the properties of the crystals of which such other units form part.

To sum up what I have said so far, the positions of the various atoms in the molecule determine the characteristic of the molecule: this is well known and has been widely studied. The positions of the molecules in the solid are equally important, especially if there is any regularity in their arrange-

FIG. 3. Diffraction photograph of sea-gull's quill.

ment, in other words, if there is any attempt at crystallisation. In a living body there must be arrangements of various kinds to various extents. We want to know what these arrangements are and their effects.

The X-rays demonstrate to us any such arrangements. It is now well known that a pencil of X-rays which passes through any substance where

molecular arrangement exists gives some sort of diffraction pattern, which may be examined photographically or electrically. From the character of the pattern, information can be obtained as to the nature of the arrangement. When there is much arrangement and great regularity, the pattern is sharply defined. As an example, we may take the photograph of the mineral kaliophilite (Fig. 1) obtained by F. A. Bannister of the British Museum (Natural History). When the arrangement is less regular, the photograph is less definite. When the first photographs were obtained from silk and wool, nerve and muscle, they were in comparison exceedingly vague and it seemed that it would be difficult to make any useful deductions from them. However, both technique and skill in interpretation have increased materially and conclusions can now be drawn which are of great interest. The two photographs of proteins in Figs. 2 and 3 were obtained respectively from silk and from the quill of a sea-gull's feather. These are due to W. T. Astbury and Miss Marwick. The detail is sufficiently pronounced to give valuable information to the experienced observer.

In the first place, it is clear that there must be quite a considerable amount of arrangement in both cases. The silk is largely composed of a protein known as fibroin. It is remarkable that similar photographs are obtained from a great number of proteins, drawn from different sources; there is in fact a characteristic protein photograph which implies that there are elements of structure common to protein forms. Fig. 3 is an example of the diffraction pictures obtained from a peculiar class of proteins known as the keratins; their connexion with the main body has recently been beautifully demonstrated by Astbury.

(To be continued.)

The Ionosphere

By R. A. WATSON WATT

SINCE Teisserenc de Bort established the fact that at heights of the order of 10-15 km. the more or less regular fall of air temperature with height ceases, and that for some distance above this change point the temperature is substantially independent of height, it has become customary to treat our atmosphere as divided into two shells. The inner shell, in which convective motion and turbulence are recognised as the dominant physical characteristics, is now called the troposphere, and is separated from the outer shell by the tropopause, the surface at which this well-defined change of the lapse-rate of temperature occurs. So far as the older meteorological means of measurement were concerned, the outer shell, the stratosphere, must—by mere defect of evidence—be regarded as comprising the whole remainder of the sensible atmosphere.

More recently, however, it has become convenient to admit a not very sharply defined

division of the stratosphere into an inner shell, retaining the name of stratosphere, and an outer, probably beyond a height of about 35 km., called the ozonosphere. This third shell, the dominant characteristic of which is its content of ozone, is, despite the incompleteness of data and the small absolute magnitude of the ozone content, of extreme importance in the radiation balance sheet of the earth, and thence in determining the physical conditions of human existence or non-existence on earth. The most recent addition to this systematic group, troposphere, stratosphere, ozonosphere, is the ionosphere, a shell extending from a height of some 80 km., and having, as its dominant physical characteristics, the special electrical properties which result from a relatively high degree of ionisation in the low-pressure gases which constitute the atmosphere at these considerable heights.

It is now well known that the necessity for

an ionosphere was recognised by the magnetician long before the radiotelegraphist required it in explanation of his experimental results, that, in fact, Balfour-Stewart anticipated Kennelly and Heaviside by nearly a quarter of a century. But of the three means of investigation which are capable of giving the readiest information on the state and structure of the ionosphere, the newer tools of the radiotelegraphist have proved more manageable than those of the magnetician or the student of the aurora. This special success of the radiotelegraphic geophysicist is due to two special factors; his ability to stimulate from the earth's surface ionospheric responses which propagate an interpretable message back to the surface, and

which it experienced at lower levels, and none as to the state of the ionosphere at higher levels—are far less stringent than these, especially in view of the wide spectrum of radio frequencies to which can be entrusted the task of bringing back data from different levels.

