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THE NATURE OF NOCTILUCENT CLOUDS AND CERTAIN QUESTIONS CONCERNING THE PHOTOCHEMISTRY AND DYNAMICS OF THE EARTH'S ATMOSPHERE

I. A. Khvostikov

ABSTRACT

In contrast to a number of former investigations the recent careful measurements indicate a low humidity of the air above the level of 30 km (the order of $\beta = 4 \cdot 10^{-6}$ $\frac{gH_2O}{g \cdot air}$), but the Swedish-American sounding of noctilucent clouds confirms their water nature. The report discusses an interesting and difficult situation, revealed by comparison of the two mentioned facts--the presence of ice as the component of noctilucent cloud particles and the low humidity of air in the mesosphere. These difficulties are redoubled by the presence of the intensive photodissociation of H_2O molecules of the Sun's ultraviolet radiation at a height of 65-90 km. The report indicates the three possibilities which explain the episodical rise of the conditions, favorable to the humidity precipitation on the condensation centers of noctilucent cloud particles. One /57*

*Numbers given in margin indicate pagination in original foreign test.

of these possibilities is considered at greater length: a formation of additional quantities of H_2O molecules directly in the mesosphere (a sharp increase of the level of the equilibrium concentration of H_2O molecules). One of the mechanisms is related to the role of corpuscular solar streams in the increase of the hydrogen concentration at the height of 100 km mentioned in 1952 (ref. 7). This mechanism is considered in relation to modern data on solar wind ("solar rain"). The other mechanism is related to the influence of the dynamic factors (equation 23), which have not yet been considered by the theory. This mechanism is explained by the examples of reactions (9) and (22).

1. The present status of the problem of the nature of noctilucent clouds is characterized by three results of fundamental importance.

It was recently established that the particles of noctilucent clouds are solid dust particles (probably of meteoric origin), the largest of which are encased in ice (ref. 1). It has thus been demonstrated that in the high layers of the atmosphere, in the mesopause region, under certain conditions (in summer, in the high latitudes $\sim 60\text{-}70^{\circ}$N), there can be an accumulation of such a large quantity of water vapor that the air becomes saturated, and condensation, sublimation or precipitation of moisture on condensation nuclei (mostly on dust particles of meteoric origin) can occur.

More careful recent measurements indicate an absence of significant air humidity in the upper stratosphere and mesosphere; the earlier results of some investigators on a high moisture content of the atmosphere above the 23-30 km

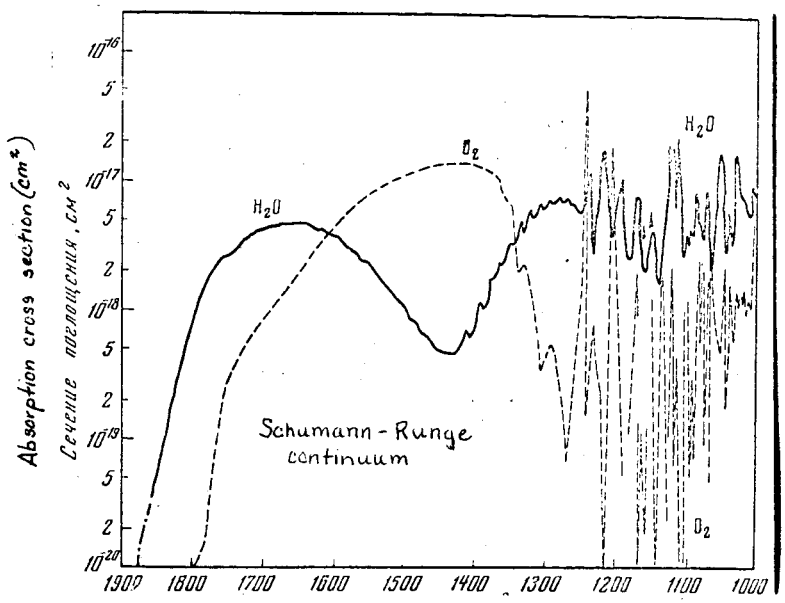
level apparently were caused by inadequacies of the measurement method (ref. 2). There is basis for assuming a humidity of about $\beta \cong 4 \cdot 10^{-6}$ (g H_2O/g air) to be typical for the atmosphere at heights of 30-85 km. In any case, for heights of 70-75 km the theory of aeronomic reactions for hydrogen and its compounds gives $\beta \cong 4 \cdot 10^{-6}$ (ref. 3).

