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PHOTOMETRIC OBSERVATIONS OF TWILIGHT AS A METHOD OF STUDY OF THE UPPER STRATOSPHERE

by

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continued

(*) Editor S. I. Vavilov. Origin of the memoir is uncertain.

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N.B. Chapters V, VI, VII missing from the Table of Contents, but it is apparent that the entire memoir has 162 pages.

PHOTOMETRIC OBSERVATIONS OF TWILIGHT AS A METHOD OF STUDY OF THE UPPER STRATOSPHERE

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ABSTRACT

Chapter I contains a short account of chief indirect methods of temperature measurements in the stratosphere: the methods of radiation equilibrium, of meteorics, of sounding balloons; also the twilight method of polar lights, the altitude method of spectral lines' width and that based on the percentage of helium content in the atmosphere and on the position of the maximum intensity in certain series of nitrogen bands. All are examined from the point of view of their up to date applicability. The meteoric, the sounding balloon and the twilight methods are to be recognized as the most effective.

In Chapter II the chief results of Fesenkov's fundamental work are given; they have been published in Vol. II of the Proceedings of the Astrophysical Observatory. Observations were visually made at the Kharkov Observatory, and according to them the average twilight curve was constructed. In order to determine the scattering coefficient a hypothesis of constant composition of the air and of gradual change of temperature at various altitudes (slow fall) was introduced. According to it, the absorption of rays was calculated from the limits of the atmosphere to the scattering volume and the numerical values F(h) of the scattering capacity thus found corresponded to the twilight curve. These Fesenkov's results were complemented by the author by examination of the quantity log F(h), which enabled him to clear the observations from the effect of scattering of big particles (the upper dust layer) and to begin the investigation of the Hevyside layer by means of twilight observations.

Chapter III treats the problem of reflecting capacity of a turbid medium. After some preliminary remarks the foundations of the electromagnetic theory of light are given, with which the theories of Rayleigh and Mies have to do. Further, the Rayleigh law of scattering is deduced according to his memoir, but with interjacent calculations, the absence of which makes the study of the original work difficult. The examination of the assumption

on which the proofs are based allows one to estimate the applicability of this theory in case of molecular scattering in gases and indicates the direction of further natural development of this problem free from Rayleigh theory restrictions. One of the chief stages of this development is the theory of Mies, constructed by him for the general case of conducting particles of non-infinitesimal size. The scattered light consists of an infinite number of separate waves; for the infinitesimal particles only the first electric, the so-called Rayleigh's wave, is of importance; as the size of particles increases, it is joined by the first magnetic, then the second electric wave and so on. The investigations of V. V. Schuleikin may be considered as the continuation of the computative part of Mies' work for particles of still larger size, up to the infinitely large ones when compared with wave length.

Chapter IV is especially devoted to the examination of the problem of molecular scattering in gases based on the above theories of scattering from continuous particles. A more rigorous and complete theory of Mies leads to a formula for the scattering coefficient in which the volume of a molecule and its refraction index are involved. If a molecule is to be considered as a dielectric and if Rayleigh's idea of gas as a mixture of molecules of this gas with the surrounding ether is involved, the refraction index of a molecule may be expressed by means of the refraction index of the gas, so that the scattering coefficient will contain only one unknown quantity - the volume of the particle. In the Rayleigh formula, simplified by comparison with the Mies theory, this volume shrinks and vanishes. Thus the new formula for the scattering coefficient derived by way of Rayleigh's theory from the formula of Mies enables one to determine the diameters of molecules according to the observed scattering coefficients in gases.

The obtained experimental data are not sufficient, but the diameters deduced from them are in excellent agreement with the results obtained by other methods. But even in that context, the theory of molecular scattering is too elementary and does not correspond to the modern idea of a molecule. The theory of Cabannes is more satisfactory in this respect, but it does not even consider the principal factor - the motion of electrons, and considers the atom in its static equilibrium. Therefore experimental investigations of scattering in gases are indispensable in order to obtain data which would afford the possibility to pass a judgment about the scattering in the upper layers of the atmosphere by neutral as well as by ionized gases. Calculations prove that this problem is of practical importance for processing the observations of twilight.

