Symposium on the Problems of the Ionosphere

The President, Sir L. L. Fermor remarked that one of the objects of the Institute was to hold from time to time *Symposia* (literally *drinkings together*) for the purpose of discussion, by scientists of allied sciences, of problems of joint interest. The Symposium on the Ionosphere was the first one of its kind held under the auspices of the Institute and he hoped that the discussion would throw new light on the problems of the Ionosphere.

Letters from the undernoted gentlemen who wished the Symposium all success but regretted their inability to attend and participate in the discussion were read by the President.

Dr. C. W. B. Normand, Director of Meteorological Observatories, Poona.

Mr. K. Sreenivasan, Asst. Prof. of Electrical Engineering, Tata Institute of Science, Bangalore.

Prof. Benade, Forman Christian College, Lahore.

Mr. P. J. Edmunds, Director of Wireless, New Delhi.

Mr. S. R. Kantebet, Chief Engineer, Indian Radio and Cable Communication Company.

Dr. S. K. Banerji. Offg. Director of Meteorological Observatories, had sent a note on the Ionosphere and Magnetic Storm and Thunderstorms and wrote to say that he had every intention of coming to Calcutta to read a paper on the subject of his note but was prevented from doing so on account of sudden official business.

The President then asked Prof. S. K. Mitra to open the Symposium.

In his opening address Prof. Mitra dealt with the present state of our knowledge of the Ionosphere and his remarks are summarized below.

The Ionosphere.

The vast stretches of ionized regions which are known to exist in the upper atmosphere are collectively called the Ionosphere. The lower boundary of these regions is normally at a height of about 90 km. The upper boundary is not well defined, but has been proved to extend beyond 400–500 km.

Historical.

The existence of conductivity in the upper atmosphere was envisaged by Balfour Stewart in 1878 to explain diurnal variation of terrestrial magnetic intensity. In 1902 Kennelly and Heaviside postulated the existence of upper atmospheric ionization to explain long distance wireless wave propagation. Direct experimental evidence was obtained in 1925. Since then there has been intensive study of the properties and structure of the ionosphere by various workers in different parts of the world.

Magneto-ionic theory.

The ionosphere is experimentally explored by sending wireless waves upwards. The reflected waves or echoes are studied regarding their time of arrival, their intensity, and their polarization.

It is therefore important to have a clear understanding of the nature of wave propagation in an ionized atmosphere.

A simple theory, first suggested by Eccles in 1912, was developed by Larmor in 1924. The theory was elaborated by Appleton, Goldstein and others by taking into account the effect of the earth's magnetic field on the motion of electrons and ions. This theory is known as the magneto-ionic theory.

Experimental method of investigating the Ionosphere.

As it is not possible for any material body like an aeroplane, sounding balloons or kites to reach such heights, the only agency available for exploring the ionosphere is the radio waves.

A very ingenuous method known as the pulse or group retardation method, first employed by Breit and Tuve and subsequently developed by various other workers, is now almost exclusively used for ionospheric study. Briefly, the method consists in sending up wave packets of short duration from a radio transmitter. These waves return after a few milli-seconds being reflected from the ionosphere. Study of these echoes has given us the following information regarding the ionosphere.

What we know about the Ionosphere.

(*a*) *Height.*—

The normal lower boundary is at a height of 90–100 km.

(*b*) *Ionization density.*—

If the frequency of the exploring waves is increased, it is found that at a particular frequency the wave pierces the boundary and no echo is obtained. The square of this penetration frequency is a measure of the density of electrons and ions present. The density in the lower region is about $7{\cdot}3 \times 10^5$ electrons per c.c. and in the outermost region about 20×10^5 electrons per c.c. These values are for summer noon in Calcutta.

(*c*) *Structure of the Ionosphere.*—

Height and ionic density measurements reveal that the density of ionization of the ionosphere does not increase continuously with height. There are regions of maximum and minimum of ionization. Two principal regions of maximum ionization are always present. These are designated E and F and are at average heights of 90 and 250 km. respectively. During the daytime other regions appear, one below E called D and two others between E and F. One of these is just above E and the other below F. To distinguish these several regions during the daytime they are called, beginning from the bottom, D (55 km.), the main E or E_1 (90 km.), the subsidiary E or E_2 (150 km.), the subsidiary F or F_1 (180 km.), and the main F or F_2 (250 km.). The average maximum ionic densities are (in equivalent electrons per c.c.) E_1 ($7{\cdot}3\times10^5$), E_2 (11×10^5), F_1 (13×10^5), and F_2 (20×10^5).

