SYDNEY CHAPMAN

V. C. A. FERRARO

Sydney Chapman was born at Eccles in Lancashire on the 29th January 1888. His father, a cashier, had resolved that his son should get the best education he could afford to give him and he was sent to a good and "unusually scientific grade school" where his interest in scientific matters was first kindled. On the advice of an engineer whom his father had consulted, Chapman spent two years at a technical school. A kindly Scot, Dr. B. Prentice—one of the first Ph.Ds. in Britain—took a fatherly interest in Chapman and encouraged him to sit for a scholarship to Manchester University. He gained his scholarship and went up to read engineering: as he relates in his reminiscences there were 15 scholarships to be awarded: "I was fifteenth on the list, and I sometimes wonder what would have happened if I'd hit one place lower." He graduated in 1907 but soon after his interests turned to Mathematics; Horace Lamb, the professor of Mathematics, had told Chapman that there were good openings for applied mathematicians and that, in that case, he should go to Cambridge. Chapman sat for an open scholarship to Trinity College, which he gained, and went up in 1908. Two years later he became a wrangler and having sat for the Mathematical Tripos in his second year he had to stay at Cambridge for a third year to get his degree. It was during this time that he developed an ambition to do research in mathematics and, looking round for a subject, became interested in the theory of summable series. But he was uncertain whether to become a pure mathematician or an applied mathematician. As it was, fate intervened on the side of applied mathematics. For, returning one day to his room in Trinity College, during his third year, he was surprised to find the Astronomer Royal, Dr. Frank Dyson (later Sir Frank Dyson) waiting for him. He had come to offer Chapman a post of Chief Assistant at Greenwich Observatory—a post which he accepted and held from 1910 till 1914. It was undoubtedly during this period that he developed his interest in the study of the earth's magnetism, which he was later to rename "geomagnetism", an interest which was to last for the greater part of the remainder of his life. About this time also he approached Sir Joseph Larmor for advice on a topic for research. Larmor sent him some papers by Knudsen on the flow of gases of low density in capillary tubes; this led him to the study of the kinetic theory of gases in which he was to predict the important phenomenon of thermal diffusion—a prediction in which he took great pride. In 1914 Chapman returned to Cambridge as a lecturer in Mathematics; he was awarded the first Smith's prize in 1913 and in the same year he was elected to a fellowship at Trinity College which he held until 1919. However, the start of the First World War in 1914 depleted the student ranks at Cambridge and because the staff of the Greenwich Observatory was also depleted, Chapman was

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asked to return to Greenwich in 1916 to help out; and he stayed there until the end of the war on leave of absence from Cambridge.

During his first stay at Greenwich, Chapman had in his spare time helped in the running of a boys' club. On his return to Greenwich in 1916 his pacifist views made him unwelcome at the boys' club and he took up children's work instead for the local Labour Party. This unpopularity affected him deeply and depressed him so much that after the War he returned to Cambridge . But his stay there was short for in 1919 he was asked to succeed Sir Horace Lamb, his former teacher at Manchester, as Professor of Mathematics. He overlapped with Lamb during the session 1919–20. He stayed five years before accepting an offer, in 1924, to succeed A. N. Whitehead as Chief Professor of Mathematics at Imperial College, London. Here he found a department of Mathematics quite different from what he had expected nor what the Rector of the College, Sir Thomas Holland, wished it to be. Chapman had the difficult and unenviable task of having to breathe new life into what was in effect a rather ill-equipped department of engineering mathematics.

It would be difficult to overestimate the influence which Chapman exerted in the Department in his quiet but firm way. Once he had convinced himself that a given course of action was right he would persevere with it whatever the obstacles that might be encountered on the way and so against some opposition from more staid members of the Department but aided by H. Levy he transformed the department along more modern lines.

Chapman stayed at Imperial College 22 years in all during which time he had attracted several distinguished mathematicians to the Department (G. Temple, W. H. McCrea, W. G. Penney); the emphasis, however, was still on the side of applied mathematics. In 1946 he followed A. E. H. Love as Sadleian Professor of Natural Philosophy at Oxford; he enjoyed the graceful living that he found there but sorely missed the secretarial assistance which was practically wanting at Oxford in those days. He retired from Oxford in 1953 to two posts in America where he had been a frequent visitor during the post-war years. One was as Advisory Scientific Director at the Geophysical Institute of Alaska and the other at the High Altitude Observatory, Boulder, Colorado. Here he set about developing the research school in geomagnetism, one of his most distinguished pupils being S.-I. Akasofu whom he was particularly proud to have " discovered ". In Alaska his close cooperation with the then director of the Geophysical Institute, C. T. Elvey, was also instrumental in fostering polar atmosphere research.

