

POLAR AEROSOL HAZE IN JUPITER'S STRATOSPHERE. O. S. Shalygina, L. V. Starukhina, G. P. Marchenko, V. V. Korokhin. Astronomical Institute of Kharkov University, Sumskaya Ul., 35, Kharkov, 61022, Ukraine. E-mail: dslpp@astron.kharkov.ua

Intorduction: In our previous works [1,2], on the basis of Jupiter photopolarimetric observations during 1981-2004, seasonal variations of north-south asymmetry of linear polarization P in polar regions and anticorrelation between P asymmetry and insolation were found. Qualitative mechanism of seasonal variations of P asymmetry (through temperature variations) has been proposed [2]. We suppose that the main cause of these effects is change of aerosol concentration in the haze observed at top levels of Jupiter stratosphere at high latitudes [1-4]. Aerosols may be unstable, and temperature changes may influence upon generation and destruction of aerosol particles. According to [5-7], the observed aerosol haze is located on $p \sim 0.1$ -1 mbar pressure level and consists of benzene and polycyclic aromatic hydrocarbons (PAH) like naphthalene, phenanthrene, pyrene. In [6,7] the coupled chemical-aerosol microphysical model of benzene and PAH formation in Jupiter atmosphere was proposed.

Tempreture effect on aerosol haze formation: Average temperature in polar regions of jovian stratosphere is about 150 K [8]. This temperature is lower than triple points of naphthalene and benzene (359 K and 278 K, respectively [9]), so they may produce crystal nucleus from gaseous phase. Let's consider homogeneous particle nucleation. Such process proceeds without additional condensation centers. Equilibrium condition for nuclei of a crystal with radius r and surrounding gas is defined as follows [10]:

$$r = r_c = \frac{2\alpha\Omega}{\Delta\mu(T, \xi)}, \quad (1)$$

where r_c – critical radius (nuclei with smaller radius evaporates, and bigger ones grows); Ω is specific volume of molecule in crystal; $\Delta\mu = kT\xi$ is chemical potential; $\xi = \ln[p(T)/p_0(T)]$ is supersaturation, $p(T)$ is vapor pressure in atmosphere; $p_0(T)$ is saturated vapor pressure; α is surface tension coefficient; for particles in solid phase α is close to the value in liquid phase near melting temperature.

Equilibrium (1) is unstable. For formation of a nucleus with radius r , the system should overcome potential barrier ΔG :

$$\Delta G(\xi, r) = -\frac{4}{3}\pi r^3 \frac{\Delta\mu(T, \xi)}{\Omega} + 4\alpha\pi r^2, \quad (2)$$

where G is Gibbs potential. Homogeneous nucleation takes place when radius of critical nucleus is close to molecular sizes; at the same time, supersaturation ξ is about or larger than 1. For example, for naphthalene ($\alpha=30$ erg/cm² [9]) at $T=150$ K and $\xi=10$ critical radius $r_c=6$ Å, i. e., in jovian stratosphere homogeneous nucleation can occur.

To study the effect of temperature changes on PAH formation we have used altitude concentration profiles from [7]. Temperature values for calculations (Fig. 1) were selected from the following consideration: average temperature at the pressure level 0.1 mbar (where aerosol haze is probably located) is 150 K [8], and its season changes in north and south Jupiter polar regions amount to ± 30 K [11].

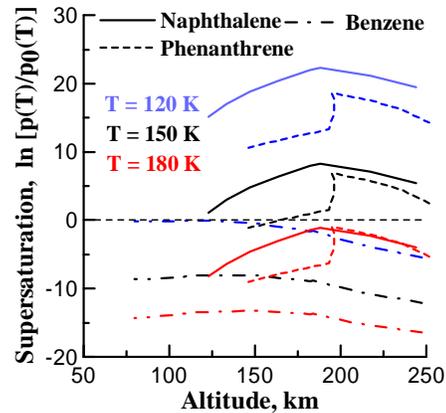


Fig. 1. Altitude distributions of PAH supersaturation in Jupiter atmosphere for different temperatures

So, our estimates show (Fig.1) that temperature changes have strong effect on processes of homogeneous nucleation in Jupiter stratosphere: benzene never condenses (negative supersaturation means vapour undersaturation), whereas probability of homogeneous nucleation of naphthalene and phenanthrene at $T=120$ K and $T=150$ K is considerable. No of the studied PAHs condenses at $T=180$ K.