(*d*) *Density gradient.*—

If the frequency of the exploring wave is varied and the corresponding heights are measured, then the nature of the curve depicting the relation between the two gives us information regarding the gradient of ionization near the boundary. The lower boundary of E_1 at 90 km. is extremely sharp. The corresponding boundary of the F_2 layer is very diffuse.

(*e*) *Intensity of the magnetic field in the Ionosphere.*—

The action of the earth's magnetic field causes the ionosphere to behave like a double-refracting medium. A single wave sent up in the ionosphere is split up into two waves of different velocities. By observing separately the penetration frequencies of these two waves it is possible to make an estimate of the intensity of the earth's magnetic field in a particular region of the ionosphere. It is found that at a height of 250 km. the value of the magnetic field is about 10% less than that at the surface of the earth.

(*f*) *Collisional frequency between electrons and neutral atoms or molecules at ionospheric heights.*—

By measuring the variation of height with wavelength and at the same time noting the intensities of the reflected waves it is possible to estimate the collisional frequency. Collisional frequency in the upper region is estimated at $1{\cdot}6\times10^3$ per sec.

Besides the pulse method another method has recently been developed for estimating the collisional frequency. This is known as the method of interaction of radio waves. It is sometimes found that when a receiver is tuned to receive a station on a particular wavelength the speech or music of another station working on a different wavelength is heard on the background. The origin of this cross-modulation is traced to the collision of electrons with neutral atoms and molecules in the ionosphere. In the lower region the collisional frequency is found to be about 10^6 per sec.

(*g*) *Polarization of the downcoming waves.*—

Measurements of the polarization of the downcoming waves afford a check on the magneto-ionic theory. An important consequence of the theory is that in the northern hemisphere the downcoming wave is polarized in a left handed and in the southern hemisphere in a right handed sense. This has been demonstrated experimentally.

(*h*) *Temperature of the Ionosphere.*—

From a study of noon-time day to day variation of ionization it is possible to make an estimate of the temperature in the upper regions of the ionosphere. The principal source of ionization being ultraviolet radiation from the sun, one expects that the ionization density should be high in summer and low in winter. In the upper region of the ionosphere, the reverse is the case. The explanation given is that on account of thermal expansion the density of the upper atmosphere is less in summer than in winter. From the observed fact that the opposite variation (and consequently the expansion) occurs only in the upper regions, Appleton has deduced that the temperature at the highest levels of the ionosphere is about 1200° K. in summer.

Sources of ionization and origin of stratification.

It has been proved beyond doubt that the ultraviolet rays of the sun is the main ionizing agency.

According to Milne, neutral particles shot off from the sun may also be one of the ionizing agencies. Experiments made during solar eclipse give strong support to the photo-ionization theory, and also indicate that corpuscles may have some influence on the outermost F region.

Charged particles of solar origin which cause magnetic storms also influence the ionization. Their effect, however, is more marked in higher latitudes, where they are concentrated, due to the effect of the earth's magnetic field.

Meteoric showers have also been proved to influence the ionization.

Thunderstorms have been found to abnormally increase the ionization of the ionosphere. According to Wilson ' run away electrons ' formed within the thundercloud are accelerated by the latter's intense electric field and are shot upward to reach ionospheric level. The path of the ' run away electron ' may be bent by the earth's magnetic field and a region of the ionosphere not directly overhead but to one side affected.

The above theory explains how a thundercloud situated only at a height of a few kilometres above the surface of the earth may affect ionospheric conditions at a height of 100 km. It has been observed in India that ionization of the ionosphere is greatly disturbed during monsoon and pre-monsoon periods.

The origin of stratification of the ionosphere into E_1, E_2, F_1, F_2, etc. regions is still not definitely known. Of the various suggestions one may be mentioned. The four regions beginning from E_1 might be associated with the four different ionization potentials of atomic and molecular oxygen and nitrogen. Division of F into F_1 and F_2 during the day may also be due to the upward movement of the atmosphere due to temperature expansion. The origin of ' D ' might be connected in some way with the formation of ozone at a lower level.

The address was illustrated with a large number of lantern slides and at the end two films were shown. One depicted the record of echoes of radio waves as seen on the screen of the cathode ray oscillograph in the group retardation experiment, and the other the emission of loops of electric lines of force, after the manner first delineated by Hertz, from a transmitting aerial. The first one was taken in the laboratory of Prof. Mitra, while the second one was shown through the courtesy of Sir Frank E. Smith, Director of the Department of Scientific and Industrial Research, England, Mr. G. R. Toshniwal next spoke on the Ionosphere at Allahabad and said :—

With a view to study the state of ionization and the structure of the various ionized layers of the upper atmosphere, a systematic study was begun early in 1934. The method of Breit and Tuve of directing an electromagnetic pulse of short duration was used, and the echoes reflected from the ionosphere were observed on the oscillograph. Both the transmitting and the receiving equipments have been so much simplified that a single observer is sufficient for taking observations.