Chapman married in 1922, Katherine Nora, daughter of A. E. Steinthal, who was a member of the University at Manchester. They had three sons and one daughter and one of the sons is a very distinguished architect. Chapman was happy in his family life and in this he was much helped by his kind and understanding wife who, in her later years, accompanied him religiously on all his travels. For Chapman was a tireless globe-trotter and especially in his younger days would travel almost anywhere by cycle. He rode from Montreal to Washington in 1939 to attend the meeting of the International Union of Geodesy and Geophysics and in 1954 walked several miles from the centre of Rome to the E.U.R. where the meetings were held to give his presidential address to the same Union. His tastes were simple but he was well read in many fields and a keen lover of the arts. Above all he had a great liking for people and though in his youth he was shy and diffdent, in his later years and especially after his visit to America, he mellowed and his quiet charm and directness won over many American colleagues who respected and revered him.

It seems appropriate at this stage to mention Chapman's long association with the late Julius Bartels which began in 1925 when Bartels was spending a year in England. They became firm friends and delighted in each other's company. In 1929 Chapman was awarded the Adams Prize of the University of Cambridge for an essay on the interpretation of the variations of the earth's magnetic field; the award carried with it a condition that the essay should be published. Chapman hoped to extend it to a treatise on the earth's magnetism but the pressure of other work made this difficult and in that same year he asked Bartels to join him as co-author. Bartels agreed and made his own contribution to the book which appeared in 1940 under the title of Geomagnetism. Much new work has been done and many new discoveries made since this work was published—some vindicating Chapman's own theories—yet to this day the work remains a standard reference book on the subject.

Mention must also be made of his collaboration with T. G. Cowling, a pupil of E. A. Milne who himself had been a pupil and colleague of Chapman. Their association began soon after Cowling had demolished a theory which Chapman had put forward to explain the supposed radial limitation of the sun's magnetic field—later proved to be illusory. Chapman acknowledged the validity of Cowling's criticism and magnanimously offered the young mathematician a post on the mathematics staff of Imperial College. Later he asked Cowling to collaborate on the second major book projected by Chapman and this appeared in 1939 under the title of " The Mathematical Theory of Non-Uniform Gases ".

It would be difficult to overestimate the debt which many young mathematicians owe to Sydney Chapman, many of whom he launched on their careers. He also exerted great influence on the scientific world at large and he was a prominent figure at all international gatherings where his counsel was sought, as it had been sought during World War II by the War Office. Chapman had modified his views on pacifism after he had realised that Hitler must be stopped. He undertook scientific work connected with incendiary problems and showed determination in opposing the generals when necessary. But he worked very hard and when he left the War Office in 1945 I over heard him mentioning to a friend that he " felt like a free man again ".

Because of his wide experience and special gifts, it was inevitable that, at its inception, Chapman should have been elected President of the Special Commission for the International Geophysical Year. He was involved in the planning, shaping and conduct over long periods till the completion. Chapman, as always, would be the first to insist that the work was the collective effort of many hands. Yet, it is doubtful whether the confidence needed for such a wide scientific venture would have been engendered without his own contribution and authority. He had always taken a leading part in the affairs of the International Union of Geodesy and Geophysics. He served as president of the filial Associations for Meteorology (1939–48), for Geomagnetism and Aeronomy (1948–51) and later as President of the Union itself (1951–54).

He was equally active and prominent in the affairs of the learned societies in this country. Our own Society honoured him by the award of the de Morgan medal and Larmor Prize in 1944 and as president from 1929–31. Although not truly an astronomer, he was a prominent figure at meetings of the Royal Astronomical Society and was one of those who helped to launch the Geophysical Supplement of that Society (now renamed the *Geophysical Journal*). He was, for many years the active chairman of the Sub-Committee for Terrestrial Magnetism of the National Committee for Geodesy and Geophysics. He was also president of the Royal Meteorological Society and medallist and also president of the Physical Society. In his stimulating presidential addresses, as well as in the named lectures he was invited to give by the learned Societies, Chapman could be relied upon to provide an excellent review of a topical subject; they were not only lucid and informative but contained the germ of many new ideas which could be turned to advantage by a young scientist with a keen eye.