In a study by Hesstvedt (ref. 4), devoted to investigation of the moisture content of the high layers of the atmosphere in relation to the noctilucent cloud problem, computations are given based on the assumption that at heights of 30-60 km the air humidity is high: $\beta = 2.4 \cdot 10^{-4}$. According to reference 2, this value must be considered exaggerated by 50-100 times; all of Hesstvedt's subsequent conclusions concerning the conditions for formation of noctilucent clouds must accordingly be reconsidered (ref. 4).

Comparison of these two results creates a difficult and interesting situation in the theory of the formation of noctilucent clouds. These difficulties are particularly emphasized by a third fundamental fact, which was established theoretically as early as 1950 (ref. 3): the presence of strong photodissociation of H_2O molecules by solar ultraviolet radiation at heights of 65-90 km. Photodissociation occurs for the most part due to the process

$$H_2O + h\nu\,(\lambda > 1750\text{Å}) \rightarrow OH\,(X^2\Pi) + H\,(^2S). \tag{1}$$

The process begins near 2400 Å (ref. 3). The dissociating radiation $\lambda > 1750$ Å penetrates into the atmosphere through the "windows of transparency" in the Schumann-Runge bands. Therefore, the value of the coefficient of dissociation of water in the mesosphere is a function of height. The dissociating effect of Lyman-alpha ($\lambda = 1216$ Å) radiation is of great importance. The dependence



Wavelength, Å

Absorption spectra of H_2O and O_2.

of the absorption cross section on wavelength for H_2O (and O_2) is shown in /58 the illustration.

2. What values of humidity should be used for the mesopause level (where noctilucent clouds are formed) with the photodissociation of water molecules taken into account? In the study by Hesstvedt (ref. 4), the author gives computations of the rate of photodissociation indicating that above the 70-75 km level moisture content β decreases by a factor of 10 approximately with each 3 km of height: for example, in summer in the high latitudes at the 82 km level the moisture content is 10^4 times less than at the 70 km level, decreasing to the value $\beta \cong 10^{-8}$.

This result differs considerably from the computations made by Nicolet, in whose studies (refs. 3, 5 and 6) there is an example of the vertical distribution of different components in the region 60-95 km under the condition that

there is photodissociation of H_2O molecules. According to these data, at heights of 68-75 km $\beta \cong 4 \cdot 10^{-6}$, at a height of 80 km $\beta \cong 1.2 \cdot 10^{-6}$, at a height of 85 km $\beta \cong 1.6 \cdot 10^{-7}$ and at a height of 90 km $\beta \cong 2.6 \cdot 10^{-8}$. According to these data, in the region of active photodissociation of water (above 75 km) β decreases with height considerably more slowly, by a factor of only 2.5-3 per 3 km interval; at a height of 82 km $\beta \cong 5 \cdot 10^{-7}$ (with a value β in the lower mesosphere and upper stratosphere of about $4 \cdot 10^{-6}$) in place of $\beta \cong 10^{-8}$ according to Hesstvedt's data (with a value β in the lower mesosphere and in the upper stratosphere of about $2.4 \cdot 10^{-4}$).

Hesstvedt's study (ref. 4) does not give the details of the computations, and therefore it is difficult to draw conclusions concerning his method for computing photodissociation and understand why, according to his data, the photodissociation rate is so large. One of the possible factors is that Hesstvedt's main computations were based on the assumption of infinite duration of the day. Another factor may be related to the choice of the value for the dissociation coefficient and especially its dependence on height. In his study Hesstvedt cites only the following data:

(1) $H_2O + h\nu \rightarrow OH + H$ ($J_{H_2O} = 1.5 \cdot 10^{-5}$ sec^{-1} for a zero optical thickness)

and

(2) J_{H_2O} was computed for the Lyman-alpha and the continuum 1500-1900 Å.

It was established that Lyman-alpha radiation exerts a substantial influence on the dissociation rate to 60 km in the low latitudes, to 65 km in the high /59 latitudes in summer and to 75 km in the high latitudes in winter. It was found that for a zero optical thickness one-third ($5 \cdot 10^{-6}$ sec^{-1}) of the total dissociation coefficient is caused by Lyman-alpha radiation.