In Chapter V a simplifying conjecture is admitted, whereby the composition of the air is the same at any altitude. In this way some difficulties arising in the problem of molecular scattering may be avoided and the twilight observations may be processed in the first approximation. One is led to this conjecture by the fact of the inalterable composition of the air at attainable altitudes which has been proved by the last elevations of aerostats up to 20 km. If it is admitted that the equation of the state of ideal gases and the conditions of static equilibrium in a vertical air column hold, one may get a simple dependence between the temperature of the air, its derivative with respect to altitude and the scattering coefficient. This differential equation is easily resolved if the derivative of the temperature is equated to zero; the temperatures obtained in this way are called "isothermic." The visual observations of Fesenkov led to impossible values for isothermic temperature of about 400° at the altitude of 30 - 40 km. Therefore, the lower part of the curve for the scattering coefficient obtained in Kharkov is not to be considered as a typical case; it is possible that it was distorted by the lights of the town railway station. Consequently one has to look for other data for the investigation of the stratosphere by the twilight method. Such data are obtained by the photographic observations of the same Fesenkov, partly published in the Astronomic Journal Vol. VII, and partly reported at the First All Union Conference for the study of the stratosphere in April, 1934. Comparison of these observations with the visual ones afforded the possibility to draw for the modification of the reflecting capacity one common curve, the lower part of which corresponds to the photographic observations. In dealing with these new data a quite acceptable temperature of about 220° was obtained for the altitudes of about 20 km accessible to our investigations. This assured us of the compatibility of the data used, and of the applicability of the method on the whole, so that the decision was made to obtain the densities of air by means of twilight observations. The results are given below; a continuous curve of densities for the altitudes from 20 up to 100 km has for the first time been obtained from observations and not through theoretical speculations as has been the case with the densities determined by Humphreys, Jeans, Miln and others.

TABLE 1

h km	ρ	p^{mm}	T	h km	ρ	p^{mm}	T
20	$8.8\cdot10^{-5}$	48.6	255°	65	$6.5\cdot10^{-7}$	0.410	444°
25	$4.3\cdot10^{-5}$			70	$4.3\cdot10^{-7}$		
30	$2.2\cdot10^{-5}$	14.4	301	75	$2.8\cdot10^{-7}$	0.200	491
35	$1.2\cdot10^{-5}$			80	$1.9\cdot10^{-7}$		
40	$6.8\cdot10^{-6}$	6.03	348	85	$1.3\cdot10^{-7}$	0.107	577
45	$4.0\cdot10^{-6}$			90	$8.6\cdot10^{-3}$		
50	$2.4\cdot10^{-6}$	2.05	391	95	$6.0\cdot10^{-8}$	0.058	659
55	[illegible]			100	$4.8\cdot10^{-8}$		
60	[illegible]	0.894	416				

The density at the surface of the earth is considered to be

$$\rho_0 = 1,233 \cdot 10^{-3}.$$

The values of pressure P were obtained according to these densities , and the absolute temperature T was determined therefrom. All these results must be considered only as a first approximation to the real values and as a first successful attempt of construction of the upper layers by twilight observations. The twilight observations do not give a uniform solution for altitudes above 100 km because there the scattering coefficient can be distorted by the presence of the dust layer.

Chapter VI discusses the simplified theory of twilight. The elaborate method used in his first work by Fesenkov when determining the reflective capacity by twilight observations is entirely inapplicable when dealing with a great number of systematical observations, which is desirable to organize. Besides, it does not afford the possibility of understanding the phenomenon as a whole. V. G. Fesenkov suggested a simplified theory of twilight for the zenith and such a theory may be developed in the same way for any point of the sky. The problem is to construct a theoretical twilight curve for different points of the sky when the density of the air is given as a function of altitude, and vice-versa: to determine for a given twilight curve the density as a function of altitude. This problem may be solved for any ideal atmosphere. In order to obtain results which would be in agreement with the reality, "the atmosphere of Fesenkov" was taken as it is described in Chapter II of the present work; this afforded the possibility to use numerical values of adsorption obtained by him.