Chapman reaped many honours and these he richly deserved: he was elected a Fellow of the Royal Society in 1919 at the early age of 31. He was gold medallist of the Royal, Royal Astronomical and Royal Meteorological Societies. He was the first recipient of the Chree medal of the Physical Society. In 1966 the Royal Society furthered honoured him by bestowing upon him their highest award—the Copley medal. A list of his honorary memberships of foreign learned Societies and honorary degrees is appended.

On the 14th June 1970, after feeling unwell the previous week, Chapman suffered a heart attack followed by a cerebral haemorrhage from which he did not recover consciousness. He died two days later. He had become a legend during his lifetime and left a monumental store of scientific papers. I have tried to give some account of his more important work in the following sections.

Mathematics

Chapman's researches in Mathematics relate principally to an extension of Cesaro summability to non-integral orders. Some of the results he obtained were not entirely novel for, unknown to him, he had been anticipated by Knopp and Riesz. Chapman's papers gave considerable insight into the nature of the convergence of series and some of the theorems he proved have found a permanent place in the literature. As a typical example, we may mention the theorem that "If $\sum u_n$ is summable (Cr), then $\lim_{n\to\infty} u_n/n^r = 0$ for $r > -1$."

He also proved certain theorems on the multiplication of series which are infinite in both directions and was able to apply some of his work on summability much later in his researches in geomagnetism!

The Kinetic Theory of Gases

The modern theory of gases was founded largely by Clausius, Maxwell and Boltzmann—especially the last two—during the latter half of the 19th century. Their methods differed greatly; Maxwell's approach was through his equation of transfer of molecular properties whilst Boltzmann sought a solution via his integro-differential equation for the velocity distribution function f. Maxwell was able to obtain expressions for some transport coefficients only for a molecular model in which the molecules of the gas repelled one another with a force varying inversely as the inverse fifth power of the distance (Maxwellian molecules). For this model, which Maxwell thought fitted the observations, the form of the velocity distribution function need not be known. However, just before his death, Maxwell realised that the molecules of a real gas did not conform to his model. In 1910 Chapman became aware of the need to obtain a general solution of Maxwell's equation of transfer and in a series of papers, written between 1912 and 1917 he obtained the general solution of these equations. In his first paper (1912), he had obtained a first approximation to the transport coefficients by assuming a form of the velocity distribution function which, however, is exact only for Maxwellian molecules. This paper was criticised by the referee, Sir James Jeans, and in consequence of this criticism in 1916 he generalised his work and obtained more accurate expressions for these coefficients. He also showed that the results obtained in his first paper were not greatly in error though this could not have been foreseen. He extended his work to gas mixtures and this extension which appeared in 1917 (preceded by a shorter version in 1916) included the predication of the phenomenon of thermal diffusion, that is, the diffusion of two constituents of a gas mixture due to the presence of a temperature gradient. As I mentioned earlier, Chapman felt great pride in this prediction, the correctness of which was demonstrated experimentally by F. W. Dootson in 1916. The reality of the phenomenon had been doubted by several authorities, J. H. Jeans, among others, who thought that the phenomenon would take place infinitely slowly. Unknown to Chapman, the phenomenon had been predicted independently by David Enskog who in 1911 had made a first essay on the problem of the solution of the Boltzmann equation at about the same time as Chapman attacked the equations of transfer. Enskog did not successfully attack the solution of the Boltzmann equation till 1917. It provided full vindication of their joint prediction of thermal diffusion. This was to find many important practical applications, notably in the separation of isotopes.