The radiotelegraphic geophysicist usually finds it convenient to project his exploring waves vertically upwards, and to examine them, on their return, in respect of (1) the time occupied by their double journey, (2) their relative intensity, and (3) their state of polarisation. By multiplying the time of travel by the velocity of light *in vacuo*, he obtains a quantity called the 'equivalent path', which must be scrutinised with considerable care—

FIG. 1. Track of corpuscular eclipse of August 21, 1933, for an assumed corpuscular velocity of 1,000 km./sec., as computed by Dr. J. C. P. Miller.

the absence of any important factor preventing unambiguous interpretation. The user of other methods must, on one hand, await the application to the ionosphere of stimuli beyond his control—the stimuli which excite magnetic disturbance or auroral activity; and, on the other hand, he is baffled by the difficulty of separating his variables—as in the magnetic method—or by the masking and absorption of the message-bearing radiation—as in the auroral method, with its almost complete limitation to dark and nearly cloudless nights.

The limitations of the radiotelegraphic method—that the wireless wave can be made to bring back clear evidence only from that particular height at which it is turned back earthward, that it brings back only obscure evidence of the vicissitudes

and indeed with a healthy scepticism—before it is related to the geometry of the ionosphere. For the very mechanism of return from above involves the reduction to zero of the group velocity of propagation, so that the equivalent path is always greater than the actual path, and this by an amount that can be inferred only in certain special cases.

By measuring the time of travel for a number of different radio frequencies in quick succession, the radiotelegraphist is able to obtain very important information as to the levels at which certain measured maxima of ionisation density are found. The early picture of a single attainable region of maximum ionisation (the 'Kennelly-Heaviside layer') the existence of which was

finally demonstrated—after two decades of doubt—in 1925, was within five years of that date shown to be inadequate, and the ‘Appleton region’ was found to be, in general, richer in ionisation than the Kennelly-Heaviside region, and to lie at approximately twice the equivalent height.

Recent issues of *NATURE*, and the discussion on the ionosphere at the meeting of the Royal Society on June 22, have revealed the existence of intermediate maxima, usually of minor importance, between the heights assigned to the main maxima. Our present knowledge of the structure of the ionosphere is more complete stratigraphically than topographically; an attempt will be made to trace what is now established and what is still in doubt in the picture of the moment.

There is no firm evidence of the return of wireless waves from levels below about 75–80 km., and this may be taken to be the lower limit for the extreme base of the ionosphere. If reflection at such a low level does in fact take place, it is effective only for the lowest frequencies, the longest wave-lengths, in commercial use. The level of maximum ionisation in the Kennelly-Heaviside region, or region *E*, is very close to 100 km. above ground in middle latitudes. This region is found to contain at noon on an equinoctial day the equivalent of 1.8×10^5 free electrons per cubic centimetre, and the summer noon ionisation content is about 2.2 times that of winter. The ionisation content usually reaches its maximum very near noon, and during the hours of darkness the ‘normal’ content falls, not to zero, but to a minimum of about one-twentieth of the noon value.

The intermediate region recently reported, virtually simultaneously, by American and British workers, lies at equivalent heights between 130 km. and 180 km., and the evidence as to its ionisation density requires amplification before it can be fully discussed. The observations in America, in lat. 40° N., indicate that its winter ionisation content exceeds that of the *E* region only for a few hours round noon, and that during the hours preceding noon it has the same order of density as has *E*. Independent observations reported by Appleton and by Ratcliffe in Great Britain (lat. $51\frac{1}{2}^\circ$ – $52\frac{1}{2}^\circ$ N.) agree in showing the intermediate region as being more heavily ionised, and consequently more prominent, than *E* in the early morning and the late evening; but while Ratcliffe finds this region more heavily ionised than *E* throughout many winter days, Appleton concludes that its ionisation content is usually less than that of *E*.