Calculation shows that, on the whole, the scattering of light, responsible for the twilight phenomenon at any given moment of time, is confined to a comparatively thin layer and is not spread in the entire atmosphere. Besides, this layer's altitude decreases gradually as the sun sets below the horizon.

Not all the beams penetrating into the atmosphere of the earth are of equal importance for the phenomenon of twilight: the beams passing near the surface of the earth are subject to a strong absorption and take no part in the phenomenon; the very high beams fall upon too rarified air layers, and are of a small influence. Most effective for any sinking of the sun are the beams bending round the earth at the altitude of about 20 km; they are called the twilight beams. Their totality forms "the surface of the twilight beams" which in the first approximation may be considered as a circular cylinder with a radius exceeding the earth's radius by about 20 km. The brightness of the sky in the zenith during twilight is proportional to the density of the air layer, upon which the twilight beam is incident at the given moment.

In the same way the value of the air density is involved in the expression for the brightness of twilight for any point of the sky, but there it is multiplied by a certain coefficient depending upon the position in the sky of the region considered. This circumstance affords us the possibility to obtain easily the distribution of twilight brightness in the sky at the given moment according to the given densities and, reciprocally, to determine the density at those points of the surface of twilight beams which are lying on the visual ray.

As far as the author is aware the existence of these twilight beams and the consequences following therefrom - the theory of the distribution of the twilight brightness on the sky and the possibility to apply it to the investigations of the stratosphere are stated for the first time, though some hints about the twilight beams are to be found in the works of Fesenkov when he speaks about the unimportance of the part of the troposphere in the phenomena of twilight.

Chapter VII deals with the working up of the photos of twilight taken by N. M. Staude at Pulkovo in summer, 1934 by means of a tube photometer.

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The above material, alongside with the following excerps from chapter 2, has been prepared by
Andre L. Brichant
28 September 1967.

N.B. Despite its old age (1936), this memoir has been recommended for a cover-to-cover translation.

EXCERPS FROM CHAPTER 2

RELATIVE TO THE ROLE OF THE DUST LAYER

It was stressed in Chapter 1 that when applying the twilight method for the study of the stratosphere, the main difficulty of theory and calculation resides in the reflection factor of the air as a function of height on the basis of observation data. These observations consist in the determination of brightness of a certain part of the sky situated at invariable height and in the Sun's vertical, and they provide the possibility of constructing a curve linking the logarithm of brightness observed with the zenithal distance of the Sun at the time of observation.

In order to pass from this curve to the distribution of reflection capability in height, one should take into account the absorption of light in the Earth's atmosphere to which were subject all the Sun's rays; at that time the Sun was already below the horizon for the observer, but it was still illuminating the air particles over the visual ray path. These rays will be rejected toward the observer by the atmosphere molecules and by admixing particles, which, summed up, will provide the value of the observed brightness.

The derivative of the reflection capability plays a substantial role and has a concrete physical sense in the assumption of mixed atmosphere of uniform composition, in which case it represents the derivative of the density. Its very variation makes much more sharply apparent the peculiarities of air's reflection capabilities at different heights than does the course of the curve of log F(h). Some conclusions on the structure of the upper layers may be made only on the basis of the graph of the values of [log F(h)]' with no assumptions of any kind. The whole study rests upon the values of the derivative of the reflection capability. These values were obtained by numerical method on the basis of a series of values of log F(h) applying the graphical method (see fourth column of the Table 2 (V in the original text). The meter is taken as the unit of length. The values of [log F(h)]' were found in reverse by integrating for the purpose of control the quantity log F(h), resting upon the number log F(h) = 2,245 for the altitude of 30 km. From the practical standpoint the integration amounted to the summation of areas with 1 km height and with the mean values of the derivative for that interval. The results of integration were found to be quite close to the values of log F(h) in the entire altitude interval, as this may be seen from the fifth column of Table 2 for [log F_c(h)]. Plotting the values of log F(h) and [log F(h)]' on the graph, we see (curves I and II of Fig.1) that the reflection capability decreases sufficiently smoothly and constantly with height without giving us specific indications relative to any peculier regions of the stratosphere, while the shape of the graph for its derivative gives us these indications directly. It is thus natural to break down this curve into three parts:

a) region X, from 30 to 70 km, where the derivative is nearly constant;
b) region Y, between 70 and 110 km, characterized by its rapid drop in absolute value;
c) region Z, above 110 km, which is a new region of derivative's constancy.