Soon after the end of World War I Chapman expressed his intention to fuse in a book on gases the methods of himself and Enskog; by the late twenties he had written about a third of the book—this might have remained in draft form had he not found, after two abortive attempts, an able collaborator in T. G. Cowling. The book was published in 1939 under the title " The mathematical theory of non-uniform gases ". Though Chapman's method of solution of the equations of transfer was fully effective, it was, as he says, " intuitive rather than systematic and deductive ". The method of Enskog was mathematical and more elegant and Chapman and Cowling chose this approach in their joint book. The central problem is the solution of the Boltzmann equation for the velocity distribution function f, namely*,

$$\frac{\partial f}{\partial t}+(\mathbf{v}\cdot\nabla)f+(\mathbf{F}\cdot\nabla_{\mathbf{v}})f=\frac{\partial_e f}{\partial t} \tag{1}$$

where $\mathbf{v}$ is the molecular velocity, $\mathbf{F}$ the acceleration on a molecule due to body forces and $\partial_e f/\partial t$ is the " collision integral " involving the unknown function f and represents the rate of change by collisions in the number of molecules of the class which have a small velocity range about $\mathbf{v}$. The form of $\partial_e f/\partial t$ need not concern us here. The solution of Boltzmann's equation for non-uniform gases is found by the method of successive approximations. In the steady state, and in the absence of body forces, the solution of (1) is given by Maxwell's velocity distribution function f_0. The next approximation is obtained by writing $f=f_0(1+\varepsilon)$, where ε is small compared with unity. This corrects the distribution function by terms proportional to the gradient of temperature (giving rise to the phenomenon of heat conduction), velocity (viscosity) and gradient of composition (diffusion). Further approximations yield an infinite series the convergence of which was not considered by Chapman or Enskog who were content to trust to Nature as far as this was concerned. The convergence of the series solution for the first approximation was demonstrated by Burnett in 1935, though the convergence of the series solution for f had been considered earlier by Lorentz for a special case.

Stimulated by certain stellar problems, Chapman in 1922 considered transport phenomena in ionized gases and showed that because the Coulomb forces between electrical charges are long range forces, certain difficulties of convergence arise. Chapman introduced the idea of a cut-off distance (the mean intermolecular distance) and obtained results essentially the same as those derived from more exact approaches. The last chapter of the book by Chapman and Cowling contained what was the first systematic account of the kinetic theory of plasmas, embodying many new results when a magnetic field is present due to Cowling.

Geomagnetism

Chapman's first researches in geomagnetism related to the small daily variations of the earth's magnetic field. In a celebrated article in the 11th edition of the *Encyclopaedia Brittanica*, Balfour Stewart had suggested that these small variations were due to fluctuating electric currents induced in a conducting layer in the upper

* Here ∇ is the gradient operator in ordinary space and $\nabla_{\mathbf{v}}$ is the gradient operator in velocity space.

atmosphere by tidal motion across the earth's magnetic field. His chief reason was that neither the solid earth, nor the lower atmosphere is affected by the Sun in a way that could account for the changes in these variations from sunspot maximum to sunspot minimum. Schuster made the first attempt to put the theory (now generally referred to as the " dynamo theory ") on a quantitative basis and showed that the greater part of the variation was of external origin. Chapman now took up the investigation and argued that if the theory were correct then insofar as such variations are due to tidal motion there should be a lunar component in the daily variations of the earth's magnetic field. In 1913 he determined its Fourier components at three stations and compared his results with the deductions from the dynamo theory. The fourth component suggested that the electrical conductivity of the upper atmosphere was higher over the sunlit hemisphere than over the dark hemisphere. This possiblity had also been considered earlier by Schuster. In 1919 Chapman made a more extensive harmonic analysis in which he showed that the field responsible for the solar and lunar variations could be separated into a part originating above the earth's surface and a part within the earth's surface due to the induction of electric currents within the earth. He found that although the dynamo theory was able to explain many of the observed facts, there remained one difficulty, namely, that the semi-diurnal tidal convective motion deduced from theory is reversed in phase as compared with the barometric variations at the earth's surface.

