PROBABILITIES OF COLLISIONS OF BODIES FROM THE FEEDING ZONE OF THE TERRESTRIAL PLANETS WITH THE PLANETS, THE MOON, AND THEIR EMBRYOS. S. I. Ipatov, Vernadsky Institute of Geochemistry and Analytical Chemistry, Kosygina st., 19, Moscow 119991, Russia, siipatov@hotmail.com.

Introduction: Ipatov [1, 2] made computer simulations of the evolution of disks of gravitating bodies, united at collisions. The mutual gravitational influence of bodies was taken into account by the method of spheres of action (i.e., the mutual gravitational influence of bodies was simulated only inside their spheres of action, and outside the spheres the bodies moved around the Sun in unperturbed orbits). The initial disk of initially identical bodies, corresponding to the feeding zone of the terrestrial planets, was divided into four zones depending on the distances of the bodies from the Sun. It was obtained that the bodies, originally located at different distances from the Sun, became part of the Earth and Venus in close proportions.

The model of calculations: Below in the series *MeN* of runs, the migration of bodies, originally located in a relatively narrow ring, is studied under the gravitational influence of all planets (from Mercury to Neptune). In the series $Me_{01}S$ of calculations, I considered the embryos of the terrestrial planets with masses equal to 0.1 of the present masses moving in present orbits of the planets, and also Jupiter and Saturn with their present masses and their present orbits (Uranus and Neptune were excluded). The symplectic integrator from the Swift integration package [3] was used. In this integration, the collisions of bodies with planets were not simulated, but the bodies were excluded from integration when they collided with the Sun or their distances from the Sun exceeded 2000 AU. The orbital elements of the migrated bodies were recorded in the computer memory with steps of 500 years. Based on these arrays, similar to the calculations presented in [4-5], for the considered time interval *T,* I calculated the probabilities of collisions of bodies with planets and the Moon and with their embryos.

In each variant of calculations, 250 initial bodies were considered. The initial values a_o of the semimajor axes a of the orbits of the bodies changed from a_{omin} to $a_{omin}+d_a$ AU, and the number of bodies with a_o was proportional to $a_o^{1/2}$. The values of a_{omin} varied with a step of 0.2 AU from 0.3 to 1.5 AU. d_a=0.5 AU for a_{omin}=1.5 AU. For other runs d_a=0.2 AU. Below all distances are presented in AU. In some variants of the *MeN* calculations, initial eccentricities e_o of orbits equaled to 0.05, and in other runs they were 0.3. For $Me_{01}S$ calculations I considered only e_o=0.05. The initial inclinations i_o were equal to $e_o/2$ rad. It was obtained in [1-2] that, due to the mutual gravitational influence of bodies, the average eccentricity of orbits of bodies in the feeding zone of the terrestrial planets could exceed 0.2.

The probabilities of collisions of bodies during considered time interval T (equaled to 1, 2, 5 or 20 million years) with the Earth, Venus, Mars, Mercury, Jupiter, Saturn, the Moon and the Sun are denoted by p_E, p_V, p_{Ma}, p_{Me}, p_J, p_S, p_M and p_{Sun}, respectively. The probabilities of collisions of bodies with embryos of the Earth, Venus, Mars, Mercury, Moon with masses equal to 0.1 of their present masses are denoted by p_{E01}, p_{V01}, p_{Ma01}, p_{Me01}, and p_{Mo01}, respectively. For some runs, based on the obtained arrays of the orbital elements of the migrated bodies, the values of p_{E01}, p_{V01}, p_{Ma01}, p_{Me01}, p_{Mo01} were calculated for *MeN* runs, and the values of p_E, p_V, p_{Ma}, p_{Me}, p_J, p_S, p_M were calculated for $Me_{01}S$ runs.

Probabilities of collisions of bodies with embryos of the terrestrial planets: Based on the obtained probabilities of collisions, I made a few estimates of the growth of the embryos of the terrestrial planets. The considered model doesn't take into account the mutual gravitational influence of bodies, which increased their eccentricities and mixing of bodies in the zone of the terrestrial planets. The greater are masses of the embryos, the faster is their growth.

The results of $Me_{01}S$ calculations showed that at masses of the embryos of the terrestrial planets of about 0.1 of the masses of the planets, an embryo grew mainly by accumulation of bodies from its neighbourhood, and the embryos of the Earth and Venus grew faster than the embryos of Mercury and Mars. For $Me_{01}S$ runs, at each considered zone, bodies collided mainly only with one embryo, and probabilities of collisions of bodies with other embryos were zero or were much smaller than those for that embryo.

For $Me_{01}S$ runs and the zone at 0.9-1.1 AU (for which the total mass of bodies could be $\geq 0.5m_E$, where m_E is the mass of the Earth), p_{E01} equaled to 0.2, 0.5 and 1 at T equaled to 1, 2, and 5 Myr, respectively. For the zone at 0.7-0.9 AU (for which the total mass of bodies could be about $0.4m_E$) and $Me_{01}S$ runs, p_{V01} equaled to 0.2, 0.4 and 7 at T equaled to 1, 2, and 5 Myr, respectively. For the zone at 0.5-0.7 AU, p_{V01} equaled to 0.36 and 9 at T equaled to 5 and 20 Myr, respectively. It shows that Venus and the Earth could accumulate most of the bodies from the zone at 0.7–1.1 AU in less than 5 Myr, and Venus could accumulate most of the bodies from the zone at 0.5–0.7 AU in not more than 10 Myr. So inner layers of the Earth or Venus were formed by accumulation mainly of material from the neighbourhood of the planet.

