The Lowest of the Ionized Layers of the Upper Atmosphere

By DIETRICH STRANZ

(Manuscript received 9 December 1949)

Abstract

The "Stockwerk-Gliederung" of the Earth's atmosphere introduced by PENNDORF and FLOHN is a promising method to describe the different atmospheric regions from the nearest to the ground up to the highest levels. The region above the upper inversion (at ca. 75 km) up to 100 km height is generally called the D-layer which means the lowest of the ionized regions in the upper atmosphere of the Earth.

The behaviour of the D-layer, its most reasonable theory of formation, and its function with regard to the propagation of electromagnetic waves are discussed. Features related to solar-terrestrial phenomena are shown. Theories and ideas by various authors are compared with each other.

The complete investigation from which this paper gives an extract is being published elsewhere.

1. The three principal known ionized-layers of the Earth's atmosphere (D-, E-, and F-layer) show different behaviour owing to their various altitudes and origins. It is reasonable, though not generally accepted, to ascribe the uppermost layer (F) to the shortest wavelengths of an ultraviolet spectral band between 500 and 1 300 Å, while with increasing penetration into the lower regions of the atmosphere longer and longer wavelengths of that band of solar spectrum are responsible for the formation of the lower layers. Photochemistry has revealed to us a number of dissociation and ionization processes acting on atmospheric oxygen and nitrogen (table 1). Thus the layers formation is clear in principle, although many difficulties as to quantities still have to be overcome. Often there must be several processes operating simultaneously.

All reactions with nitrogen and atomic oxygen occur at wavelengths below 1 000 Å as can be seen from table 1. The dissociation and first ionization potentials, however, of molecular oxygen lie above 1 000 Å. According to PENNDORF (1949 b) there is practically no O_2 above the height of 115 km, i.e. all the latter reactions take place in the E-layer and below it, requiring a radiation which will not be appreciably absorbed down to that level. Between 115 and 90 km, rather disruptive at 108 km, oxygen is dissociated.

2. In this paper the photochemical processes of the D-layer are of interest. Reactions 7) and 8) are at our disposal. The absorption of oxygen is very weak between 910 and 1 300 Å, likewise the weakening by nitrogen is negligible. This allows a considerable portion of this spectral band to penetrate down to 100 km and still lower in order to ionize the oxygen molecule and further to dissociate it into O^+ via excited states of the oxygen atom. The excitation-energy is used for the ionization of an oxygen atom reacting by three-body collision. Assuming a probable model of the atmosphere (temperature-height function) and a reasonable effective recombination coefficient

Table 1.

1)	$N_2 + h\nu \rightarrow N_2^+ + e$	$\lambda \leq$ 661 Å	$\alpha_{10} = ?$	F_2-layer
2)	$O + h\nu \rightarrow O^+ + e$	$\leq$ 667 Å	$= ?$	F_2-layer
3)	$O + h\nu \rightarrow O^+ + e$	$\leq$ 732 Å	$= ?$	F_2-layer
4)	$O_2 + h\nu \rightarrow O_2^+ + e$	$\leq$ 765 Å	$= 500$	E-layer
5)	$N_2 + h\nu \rightarrow N_2^+ + e$	$\leq$ 795 Å	$= 10$—50	E-layer
6)	$O + h\nu \rightarrow O^+ + e$	$\leq$ 910 Å	$= 260$	F_1-layer
7)	$O_2 + h\nu \rightarrow O_2^+ + e$	$\leq$ 1 010 Å	$= 0.3$	D-layer
8)	$O_2 + h\nu \rightarrow O^\star + O$	$\leq$ 1 330 Å	$= 0.1$	O atom layer$\rightarrow$D-layer
9)	$O_2 + h\nu \rightarrow O^\star + O$	$\leq$ 1 715 Å	$= 200$	O atom layer
10)	$O_2 + h\nu \rightarrow O + O$	$\leq$ 2 424 Å	$= 10^{-3}$	O_3-layer

Table 2. Electron density in the D-layer obtained by processes 7) and 8). — Model atmospheres (A) — (B) — (C) — (D). — n_e [cm³].