Chapman's long series of papers on Magnetic Storms began in 1918 with an analysis of the morphology of storms. In this he extended the work of the Indian magnetician N. A. F. Moos at Bombay relating to the average characteristics of magnetic storms. Chapman considered the data of 40 moderate storms with sudden commencement at 12 observatories in middle and low latitudes. He showed that the variations of the geomagnetic field from the time of the sudden commencement of the storm could be divided into two distinct phases. In the first, and one of shorter duration (called the initial phase), the horizontal force is increased above the mean during the first few hours of the storm. This is followed some hours later by a larger and slower decrease lasting several days, called the main phase. There is also a slow recovery to the undisturbed mean which may last several days. In fact, the earth may be said to be for ever recovering from the effect of magnetic storms. He also showed that the form of the magnetic disturbance did not change much within wide range of intensity and that great storms were often of shorter duration than weak storms. In 1927 Chapman extended his analysis to the polar regions and showed that these were characteristic of large complex disturbances though there appears to be an overall decrease in the horizontal force as in lower latitudes. He also showed that the storm variations contain a component dependent on solar time, D_s, but not necessarily in the nature of a diurnal variation. He also briefly discussed the hypothetical current system which, if flowing in a spherical current sheet concentric with the centre of the earth, would reproduce the observed field at the earth's surface. In 1935 he gave a more complete analysis of this current system and showed that it was especially intense in two narrow belts, one around each magnetic pole, and coinciding very nearly with the location of the auroral zones. This strongly suggested that part of the hypothetical current system might flow in the upper atmosphere.

In 1952 Chapman showed that the averaged D_s part of the magnetic disturbance field varied in amplitude with storm-time (that is, time reckoned from the sudden commencement of the storm) and also to some extent with the position of the sun relative to the station. In collaboration with Akasofu, he made several analyses of individual storms, bays and pulsations, thus following up the work he had begun with E. H. Vestine and E. Wakil in the early thirties. Chapman and Akasofu have also systematically catalogued in a series of papers, examples of a variety of magnetic storms which have greatly added to our knowledge of how individual storms depart from the average characteristics discussed in earlier papers.

It was characteristic of Chapman that nearly all such statistical analyses were followed by a theoretical discussion of the results. Thus to his long paper of 1918 Chapman added a dynamo theory of magnetic storms in which he attributed the source of the energy to the entry in the atmosphere of fast solar particles of one sign. It may seem surprising that he should have entertained this hypothesis in view of the destructive criticism which Schuster had earlier directed against one-sign theories of aurorae proposed by Birkeland and Stormer, namely, that a stream of such particles could not hold together during its passage from the sun to the earth because of the mutual electrostatic repulsion of its parts. Chapman abandoned his theory in consequence of a similar criticism by Lindemann (later Lord Cherwell) in 1919. Lindemann added to his criticism the suggestion that magnetic storms were due to the interaction of a neutral ionized stream emitted from the sun with the earth's magnetic field. This interaction posed a difficult novel problem which Lindemann did not attempt to solve in his paper. In 1923 Chapman made the first attempt to solve the problem of the interaction of a neutral ionized solar stream with the earth's magnetic field; he showed that the particles would move approximately together and would only be slightly deflected by the earth's magnetic field. However, Chapman's investigation, whilst correct in this respect, was defective partly because of the limitation he imposed on his solution at the outset by assuming that the stream enveloped the earth whereas the phenomena of importance are associated with the approach of the stream to the earth.

In 1927 the present writer became one of Chapman's first research students at Imperial College and he suggested that we should make a fresh attempt to develop a theory of magnetic storms. A re-examination of the conditions of passage from the Sun to the earth removed the hope that the stream might carry a small residual charge which would suffice to produce aurorae by bending the beam in the same manner as separate charge particles. The work confirmed Lindemann's conclusion that the only streams available for a corpuscular theory of storms must be electrically neutral to a high degree of approximation. After several false starts success was attained when it was realised that a neutral ionized gas is a good conductor of electricity so that electric currents must be induced in the stream by its motion across the earth's magnetic field, and that this might account for the field of magnetic storms. It was found that the stream behaved as if it were a perfect conductor so that the induced currents flowed mainly in the surface of the stream. The surface currents shield the interior of the stream from the earth's magnetic field so that the particles in the stream are able to describe rectilinear paths up to the point where they enter the surface current layer. The action of the earth's magnetic field on the surface currents repels the surface of the stream, the retardation being greatest over the parts of the surface nearest the earth. A cavity is thereby formed in the surface of the stream which deepens continually until a steady state is reached. We then have equilibrium between the kinetic pressure of the stream $\frac{1}{2}\rho v^2$ and the magnetic pressure $B^2/8\pi$ on its surface (here ρ is the density, v is the undisturbed velocity of the stream and B the surface magnetic field), that is,

$$\tfrac{1}{2}\rho v^2 = \frac{B^2}{8\pi}.$$

This simple equation, first given by D. F. Martyn, enables the location of the surface of the cavity to be inferred from a knowledge of the particle flux and velocity, both of which are amenable to measurement by means of space probes. The dimensions of the cavity so calculated, of the order of a few earth radii, were found to be in excellent accord with the values obtained from direct measurements made by magnetometer-borne space probes of the location of the discontinuity of the magnetic field at the surface of the stream. These results also agreed with the quantitative discussion first given by Chapman and the writer.