TABLE 2

h^{km}	$\log f(h)$	$\log F(h)$	$[\log F(h)]'$	$\log F_c(h)$	$[\log F_1(h)]'$	$\log F_1(h)$	$\log F_2(h)$	$\frac{F_2(h)}{F_1(h)}$
1	2	3	4	5	6	7	8	9
30	2.279	2.215	$-3.623 \cdot 10^{-5}$	2.215	$-3.623 \cdot 10^{-5}$	2.216		
35	2.096	2.064	-3.620	2.064	-3.620	2.064		
40	1.913	1.883	-3.618	1.888	-3.618	1.883		
45	1.730	1.702	-3.615	1.702	-3.615	1.702		
50	1.547	1.521	-6.613	1.521	-3.613	1.521		
55	1.364	1.341	-6.610	1.341	-3.610	1.341		
60	1.182	1.161	-3.607	1.160	-3.608	1.160		
65	1.000	0.981	-3.600	0.980	-3.605	0.980		
70	0.817	0.800	-3.587	0.801	-3.603	0.800		
75	0.635	0.620	-3.563	0.622	-3.600	0.620		
80	0.455	0.442	-3.520	0.445	-3.598	0.440		
85	0.280	0.269	-3.430	0.271	-3.595	0.260		
90	0.110	0.101	-3.278	0.103	-3.593	0.090	$\bar{2}.505$	0.026
95	$\bar{1}.950$	$\bar{1}.913$	-3.017	$\bar{1}.914$	-3.590	$\bar{1}.911$	$\bar{2}.794$	0.076
100	$\bar{1}.803$	$\bar{1}.798$	-2.708	$\bar{1}.800$	-3.588	$\bar{1}.731$	$\bar{2}.958$	0.167
105	$\bar{1}.678$	$\bar{1}.670$	-2.474	$\bar{1}.671$	-3.585	$\bar{1}.552$	$\bar{1}.016$	0.312
110	$\bar{1}.550$	$\bar{1}.549$	-2.401	$\bar{1}.550$	-3.583	$\bar{1}.373$	$\bar{1}.072$	0.500
115	$\bar{1}.428$	$\bar{1}.429$	-2.398	$\bar{1}.430$	-3.580	$\bar{1}.194$	$\bar{1}.050$	0.718
120	$\bar{1}.305$	$\bar{1}.308$	-2.395	$\bar{1}.310$	-3.578	$\bar{1}.015$	$\bar{1}.001$	0.968
125	$\bar{1}.184$	$\bar{1}.189$	-2.392	$\bar{1}.190$	-3.575	$\bar{2}.836$	$\bar{2}.934$	1.25
130	$\bar{1}.062$	$\bar{1}.069$	-2.390	$\bar{1}.071$	-3.573	$\bar{2}.657$	$\bar{2}.856$	1.58
135	$\bar{2}.941$	$\bar{2}.950$		$\bar{2}.951$	-3.570	$\bar{2}.469$	$\bar{2}.776$	2.03
140	$\bar{2}.820$	$\bar{2}.831$		$\bar{2}.832$	-3.568	$\bar{2}.290$	$\bar{2}.684$	2.48
145	$\bar{2}.698$	$\bar{2}.711$		$\bar{2}.712$	-3.565	$\bar{2}.112$	$\bar{2}.585$	2.97
150	$\bar{2}.576$	$\bar{2}.591$		$\bar{2}.593$	-3.563	$\bar{3}.934$	$\bar{2}.483$	3.54
155	$\bar{2}.455$	$\bar{2}.472$		$\bar{2}.473$	-3.560	$\bar{3}.756$	$\bar{2}.379$	4.20
160	$\bar{2}.333$	$\bar{2}.352$		$\bar{2}.354$	-3.558	$\bar{3}.578$	$\bar{2}.272$	4.94
165	$\bar{2}.212$	[illegible]3	$-2.390 \cdot 10^{-5}$	$\bar{2}.234$	$-3.555 \cdot 10^{-5}$	$\bar{1}.400$	$\bar{2}.164$	5.81