h [km]	(A)			(B)	(C)	(D)	
	$\chi = 0°$	40°	85°	80°	40°	80°	
130	$4.5 \cdot 10^2$	$5.0 \cdot 10^2$	$1.4 \cdot 10^3$	$5.1 \cdot 10^2$	$6.6 \cdot 10^2$	$1.2 \cdot 10^3$	Contribution to the E-layer
125	$6.3 \cdot 10^2$	$7.2 \cdot 10^2$	$1.9 \cdot 10^3$	$8.9 \cdot 10^2$	$1.1 \cdot 10^3$	$1.8 \cdot 10^3$	
120	$1.0 \cdot 10^3$	$1.5 \cdot 10^3$	$2.8 \cdot 10^3$	$1.6 \cdot 10^3$	$2.1 \cdot 10^3$	$3.5 \cdot 10^3$	
115	$1.9 \cdot 10^3$	$2.3 \cdot 10^3$	$4.6 \cdot 10^3$	$3.2 \cdot 10^3$	$3.8 \cdot 10^3$	$7.9 \cdot 10^3$	
110	$3.7 \cdot 10^3$	$4.5 \cdot 10^3$	$8.1 \cdot 10^3$	$6.3 \cdot 10^3$	$7.2 \cdot 10^3$	$1.6 \cdot 10^4$	
105	$7.8 \cdot 10^3$	$8.7 \cdot 10^3$	$1.4 \cdot 10^4$	$1.2 \cdot 10^4$	$1.3 \cdot 10^4$	$1.8 \cdot 10^4$	
100	$1.4 \cdot 10^4$	$1.6 \cdot 10^4$	$1.3 \cdot 10^4$	$1.5 \cdot 10^4$	$1.7 \cdot 10^4$	$1.1 \cdot 10^4$	
95	$1.8 \cdot 10^4$	$1.9 \cdot 10^4$	$7.5 \cdot 10^3$	$1.5 \cdot 10^4$	$1.4 \cdot 10^4$	$3.4 \cdot 10^3$	
90	$1.9 \cdot 10^4$	$2.0 \cdot 10^4$	$2.3 \cdot 10^3$	$1.1 \cdot 10^4$	$1.1 \cdot 10^4$	$5.2 \cdot 10^2$	
85	$1.6 \cdot 10^4$	$1.4 \cdot 10^4$	$1.1 \cdot 10^2$	$4.0 \cdot 10^3$	$5.0 \cdot 10^3$	$1.8 \cdot 10^1$	
80	$5.6 \cdot 10^3$	$3.6 \cdot 10^3$	—	$1.9 \cdot 10^2$	$6.0 \cdot 10^2$	—	
75	$4.3 \cdot 10^2$	$1.8 \cdot 10^2$	—	—	$4.5 \cdot 10^0$	—	
70	$2.7 \cdot 10^0$	$(1 \cdot 10^0)$	—	—	—	—	
Max. Dens.	90	90	103	97	101	107	km

Model atmosphere (A) means an average distribution of temperature with height taken from a number of various papers, while (B) represents a mean atmosphere in temperate latitudes in winter, and (C) and (D) a mean atmosphere in temperate latitudes in summer. — It is referred to original paper. — χ = solar zenith distance.

with these two processes of ionization and dissociation the vertical distribution of electrons can be calculated if the solar energy and the absorption coefficients in the spectral band under consideration are given. The result is shown in table 2.

Diurnal and seasonal variations are affected by changes of the Sun's zenith distance; and, moreover, seasonal variations are influenced principally by the temperature changes in the upper atmosphere. Therefore calculations of D-layer at the same solar height, but with the summer temperatures in the one case (D) and with winter temperatures in the other (B) produce quite different results, while the difference between maximum solar height (noon) in winter (B) and summer (C) becomes rather small. This difference is evident only at the lower border of the layer. The upward movement of the isobaric surfaces in summer causes increased absorption, already at higher altitudes, of the energy flux of solar radiation although this flux is greater at smaller zenith distances. It is quite striking that large annual variations of the maximum electron density in the D-layer are suppressed; the lower border, however, makes a marked yearly cycle. The "penetration frequency" of the D-layer at winter noon is not much lower at summer noon, when it may occasionally approach 2 Mc/s (in middle latitude). This was determined — though approximately of course — from measurements of the attenuation limit of pulsed high frequency signals with continually changing wavelength (multi-frequency record). The diurnal variation, however, of this attenuation limit is quite impressive. Normally there is no damping at all at D-layer heights during the night. The electron density decreases to very low values.

