanied by bursts of X-radiation from the sun. The discovery was reported by the United States Naval Research Laboratory, Washington, from preliminary experiments with rockets launched at sea. The experiments were carried out in co-operation with the Climax High Altitude Observatory, Colorado, which keeps a regular watch on the sun's surface. X-ray measurements were made during only one flare – a small one on 20 July 1956 – but the expected X-ray burst was found. A similar, but greater, increase in X-ray emission from the sun is suggested as the chief cause of the fade-outs on short-wave radio that accompany major flares.

The origin of the experiments was the knowledge, obtained from a dozen rocket flights scattered over seven years, that the undisturbed ('quiet') sun radiates sufficient energy in X-rays to account for the ionization of the *E*-region of the atmosphere, at an altitude of 100 to 140 kilometres. This is, in fact, the mechanism that is now thought to maintain daylight ionization in this region. The range of wavelengths concerned is between 10 and 100 ångströms. To the radiologist, these are 'soft' X-rays; they correspond with the output of X-ray tubes in the range from about 1.5 to 15 kilovolts, the higher energy corresponding with the shorter end of the wavelength range. Ionization of the *D*-region, which is sometimes recognized below the *E*-region at altitudes between 75 and 95 kilometres, has been attributed to ultraviolet radiation from the sun – Lyman-alpha radiation originating in solar atomic hydrogen. It is a sudden increase in

ionization in this, the lowest, radio-reflecting region of the atmosphere, accompanied by a lowering of its radio-reflecting base, that is responsible for the fade-outs on short-wave radio already mentioned. Although there is good evidence for the part played by ultraviolet radiation in causing ionization in this region under normal conditions, it has been difficult to account in the same terms for at least the more drastic fade-outs observed. In an extreme case, an increase of more than ten-thousand-fold in Lyman-alpha radiation would be necessary. Hence the interest of these new observations on X-ray wavelengths, and the suggestion that it is the increased X-ray emission during a solar flare that upsets short-wave radio communications.

The purpose of the rocket programme, to which the experiments now reported were a preliminary, is to make simultaneous observations of solar X-rays and Lyman-alpha radiation during solar flares. Because of the violent disturbances on the sun that accompany a flare, it was arranged to measure X-ray emission on shorter wavelengths than those found in 'quiet sun' conditions. Detectors responsive to two ranges of X-ray wavelengths were provided – one from 1 to 8 ångströms, and the other from 0.05 to 1 ångström – and the lower limit of wavelength received was also measured.

The initial tests of the equipment were made at sea – 300 miles off the coast of California – using the 'rockoon' combination, in which a rocket is launched from a high-altitude plastic balloon. The advantage of this arrangement is that the rocket is fired above the main mass of the atmosphere, so that a relatively small and quick-burning rocket can be employed. For use in solar flare observations, the 'rockoon' had to be launched in advance, and the rocket fired by radio. In an 11-day test programme, the 'rockoons' were launched in the mornings, and if the day passed without a flare, the rocket had in any case to be fired by nightfall.

In the usual way that things happen, the two best flares during the test period occurred on the one day out of the eleven when a 'rockoon' had not been launched. They were accompanied by

radio fade-outs, which were detected on the ship – no doubt to the annoyance of the party. The smaller flare, during which a rocket was launched, was notified by radio from Climax Observatory, which had observed it visually, and no radio fade-out was detected. The interval from the beginning of the visual flare to the time when the rocket was at its peak altitude of 100 kilometres was between 11 and 13 minutes. The strength of the visual flare was by then declining. X-rays were observed from 75 kilometres upwards. Wavelengths down to 3 ångströms were recorded, and the measured intensity would have sufficed to double the normal density of electrons in the D-region. The flare, as has been said, was a small one. The biggest effects observed in the D-region and in practical radio communication could be accounted for, it is pointed out, by a comparatively modest increase in X-ray emission, accompanied by a slight further drop in the lower limit of wavelength. The mechanism suggested is thus plausible, so far as evidence yet goes. Further observations are to be made during the International Geophysical Year using ground-launched rockets.

Chubb, T. A., Friedman, H., Kreplin, R. W., and Kupperian, J. E.:
Nature 1957, 179, 861.