Because the geomagnetic field is excluded from the main body of the stream, as the cavity deepens and diminishes in size, the magnetic field of the earth inside it is compressed by the cavity, the resulting increase in the horizontal force at the earth's surface being identified as the increase in the horizontal force during the first phase of a magnetic disturbance.

The main phase of the storm was ascribed to a westward ring current encircling the earth placed at a distance of a few earth radii away. Although correct as regards the scale of the phenomenon, the formulation of the theory was vague and generally unacceptable. The true nature of the ring current was not recognised until 1957 when S. F. Singer saw that it must consist of charged particles trapped in the earth's magnetic field describing small orbits, as had been described by Alfvén in his interesting, but faulty, theory of magnetic storms. The theory proposed by Chapman and the writer in 1930 was not well received at first but, gradually, and long before satellite measurement verified the prediction of the theory of the first phase, it was considered all over the world and generally accepted.

Although Singer's exposition was only partially correct, his suggestion for the formation of a ring current was vindicated with the discovery by van Allen of the radiation belts which encircle the earth. However, because Singer's development of the theory was incomplete, with his Japanese pupil, S.-I. Akasofu, Chapman began to extend the theory of the radiation belts. With P. C. Kendall they calculated the equivalent current distribution in such belts and later they applied their work to the discussion of the formation of the ring current.

Chapman and Akasofu have, in recent years, done much to increase our knowlege of the polar and auroral substorms, and showed that during magnetic storms, there is often asymmetry in the variation of the horizontal force and ascribed it to the asymmetry of the ring current.

Schuster in 1889 in his study of the daily variations was led to the conclusion that a part of the variation was due to electric currents induced in the *earth* flowing in a uniform sphere whose radius was somewhat smaller than that of the earth. The first quantitative estimates of the radius and conductivity of this inner conducting sphere were made by Chapman in 1919. The value of the conductivity he deduced differs from estimates derived since from other variations. This investigation did not take into account the influence of the oceans and other conducting strata near the earth's surface. In 1923 Chapman and Whitehead examined this problem and found that if the existing oceans were spaced uniformly over the entire earth, the currents induced in them would have a magnetic field comparable with that observed.

In 1930, with A. T. Price, Chapman investigated the induced part of the storm-time variation (D_{st}) of magnetic storms. They expressed these storm-time changes for a group of storms using harmonic analysis and found that the first harmonic was by far the most important. They separated this component into parts of external and internal origin and found that the latter part could arise from currents induced in an earth-conductivity model which, however, differed appreciably from that found by Chapman for the daily (S_q) variation. They also showed that the calculated induced currents associated with the D_{st} variations penetrate to appreciably greater depths than those associated with the diurnal variations. This implied that the conductivity must increase with depth but their calculations were not such as would lead to precise estimates. Price, with Lahiri, was later able to show that the above discrepancies between the results derived from S_q and D_{st} data could be removed by using more elaborate earth models, one feature common to them being a rapid (and possibly sudden) increase of conductivity with depth. Price and others later showed that this fits in well with known effects of the increase of temperature with depth.

Atmospheric tides

The third major field of research to which Chapman has made important contributions is the theory of atmospheric tides. His earliest work in this field, in 1918, related to the determination of the lunar atmospheric tide which up till then had only been successfully determined in equatorial regions. The problem was extremely difficult owing to the smallness of the variation to be determined. But by using a simple direct method in which he selected barometrically quiet days to cut down errors, Chapman was able to isolate the semidiurnal component of the variation at Greenwich and found its amplitude to be 0·0088 mm. The method used is remarkable for the fact that random variations may be eliminated or reduced by the theory of errors and thereby reveal the smaller variation sought. He improved his method in a joint work with J. C. P. Miller and since then the lunar tide has been determined at a large number of stations, much of the work connected with such a great undertaking being done by Chapman.