The communicated data for the Appleton, or *F*, region is less copious than that relating to the *E* region, although it is naturally more complete than that for the ‘new’ intermediate region. The noon ionisation density of *F* is some $3\frac{1}{2}$ –4 times that of *E*, and the diurnal maximum is reached an hour or two after noon. The actual height at which the maximum ionisation content is found in the *F* region is less certain than in the case of

E, because of the group retardation effects in the *E* and intermediate regions, but it cannot be far from 180 km. This figure is justified by recognising that, on occasions when the lower regions are comparatively lightly ionised, so that the highest frequency which they will return earthward is still relatively low, the group retardation effect, in these regions, on waves of the considerably higher frequencies which are returned by *F*, will be quite small. An extrapolation, towards zero frequency, of the curve relating equivalent path to frequency for waves returned from *F* will then give, in the simplest and most favourable cases, an approximation to the actual height reached, and this height may, as Prof. Appleton stated in opening the discussion, be taken as 180 km.

The seasonal and diurnal variations of the ionisation in *F* region are still under investigation, but they may both be stated to be of less relative amplitude than those of *E* region. Appleton gives the ratio of summer to winter maxima for *F* as 1.5–1.8. The recent contributions to our knowledge of the fine structure of the ionosphere establish the existence of a stepped structure for *F* region; Schafer and Goodall, the American observers, find evidence of ‘remarkably abrupt ionic density gradients at heights near 200, 240, and 280 km. This type of phenomenon has been found only during daylight hours’. Appleton finds on a particular occasion the following maximum ionisation contents (in electrons per c.c.): region *E*, 1.8×10^5 ; intermediate region, 2.5×10^5 ; region *F* ledge, 3.8×10^5 ; and region *F* main, 6.1×10^5 .

It will have been appreciated that evidence of the existence of any particular maximum in the curve of ionisation plotted against height can only be obtained if there is no more prominent maximum at a lower height; thus we are able to say confidently that there is normally no region above *F* with a greater density of ionisation than that found in *F*, but we cannot say anything about the possible existence of lesser maxima at greater heights. For corresponding reasons, we cannot readily obtain information about the upper parts of the main divisions of the ionosphere; occasionally, however, evidence is obtained of an ‘*M* reflection’ by way of the under side of *F* region, the upper side of *E*, again the under side of *F*, and so to ground. This indicates that on these occasions, at least, the upper surface of *E* is also characterised by a steep gradient of ionisation density.

The importance of determinations of the polarisation of the received wave arises from the effects of the terrestrial magnetic field on ionic motions in the ionosphere. Appleton laid the foundation of the magneto-ionic theory in 1925 by pointing out the importance of the gyratory terms in the equations of motion of the individual charged particles set in motion by the incident wireless waves. If these carriers are of electronic mass, the gyratory terms become of great importance, and the ionospheric medium exhibits doubly

refracting properties. In fact a single pulse of energy sent vertically upwards frequently returns from region *F* as a doublet, of which the 'extraordinary ray component' of less delay is approximately circularly polarised, with (in the northern hemisphere) a right-handed sense of rotation, and is more heavily absorbed than is the 'ordinary ray' of lower group velocity.

The quantitative development of the magneto-ionic theory has been vigorously prosecuted by Appleton, Hartree and Taylor, while an experiment by Green in Australia established its validity by the very direct and striking evidence of a reversed sense of polarisation associated with the reversed sign of the magnetic field in the southern hemisphere. Reasons for the comparatively rare appearance of both magneto-ionic components in pulses returned from *E* region have recently been given (but not yet published) by F. W. White. There is, in sum, no doubt that the effective carriers in both the main regions, and also in the intermediate region, are of electronic mass and sign.

There is need of special emphasis on the qualifying adjectives 'normal' and 'usual' employed in this summary. Much of the discussion at the Royal Society went to show that 'normal' conditions in the ionosphere are somewhat unusual. Considering only region *E*, we may note that Ratcliffe discussed a nocturnal replenishment of electron content which is frequently found to take place at times when no direct solar radiation is incident on the ionosphere near the observing station, while Watson Watt dealt with sudden daytime increases of local electron content. These increases frequently lasted for only three to five seconds, although the density temporarily increased to three times that measured immediately before or after the 'spot'.

