THE EXPLOSION IN THE ATMOSPHERE OF MARS CAUSED BY A
SPEED IMPACT OF COSMIC BODIES.
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The cosmic bodies entering the atmosphere of the planet are being
decelerated and ablated during their flight. These processes can be
neglected [1,2] for large bodies having the diameters \(d > (\rho_0 / \rho_a) \text{H}\), where
\(\rho_a\) is the density of the atmosphere near the surface of the planet, \(\rho_0\) is
the density of the body and \(\text{H}\) is the scale height of the atmosphere.

The density of the atmosphere of Mars is much lower than on the Earth
and on Venus. So the diameter \(d\) of the body for which the deceleration and
the ablation are not important is also lower. Estimates of this diameter for
stone and icy bodies entering the atmosphere of Mars are 3 and 10 cm.

The aerodynamic forces can smash the cosmic body during its flight at
very high speed through the atmosphere. But for the atmosphere of Mars these
stresses are also much lower than on the surface of the body moving at the
same velocity through the atmosphere of the Earth and Venus. For instance
the maximum pressure at the blunt nose of the body is only 100 bar when the
velocity is 30 km/s. Even this pressure can lead to the fragmentation of the
body. The broken fragments may not be scattered if \(3d > 2H(\rho_0 / \rho_a)^{1/3}\). The
critical diameter \(d_c\) is also much lower for Mars (40 m for the stone body).

The hypervelocity impact of the body at the surface of the planet
leads to the generation and following expansion of hot, melt and vapor plume
and the shock wave is generated in the atmosphere [3]. The kinetic energy of
the body is transformed into the kinetic and thermal energy of the
explosion. When the pressure behind the shock falls to the atmospheric
pressure the fireball reaches its maximum diameter \(d_m = d_0 M_a (1 - (1/3)^{1/3})\),
where \(M_a = V/C_a\) is Mach number, \(V\) is the velocity of the body and \(C_a\) is the
sound speed. The diameter of the fireball at the surface of Mars is higher
than at the surface of the Earth and Venus for the same velocity and the
diameter of the body. For \(M_a = 100, V = 1.2\) and \(d_0 = 20 m\) we get the \(d_m = 7\) km. So
the diameter of the fireball is of the same order of magnitude as the scale
height of the atmosphere and the fireball does not spherically symmetric.

Another reason that the two dimensional effects must be taken into
account is that the explosive wave interacts with bow shock wave which has
been generated during the flight and the wake behind the body [4]. The
density in the wake is lower than the density of ambient gas. Vapor of the
body and of the surface layers of the planet mixed with the air escape
through this "empty" channel. The diameter of this channel for \(z < H\) can be
estimated using the theory of cylindrical explosion which gives the equation
\(d_c = (d_0 z)^{1/4}\), where \(z\) is the height above the surface. For \(d_0 = 20 m\) and \(H = 10\) km
we get \(d_c = 0.7\) km, and so we have \(d_c << d_m\).

The specific feature of the explosion at the surface of Mars is the
very intensive radiative heat transfer. The thermal radiation flux of the
black body \(\delta T_s^4\), where \(\delta\) is the Stefan-Boltzman constant and \(T_s\) is the
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temperature of the shock wave having the speed \( D \), is higher than the hydrodynamics flux of the energy \( \frac{1}{2} D^2 \) for \( T_s\geq 3eV \) or \( D>15 \) km/s. So the critical temperature and critical velocity of the shock wave [5] in the atmosphere of Mars is much lower than at the Earth surface. The estimate of the thermal radiation impulse emitted from heated volume is 60-70% of the explosion energy. This radiation impulse is much higher than in the case of the Earth or the Moon. The thermal radiation transfer must be taken into account even during the flight of the body, because it drastically changes the amplitude of the bow shock and a density in the wake.

The absorption of the emitted radiation on the surface of the planet rises the temperature of the surface and leads to the generation of the thin thermal layer in the atmosphere near the surface and the wedge like precursor before the main shock wave.

The computer simulation has been completed to describe the radiation heat transfer, the dynamics of the explosion wave, its interaction with the bow shock wave, the wake and with the thermal layer. A numerical solution of the two dimension gas dynamics equations combined with the equation of radiative transfer was obtained.

In the case of \( V=50 \) km/s, \( d=10 \) m the explosion wave is nearly spherical during first 10 seconds. The maximum diameter of the fireball is about 5 km. As the density in the wake is 10 times lower than that of the ambient gas, the shock wave along the wake propagates much quicker and generates the stream out of the surface. A small part of the cosmic body material and some mass of the atmosphere gas escape the planet through this "hole". The cloud involving the large part of the meteor material rises above 10 km at the moment 120s.

For \( d=1 \) km the explosion generates the powerful upward stream having the velocity greater than escape velocity (5 km/s for Mars). Such explosions may be significant for the evolution of the atmosphere [6].

The optical depths of the fireball are larger than unity for several seconds while the brightness temperatures are 0.5-3.0 eV, so most of the radiation is emitted in the visible near ultraviolet or infrared. These explosions can be detected by the optical and electronic equipment of the special Martian artificial satellites or even from the Earth. The energy of the thermal impulse, its duration spectrum, the frequency and location of the impact, and dimensions of the fireball, the cloud and of the fresh crater can be registered. The results of the above mentioned computer simulations can help to determine the parameters of the cosmic bodies striking the surface of the planet.