Equivalent height.—It has been found that normally a 4-megacycle wave is reflected from the F layer at a height of about 250 km. The ionization gradually decreases after sunset and the equivalent height from which the reflected wave comes gradually increases and at about 2 hours after sunset the 4-megacycle wave is not reflected from the ionosphere. At times a sudden increase in ionization takes place during the night and echoes appear after midnight. One such occasion was December 13th when echoes appeared at 03h. 19m.

Occasionally, due to increased ionization in the lower layer, reflection occurred from the E layer as well.

Magneto-ionic splitting.—Usually a doublet—consisting of a right-handed and a left-handed circularly polarized component—is visible near about sunset. But on more favourable occasions a triplet has also been seen, as demanded by the magneto-ionic theory.

Lunar eclipse.—On January 19th, 1935 using a 75-metre wavelength, it was found that the equivalent height of the F layer was almost constant up to 18h. 20m., after which it rapidly rose to 400 km. and then began to fall and was at a minimum when about three quarters of the moon was dark. After totality the equivalent height again began to increase and within 20 minutes no echo could be seen due to electron limitation.

Ionization.—Ionization of the E layer has been found to be $2{\cdot}5\times10^5$ electrons per c.c. in the morning and evening hours in April, 1935. The ionization diminishes after sunset, but in April, with little exception, the so-called ' evening concentration ' has been observed and the ionization has been found to increase from $2{\cdot}4\times10^5$ electrons per c.c. to $5{\cdot}2\times10^5$ electrons per c.c.

The next speaker Prof. M. N. Saha in dealing with the problems of the upper atmosphere said :—

Prof. S. K. Mitra, in his opening address, has talked of the ' Ionosphere ', and has given details of experimental methods perfected within recent years for its study, and an admirable summary of the results so far obtained. It may be mentioned that the term ' ionosphere ' is only a phrase for the upper atmosphere extending from 20 kms. upwards, and that there are several methods available for its exploration. These are :—

(1) Direct studies, by the sending of pilot balloons, stratosphere flights, etc. ; such studies are confined only to the lower layers.

(2) Investigation by radio methods as sketched out by Dr. S. K. Mitra and the other speakers.
(3) Investigations of the spectra of the aurora and the night sky.
(4) Investigation of the upper atmosphere from studies on the propagation of sound through it.
(5) Investigations of the ozone content and its periodic variations.
(6) Study of the fall of meteors, fire balls and meteorites through the upper atmosphere.

My submission is that we can hope to obtain a complete picture of the upper atmosphere only when the materials collected from these different lines of study are utilized in a synoptic study.

My own work is an attempt on these lines, and is entirely theoretical. The problems which I am going particularly to discuss are very ably summarized by Dr. Mitra in the concluding parts of his address.

It is now well established that the ionization of the E_1, E_2, F-layers are undoubtedly due to sunlight, as early envisaged by Schuster. But the mechanism of ionization has not been rendered clear. In fact, Swann questioned the capacity of ultraviolet solar rays to produce the amount of requisite ionization. He was followed by Chapman who calculated, from variation of ion-content in the E layer, the coefficient of recombination, and the number of ions which must be produced by sunlight to maintain the requisite amount of ionization. Chapman showed that if it be supposed that the sun radiates like a black body at a temperature of 6000°K., and rays possessing a wavelength 1350Å. units are capable of ionizing the atmosphere, the required amount of ionization can be maintained. Many investigators do not appear to be satisfied with Chapman's calculations, for in a recent note to *Nature* Müller invokes the aid of soft X-rays supposed to be emitted from the sun for maintaining the ionization.

It can be proved from recent spectroscopic investigations that Chapman's assumptions that 9 Volt-rays can produce ionization in the constituents of the solar atmosphere is totally erroneous. The chief constituents are molecular oxygen and nitrogen, and probably atomic oxygen and nitrogen, as is revealed by the spectra of the night sky, and the aurora. There may be small quantities of helium, but its existence is not yet spectroscopically established. Recent investigations show that the minimum ionization potentials of N_2 is 15·52 volts, that of O_2 is 12·1 volts and those of O, and N are 13·56 and 14·48 volts respectively. If we recalculate the ionization of the atmosphere using these data, it is found that the sun, if it be regarded as emitting like a black body at a temperature of 6000°K. cannot maintain the observed ionization of the upper atmosphere. We are thus placed on the horns of a dilemma as the radio experiments establish beyond doubt that the ionization is due to some kind of light coming from the sun.