Ref. 4 gives no indication of the method used in computing the dependence of J_{H_2O} on height; however, this dependence is very strong and can be computed precisely only with difficulty. The dissociation coefficient as a function of height is computed more simply for narrow parts of the spectrum, and it is far more complex to compute the full dissociation coefficient. According to Nicolet's estimate (ref. 5), the full dissociation coefficient for a zero optical thickness can be assumed to equal

$$J_{\infty}(H_2O) \cong 10^{-5}\ \mathrm{sec}^{-1}.$$

A rough estimate of absorption in the Schumann-Runge bands gives for the level of the mesopause

$$J_{\mathrm{mesopause}}(H_2O) \cong 10^{-6}\ \mathrm{sec}^{-1},$$

and in the middle part of the mesosphere

$$J_{\mathrm{mesosphere}}(H_2O) \cong 10^{-7}\ \mathrm{sec}^{-1}.$$

It is necessary to add to this the dissociation caused by Lyman-alpha radiation. This may also be another factor responsible for the exaggerated values J_{H_2O} obtained by Hesstvedt (ref. 4). In any case, the value of the dissociation coefficient which he used, $5 \cdot 10^{-6}\ \mathrm{sec}^{-1}$ (see above), corresponds to a dissociation cross section $1.4 \cdot 10^{-17}\ \mathrm{cm}^2$. In actuality, the dissociation cross section is almost five times less than this value (ref. 5) (see illustration).

Thus, computation of humidity at the level of the mesopause, where noctilucent clouds are formed, with allowance for the photodissociation of water molecules, requires further refinement. As the minimum values we can use the estimates made by Nicolet in reference 5, cited above, indicating that air

humidity β above 75 km decreases as a result of photodissociation by a factor of 2.5-3 for every 3 km and is a value of about $\beta \cong 5 \cdot 10^{-7}$ at the level of the mesopause.

3. We could explain the possibility of precipitation of moisture on condensation nuclei in the mesopause under these conditions either by assuming an extraordinarily intense cooling of the mesopause (in periods of appearance of noctilucent clouds) or by assuming the possibility of a sporadic increase of humidity β. The latter in turn could happen by two methods: either as a result of a sporadic uplifting of masses of moist air from the troposphere through the stratosphere into the mesosphere, or as a result of formation of additional quantities of water molecules directly in the high layers of the atmosphere (that is, as a result of a sharp increase of the level of equilibrium concentration of H_2O). We will now consider in greater detail the latter of these mechanisms, taking into account present-day data on the solar wind.

As we mentioned in reference 7, the formation of additional quantities of water molecules directly in the high layers of the atmosphere can be stimulated by solar corpuscular streams, which, as is well known, contain a considerable number of hydrogen atoms. The related increase of the concentration of atomic hydrogen above the equilibrium value could also be a cause of increase of the concentration of water molecules.

An interesting illustration of this idea was given in the computations of the accretion of hydrogen published in 1961 by de Turville in references 8 and 9. He postulated that the geomagnetic field, effective in trapping protons and electrons from the solar wind, has a dimeter $d_m = 24.6\ r_E$ (r_E is the earth's radius), and that in the course of the time $T = 3.3 \cdot 10^9$ years the accretion of

hydrogen occurred at the same rate as in our era. In this case the total /60
mass of hydrogen trapped by the geomagnetic field is

$$M = \pi r_m^2 n_1 m_H v_1 T, \tag{2}$$

where n_1 is the concentration of hydrogen atoms (protons) making up the plasma of the solar wind; V_1 is the velocity of this wind; m_H is the mass of a hydrogen atom. De Turville uses the values $n_1 = 12$ protons/cm^3 and $v = 4.33 \cdot 10^8$ cm/sec and with formula (2) obtains the mass $M = 1.70 \cdot 10^{23}$ g. The total oxidation of this hydrogen would give $M_1 = 1.53 \cdot 10^{24}$ g of water, which is close to the mass of water in the oceans of the earth $M_2 = 1.42 \cdot 10^{24}$ g. Therefore, the reserves of water in the oceans could be accumulated gradually by accretion of solar hydrogen in a quantity of approximately 1.5 tons/sec. This mechanism of accumulation of water on the earth by the influence of the solar wind has been cleverly called by Haurwitz "solar rain" (ref. 10).