How far can the presumptions involved in the calculations be supported by other observations or theories, and what are the uncertainties? The UV-spectral band of solar radiation cannot be measured direcly by a radiation receiver on the ground. The energy distribution in the band below 2 900 Å was obtained indirectly by investigating various photochemical processes in the stratosphere and ionosphere. The ozone formed in the upper part of the ozone layer can be measured because of the absorption of solar radiation, and the energy necessary for its formation can be estimated. Similar reasoning can be applied to the E-layer and F-layer, the maximum electron densities of which are measured by the echo-method. The study of formation processes in the ionospheric layers clearly shows that the UV-continuum of a 6 000° K radiator does not suffice for all the processes involved. In other words the radiation of the Sun's photosphere is not capable of building up and maintaining the Earth's ionosphere, or even the ozonosphere, as they are known from observation. It is indispensable when considering the different processes or their spectral bands, to assume different energy sources (ALLEN, 1948) and to place them at different heigts in the solar atmosphere (chromosphere and corona) where especially hydrogen, helium and calcium and other elements, emit in lines and bands. The energy flux densities applied in this investigation are in good agreement with those of other papers (DÜTSCH, 1948; KIEPENHEUER, 1945, 1948; KUIPER, 1949; NICOLET, 1945; SCHRÖER, 1947). For processes 7) and 8) the results require quantum flux densities of a continuum radiator (black body) with 5 740° resp. 5 200° K.

The absorption path in the atmosphere depends not oly on the Sun's zenith distance, but also on the gas density along the path. Besides the composition of the atmosphere it is essentially the temperature distribution with height which determines the atmospheric model to be applied. Up to 50 km it seems to be quite well known, above that height uncertainty increases. The temperatures used in calculations are in good agreement with values obtained from pressure measurements (PENNDORF, 1949 a) made during German V2-rocket ascents performed in New Mexico (USA). A result important for the D-layer was the low temperature of about 180° K found in the upper inversion at 75 km height. Such a low value has not yet been published by any other author.

The absorption coefficients α_{10} for oxygen and nitrogen in the region between 910 and 1 300 Å demand more experimental investigation. At the present time no more can be stated but that they must be very small in order to pass sufficiently intense radiation of that spectral range down to 100 km and less. Other theories, as for instance the ionization of sodium or the sudden reinforcement of the D-layer by X-rays, will not be discussed here (see end). They require quite different spectral suppositions and, moreover, can not be accepted without objections. Measurements of the absorption coefficient of oxygen have advanced to the spectral region in question (LADENBURG u. VOORHIS, 1933) so that appreciable changes of the numerical magnitudes and, in turn, serious corrections of the structure of the D-layer are scarcely expected.

Finally, one must discuss the influence of the effective recombination coefficients at 70 to 110 km which were used for the calculations. Unfortunately, one must depend upon interpolation. Measurements during various solar eclipses have yielded a rather safe value for the E-layer, i.e. an altitude of 115 km. Also three-body collision factors for the ozone layer are known from which an idea of the reaction speed may be determined. Thus the effective recombination coefficient in the D-layer is limited to a certain range which is rather definitive. Of all the assumptions made, that dealing with the recombination coefficient is of the greatest uncertainty.

Fortunately, however, there exist several observational results confirming the calculation. Records of very long waves (kilometer waves) serve as a very good indicator of the behaviour of the D-layer, since these waves are reflected from its lower border. Thus the height of this lower border is known, and it is possible to observe the increase in height of this lower border at sunset on undisturbed days and after shortlived reinforcements of the D-layer (sudden ionospheric disturbances). From both we get recombination coefficients in good agreement with each other. The following values have been used for calculating the D-layer.