In fact, the night sky data establish the point beyond doubt. The negative bands of nitrogen, which have been conclusively shown to be due to N_2^+, occur very strongly in the aurora, but very feebly in the night sky. But Slipher of the Lowell Observatory, Arizona, showed that the N_2-band occurs very strongly in the morning sunlight, when the upper atmosphere is just being illuminated by sunlight, as well as in the evening hours when the last rays of the sun are disappearing from the upper atmosphere. The bands weaken during the night. It is therefore clear that the solar rays contain radiation capable of producing the upper state responsible for the excitation of N to the upper state of N_2^+. Calculation shows that the energy required for this stimulation is nearly 21 volts.

We are therefore forced to abandon the idea that the sun radiates like a black body, a view long advocated by the present speaker. He has recently carried out certain investigations which show that if it were possible to observe the ultraviolet part of the solar spectrum, which is unfortunately cut off by the ozone absorption, it would be found that the following lines would appear as intensely bright lines on a continuous background :—

(1) The early lines of the Lyman series of hydrogen, energies 10·12, 12·0 volts.

(2) The fundamental line of *He*, 584, energy 21·12 volts.

(3) There may be certain other lines of metallic origin.

The investigations on which these conclusions are based are entirely astrophysical and deal with a general theory of emission from stellar atmospheres. As the results are not yet completed, the results are given out with a certain amount of hesitation.

The remaining part of the address dealt with the action produced by these rays on the constituents of the earth's atmosphere, and showed that they are capable of explaining the night sky spectrum, and to some extent, the layer ionization of the earth's atmosphere. It was opined that the upper atmosphere is largely made up of atomic oxygen and nitrogen, which may partly account for the observed bending and acceleration of sound rays when propagated through the upper atmosphere. The speaker declined to accept the recent theories which assign to the highest layers a temperature of 1200° C.

Mr. P. Syam next dealt with the low-lying absorbing *D* layer of the ionosphere and said :—

It is well known that the ionosphere consists of two main regions of ionization *E* and *F*, beginning from heights of about 90 km. and 230 km. respectively. Besides these two regions, the existence of an absorbing region below the *E* region has been postulated by several workers. Of late, there has, however, been a tendency to discredit the existence of such a layer. But, as reported in a recent note in *Nature*, Prof. Mitra and the speaker have been able to detect echoes from a virtual height of about 55 km., giving direct proof of the existence of a low layer at this height, during the daytime. Besides the echoes, which are of infrequent occurrence, other evidence has been obtained in support of the existence of this layer. It has been found that during the daytime there is a frequency band which is reflected from the *E* region. The upper limit of the frequency band is due to penetration of the *E* layer and may be termed the 'penetration limit'. The lower limit, which may be termed the 'absorption limit', is due to absorption by the *D* layer on account of large collisional frequency present therein. There are other reasons which point to the conclusion that the complete disappearance of echo, as has been observed, cannot be caused by the formation of a diffuse *E* layer boundary and lowering of the same in the daytime.

The formation of the *D* layer may have some connection with the formation of ozone, though recent investigations show that the ozone layer may actually be at a somewhat lower height than the *D* layer.

The following note on *Thunderstorms and Magnetic Storms in Relation to the Ionosphere* was communicated by Dr. S. K. Banerji (Poona).

Correlation of wireless data with sunspots and magnetic storms and the existence of a 27 day recurrence tendency.

The maximum of region *E* ionization is reached at a height of about 100 km. above ground; this is the level where the lower edge of the aurora is met with. Magnetic phenomena support the existence of sunspot period in atmospheric conductivity at a height of 90 km. and upwards. The ionization at sunspot maximum appears to be about 50% to 60% greater than at sunspot minimum.

The experimental ratio of summer noon to winter noon ionization is about 2·2 for region *E* and about 1·5 to 1·8 for region *F*; there is a corresponding variation in magnetic activity.

The influence of the earth's magnetic field is such as to make the ionosphere an aelotropic medium and, owing to the difference in the group velocities of the two components, a single wireless pulse may be split into a doublet. Magnetic storms are connected with abnormal ionization and this is probably associated with high speed charged particles from the sun.

Large scale motion or wind in the ionosphere tend to produce corresponding magnetic variation. The most typical example is the relationship between the lunar atmosphere tide and the lunar magnetic variation found by Chapman. There seems to be an extraordinary variability in ionospheric weather and it would be interesting to correlate them with magnetic variability.

Correlation of wireless data with thunderstorms.