The problem of the source or sources of ionisation was, naturally, prominent in the discussion, and there was some suggestion of an *embarras de richesse*. Appleton outlined the eclipse evidence, obtained by Henderson in Canada last year, which established the predominant part played by ultra-violet light. Appleton said: "The normal cause of ionospheric ionisation is ultra-violet light from the sun. Now our picture of the structure of the ionosphere is that there are two main regions each of which is probably made up of two elements during the day-time. Probably the four components are associated with ionisation potentials of different atmospheric constituents, atomic and molecular."

Chapman crystallised the picture of ozonospheric and ionospheric stratification as an absorption spectrum. His computations of the effects of optical eclipse agreed with Henderson's observations; there was no need to suppose that the residual ionisation found by Henderson was due to another agent than ultra-violet light; and the effect of the eclipse on the *F* region should, as Henderson actually found, be notably less than that on *E* region.

Although the possible effects of corpuscular bombardment from the sun were not taken up in the discussion, this summary would be incomplete without some reference to the unfavourable nature of last year's eclipse for the *experimentum crucis* on ultra-violet light versus solar corpuscles as contributory ionising agents. This was indicated in the summary of eclipse observations given in NATURE of September 6, 1932, and the special merits of the coming eclipse of August 21, 1933, were there enumerated. Prof. S. Chapman kindly arranged for computations leading to the diagram reproduced as Fig. 1, which shows the eclipse track for an assumed corpuscular velocity of 1,000 km./sec.

Wilson developed further his suggestions, first made nearly ten years ago, on the rôle of thunderstorms in modifying the ionisation content of the ionosphere; suggestions which Appleton and Naismith had recently taken up in relation to the experimental evidence. Ranzi had found a relation between nocturnal replenishment of *E* region and the proximity of depressions; Lutkin had found a correlation coefficient of 0.75 between ionisation density in *E* region and a 'thunderstorm index' figure representing the intensity of atmospherics originating within 3,000 km. of the observing station; Ratcliffe also found relations between 'nocturnal *E*' and thunderstorms, while Watson Watt, in the discussion, related the sudden daytime increases in local electron density, already mentioned, to local thunderstorm activity. Wilson now showed quantitatively how important may be the 'runaway electron', accelerated by the electric field of the thundercloud, and the very numerous secondary electrons released by each 'runaway electron'. It appeared, finally, that there is sufficient energy dissipation in thunderstorms to supply, several times over, the whole energy of ionospheric processes; that there is sound theoretical reason for supposing that a substantial part of this energy dissipation goes to increase the ionisation content of the ionosphere; and that there are equally sound observational grounds for believing that such increases do take place.

Ratcliffe inclined to the suggestion of a common ionising agent for the *F* and intermediate regions, with a different agent for *E*. This suggestion is, however, difficult to reconcile with Watson Watt's earlier comments on "Winter in the Ionosphere" (NATURE, 129, 761, May 21, 1932) in which he brought together Hollingworth's evidence on very long wave reflection and Wilkins's evidence on ultra-short wave reflection, in support of a very close community of ionising agency between the extreme maximum of *F* region and the extreme base of *E* region.

On the converse problem of the opposing process of electron capture, which maintains the equilibrium values of the day-time and determines the rate of nocturnal decay, Chapman and Eckersley favoured the ordinary process of recombination between electrons and positive ions. Chapman showed that the predominance of this

process would lead to a ratio of maximum ionisation contents, as between summer and winter, which was in very good agreement with the observational material. Appleton leant towards the alternative process of attachment of electrons to uncharged atoms, and Chapman pointed out that if this process were of comparable importance with recombination in *F* region, it would be predominant in *E* region. The evidence seems, however, to be so acutely complicated by the known facts of nocturnal replenishment, that judgment may well be reserved.