BELOW THE GULF STREAM

A southwards deep-ocean current below the Gulf Stream has been followed by methods developed by Dr J. C. Swallow of the National Institute of Oceanography. Enough measurements to establish the variation of water movement with depth were made in a recent joint expedition in which the Royal Research Vessel *Discovery II* collaborated with the Woods Hole research vessel *Atlantis*.

The essential apparatus consists of a pair of aluminium tubes, sealed at both ends, to which an acoustic transmitter is attached. The tubes are of the kind used in scaffolding. The containers formed from them are less compressible than sea water. Hence, if suitably loaded, they will sink at the surface; but, on reaching a level determined by the loading, they will float thereafter at a

constant level (strictly, at constant pressure). To measure the rate of water movement at that level, all that is necessary in principle is to follow the movement of the floats with hydrophones from a surface vessel and to navigate with great enough accuracy.

Until a few months ago, *Discovery II* had followed 12 floats for several days in several parts of the eastern North Atlantic, as much of the work as possible being done in co-operation with other marine laboratories. With the help of navigational aids, echo-sounding, anchored marker buoys, and radar, it was shown that the deep floats could be tracked sufficiently accurately to show the deep tides and currents. Co-operation with the Woods Hole Oceanographic Institution, Massachusetts, brought together this British experience in measurement and recent American progress in the theory of oceanic circulation. In particular, Dr H. Stummel, of Woods Hole, had predicted the existence of a considerable southwards movement below the Gulf Stream, and had pressed for measurements to be made.

In the combined expedition, *Discovery II* used its constant-level floats, and *Atlantis* carried out close measurements and sampling of the water, from surface to bottom, along representative lines across the area under investigation. Such observations allow the construction of constant-pressure charts for the oceans, analogous to those used in weather forecasting; from charts of this kind, the course of water movements can be calculated, provided that certain initial assumptions can be checked by measurement. There was thus an additional – and probably a permanent – value from the use of these two methods in conjunction.

The predicted southwards movement at depth was found. At the surface the Gulf Stream was strong to the north; between 4,500 and 6,000 feet there was little or no movement; at a greater depth, three floats followed at 8,200 feet, and four at 9,200 feet went to the south. One of the deepest floats did a steady third of a knot, travelling 23 miles in 66 hours. An adaptation of sea-bed photography showed that there was still movement, almost down to the ocean bed. Photographs of the

deflection of a ball suspended by string from a compass only 18 inches above the bottom showed an appreciable movement to the south. The existence of a deep current, southwards in the southern hemisphere as well as the northern, is probably the reason why the Gulf Stream is more powerful than its southern counterpart, the Brazil current.

Admiralty Bulletin No. 90, May, 1957.

DOUNREAY AND NIOBIUM

The most general interest of the Dounreay station of the United Kingdom Atomic Energy Authority is the extent to which it has been planned as a research station – and not merely as the home of an experimental reactor, the biggest 'fast breeder' power reactor yet built. Till recently it was not appreciated outside the Authority to what an extent this reactor would be used as a tool for research; or how far the station that was being built round it had been conceived as a self-contained unit. In addition, there is the more specialized interest that the new metal, niobium, is being used for the first time as a material in its own right, and not merely as a minor alloying constituent – notably in special stainless steels intended for uses that involve welding.

The use of niobium is to 'can', or sheathe the fuel elements of the 'fast breeder'. These, for the present, will be made of highly enriched uranium. Later, there may be trials of individual fuel elements made of different alloys of plutonium. Later still, the reactor may be adapted to use entirely plutonium fuel. The reactor has been designed on the basis that heat, at the rate of 60 megawatts, will be released in the small reactor core – 21 inches across and 21 inches in height. But it is envisaged that the designed heat rating, already high, will later be increased. In terms of heat transport the design rating represents an average output of two-thirds of a kilowatt through each square centimetre of can surface. For the removal of this heat, there appeared to be no alternative but to use a molten metal – sodium-potassium alloy. The operating temperature of the cans has not been stated. However, some form of rough guess may be made

from the overall efficiency of 25 per cent which is implied by the installation of 15 megawatt generators. Probably can temperatures will be in the neighbourhood of 400° C under the initial conditions of working. But, again, a move to higher working temperatures is envisaged.