We obtained directly and outright the result whereby the regions X and Z of the stratosphere are in a relatively "steady" and "uniform" state (omitting the definition of these terms in a more precise fashion) independently of any further assumptions about the relationship between the reflection factor and the density on the one hand, and between the density and temperature on the other, whereas the transition region Y between them differs by the rapid variation of its reflection properties, and may accordingly be characterized as "unsteady" and "nonuniform". Let us recall that in the region Y the appearance of noctilucent clouds was noted more than once, and the slowing down of the reflection capacity in it, as compared to that of the region X, may possibly be explained by their continuous presence in a certain amount not perceptible to the naked eye.

THE DUST LAYER.

The scattering of light by the meteoric dust still remaining in the upper atmosphere layers after the flight of meteors as the product of their combustion may also explain this additional brightness of light reflection at great altitudes. In his investigations Fesenkov assumed that the scattering takes place only by air molecules and that the influence of tiny dust particles and other coarser particles is negligibly small. One may attempt, however, to separate two forms of reflection: from molecules and from coarse particles, if it is assumed that the influence of the latter is not too small and explains entirely the variation of the course of the reflection capacity at altitudes above 70 km. So far it is a hypothesis, the verification of which could only be provided by involving the results of stratosphere study by means of other methods, upon which it is not insisted at all. But the hypothesis is rather natural because of abundance of small falling stars burning above 70 km, and of all other sorts of particles penetrating into the atmosphere from without.

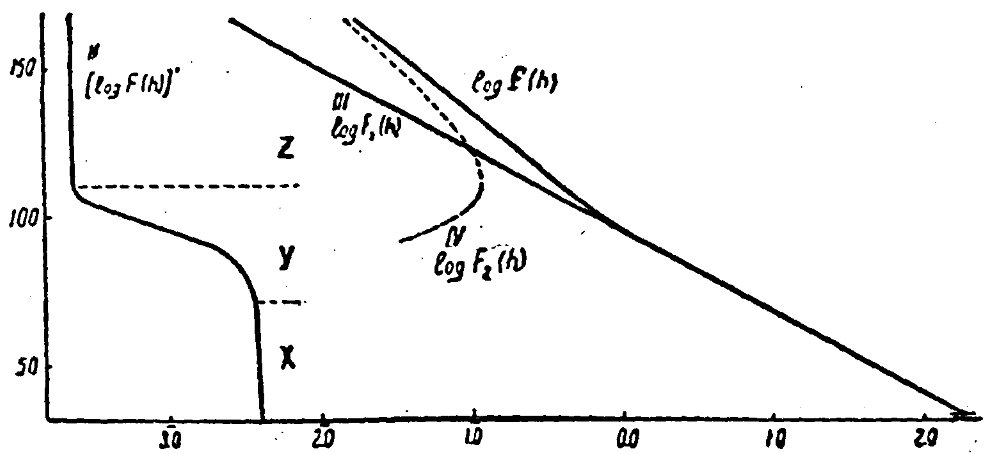

Fig.1

In order to make a rough verification of the probability of such a hypothesis on the influence of coarse particles (or generally particles not identified with air molecules), attempt was made to compute the reflection capacity $F_1(h)$ in the assumption of its variation for heights greater than 60 km following the same law according to which it drops to 60 km (curve III). The respective values of its derivative $[\log F_1(h)]'$ and of the values of $\log F_1(h)$ found from them, are compiled in Table 2. Then the difference $F_2(h) = F(h) - F_1(h)$ will correspond to the reflection from extraneous particles.

If we plot on the graph the values of $\log F_2(h)$ (curve IV), it will be found that they fit very well the curve which has a clearly expressed maximum at 110 km and offers a graphical representation of the number of extraneous particles conditioning in our assumption the complementary reflection $F_2(h)$. Thus, having decomposed the reflection capacity into a sum of two components, we may explain the singularities of its variation with height in the assumption that

1) the region X differs from the others by the absence of extraneous particles, which begin to affect the twilight phenomenon only beginning from the altitude of 90 km;

2) the region Y corresponds to the accretion of the number of these particles with height, and

3) the region Z corresponds to the decrease of not only the number of air molecules, but also of that of extraneous par icles.