It was a disappointing feature of a long discussion that the geophysicists who were not

actively engaged in accumulating and interpreting radiotelegraphic evidence were inarticulate. Many fascinating possibilities awaited discussion: the relation between thunderstorms and magnetic disturbance, solar control and recurrence tendencies, the composition of the atmosphere at ionospheric levels, the possibility of approximate measurement of gas density and temperature from radiotelegraphic evidence on collisional damping, and the radiotelegraphic measurement of ionospheric air velocities for use in studies of terrestrial magnetism. There is room for another, and an early, discussion, with the radiotelegraphists in the back benches.

Obituary

SIR WALTER MORLEY FLETCHER, K.B.E., M.D., F.R.S.

SIR WALTER FLETCHER died on June 7, with unlooked-for suddenness when he was just approaching his sixtieth birthday, but when his physique and brain were still those of a man in the most vigorous prime.

The first twenty years of Fletcher's active life were all spent in Cambridge, and during that time he completed the work for which in 1915 he was elected to the Royal Society. His thoughts were steadily concentrated on the problem of the respiration of muscle. The laboratory work was interrupted from time to time and his papers appeared intermittently, but each one marked a definite step forward in knowledge. At last, in co-operation with Sir Frederick Gowland Hopkins, he succeeded in unravelling the web of confusion spun by earlier workers and made one main point perfectly clear. Muscular contraction is not related directly and simply to intake of oxygen and expiration of carbon dioxide. It may proceed vigorously in the absence of oxygen and is then attended by the formation of lactic acid, not of carbon dioxide. This lactic acid is not present in resting muscle but appears during contraction and largely vanishes again during the subsequent oxidative changes of recovery. Oxygen enables the muscle to regain activity after exhaustion and to get rid of accumulated lactic acid, some carbon dioxide then appearing during this period of recuperation. But the act of contraction is anaerobic and in itself makes no call on any fresh oxygen supply, oxidation being concerned solely with the processes of recuperation.

These strikingly clear results were presented by Fletcher and Hopkins in the Croonian lecture of 1915 before the Royal Society, and they have not been controverted in any essential detail since. They gave the secure foundations upon which was erected the modern thermodynamic work of Meyerhof and Hill, who carried the analysis further and by measurement of total heat production deduced the formation during muscular contraction of lactic acid from glycogen and the re-synthesis of four-fifths of it back to glycogen during the oxidative processes of recuperation.

Fletcher's impulse must be recognised in this work of A. V. Hill as well as in that of Keith Lucas, who added so greatly to the knowledge of muscular contraction on the electrical side. Both were his juniors at Trinity College, and Fletcher's enthusiasm and clear outlook over the ill-mapped lands of muscular activity captured their interest from other intellectual occupations, just as Michael Foster had done with younger men in the generation before. Keith Lucas left classics to work at physiology. A. V. Hill was definitely persuaded to abandon mathematics and to learn physiology as a field in which his special knowledge might find a novel and delightful application.

The researches of Fletcher with Hopkins hold a classical place among the first exact studies of the internal metabolism of the cells of any tissue, though the lapse of twenty years has given them an air of almost primitive simplicity when contrasted with modern knowledge of the intricate systems of intra-cellular oxidation and chemical change that is emerging from the later work of Hopkins and his school. But though Fletcher's own work in the laboratory always showed perfect execution of the experiment and exact argument to a clear end; and though his thought could envisage far prospects of physiological research with a confident hope that won many younger men to eagerness in sharing the adventure, it never seems that he found full satisfaction in laboratory research. Many other affairs claimed his time and his energies at Cambridge. Trinity College held his affection and received his services fully as much as Michael Foster's School of Physiology, which he often proudly traced to its source in the action of Trinity College in making Foster praelector of that subject. His unquenchable interest in every vivid side of life, his keen intellect, his artistic sense, and the athletic ability that was simply natural for a man of his big well-balanced frame, all these from undergraduate days had given him friendships and attractions outside the ambit of physiology and none of these was he willing to suppress. President of the Pitt Club for fifteen years and a don of a