A first requirement in the canning material is thus to withstand contact with molten sodium and potassium at temperatures of 400° C and upwards. Niobium is resistant to sodium and potassium at all temperatures up to the boiling point of the alloy – about 900° C. It is compatible with uranium up to 1250° C. But these, unfortunately, are not the only limitations in respect of temperature. There is the further requirement of structural rigidity in face of the rapid production of fission products, some of them gaseous, and in conditions of intense neutron irradiation. Niobium has a high melting point: 2415° C. But it has been said earlier by Sir John Cockcroft that, in relation to its melting point, it begins to show significant 'creep' at a disappointingly low temperature. This, then, may be the most serious limiting factor – although it may be reduced in part by alloying. The impression given was, that although the design temperature might later be improved upon, no very great advance was probable. Lastly, but by no means least in view of the heat rating, niobium has a thermal conductivity 2½ times that of zirconium, while being also an easier metal to work. With these advantages, it is comparatively a minor drawback in a reactor of this type that the absorption-rate of niobium for neutrons is some eight times greater than that of zirconium. At that, it is better than stainless steel by a factor of roughly four, and has about the same advantage in respect of thermal conductivity.

The manufacture and fabrication of niobium metal are being carried out directly by the Authority for the present. The necessary techniques, which include powder metallurgy, have been developed at the Culcheth Metallurgical Laboratories and Springfields factory, both in Lancashire. The fabrication of fuel elements – including canning – will be at Dounreay. Chemists who have been concerned with its development forecast later uses in industry, once production has been established. In ap-

pearance, niobium is a typical steel-grey metal; its density is 8.57. It is fairly widely distributed in tantalite ores, the chief present sources being in West Africa.

In explanation of the probable later changes in operating conditions of the Dounreay 'fast breeder', some further points should perhaps be added. The primary heat exchangers, which are inside the reactor shell, are understood to have been deliberately over-designed in order that an increased heat output could be handled. In the case of the secondary heat exchangers, there is provision in any case for the 'dumping' of surplus heat. Trial runs at a higher working temperature could be arranged, too, without any major change in equipment. But if the temperature were to be permanently ranged, then new turbo-generators would be needed.

NEW PLASTICS

New possibilities for making 'tailor-made' polymers have been opened up by the combination of a new process and a new approach. The process, introduced to British production at the Shell Petrochemicals plant at Partington, near Manchester, is the Ziegler process, applied in the first instance to the polymerization of ethylene at ordinary pressures. Instead of polymerization under the blind, but effective, compulsion of high pressure, an organo-metallic 'catalyst' is used; this is made on the job from titanium trichloride. Strictly speaking, however, it appears not to be a catalyst, since it emerges changed from the production process. By varying the conditions the properties of the polymer obtained can be varied. But the method offers greater flexibility than the making of different polyethylenes; it is a method for the polymerization of unsaturated hydrocarbons in general, and the catalyst also can be varied.

The new approach is indicated by the appearance of a new set of words – 'isotactic', 'syndiotactic', and 'atactic'. The idea is that when a controlled process of polymerization is applied to an unsaturated molecule with side chains, it should be possible in principle to produce a number of different polymers with

differing distributions of the side chains in space. The side chains can all lie either above or below the main plane of the molecule; this is the 'isotactic' arrangement. Or they can be alternately above and below it – when the arrangement is described as 'syndiotactic'. Or, again, they can be randomly disposed – and then are 'atactic'. Either of the first two arrangements will be highly ordered, and hence crystalline. The third will be amorphous or only slightly ordered, and less dense. The words are not important, and the clear-cut distinctions that they suggest are perhaps unlikely to be realized. What does appear to be happening is that industrial chemists are thinking, and in the research laboratory acting, on the principle that they can choose the structures that they want and produce them – if they find out how.

In practical terms, we have so far 'linear', otherwise 'high density', polyethylene, higher in tensile strength than ordinary polyethylene; 'isotactic polypropylene', made on a pilot-plant scale in Italy, reputedly of about the same strength as 'linear' polyethylene and with a higher melting point; and talk of new synthetic rubbers, one of which has been made seemingly to order. Polypropylene should perhaps be regarded as the true point of entry to this promised new world; since propylene, from which it is polymerized, is the simplest unsaturated hydrocarbon that has a side chain to dispose of.

SOME BOOKS RECEIVED

VOICES OF THE WILD by Eric Simms (London, Putnam, 1957), pp. 230, 21s.

In his introduction to this delightful book, Peter Scott aptly puts his finger on a change that has taken place in man's attitude to nature during living memory. The invention of the gun having, unhappily, preceded that of the camera, both still and ciné, a generation ago, as he puts it, 'there was only one recognized objective if a man would pit his wits against animal and bird. It was to exercise the ultimate sanction – the power of life and death.'

