RAREFACTION WAVES IN METEOR TRACES. B. E. Zhilyaev[1], A. F. Steklov[1], A. P. Vidmachenko[1] and I. A. Verliuk[1], [1]Main Astronomical Observatory of National Academy of Sciences of Ukraine, Ak. Zabolotnogo Str., 27, Kyiv, 03143, Ukraine, stec36@i.ua, vida@mao.kiev.ua.

Consider the motion of a meteoroid in the framework of the dynamics of a compressible gas. The simplest example of such a movement is the movement of gas in a cylindrical tube in which the piston moves at a constant speed. It was shown in [3] that such a motion is self-similar, adiabatic, and isentropic. It is also shown that the gas movement behind the piston is accompanied by an unsteady rarefaction wave. The rarefaction wave propagates along the axis of movement of the piston only to a finite distance.

According to the proposed model, the gas in the meteor traces consists of these three areas:

(1) a gas moving with a meteor at a constant speed;

(2) a rarefaction region in which the velocity gradually decreases to zero;

(3) stationary gas area.

In an adiabatic process, according to [3], the expressions for density, pressure, and temperature in the rarefaction region have the following form:

$$\rho = \rho_0 (1 - \frac{\gamma - 1}{2} \frac{v}{c_0})^{\frac{2}{\gamma - 1}},$$

$$p = p_0 (1 - \frac{\gamma - 1}{2} \frac{v}{c_0})^{\frac{2\gamma}{\gamma - 1}},$$

$$T = T_0 (1 - \frac{\gamma - 1}{2} \frac{v}{c_0})^2,$$

where v is the speed of the meteor, c_0 is the speed of sound, γ is the adiabatic index (γ = 1.4 for water vapor).

Characteristics in a stationary gas region are indicated by a zero index. We note, in particular, that when a meteor moves with the speed of sound, in the rarefaction region, the pressure can drop by 5 times, the density by three times, and the temperature will decrease by a third. For the so-called self-similar motion, the velocity dependence v on the x coordinate and time t has the form [3]:

$$v = \frac{2}{\gamma + 1} (c_0 - \frac{x}{t}).$$

Particles formed during the combustion of a meteorite serve as condensation centers for water vapor. If the vapor is saturated, then, as will be shown below, condensation occurs almost instantly. If the steam is not saturated, then under normal conditions condensation will not occur at all. However, in the rarefaction wave, during a short time, conditions can be created for condensation of the vapor and then an inversion trace will appear [1].

After attenuation of the rarefaction wave, the conditions for condensation return to their original state.

Thus, even if the water vapor in the atmosphere is not saturated, an inversion trace may appear on the trajectory of the meteoroid in the rarefaction wave for a short time [2].

In Fig. 1 shows a state diagram of water vapor in the coordinates "temperature – pressure". The solid curve shows the pressure for saturated steam; and the dashed line indicates the change in vapor pressure in the rarefaction wave. By the square marks the characteristics for stationary conditions of gas: temperature 283 K (+10 °C), pressure 5.53 mm Hg, relative humidity 60%. With these parameters, condensation of water vapor does not occur.

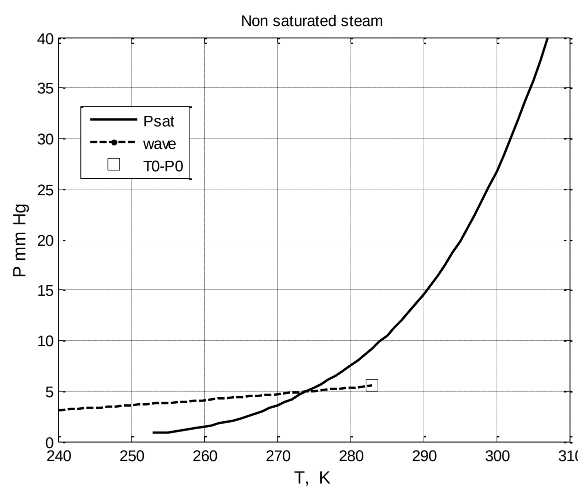

Fig. 1. The state diagram of water vapor in the coordinates of the “temperature-pressure”.

Calculations show that in the rarefaction wave the temperature and pressure decrease to values of T = 181 K (-92 °C), P = 1.16 mm Hg. Under such conditions, the steam is very saturated, and this leads to its condensation. However, this is a highly unsteady process. The point of this state on the adiabatic line will shift towards an increase in temperature and pressure. And then – the conditions will be return to their original state when the steam becomes unsaturated again, and the inversion trace disappears.

The above estimates allow us to make such an important conclusion. Almost all space intrusions (be they meteors, or fragments of space debris) are accompanied in the troposphere by the appearance of an inversion trace [4]. In the case of saturated steam, the trace will remain for a long time. In the case of not saturated steam, we will witness only the short-term appearance of an inversion trace.

Let us estimate the time of formation and disappearance of the inversion trace. The droplet growth rate in water vapor is represented by the following expression [5]:

$$\frac{dr}{dt} = \frac{m}{\rho}\left(n\sqrt{\frac{8kT}{\pi m}} - \frac{p_{sat}}{kT_d}\sqrt{\frac{8kT_d}{\pi m}} \right),$$

where r is the radius of the droplet, ρ is the density of the droplet, T is the temperature of the gas and Td is the temperature of the droplet, m is the mass of the water molecule, p_{sat} is the pressure of saturated vapor, k is the Boltzman constant; $n_c = \frac{p_{sat}}{kT_d}$ is the concentration of saturated vapor.

From this equation it follows that if T — the gas temperature and Td — the droplet temperature — coincide, then for n> nc, when the vapor density exceeds the density of the saturated vapor, the process of droplet growth in water vapor begins. For the drop growth time, we obtain the following estimate:

$$\Delta t \approx 9.7 \cdot 10^{18} \cdot \frac{r}{n\sqrt{T}}.$$

Assuming the droplet size to be 5 μm, n is the concentration of saturated vapor at T = 280 K, we obtain an estimate for the growth time of such a drop Δt = 0.001 sec.

Thus, the inversion trace is formed almost instantly: a few thousandths of a second. And the lifetime of inversion trace strongly depends on the specific physical conditions in the atmosphere at the place of the passage of the meteoroid.

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