Of course, such a close agreement of the masses M_1 and M_2 obviously is random, and computation of the mass of the "solar rain," forming from the mass of hydrogen trapped by the geomagnetic field, undoubtedly is considerably more complex than indicated in reference 8. More rigorous estimates of this kind can now be made, using as a point of departure the theory of the geomagnetic trap (refs. 11-13); this requires consideration of the interaction of the plasma stream and the earth's "electromagnetosphere" (refs. 12 and 13), taking into account the kinetics of chemical reactions leading to the formation of hydrogen compounds in the high layers of the atmosphere (ref. 3). Here we will limit ourselves to individual comments on such a more rigorous estimate of the intensity of the "solar rain."

4. Computations based on formula (2) for the hydrogen trapped by the geomagnetic field apparently give a highly exaggerated result, because the plasma stream of the solar wind is not intercepted by the geomagnetic trap, but flows around it. According to modern concepts, only individual parts of the magnetopause (boundary layer) "pass" the corpuscles of the solar wind into the depths of the earth's magnetosphere (ref. 11). Thus, the factor πr_m^2 in formula (2) should be replaced by another, decreased by a factor of N_1, where N_1 is scarcely greater than 0.1-0.01. In addition, the capture of plasma wind by the geomagnetic trap does not occur identically at all times. The majority of the charged particles possibly penetrate into the geomagnetic field at the time of auroras of intermediate and great intensity (ref. 12); therefore, factor T in formula (2) can be decreased by N_2 times, where N_2 is the period of time when more or less strong auroras are observed (refs. 13 and 14). As an estimate we can use $N_2 \leq 10^{-1}$. Thus, the refined value of the mass of trapped hydrogen M' can differ from M obtained using formula (2) by N times

$$M' = NM,$$

where $N = N_1 \cdot N_2$; N can be a small value of the order of 0.01 or 0.001. In this case M' = 15 kg/sec or 1.5 kg/sec. For a rough estimate we will assume that 10^4 g of hydrogen penetrates into the earth's upper atmosphere to the 100 km level each second, which gives a mean density of the hydrogen (proton) flux for the earth of about $2 \cdot 10^{-15}$ g/cm^2·sec, or approximately $1.2 \cdot 10^9$ hydrogen atoms/cm^2·sec. This exceeds by almost two orders of magnitude the rate of dissipation of terrestrial hydrogen, which according to the computations made by Kockarts and Nicolet in references 15 and 16, is a flux of $2.5 \cdot 10^7$ cm^{-2}·sec^{-1}.

Thus, in the Earth's upper atmosphere there could be an accumulation of hydrogen of solar origin. If this hydrogen accumulated continuously in the high layers of the atmosphere at heights such as from 100 to 200 km and if its concentration n cm^{-3} were distributed vertically in conformity to the formula $n = n_0 \cdot e^{-h/H}$, then (assuming for H the value of H = 25 km) after only a /61 year the concentration n_0 at the 100 km level would attain the values $n_0 = 1.6 \cdot 10^{10}$ cm^{-3}, and at the 200 km level, values $n_{200} = 4 \cdot 10^8$ cm^{-3}. These values considerably exceed (by three orders of magnitude) the actual concentrations. Therefore, if in actuality there is a trapping of the hydrogen of the solar wind approximately in those quantities mentioned, there should be a leakage of hydrogen from the earth's upper atmosphere at a rate of about 10^9 $cm^{-2} \cdot sec^{-1}$.

The dissipation of hydrogen from the exosphere occurs many times more slowly. However, there may be a leakage of hydrogen from the thermosphere into the mesosphere with subsequent localized formation of a "solar rain." However, it is necessary to take into account the complex character of those physical processes and aeronomic reactions in the high layers of the atmosphere which can lead to an increase in concentration of water molecules in the mesosphere as a result of the appearance of additional quantities of hydrogen of solar origin in the thermosphere. The present status of the theory of the corresponding processes does not make it possible to form a clear picture of such transformations, but we believe that a major role must be played here by dynamic processes (especially turbulent diffusion), which for the time being have not been adequately considered to formulate a quantitative theory. This problem will be considered in greater detail in the last part of this article.