Advancing techniques and the pursuits based on them have altered that: today, the still and ciné picture, obtaining which may entail all the arduous of the chase, are supplemented by the sound recording. In this Eric Simms is a leading exponent. The pioneer in recording the voices of birds and animals was the inimitable Ludwig Koch, whose invaluable collection of nature recordings now repose in the archives of the B.B.C. But innovators always pay a price for their pioneering. Simms, who is responsible for making the natural history recordings used by the B.B.C., has all the advantages of midgey tape-recorders, walkie-talkies, parabolic reflectors, super-sensitive microphones, and so on. His own broadcasts, particularly those studies of single species he broadcasts from time to time in the Third Programme, are of acknowledged scientific value. Now he has written for us the adventure of making the recordings on which these broadcasts were based.

He takes us to a badger set in Surrey, to the great reservoirs round London where man has created a habitat that nature is not slow to seize, to the Brecklands, the estuary of the Dee, and to the sub-arctic tops of the Speyside mountains, in all of which he pursues his quarry with all the avidity of the most pertinacious hunter – but a hunter whose prize is not a stuffed specimen in a glass case, but a few 'ter-chees', 'kek-keks', or 'teek-adoos' on a piece of magnetic tape.

THE ATOMIC AGE AND OUR BIOLOGICAL FUTURE by H. V. Brondsted (London, Watts, 1957), pp. 80, 9s 6d.

The most significant part of this little book is perhaps the postscript, of which the first sentences read: 'Many readers will doubtless

have gained the impression that the author of this book had painted a gloomy picture; this has been his deliberate aim. When one is dealing with dangerous things, it is better to be over-cautious than too daring. Radiation is dangerous.'

Its author has been professor of zoology in the University of Copenhagen since 1948 and the book is based on a series of lectures he gave to the general public. Ten short chapters deal with, among other things, radiation, mutation, isotopes, and the relation between radiation and, for example, sterility, embryonic development, and the transmission of genes. It is, however, in its short introduction and postscript that its true value lies. In the introduction Professor Brøndsted makes the point that the coming of the atomic age has confronted Man with an altogether new ethical problem. Are we today responsible for the men of the future, for distant generations in days to come? This new moral problem arises because by our activities now we may increase the mutation rate of future generations, and so bring about some incalculable disturbance in our biological equilibrium. As Professor Brøndsted says: 'We are responsible for some of the mutations that will place their stamp on mankind in future generations. In education there is always a way back or aside or forward, if the education has proved to be wrong. If the social order is bad, there is always a possibility of having it altered into something that seems better. But there is no way back if in our ardour and imprudence we have altered our genetical constitution, whether it be for better or for worse, and the chances are by far the greater that it will be for worse. This is our new and immense responsibility.'

With little difficulty one could read this book in an hour: the questions it raises will not be put out of mind in a generation. There is a well-chosen short bibliography of which two items, those in *Impact*, vol. 4, merit further careful study by anyone trying to reach a decision in the ethical dilemmas that now faces mankind.

CONCISE ENCYCLOPEDIA OF ATOMIC ENERGY edited by Frank Gaynor (London, Peter Owen, 1957), pp. 204, 37s 6d.

In no field of scientific endeavour is the need to be up to date more pressing than in the field of atomic energy. One is, therefore, rather taken aback to discover that while this Encyclopedia purports to be a 1957 publication, the date at the end of the preface is New York 1950, and the text is presumably older still.

Only an expert in the subject could pronounce on the scientific

data, but any scientist will undoubtedly notice that Einstein, Soddy, Fermi, and Irene Curie, at least, are represented as still alive. They will also notice that British Nobel Prizewinners who have made outstanding contributions to nuclear research are not included while many 'officials' from the American nuclear scene are. Cockcroft is described as a professor of physics at Cambridge and the quondam scene of his labours the Cavendish Institute. Harwell, which he now directs, had only acquired two reactors: Calder Hall is a far-off dream.

The neutrino, negative proton, and parity are naturally absent. Titanium is described as a rare metal – curious for an element that comes directly after aluminium, iron, and magnesium as a possible structural metal. All this is most disappointing because it could have been an invaluable reference book. Perhaps it was, once.