Table 3.

h km	k_D [cm^3 sec^{-1}]	
130—110	10^{-8}	(measured)
110—100	10^{-7}	
100— 80	$7 \cdot 10^{-7}$	(measured)
80— 70	$5 \cdot 10^{-6}$	

The infrequent observation of fade-outs on medium wavelengths (1 149 kc/s) during a chromospheric eruption gives a "penetration frequency" of the D-layer of about 570 kc/s, corresponding to a maximum ionization of $n_e = 4 \cdot 10^3$ [cm^{-3}]. This value has the same magnitude as the average noon value ($5 \cdot 10^3$ to 10^4 [cm^{-3}]). The observation was made in the afternoon at a zenith distance of the Sun of $\chi = 65°$.

Investigations of short distance fading of the wireless station at Beromünster by GERBER and WERTHMÜLLER (1947) also confirm the preceding calculations. At vertical incidence its frequency lies not far from the noon "penetration frequency" of the D-layer. After its disappearance in the evening the echoes return from the lower E-layer.

In this connection it may be emphasized that in the morning the D-layer distinctly emerges from the lower region of the E-layer while later on it represents a separate layer with maximum ionization at ca. 90 km height, depending on season and latitude. Dissolution during the evening, of course, begins from the lowest regions leaving electrons after a time in the lowest E-level (100 km), until a night there is only a single layer left at that height. Recombination in the E-layer is not sufficiently rapid to make it disappear during one night. This is possible only during the polar night, and only occasionally has it been observed that the electron density decreased below 10^3 [cm^{-3}].

Good records of a pulsed fixed frequency sometimes show a laminated structure of the E-layer at 100 to 110 km in the morning hours, whereafter the echoes gradually move downward becoming invisible at levels below 95 km in height. Here the influence of attenuation has become so strong as to make the return of D-layer echoes impossible. Indeed, one can characterize these very low echoes as coming from the D-layer during formation. The gradient of charged particles at the lower border of the layer is, at the onset, very high and therefore favours reflection of the electromagnetic wave.

3. The undisturbed D-layer follows, as can be seen, the daily solar course practically without delay. Short periods of slightly fluctuating ionization are superposed on it and probably are due to corresponding changes in the lower chromosphere (granulation). These fluctuations of the D-layer reveal themselves very distinctly in the records of the field intensity of kilometer waves. Eruptions on the Sun (WALDMEIER, 1937) are observed to be of all intensities from the very frequent, but weak, fluctuations to the rare, but very strong, ones whose effect can be detected on the Earth in various ways. Most striking is the sudden, often complete, fade-out of short-wave transmission on certain communication channels during such a chromospheric eruption of high energy. During such occurences the resonance emission of solar hydrogen can rise for a short while up to 10^6-times the intensity of the black-body radiator at 6 000° K in the spectral band under consideration. Simultaneously the propagation of very long waves can often be observed to improve. The magnetograms of the geomagnetic observatories on the daylight side of the Earth frequently show quite typical variations (impetus of some gammas with gradual return to the normal state after some minutes depending upon the duration of the disturbance). They can be detected very easily when they rise above the general activity of the magnetic field. Therefore, they can be most easily detected on magnetically quiet days.

Chromospheric eruptions on the Sun can be observed in the light of the BALMER series (Hα, β, γ) of hydrogen. Simultaneous emission in the far ultraviolet must be assumed though it can not be observed directly; only its photochemical effect upon the upper atmosphere of the Earth (oxygen molecule) may be detected. Ly-α lies just in the gap of low oxygen absorption so that energy of the hydrogen emission line at 1 216 Å with a

Table 4. Ionization of the D-layer during a strong sudden ionospheric disturbance. n_e [cm^{-3}]. — Model atmosphere (C). — $\chi = 40^\circ$.