5. Is it possible that there are still other mechanisms for the formation of H_2O molecules directly in the high layers of the atmosphere in addition to

the "solar rain" mechanism? Important reactions can occur with the participation of methane CH_4, as has been pointed out by Bates and Nicolet in references 5, 16 and 17. Methane is of biological origin and is introduced into the atmosphere at the level of the earth; its quantity in the lower layers of the atmosphere is quite constant, $1.5 \cdot 10^{-6}$ in volume. At the level of the tropopause methane can be oxidized rapidly; its lifetime is less than 100 years. Above the level of the stratopause the quantity of CH_4 molecules is about $3 \cdot 10^{16}$ cm^{-2}; its mean lifetime at a height of 50 km should be about 40 years, provided we use the coefficient of the rate of oxidation reactions

$$CH_4 + O \rightarrow CH_2 + H_2O + 30 \text{ kcal} \tag{3}$$

$$CH_4 + O \rightarrow CH_2O + H_2, \tag{4}$$

$$CH_4 + OH \rightarrow CH_3 + H_2O, \tag{5}$$

the total coefficient is equal to 10^{-6} sec^{-1}.

Oxidation at such a rate leads to the formation of about 10^{11} H_2O and H_2 molecules per 1 sec over 1 cm^2 (ref. 3). Computation of photochemical equilibrium leads to the following estimate: the H_2O content in the mesosphere should be $\beta \cong 3 \cdot 10^{-6}$, if we neglect the photodissociation of water molecules (that is, the value $\beta \cong 3 \cdot 10^{-6}$ applies to the lower mesosphere, below the level of appreciable H_2O photodissociation). As already mentioned, Kockarts and Nicolet (ref. 15) computed that the flux of atomic hydrogen into the exosphere through the 100 km level (with subsequent dissipation) is $2.5 \cdot 10^7$ $cm^{-2} \cdot sec^{-1}$. If it is assumed that all this hydrogen is formed by reaction (1) of phtodissociation of water molecules (but we have seen above that the source of hydrogen in the 100 km layer may be the "solar rain," see section 4), to maintain this flux it is necessary to expend about 10^7 molecules of $H_2O/cm^2 \cdot sec$ or about 10^7

molecules of $CH_4/cm^2 \cdot sec$, provided it is assumed that the reserves of water molecules are replenished at the expense of methane in reactions (3) and (5). The rate of formation of new quantities of methane is quite great--not less than 10^{10} mole/$cm^2 \cdot sec$ (ref. 16); the only problem involved is that there must be sufficiently strong transfer (mixing) of tropospheric air through the stratosphere into the mesosphere.

It is necessary to bear in mind the complex character of the reaction with the participation of oxygen and hydrogen and their compounds in the mesosphere, where many secondary reactions occur. Among the principal final reactions /62 we may mention the following (ref 16)

$$OH + OH \rightarrow H_2O + O + 17 \text{ kcal}, \tag{6}$$

the coefficient of the rate of this reaction is

$$a_{16} = 5 \cdot 10^{-12} T^{1/2} \exp(-1000/T) \text{ см}^3 \cdot \text{sec}^{-1}; \tag{6a}$$

$$OH + HO_2 \rightarrow H_2O + O_2 + 72 \text{ kcal}, \tag{7}$$

this reaction is characterized by a high rate:

$$a_{17} = 1{,}5 \cdot 10^{-12} T^{1/2} \text{ cm}^3 \cdot \text{sec}^{-1}; \tag{7a}$$

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2 + 42 \text{ kcal}, \tag{8}$$

$$a_{27} = 5 \cdot 10^{-12} T^{1/2} \exp(-1000/T) \text{ cm}^3 \cdot \text{sec}^{-1}; \tag{8a}$$

$$H + H + M \rightarrow H_2 + M + 103.2 \text{ kcal}, \tag{9}$$

$$a_{21} = 3 \cdot 10^{-32} \text{ cm}^6 \cdot \text{sec}^{-1}; \tag{9a}$$

$$H + OH \rightarrow H_2 + O + 1.9 \text{ kcal}, \tag{10}$$

$$a_{22} = 2 \cdot 10^{-13} T^{1/2} \exp(-3400/T) \text{ cm}^3 \cdot \text{sec}^{-1}. \tag{10a}$$