Chapman's other main contribution to atmospheric tides relates to the solar semi-diurnal variation. Laplace had recognised the importance of thermal effects on solar tides. In 1910 Lamb sought to improve Laplace's theory and during the course of this work reached the conclusion that the period of the free oscillation of the atmosphere cannot differ greatly from twelve hours required by the resonance theory, since abandoned. In 1924 Chapman extended the theory still further and without attempting the evaluation of the period of free oscillations was able to calculate the phase of the thermal component of the oscillation taking into account the progressive change of phase of the semi-diurnal fluctuation as one ascends in the atmosphere. He further showed that for the semi-diurnal tide of solar origin, the components of thermal and gravitational origin are approximately equal.

Shortly before his death, there appeared a book on " Atmospheric Tides " written jointly with R. S. Lindzen. Chapman's share relates principally to the evaluation of the solar and lunar atmospheric tides as revealed by meteorological data. The writing is concise and lucid—remarkable for a man of over eighty.

Ionospheric problems and aeronomy

Chapman's researches on the upper atmosphere include contributions to the theory of the formation of the ozone layer, the ionospheric layers and the aurora. Chapman considered the hypothesis that the ozone layer is formed by photo-dissociation of molecular oxygen, the liberated atoms uniting with the molecules to form ozone provided a third molecule takes up the excess energy and momentum.

He also suggested that volcanic and meteoric dust might be two possible sources of sodium in the atmosphere. To account for the existence of free atoms of such an active element in the atmosphere Chapman pointed out that the conditions in the upper atmosphere were wholly favourable to the sodium oxide formed being reduced by reacting with oxygen.

The daily and seasonal variations shown by the ionosphere, as well as its behaviour at times of solar eclipses, strongly suggest that the ionosphere is formed by the ionizing action of solar ultraviolet and X-ray radiation. In a fundamental paper in 1931 Chapman developed the general mathematical theory of the process. He showed that the maximum electron density varies with the sun's zenith distance in a manner which was in good agreement with the observed results for the two lowest layers of the ionosphere. The profile of the vertical distribution of the ionization which he found is now universally referred to as a " Chapman layer ".

Chapman also discussed the theory of the formation of the aurora and the light of the night sky. In 1931 he suggested that the latter might be formed when three oxygen atoms collide, two of them might associate to form an oxygen molecule releasing sufficient excess energy to exicte a third oxygen atom to a metastable state which then radiates. This process is generally referred to as the Chapman process.

Later, in 1965, with P. C. Kendall, he gave a possible explanation of noctilucent clouds in terms of the diffusion of dust particles and water vapour near the sharp temperature minimum at the mesopause in the summer polar regions.

Miscellaneous

Finally, mention must be made of some contribution to the theory of crystals. With W. L. Bragg he calculated theoretically the rhombohedral angle of crystals of the calcite type and with J. Topping he considered the electrostatic potential energy and rhombohedral angles of carbonate and nitrate crystals of calcite.

In his early years at Greenwich, Chapman published several papers, some with P. J. Melotte, on the number and galactic distribution of stars. However, the results of one paper were vitiated by an error of arithmetical principle.

Membership of Foreign Societies and Honorary Degrees

Honorary Member New York Academy of Science.
Honorary Member Indian Academy of Science.
Member of the Norwegian and Swedish Academies, Swedish Royal Society, Academy of Finland, Meteorological Society, National Academy of Science, U.S.A., Accademia dei Lincei, Rome; Göttingen Academy of Science, Leopoldina Academie Halle.
Senior research fellow, NCAR.
Honorary Sc.D., University of Cambridge, 1958.
Honorary D.Sc., University of Alaska, 1958.
Honorary D.Sc., University of Michigan, 1960.
Honorary D.Sc., University of Colorado, 1962.
Honorary D.Sc., University of Paris, 1962.
Honorary D.Sc., University of Exeter, 1963.
Honorary D.Sc., University of Newcastle, 1965.
Honorary D.Sc., University of Sheffield, 1968.
Honorary D.Tech., University of Brunel, 1968.

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