Irregular factors that affect the observed polarization values: In addition to the above considered variations of temperature, solar activity can also affect physical and chemical processes in jovian stratosphere. Earlier (Fig. 3 in [2]) we studied the relation between parameters of solar activity and polarization of polar regions using observational data of 1989-2003. As a result, possibility the influence of high energy protons

(solar cosmic rays) on polarization values for years 1998, 2000 and 2001 has been found [2]. This has been confirmed by our calculations with TRIM program (Transport Ions in Matter) [12]: sufficiently great amount of energetic particles penetrates deep into the stratosphere (Fig. 2).

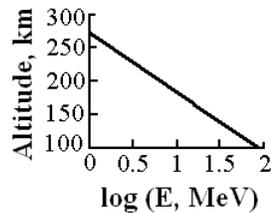


Fig. 2. Depth of energetic proton penetration in jovian atmosphere vs. their energy. Altitude scale is taken from [13]

Mechanism of the effect of solar cosmic rays on aerosol haze: First, high-energy protons may increase concentration of ions that participate in chemical reactions, which can enhance synthesis of source material (PAH molecules) for aerosol formation. Second, the ions may serve as additional condensation centers of aerosols. At last, chemical reactions stimulated by additional ionization of the atmosphere occur with heat release or absorption, which may result in temperature change at high altitudes (similar effect is well known for the Earth stratosphere [14]). This can change aerosol concentrations and, consequently, polarization values at both poles. Because of nonlinear dependence of vaporization-condensation processes upon temperature, the stratosphere aerosol concentration is different in both polar regions, which may produce polarization asymmetry. Only second mechanism (nucleation in gas containing ions) can be described quantitatively. Gibbs potential in this case is:

$$\Delta G(\xi, q, r) = -\frac{4}{3}\pi r^3 \frac{\Delta\mu(T, \xi)}{\Omega} + 4\alpha\pi r^2 - \frac{q^2}{2} \frac{\varepsilon - 1}{\varepsilon} \left(\frac{1}{r^*} - \frac{1}{r} \right), \quad (3)$$

where r is the radius of charged sphere, r^* is the ion radius; q is ion charge, and ε is dielectric permeability of nucleus. The new term on the right in (3) describes screening of a charge q by growing particle. Assuming $\varepsilon = 2.3$, $r^* = 2$ Å the plots in Fig. 3 were obtained. As shown in Fig. 3a, additional domain of stability (local minimum of function $\Delta G(\xi, q, r)$) does not appear in the range of our interests (particles sizes ~ 1 μm) even for unreally great charges (Fig. 3a, lines 2, 3). At real values of charges (1-2 charge of electron), stability appears only very close to molecular sizes (Fig. 3b, line 3), i.e., only charged molecular clusters (not particles) can be stable (not evaporating and not growing). Thus, mechanism of aerosol particles formation on charges is not effective.

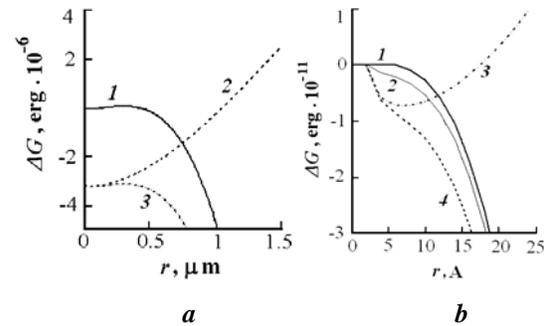


Fig. 3. Thermodynamic potential $\Delta G(\xi, q, r)$ changing of system which content nucleus with radius r was formed on ion with charge q (q in charges of electron): **a:** small supersaturation, big charges, $r \sim 1$ μm , $\Delta G(0.01, 0, r)$ (1), $\Delta G(0.001, 10^3, r)$ (2), $\Delta G(0.01, 10^3, r)$ (3), **b:** high supersaturation, real charges, r near molecular sizes, $\Delta G(8, 0, r)$ (1), $\Delta G(8, 1, r)$ (2), $\Delta G(0.01, 2, r)$ (3), $\Delta G(8, 2, r)$ (4)

Conclusions:

(1) Jovian stratospheric haze which consists of PAH (naphthalene, phenanthrene) particles may be formed by homogeneous nucleation.

(2) Temperature variations in jovian stratosphere have strong influence on PAH condensation; benzene does not condensate at temperatures > 120 K.

(3) Flux of solar cosmic rays may influence upon concentration of aerosol haze particles only through series of chemical reactions that produce source material for aerosol formation.

More details of this work can be found on our site (<http://www.astron.kharkov.ua/dslpp/jup/>).

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