h (km)	Process 7) + 8) 10^4-fold continuum	Process 8) Ly-system	Processes 7) + 8) 10^4-fold contin. + max. Ly-system	
130	$8.1 \cdot 10^4$	$4.0 \cdot 10^4$	$1.2 \cdot 10^5$	Contribution to the E-layer
125	$1.3 \cdot 10^5$	$6.6 \cdot 10^4$	$2.0 \cdot 10^5$	
120	$2.2 \cdot 10^5$	$1.2 \cdot 10^5$	$3.3 \cdot 10^5$	
115	$3.8 \cdot 10^5$	$2.2 \cdot 10^5$	$5.6 \cdot 10^5$	
110	$6.9 \cdot 10^5$	$4.1 \cdot 10^5$	$1.1 \cdot 10^6$	
105	$1.2 \cdot 10^6$	$7.2 \cdot 10^5$	$2.0 \cdot 10^6$	
100	$1.6 \cdot 10^6$	$1.1 \cdot 10^6$	$2.8 \cdot 10^6$	
95	$1.5 \cdot 10^6$	$1.3 \cdot 10^6$	$2.8 \cdot 10^6$	
90	$1.1 \cdot 10^6$	$1.3 \cdot 10^6$	$2.5 \cdot 10^6$	
85	$5.3 \cdot 10^5$	$1.1 \cdot 10^6$	$1.6 \cdot 10^6$	
80	$4.0 \cdot 10^4$	$3.2 \cdot 10^5$	$3.6 \cdot 10^5$	
75	$6.1 \cdot 10^2$	$1.5 \cdot 10^4$	$1.5 \cdot 10^4$	
70	10^0	$7.1 \cdot 10^1$	$8.0 \cdot 10^1$	
Max. Dens.	99	95	94 km	

width of some tenths of Ångströms can produce a considerable amount of ionized oxygen atoms down to 70 km, by way of dissociation of excited oxygen molecules. It has, however, been stated that not every strong increase of the D-layer ionization is accompanied by emission in the BALMER series. Since emission in Hα, β, γ and in the LYMAN system are supposed to occur simultaneously, it can be concluded that not every increase of D-layer ionization is due to Ly-α (process 8), but that an intensified emission of the continuum is also able to produce an abnormal D-layer with similar features to those described above. Table 4 shows the electron density of the increased D-layer produced by process 7) + 8) [with a continuum radiator supposed to have been intensified by 10^4], by process 8) with Ly-α alone, and finally by the cooperation of both processes. The continuum extends from 910 to 1 300 Å containing ca. $3 \cdot 10^{13}$ quanta per cm^2—sec of extraterrestrial radiation. NICOLET (1945) gave an estimation of maximum possible LYMAN energy which is involved in this calculation. A very strong emission in Ly-α yields an extraterrestrial quantum flux density of $3 \cdot 10^{13}$ [$h\nu$ cm^{-2} sec^{-1}]. Thus a weak UV eruption in the chromosphere produces in Ly-α twice the energy of that produced by the granulation continuum between 1 000 and 1 300 Å!

The excessive hydrogen emission of the Sun probably comes from the higher levels of the chromosphere, as can be deduced from the fact that limb darkening is only very faint. In fact, short wave fade-out was observed when eruptions occurred at the limb of the Sun. In most cases the emission centres are found near sunspots or active centres which soon became visible as sunspots. It must be supposed, however, that the continuum radiation originates from the granulation, that is from the lower levels of the solar atmosphere where it can sometimes increase considerably in limited regions covering say 1/1 000 of the solar disc. It may be that these areas of higher energy production represent the predecessors of later chromospheric eruptions, where according to KIEPENHEUER (1948) the turbulent movement of ionized gas produces, by its retardation in the strong local-magnetic field, sufficient energy to make possible the heavy hydrogen emission occurring in the upper regions of the chromosphere. At a later stage in this enormous energy transfer a rising temperature of the corona, accompanied by increasing penetration frequency of the F2-layer, can be observed. ALLEN (1948) reports on the chronological sequence of solar and terrestrial events with regard to the relative sunspot number R. The author was able to show that an intensified D-layer caused by a chromospheric eruption would occur some days *before* the zero day for *R*. The maximum of *R* is found on the average 5 days after a fade-out effect. Unfortunately, the material was not sufficient for statistical investigation when divided into cases with and without emission of $H\alpha$, that would, so to say, separate LYMAN and continuum processes, but it would require the observation of the Sun simultaneously with the fade-out in each single case. If a separation of the two processes were possible in this way any delay element existing between the phenomena could be seen in terms of *R*. The continuum should be expected somewhat before the zero day of *R*.