UNESCO SOURCE BOOK FOR SCIENCE TEACHING (Wakefield, Educational Productions Ltd for Unesco, 1956), pp. 222, 15s.

The fascination of this book is that it successfully explodes the mistaken idea that to teach a useful amount of science special 'apparatus' is really necessary. The kitchen, hardware store, cycle and radio shop, and the builders' merchant can supply a wide variety of requirements that can be used as the foundation for the observation and experiment that are fundamental to good science teaching at any level. This reflects its origin which was a collection of suggestions made to science teachers in devastated countries at the end of the war.

Teachers from fortunate schools with well-equipped laboratories may look askance at many of the rough and ready improvisations, and let it be admitted that they are not all above suspicion. Nevertheless, the volume contains a wealth of fascinating suggestions for simple experiments, many of which have the virtue that, by contriving them with, as it were, string and sealing wax, they never suggest that science is something apart from everyday life.

There are several appendices of useful data. The reviewer has not checked the figures given, but it was unhappily noticeable that the prices for English scientific periodicals are those operating in some instances up to six years ago. Fortunately physical constants are not subject to such rapid alteration.

HUMAN BLOOD GROUPS AND INHERITANCE by Sylvia D. and L. J. Lawler (London, Heinemann, 1957, second edition), pp. 103, 7s 6d.

With three centuries passed since its circulation was scientifically demonstrated by William Harvey, blood is still a subject of prime interest to biologists. As R. R. Race, director of the Medical Research Council's Blood Group Research Unit, points out in the foreword, only in eleven normal human characters is the exact manner of inheritance known with certainty and nine of these eleven are blood groups. It is not surprising, therefore, that blood groups are of fundamental importance not only in biological research but in clinical and forensic medicine, anthropology, and so on.

All these aspects are treated by the Lawlers with commendable clarity. They describe the history of the subject, the technique of blood grouping, the national blood transfusion service, the A_1A_2BO , Rhesus, and other more recent, systems, and finally the implications of a knowledge of blood groups in biology. There is a useful short glossary: a good buy for the school library.

FOUNDATIONS OF WIRELESS by M. G. Scroggie (London, Iliffe, 1957, sixth edition), pp. 349, 12s 6d.

As successive generations of scientists and technologists grow up, the books they use, if they are to keep alive and useful, must grow up with them. *Foundations of Wireless*, first published in 1936 under the authorship of A. L. M. Sowerby, M.Sc., has done this successfully. During the twenty years of its existence it has been the indispensable handbook of scores of thousands of radio engineers. Now, in a sixth edition, produced by M. G. Scroggie, it is once again brought up to date, in particular by the addition of a new chapter on the increasingly important semi-conductors.

Only a minimum of mathematics is required to follow Mr Scroggie's explanations. An introductory section deals with algebraic symbols, graphs, and circuit diagrams, and then follows the whole basic theory of radio; the fundamental laws, the theory of valves, transmitters, and all types of modern receivers. There are short chapters on radar, television, and such topics as power supplies, transmission lines, aerials, and so on.

All one needs to be able to talk learnedly about cross-modulation and kinkless tetrodes is 12s 6d and plenty of time.

WILLIAM HARVEY: HIS LIFE AND TIMES: HIS DISCOVERIES: HIS METHODS by Louis Chauvois (London, Hutchinson Medical Publications, 1957), pp. 271, 25s.

DE MOTU CORDIS BY WILLIAM HARVEY translated from the original Latin by Kenneth J. Franklin (Oxford, Blackwell Scientific Publications for the Royal College of Physicians of London, 1957), pp. 209, 17s 6d.

In June the world of science and medicine celebrated the tencenary of the death of William Harvey, whose clear demonstration for the first time of the circulation of the blood is one of the great milestones of the history of biology.

Dr Louis Chauvois is a distinguished French specialist and medical historian who holds the *Prix d'Histoire et de Philosophie des Sciences* awarded by the *Academie des Sciences*. His training in the classics has enabled him to go afresh to Harvey's own writings, and his admiration for the great anatomist impelled him to make pilgrimages to many, if not all, of the scenes of Harvey's labours. On all sides, therefore, he writes from expert knowledge, with the result that he has produced not only a biography, and an excellent one, but a valuable study of Harvey in relation to his time and his contemporaries.