All these reactions were exothermal. The endothermal reactions should also be mentioned

$$H_2 + O \rightarrow OH + H - 1.9 \text{ kcal}, \tag{11}$$

$$a_{24} = 5 \cdot 10^{-13} T^{1/2} \exp(-4400/T) \text{ cm}^3 \cdot \text{sec}^{-1}. \tag{11a}$$

The reaction

$$H + HO_2 \rightarrow H_2 + O_2 + 57 \text{ kcal},$$
$$a_{23} = 5 \cdot 10^{-12} T^{1/2} \exp(-1000/T) \text{ cm}^3 \cdot \text{sec}^{-1} \tag{12}$$

plays the main role in the formation of molecular hydrogen.

Reactions (6)-(12) transpire during both daytime and nighttime; in addition, the field of solar radiation exerts its effect, and it is necessary to take into account the photodissociation of H_2O molecules (coefficient of photodissociation J_{H_2O}) and molecules of H_2O_2 (coefficient of photodissociation $J_{H_2O_2}$). In this case the equation of photochemical equilibrium in the mesosphere can be written in the form (ref. 16)

$$\begin{aligned} n(H_2O) J_{H_2O} + n(H_2O_2) J_{H_2O_2} + a_{24} n(O) n(H_2) = a_{16} n^2(OH) + \\ + a_{17} n(OH) n(HO_2) + a_{27} n^2(HO_2) + a_{21} n(M) n^2(H) + \\ + a_{22} n(H) n(OH) + a_{23} n(H) n(HO_2). \end{aligned} \tag{13}$$

Processes (6)-(12) do not take into account all of the reactions in which atomic hydrogen participates. We will write four additional reactions

$$H + O_2 + M \rightarrow HO_2 + M + 46 \text{ kcal}, \tag{14}$$
$$a_1 = 3{,}3 \cdot 10^{-33} \exp(800/T) \text{ cm}^6 \cdot \text{sec}^{-1}; \tag{14a}$$

this reaction having a negative temperature coefficient. The reaction

$$H + O_3 \rightarrow OH + O_2 + 77 \text{ kcal} \tag{15}$$

differs by the large coefficient a_2

$$a_2 = 1.5 \cdot 10^{-12} T^{1/2} \text{ cm}^3 \cdot \text{sec}^{-1}; \tag{15a}$$
$$OH + O \rightarrow H + O_2 + 16.6 \text{ kcal}, \tag{16}$$
$$a_3 = 3 \cdot 10^{-12} T^{1/2} \text{ cm}^3 \cdot \text{sec}^{-1}; \tag{16a}$$
$$HO_2 + O \rightarrow OH + O_2 + 55 \text{ kcal}, \tag{17}$$
$$a_7 = 1.5 \cdot 10^{-12} T^{1/2} \text{ cm}^3 \cdot \text{sec}^{-1}. \tag{17a}$$

Among the reactions leading to the formation of water molecules we also must mention /63

$$H + H_2O_2 \rightarrow OH + H_2O + 69 \text{ kcal}, \quad (18)$$

$$a_{29} = 5 \cdot 10^{-13} T^{1/2} \exp(-3000/T) \text{ cm}^3 \cdot \text{sec}^{-1}; \quad (18a)$$

$$OH + H_2O_2 \rightarrow HO_2 + H_2O + 30 \text{ kcal}, \quad (19)$$

$$a_{30} = 1{,}5 \cdot 10^{-12} T^{1/2} \text{ см}^3 \cdot \text{sec}^{-1}; \quad (19a)$$

$$O + H_2O_2 \rightarrow O_2 + H_2O + 75 \text{ kcal}, \quad (20)$$

$$a_{31} = 1{,}5 \cdot 10^{-13} T^{1/2} \exp(-2000/T) \text{ cm}^3 \cdot \text{sec}^{-1}; \quad (20a)$$

$$OH + H_2 \rightarrow H_2O + H + 15 \text{ kcal}, \quad (21)$$

$$a_{19} = 5 \cdot 10^{-13} T^{1/2} \exp(-3000/T) \text{ cm}^3 \cdot \text{sec}^{-1} \quad (21a)$$