The ratio of the quantity of light $F_2(h)$ / $F_1(h)$ can be computed at various heights.

It is found that the hypothetical extraneous particles would reflect 2.5 percent at 90 km altitude, 50% at 110 km and nearly 500 percent at the height of 160 km of the quantity of light reflected by air molecules (column 9 of Table 2). It is difficult to judge about the ratio of the number of particles to that of molecules, since we are unaware of the ratio of the respective reflection capacities of the particle and of the molecule, but we may throw in a relative number of particles at various heights in the assumption that all of them scatter the light identically. In such a case the number $\underline{n}$ of them in the unit of volume will be proportional to the quantity $F_2(h)$ and will be represented by the curve of Fig.2. The number of particles at 95 and 135 km constitutes half of the maximum, at 90 and 150 km -- 25 percent of it. In the direction toward the Earth the number of particles drops sharply, whereas upward from the maximum the drop of their number is, to the contrary, slowing down. The height at which the thickness of the light-reflecting dust cloud was obtained according to twilight observations, agrees splendidly with the height of the Hevyside layer.

Thus, in the Appleton and Green work three heights of ionized layers are brought out, respectively at 105, 235 and 470 km, of which the first (the E-layer in their denotation) precisely is the Hevyside layer. Judging from the reflection of electromagnetic waves it acts only in daytime. If this assumption is correct the twilight method provides the possibility of observing this layer not only prior to sunset, as the radiotelegraphic method, but also further, during the entire duration of twilight.

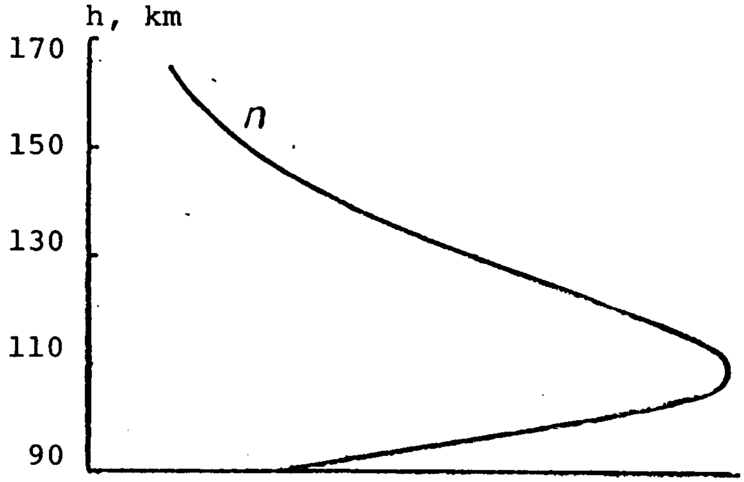

Fig.2

This circumstance only is already sufficient to justify the broadening of photometric observations of twilight. But they provide the possibility of determining not only the height of Hevyside layer's center of gravity, but also of studying its structure in height, which could not be made to date by another method. Note also that the boundary of this layer's spreading, as presently obtained (90 to 150 km) coincide well with the limits of luminescence of falling stars. Multon gives for the latter the average heights of 90 and 160 km, while Lindemann and Dobson take them, as an average, within the limits from 80 to 160 k. Both the strong ionization of the Hevyside layer, always attending the meteor flight, and the strong reflection capacity in connection with the abundance of products of burning, often remaining in the form of glowing wakes, and then accumulating and forming the scattering dust cloud, are well explained by the flight and combustion of meteors in this region. All the indicated coincidences render the hypothesis brought forth sufficiently probable and allow us to hope for the possibility of dividing the twilight brightness into the "molecular" and "dust" even without the aid of light filters.
In the subsequent study of twilight both the values of F(h) and of the hypothetical $F_1(h)$ will be taken for the "molecular" reflection capacity of the air. Comparison of the results obtained from direct observations and of observations thus liberated from the influence of the dust cloud with the data from other methods will allow us to obtain some clarification of the complex phenomenon of twilight.

E N D