The calculated effect of the two processes 7) and 8), when excessive UV radiation is departing from the Sun, differs less for the ionization maximum of the layer than for the height of the lower border which moves downward quite remarkably. Ly-α penetrates deeper into the atmosphere causing a greater displacement of the lower border of the D-layer. The experiments already mentioned in connection with ascents of German V2-rockets in New Mexico (NEWELL, 1948) were a remarkable success, in that field intensity measurements from two transmitters on two different wavelengths were obtained just on a day with worldwide fade-out (MÖGEL-DELLINGER effect). The lower border of the D-layer, where on both frequencies very strong, but different absorption suddenly began, was found rather distinctly at 64 km height. Qualitatively this observation agrees with the calculation though the latter, representing a general case for average conditions, differs from the observed special case quantitatively. The place of ascent is situated at 37° N, the start was in March. The model atmosphere should be fitted to this special experiment.

An interesting question may be raised: During a chromospheric eruption are there frequencies, below the penetration frequency of the intensified D-layer, but suffering so little absorption as to be reflected from the layer (though perhaps only sporadically) so that echoes can be received at the ground? In other words the frequency must be sufficiently higher than the collision frequency of the ionized gas particles with the molecules. In order to make this effect possible a rather high ionization of the D-layer with regard to its lower border is necessary. The calculation yields maximum figures of 1—$3 \cdot 10^6$ [cm^{-3}] at 95 km altitude. This maximum, however, is rather extended covering a height interval of 10 to 15 km. At greater Sun heights the absorption of frequencies of 10 to 15 Mc/s is complete at 85 km (collision frequency at summer noon about $2 \cdot 10^6$ [sec^{-1}]), and there is no measureable reflection of energy. This, however, does not hold in the early morning hours (or shortly before sunset) when the lower border of the D-layer is high, i.e. at a level where the collision frequency is still sufficiently low (summer morning about $5 \cdot 10^5$ [sec^{-1}] at 100 km). A very strong Ly-α eruption would for a short instant produce a penetration frequency of 10 Mc/s in the D-layer at that height. Echoes should thus be possible if the ionization does not reach farther down. The author can refer to such a case, though not of such extreme conditions, which agrees well with the calculated data of the intensified D-layer. Occasionally during the partial solar eclipse in the morning hours of April 28, 1949, there were echoes from a height of 87 km, approximately, on the 3 and 5.8 Mc/s records, lasting about 5 minutes (ionization ca. $3 \cdot 10^5$ [cm^{-3}], collision frequency ca $\cdot 2 \cdot 10^5$ [sec^{-1}]). The lower border of the layer owing to the great solar zenith distance was still very distinct, and the echoes must be supposed to have been favoured by unusual irradiation conditions in the ionosphere that morning.

The transfer of ultraviolet radiation energy in the spectral band (910—1 300 Å) under consideration, which takes place in the atmosphere between 100 and 75 km height, into kinetic energy of the molecules by means of the ionization and dissociation products causes the temperature of this lowest part of the ionosphere to rise but negligibly under normal conditions (temperature in the upper inversion 180° K). The increments of energy input of short duration during chromospheric eruptions, can, however, produce a temperature rise of 30° C in half an hour (maximum of layer at 95—100 km) in winter. In summer the influence is considerably weaker. Recent papers (BAUR, 1949, DÜLL, 1948) point out the importance of these sudden disturbances of the baric state on the daylight side of the Earth on atmospheric movement. Statistical investigations of these phenomena will, no doubt, reveal interesting results in future.

4. Twenty years ago CHAPMAN (1929) mentioned the effect on solar radiation produced by absorption by matter emitted from disturbed solar regions. RICHARDSSON (1944) and later BRÜCK and RUTLLANT (1946) could observe a very weak self-absorption of the hydrogen radiation ($H\alpha$) in the corpuscular stream envelopping the Earth when sweeping over it. From the DOPPLER effect (violet shift) they could calculate the velocity of the particles.