Taking into account all of these reactions, it is possible to compute the concentration $n(H_2O)$ of water molecules in the mesosphere, corresponding to the conditions of chemical and photochemical equilibrium. Computations in reference 3 give for h = 70 km $n(H_2O) \cong 10^{10}$ cm^{-3}; for h = 80 km the computations give $n(H_2O) = 5 \cdot 10^8$ cm^{-3} and for h = 90 km, $n(H_2O) = 2 \cdot 10^6$ cm^3. However, such computations do not take dynamic processes into account. The descending and ascending air currents, turbulent diffusion, will change the vertical distribution of the different components, if it was determined (as occurs in the mesosphere and lower thermosphere for hydrogen, atmospheric oxygen and their compounds) by phtochemical equilibrium and differed from the distribution corresponding to constancy of composition. Under certain conditions dynamic processes may be the cause of considerable increases of air humidity in the mesosphere and mesopause. We will consider several examples.

(a) According to Nicolet's computations in references 3 and 6, the concentration of molecular hydrogen $n(H_2)$ under conditions of photochemical equilibrium has a sharply expressed maximum $n(H_2) = 10^{10}$ cm^{-3} at a height of about 67 km; above this level the H_2 molecules are subjected to photodissociation, the rate of which increases rapidly with height. According to reaction (9), the

reduction of molecular hydrogen can occur as a result of triple collisions with the participation of two hydrogen atoms. At heights of 100-110 km, which can be reached by the penetrating protons of the solar wind, the probability of triple collisions is small (ref. 18). In the presence of descending air currents or intense turbulent mixing additional quantities of hydrogen atoms of solar origin could be transported from the 100-110 km level into the mesosphere, where the rate of reaction (9) increases many times. The increase of the $n(H_2)$ concentration in conformity with reaction (21), associated with this, could lead to an increase of the concentration of water molecules.

This is one of the possible mechanisms of formation of the "solar rain," almost ceasing its activity in the absence of dynamic processes.

(b) Now we will consider the reaction

$$H_2 + O + M \rightarrow H_2O + M. \tag{22}$$

For such reactions to occur it is necessary that the H_2 molecules, the maximum concentration of which is situated (under equilibrium conditions) below the 70 km level, encounter oxygen atoms whose concentration (under equilibrium conditions) has a maximum below the mesopause. The transporting of H_2 molecules by ascending air currents from the mesosphere into the thermosphere accelerates reactions (22) only by a relatively small number of times, because the probability of triple collisions in the thermosphere is relatively small. Descending currents which would transport atomic oxygen from the 90-100 km level to the 65-70 km level could lead to a great acceleration of the reactions. However, below 75-80 km the recombination of atomic oxygen leads to a considerable /64 reduction of the n(O) concentrations. The maximum acceleration of reactions (22) therefore would be attained, if the "place of the encounter" of hydrogen

molecules and oxygen atoms was an intermediate level of about 80 km. This result may come either from a combination of a descending current (from the height 90-100 km to the 80 km level) and an ascending current (from the level 65-70 km to a height of 80 km) or turbulent diffusion.

How does the vertical distribution of different components, initially determined under conditions of photochemical equilibrium, change under the influence of dynamic factors? In a general case this can be computed by the continuity equation, taking into account the presence of sources (formation and destruction of atomic oxygen, molecular hydrogen, water molecules and others as a result of photodissociation, recombination, etc.)

$$\frac{\partial n}{\partial t} + \frac{\partial (nw)}{\partial h} = \alpha (n_0 - n) + \frac{\partial}{\partial h}\left(D \frac{\partial n}{\partial h}\right); \tag{23}$$

here n_0 is the equilibrium (in the sense of photochemical equilibrium) concentration of the particular component; w is the vertical velocity of the air current; D is the coefficient of turbulent diffusion; $\alpha = 1/\tau$, there τ is the time of half-restoration of photochemical equilibrium.

Preliminary estimates, based on equations of type (23), show that dynamic processes can considerably change the vertical distribution of atomic oxygen and exert a great influence on the rate of reaction (22) and on the vertical redistribution of water molecules.

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