For $Me_{01}S$ runs and the zone at 0.3-0.5 AU, p_{Me01} equaled to 0.03 at T=5 Myr. For the total mass M_b of bodies in the zone equaled to $0.1m_E$, $M_b p_{Me01}=0.03m_E$ is about a half of the mass of Mercury ($0.055m_E$). Therefore, Mercury also could accumulate a considerable fraction of its mass from its neighbourhood.

For $Me_{01}S$ runs and the zone at 1.3-1.5 AU, p_{Ma01} equaled to 0.011 and 0.035 at T equaled to 5 and 20 Myr, respectively. For the total mass of bodies in the zone $M_b=0.2m_E$ and p_{Ma01} equaled to 0.011 and 0.035, we have $M_b p_{Ma01}=0.02m_E$ and $M_b p_{Ma01}=0.07m_E$, respectively. For $Me_{01}S$ runs and the zone at 1.5-2.0 AU, p_{Ma01} equaled to 0.0075 and 0.032 at T equaled to 5 and 20 Myr, respectively. So compared to other terrestrial planets, Mars (with its present mass of $0.107m_E$) could acquire a smaller fraction of its mass during the considered 5 Myr. However, at T=20 Myr and the mass of material in the zone at 1.3-2.0 AU greater than $0.3m_E$, Mars could acquire most of its mass from this zone.

Probabilities of collisions of bodies with the terrestrial planets: The estimates based on *MeN* calculations correspond to the last stages of the formation of the planets. The ratio p_V/p_E of the probabilities of collisions of bodies with Venus and the Earth was in the range from 0.5 to 1.9 for a_{omin} in the range from 0.7 to 1.1 AU. For a_{omin}=1.3 AU, the ratio was also close to this interval (0.5, 1.9), e.g., at T=5 Myr it was 0.48 and 0.38 for e_o=0.05 and e_o=0.3, respectively (p_V/p_E=0.78 at T=20 Myr and e_o=0.3). Therefore, the amounts of material from different parts of the zone from 0.7 to 1.5 AU from the Sun, which entered into almost formed the Earth and Venus, differed, probably, by no more than 2 times. For initial bodies with a_o<0.7 AU, the fraction of bodies that fell onto Venus was at least several times higher than the fraction of bodies that fell onto the Earth. The tables with the values of p_E, p_V, p_{Ma}, p_{Me}, p_J, p_S, p_M and p_{Sun}, and with their ratios to p_E for *MeN* calculations were presented in [6].

The ratio p_{Ma}/p_E exceeded 0.1 in the majority of calculations for a_{omin}≥1.1 AU, and for a_{omin}≤0.9 AU in two calculations it reached 0.045 and 0.087. The p_{Me}/p_E ratio was close to 100 at a_{omin}=0.3 AU, and p_{Me}≈0.5 for a_{omin}=0.3 AU, e_o=0.05, and T=5 Myr. In other variants, p_{Me}/p_E was significantly smaller, although it reached 0.07 for a_{omin}=0.7 AU, e_o=0.3 and T=20 Myr. The results of the *MeN* calculations testify in favor of the accumulation by almost formed terrestrial planets and the Moon of the matter originally located near other planets. In some runs at e_o=0.3 and T=20 Myr, more than 20% of the original matter could fall onto the Sun. The ejection of matter into hyperbolic orbits and the probabilities of collisions of bodies with the giant planets were insignificant.

Relative probabilities of collisions of bodies with the Earth and the Moon: The ratio p_E/p_M of the mass of the bodies that fell onto the Earth to the mass of the bodies that fell onto the Moon, in the considered *MeN* variants of calculations ranged from 16.9 (for a_{omin}=1.1 AU and e_o=0.3) to 35.6 (for a_{omin}=0.9 AU and e_o=0.05). At T=5 Myr the ratio p_{E01}/p_{Mo01} of the mass of the bodies that fell onto the Earth embryo to the mass of the bodies that fell onto the Moon embryo, in the considered $Me_{01}S$ variants of calculations were 24.3 and 15.3 for a_{omin}=0.9 AU and a_{omin}=1.1 AU, respectively. At T=20 Myr the ratio was 23.6 and 23.3, respectively, for the above values of a_{omin}.

Conclusions: Relatively small embryos of the terrestrial planets accumulated mainly materal from their neighbourhood. The amount of material from different parts of the zone from 0.7 to 1.5 AU from the Sun, which collided with almost formed the Earth and Venus, differed, probably, by no more than 2 times. Inner layers of each terrestrial planet could be accumulated mainly from materal from the neighbourhood of this planet. The outer layers of the Earth and Venus could accumulate similar material from the feeding zone of the terrestrial planets. The ejection of matter into hyperbolic orbits and the probability of collisions of bodies with the giant planets were insignificant.

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