In quite another way the author (STRANZ, 1950) succeeded in demonstrating the absorbing effect of corpuscles envelopping the Earth on their way from the Sun by utilizing half a year's fade-out observations[1] together with solar and geomagnetic data (RYDBECK and STRANZ, 1949). Using the method of sample days of BARTELS an equal number of days with and without MÖGEL-DELLINGER effect (SID) were compared, and it is possible to show that the effect preferably occurs on days with a mean magnetic character somewhat lower than average. In other words the probability of fade-out is reduced slightly due to the weak absorption of active UV radiation when the magnetic character is higher than normal. The countertest used in checking the reality of the phenomenon (the selection of an equal number of days free from sudden ionospheric disturbances chosen from amongst the different months when the SID-days occurred) proved to be positive without any doubt. Higher magnetic activity, i.e. increased corpuscular emission from the Sun towards the Earth, caused a bit more intense absorption of short wave radiation (hydrogen resonance radiation) and less probability of disturbances in the D-layer of the kind described in this paper (SID).

In fact, extraordinarily impressive fade-out phenomena were observed on days when magnetic activity was absent, i.e. when 26—30 hours after the MÖGEL-DELLINGER effect $K = 0$ or 1. Not until after 50 hours did the percentage of $K \geq 5$ rise again in the group of 130 cases treated statistically. $K = 5$ was chosen as a reasonable limit between the less disturbed days and those with a corpuscular stream directed towards the Earth worth while considering.

From an analogous investigation, using sunspots distributed over the visible hemisphere of the Sun and divided into 12-day sectors, a similar result is obtained. The correlation seems to be lower, because one must not expect each spot in sector + 1 (west of central solar meridian) to throw matter in the direction toward the Earth. Magnetic effects give particular security that the Earth will be envelopped by corpuscles from the Sun which the day before had departed from it. The parallelism between the results obtained from the experiments with magnetic K-indices from the Geomagnetic Division of the Sjökarteverket, Stockholm, and from the solar data from the Saltsjöbaden Observatory gives a particularly good confirmation of the hypothesis developed concerning the absorption effect.

5. A. and E. VASSY (1948) have ascribed the formation of the D-layer to the ionization of Na detected in the upper stratosphere or lower ionosphere. According to their opinion Ly-α will be consumed already at altitudes above 100 km so that the formation of the D-layer in this way will not be possible. On the contrary they believe radiation of wavelengths greater than 1 800 Å is responsible for the ionization of Na; this radiation is said to be the emission of Ca^{+}. In fact, the D-layer usually shows a cloudy structure which could be identical with Na-clouds. PENNDORF (1947), however, found from calculations of the border of the ozone shadow that sodium luminescence observable at twilight comes from the E-layer (110—120 km). What occurs during the day cannot be stated from these considerations.

SIEDENTOPF (1948) recently published a new theory of formation of the D-layer and postulates an X-ray radiation of 1—2 Å originating from the Sun's corona as the causitive agent. The very hot corona can deliver enough electron energy to produce X-rays. According to this author this radiation only is capable of ionizing molecules in the atmosphere at the level of the D-layer. All other types of radiation are not able to penetrate as far down as this altitude.

---

[1] The observations were carried out by the author when working at the Chalmers Institute of Technology, Gothenburg. The author wishes to express his gratitude to the Stockholm Observatory at Saltsjöbaden and to the Geomagnetic Division, Kgl. Sjökarteverket, Stockholm, for their kind permission to use solar and geomagnetic data which they have collected.

The statistical result, that D-layer disturbances preceed corona disturbances (ALLEN, 1948) when referred to sunspot number R zero-day, makes this explanation questionable.

In addition to these theories which deviate essentially from the one described here, there were earlier attempts of other authors to explain the D-layer formation which agree in general with this one. Only certain differences in the photochemical processes and in the amounts of energy assumed in the calculations exist, but these produce no significant difference in the results.

This investigation, described in full elsewhere, should contribute some essential ideas and observations toward a better understanding of the D-layer which has been only indirectly accessible to experiments. For a more complete description one is referred to the original paper.