For those who have neither the leisure nor the learning to read Harvey in the original Latin, Professor Kenneth J. Franklin has produced a new and valuable translation of the short but great work on which Harvey's fame rests. As with Dr Chauvois, this is an act of homage (Professor Franklin explains that Harvey has long been one of his heroes), and it is indeed fortunate that one with the necessary qualifications as a humanist and a scientist was prepared to desert the laboratory, in part at least, for long enough to undertake this task. As the volume also includes the Latin text, might it not be tried as an alternative the Caesar's Gallic Wars, perhaps in an attempt to bridge the gap which separates the humanists from the rest.

ABOUT OUR CONTRIBUTORS

D. W. ALLAN is a graduate in mathematics of the University of Toronto, and did research on the age and thermal history of the Earth at the Geophysical Laboratory of the Department of Physics there. He is spending 1956-7 at the Department of Geodesy and Geophysics, Cambridge, on a post-doctorate fellowship from the National Research Council of Canada and a Rutherford Memorial Fellowship from the Royal Society of Canada.

S. A. BARKER was educated at Handsworth Grammar School, Birmingham, and at the University of Birmingham, where he obtained a First Class Honours B.Sc. in 1947, and his Ph.D. in 1950 in Chemistry. In 1954 he was appointed Lecturer in Organic Chemistry at the University of Birmingham and the following year was awarded a Rockefeller Fellowship. The tenure of his Fellowship was spent at the Radiation Laboratory, California University, and at the Institute of Microbiology, Rutgers University, New Jersey. His research has been mainly concerned with the synthesis of polysaccharides using enzymes isolated from plants, moulds, and bacteria, and with the development of new methods of determining carbohydrate structure.

THOMAS M. DUNN is a graduate of Sydney University, Australia, who in 1952 came to England as an 1851 Science Scholar and has since joined the staff of University College London Chemistry Department. He is engaged in research on the ultra-violet spectra of organic polyatomic molecules and is also interested in the spectra and structure of inorganic molecules, hence his interest in the Rare Earth elements on which he writes in this volume. Outside chemistry, his main interests are cricket, tennis, and listening to music. He is married and lives at Sutton in Surrey.

F. H. GEORGE read both the Moral Science Tripos and the Mathematical Tripos at Cambridge, and also studied physiology in the Natural Science Tripos. For the last eight years he has been Lecturer in the Department of Psychology at Bristol University, except for a year's leave of absence in 1953-4 when he did research at McGill University and was Visiting Professor at Princeton University. Apart from his special interests in behaviour, philosophy of science, and mathematics, he is especially interested in cybernetics and its application as automation. He also takes a keen interest in literature, rugby football, and cricket.

P. E. HODGSON graduated in physics at Imperial College, London, in 1948, and subsequently studied the nuclear disintegrations caused by the cosmic radiation, for which research he was awarded a Ph.D. in 1951. Afterwards he moved to University College London and began theoretical studies on nuclear collisions. He is now Lecturer in Physics in the University of Reading.

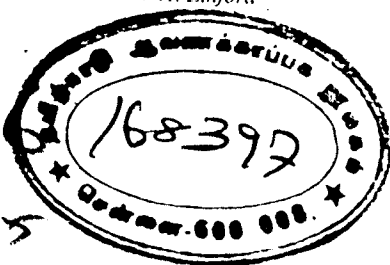
D. C. MARTIN has been Assistant Secretary at the Royal Society since 1947. He graduated at the University of Edinburgh, where he did research in physical chemistry for which he was awarded his doctorate. During the war he was in the directorate of scientific research in the Ministry of Supply and among other duties was secretary of the Explosives Research Committee (Chemistry). From 1945-6 he was General Secretary of the Chemical Society. He is Recorder of the Chemistry Section of the British Association for the Advancement of Science. He was elected a Fellow of the Royal Society of Edinburgh in 1956 and has recently assumed the Chairmanship of the I.G.Y. Publications Committee.

M. STACEY, F.R.S., was educated at Adams Grammar School, Newport, Salop, and at Birmingham University, London University, and Columbia University, U.S.A. In 1946 he became Professor of Chemistry in charge of Biological and Organic Chemistry at the University of Birmingham and in 1957 Mason Professor and Head of the Department. He is a Member of Council of the Royal Society, Vice-President of the Chemical Society, Chairman of the University Joint Recruiting Board, and Chief Scientific Adviser for Civil Defence for the Midlands Region. He has 230 scientific publications to his credit.

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