It seems to be established that the sudden appearance of bursts of abnormal ionization is associated with thunderstorms. According to Wilson thunderstorms influence upper air ionization either by 'run away' electrons or by ionization by collision produced at high levels owing to the intense electric fields involved.

If thunderstorms have effect on the ionosphere then we should expect some relationship between magnetic storms and thunderstorm activity.

Brook's work indicates close relationship between thunderstorm activity and sunspots.

Wilson supposes that if the positive potential of the upper part of a thundercloud is suddenly destroyed, then there would be a sudden rising of the negative potential at the bottom of the cloud, which might result in a discharge to the earth. The sudden rising of the potential at the bottom of the cloud will enable 'run away' electrons, which have been produced within the cloud itself and have no longer to traverse a retarding field above the cloud, to reach the upper atmosphere or to be bent round by the magnetic field and get to earth. Schonland's experiments involving the use of a single Geiger counter do not appear to be sound and point to the need for further work on 'run away' electrons.

DISCUSSION

In the discussion that followed Mr. Toshniwal, in reply to Mr. Syam's remarks about Bòntch-Bruewitch's observations, pointed out that a definite mention about the observation of echoes from 65 km. is made by Bontch-Bruewitch on page 1132 of the *Proc. Inst. Radio Eng.* 1934 ; but that the author thinks that the echoes are due to lowering of the E layer. They do not make any mention of the D layer.

Prof. A. C. Banerji remarked that Dr. Mitra had said that the absolute temperature of the ionospheric region at a height of about 250 km. above the surface of the earth might be about 1200° K. If this was a region of such high temperature enveloping our earth, the loss of heat from the surface of the earth due to radiation would be considerably reduced. Now it was an accepted fact that the surface temperature of the earth was at present practically constant, and the loss of heat due to radiation was made good from the heat received from the radio-active substances in the surface layers of the earth. If the loss of heat due to radiation become considerably less then the surface temperature of the earth would continuously increase and we should be living on a hotter and hotter earth. He also wanted to know if there was any evidence to show that cosmic rays had some effect on the ionization of the ionosphere.

Mr. Toshniwal replied that Schafer and Goodall have recently announced some effect of cosmic rays on the ionization of the F_2 region, but very little data on correlationship exists.

Prof. M. N. Saha said that the temperature referred to was molecular temperature. The temperature of the F_2 region could be very high but the quantity of heat radiated was extremely small.

Prof. S. K. Mitra in his reply to the points raised in discussion said that Prof. Saha had done injustice to Chapman in saying that according to Chapman λ 1350 from the sun is responsible for upper atmospheric ionization. Chapman had actually pointed out in his Bakerian Lecture that the ionizing radiations for N_2, O_2 and O correspond to 16·9, 16·1 and 13·6 volts respectively.

According to Chapman, if one considered the sun as a black body at a temperature of 6000° K. then there was sufficient energy in the wavelength region 910 to 770 ÅU to cause the observed ionization. The amount of energy in wavelengths below 770 ÅU was comparatively very small; hence atomic oxygen was mainly ionized in the upper atmosphere. In support of his (Chapman's) contention it could be said that according to Chapman summer noon-time ionization for the E layer at the equator is 4×10^6 per c.c. The observed value in England is 2×10^6 per c.c.

Regarding Mr. Toshniwal's remark about Bontch-Bruewitch's observation of reflection from 65 km. height, it was hazardous to draw conclusions regarding heights of the ionospheric layer from observations made in Polar regions. In these regions abnormal ionization was the 'normal' phenomena on account of bombardment by charged particles from the sun; these crowd near the polar caps due to the earth's magnetic field. Mr. Syam's observation on the D layer was quite distinct from that of Bontch-Bruewitch inasmuch as the absorption phenomenon recorded by Mr. Syam, regularly day after day, could only be explained as due to a distinct absorbing layer below E and not merely to the lowering of the boundary of E.

Regarding Prof. Banerji's queries, he said that they had already been replied to by Dr. Saha and Mr. Toshniwal. He would only add that though the molecular temperature of the F_2 layer was high yet the atmosphere being very thin, the heat capacity was extremely small. As a consequence there was no danger of one's being scorched by radiation of heat from the F_2 region.

In concluding the Symposium Sir L. L. Fermor referred to the excellent work done at the Universities of Calcutta and Allahabad under different conditions. Such work, he said, was usually done in England, Canada, Australia, the United States of America and Japan with liberal help from the respective Governments through radio-research boards. He pointed out the need of state encouragement to these Universities through the formation of National Radio Research Committees, particularly because the results of radio research had a practical bearing on problems connected with extension of broadcasting service.