REFERENCES

ALLEN, C., 1948: Critical Frequencies, Sunspots, and the Sun's Ultraviolet Radiation. — *Terr. Magn.* **53**, p. 433.

BAUR, F., 1949: Die doppelte Schwankung der atmosphärischen Zirkulation in der gemässigten Zone innerhalb des Sonnenfleckenzyklus. — *Met. Rdschau.* **2**, p. 10.

BRÜCK, H. A., and RUTLLANT, F., 1946: Some Observations of the H and K Lines in the Solar Spectrum during a Magnetic Storm. — *Mon. Not.* **106**, p. 130.

CHAPMAN, S., 1929: Solar Streams of Corpuscles: Their Geometry, Absorption of Light, and Penetration. — *Mon. Not.* **89**, p. 456.

DÜLL, B., and G., 1948: The Behaviour of Barometric Pressure during and after Solar Particle Invasions and Solar Ultraviolet Invasions. — *Smithson. Miscell. Coll.* **110**, Nr. 8.

DÜTSCH, H.-U., 1946: Photochemische Theorie des Atmosphärischen Ozons unter Berücksichtigung von Nichtgleichgewichtszuständen und Luftbewegungen. — Inaugural-Dissertation, Zürich.

GERBER, W., and A. WERTHMÜLLER, 1947: Technische Mitteilungen, herausgegeben von der Schweiz. PTT, Nr. 1.

KIEPENHEUER, K. O., 1945: Recherches de Physique Solaire. — *Ann. Astrophys.* **8**, p. 210.

— 1947: Solar-Terrestrische Erscheinungen. *Naturforschung und Medizin i Deutschland 1939—1946*, Band 20, Astronomie, Astrophysik und Kosmogonie, p. 229—284. — Wiesbaden.

KUIPER, 1949: The Atmosphere of the Earth and Planets. — Chicago.

LADENBURG, R., and van VOORHIS, C. C., 1933: The continuous absorption of oxygen between 1 750 till 1 300 Å and its bearing upon the dispersion. — *Phys. Rev.* **43**, p. 315.

NEWELL, H. E., 1948: Upper Atmosphere Research with V 2-Rockets. — *N. R. L. Report R—3 294*, June 1948.

NICOLET, M., 1945: Contribution à l'étude de la structure de l'Ionosphere. — *Mém. Inst. Roy. Mét. de Belgique*, Nr. 19.

PENNDORF, R., 1947: Der Ozongehalt der mitteren Stratosphäre. — *ZS. f. Met.* **1**, p. 345.

— 1949 a: Die vertikale Druck- und Temperaturverteilung bis 120 km Höhe über Neu-Mexico (USA). — *Ann. Met.* **2**, p. 91.

— 1949 b: The vertical Distribution of Atomic Oxygen in the Upper Atmosphere. — *J. Geophys. Res.* **54**, p. 7.

RICHARDSON, R. S., 1944: *Trans. Amer. Geophys. Un.* **25**, p. 558.

RYDBECK, O. E. H., and STRANZ, D., 1949: Ionospherci Effects of Solar Flares 1948, Preliminary Report No. 1 (March—June 1948). — *Tellus* **1**, p. 6. — Preliminary Reports No. 2 (July—December 1948) and No. 3 (January—June 1949) by the same authors have been published under the name of R. LINDQUIST in Chalmers Tekniska Högskolas Handlingar Nr. 95, Göteborg.

SCHRÖER, E., 1947: *ZS. f. Met.* **1**, p. 14.

SIEDENTOPF, H., 1948: Der Einfluss der Erdatmosphäre bei astronomischen Beobachtungen. — *Naturwiss.* **35**, p. 289.

STRANZ, D., 1950: Ergebnisse einer Fade-out-Statistik. — A. E. Ü. (in print).

VASSY, A., and E., 1948: Relations entre la région D de l'ionosphère et la radiation 5 893 Å du sodium atmospérique. — *U. R. S. I.* Stockholm.

WALDMEIER, M., 1937: Sonneneruptionen und ionosphärische Störungen — *ZS. f. Astrophys.* **14**, p. 229.