

EXCHANGE OF METEORITES BETWEEN THE TERRESTRIAL PLANETS

S. I. Ipatov, V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry of RAS, Moscow, Russia
(siipatov@hotmail.com)

The model and initial data used for calculations: In each calculation variant, the motion of 250 bodies ejected from the Earth was studied for the fixed values of an ejection angle i_{ej} , a velocity v_{ej} of ejection, and a time step t_s of integration. In different variants, the values of i_{ej} equaled to 15°, 30°, 45°, 60°, 89° or 90°, and v_{ej} equaled mainly to 11.22, 11.5, 12, 12.7, 14, 16.4, or 20 km/s. In most calculations, bodies started directly from the Earth. In each variant, bodies started from one of six considered opposite points (Ipatov, 2024). The motion of bodies was studied during the dynamical lifetime T_{end} of all bodies, which equaled to a few hundreds of Myr. Similar calculations were made for migration of bodies ejected from Mars, Mercury and Moon, but for smaller minimum values of v_{ej} close to the parabolic velocity.

Probabilities of collisions of bodies ejected from the Earth with the Earth and the Moon: The probabilities p_E of collisions of bodies ejected from the Earth with the Earth were approximately the same for calculations with different considered integration steps t_s . The fraction p_E is greater for a smaller ejection velocity. At $v_{ej} \leq 11.25$ km/s, i.e., at v_{ej} slightly greater than the parabolic velocity, most of the ejected bodies fell back onto the Earth. At $v_{ej} = 11.5$ km/s, the values of p_E were about 0.2-0.3 and did not differ much for different starting points on the Earth's surface. At $v_{ej} = 12$ km/s, p_E was about 0.16-0.27, and mean velocities of collisions with the Earth and the Moon were about 14-20 and 10-16 km/s, respectively. The ratio of the probability of collisions of bodies with the Earth to the probabilities of collisions of bodies with other planets and the Sun usually decreased with time. The probability of collisions of such bodies with the Moon in its present orbit was of the order of 0.01 (Ipatov, 2024). A large Moon embryo should be formed close to the Earth in order to accumulate material not rich in iron. For more efficient growth of the Moon embryo, it is desirable that after some collisions of impactor bodies with the Earth, the ejected bodies did not simply fly out of the crater, but some of the matter went into orbits around the Earth, as in the multi-impact model. At $11.5 \leq v_{ej} \leq 12$ km/s, the probabilities p_v of collisions of the bodies with Venus were often about 0.13-0.22 and 0.23-0.37 for $T = 10$ Myr and $T = T_{end}$, respectively. On average the values of p_v were about p_E at $v_{ej} = 11.5$ km/s, were greater than p_E at $v_{ej} \geq 12$ km/s and were less than p_E at $v_{ej} \leq 11.4$ km/s. The total number of ejected bodies delivered to the Earth and Venus probably did not differ much. Probabilities of collisions of bodies with Mercury were mainly less than 0.05 and 0.1 at $T = 10$ Myr and $T = T_{end}$, respectively. The probabilities of collisions of bodies with Mars were smaller than those with Mercury and did not exceed 0.012 and 0.025 at $T = 10$ Myr and $T = T_{end}$, respectively. More material ejected from the Earth was delivered to Mercury than to Mars. The probabilities of collisions of bodies with Jupiter were of the order of 0.001. The fraction of bodies collided with the Sun often was between 0.2 and 0.5 at $11.3 \leq v_{ej} \leq 14$ km/s. The fraction of bodies ejected into hyperbolic orbits was mainly greater for a greater ejection velocity. During a whole considered time interval it did not exceed 0.1 at $v_{ej} \leq 12$ km/s. At $v_{ej} \geq 16$ km/s and $i_{ej} \geq 60$ degrees, all bodies were ejected from the Solar System if they started from the front (in the direction of the motion) point of the Earth.

Probabilities of collisions of bodies ejected from the Moon with the Earth: For the ejection of bodies from the present orbit of the Moon (at a distance from the Earth equal to $r_{ME} = 60r_E$, where r_E is the radius of the Earth), $T = T_{end}$ and $15^\circ \leq i_{ej} \leq 89^\circ$, the value of p_E was about 0.27-0.35 at $v_{ej} = 2.5$ km/s, 0.2-0.25 at $v_{ej} = 5$ km/s, and 0.1-0.14 at $12 \leq v_{ej} \leq 16.4$ km/s. At $v_{ej} = 2.5$ km/s and $r_{ME} = 3r_E$ the dynamical lifetime of the ejected bodies was less than 5 days. At $r_{ME} = 5r_E$ and $v_{ej} = 2.5$ km/s, most of the ejected bodies quickly fell onto the Earth, but at $i_{ej} \leq 30^\circ$ some of the bodies left the Hill sphere of the Earth. At $v_{ej} = 5$ km/s (approximately the parabolic velocity of the Earth at $r_{ME} = 5r_E$), $T = T_{end}$ and $r_{ME} = 5r_E$, the value of p_E was about 0.3 (0.26-0.37) for the considered ejection angles i_{ej} from 15° to 89°.

For bodies ejected from Mars, probabilities of their collisions with the Earth and Venus were about 0.1-0.2 (each) at $5.1 \leq v_{ej} \leq 6$ km/s. Often at $v_{ej} \geq 5.2$ km/s, the probabilities were a little greater for Venus than for Earth. The probability of a collision of a body with Mars did not exceed 0.04 at $v_{ej} \geq 5.3$ km/s. It was considerable only at v_{ej} close to the parabolic velocity. The probability of ejection of a body into a hyperbolic orbit was less than 0.1 at $v_{ej} \leq 6$ km/s. Usually at $5.1 \leq v_{ej} \leq 8$ km/s more than 50% of bodies collided with the Sun. The fraction of bodies collided with Mercury was typically less than 0.06, and it was greater than that collided with Mars at $v_{ej} \geq 6$ km/s.

For bodies ejected from Mercury, most of ejected bodies collided with Mercury. Probabilities of their collisions with Venus typically were about 0.2-0.3 at $6 \leq v_{ej} \leq 10$ km/s. Probabilities of collisions of bodies with the Earth typically did not exceed 0.02 and 0.1 at $v_{ej} \leq 8$ km/s and $v_{ej} \leq 15$ km/s, respectively. The fraction of bodies collided with Venus was greater than that with the Earth typically by an order of magnitude. The difference was greater for smaller ejection velocities. The fraction of bodies ejected into hyperbolic orbits did not exceed 0.01 for most of calculation variants.

Acknowledgements: The studies were carried out under government-financed research project for the Vernadsky Institute. **References:** Ipatov S.I. (2024) *Solar System Research* 58:94-111. DOI: 10.1134/S0038094624010040.