Astronomy

B. Yu. Levin and G. L. Slonimskii

1957

SovietRxiv

Abstract

Full Text

Astronomy

B. Yu. Levin and G. L. Slonimskii

On the Question of the Origin of Meteoritic Chondrules

(Presented by Academician V. A. Kargin, 20 XI 1956)

About 90% of stony meteorites are chondrites, i.e., they consist of silicate spherules—chondrules—bound by a cementing mass. The diameters of chondrules vary widely—from microscopic dimensions to millimeters. Along with crystalline minerals—olivine and pyroxenes—chondrules contain glass, the amount of which decreases during metamorphic changes in meteorites. Purely glassy chondrules are encountered only rarely.

Owing to the presence of glass in chondrules, their formation is usually explained by the rapid solidification of silicate droplets arising either during the breakup (under the action of some internal forces) of a single parent planet of meteorites ([1]), or during collisions of many asteroid-type bodies ([2]). The hypothesis of the breakup (or "explosion") of a planet is not physically substantiated and requires additional artificial assumptions to explain the structural features of meteorites ([3]). Collisions of asteroid-type bodies undoubtedly played an important role in the evolution of meteoritic matter, but, as it seems to us, not in the formation of chondrules, rather at later stages.

Both in the hypothesis of the breakup of a parent planet and in the hypothesis of the collision of asteroid bodies, it is assumed that the interiors of this planet or of these bodies were incandescent and that differentiation of matter occurred in them. However, an explanation of the heating encounters great difficulties. The chemical composition of meteorites shows that the formation of the bodies of which they are fragments began with the accumulation of solid particles that proceeded at low temperatures ([4]). Consequently, the incandescent state of the interiors cannot be connected with this process. The ages of meteorites (found from unmetamorphosed specimens) reach 4.5–4.8 billion years. Chondrules formed still earlier and, since the age of the solar system apparently does not exceed 5½ billion years, it thus turns out that the interval of time from the formation of the parent planet or asteroid bodies to the formation of chondrules is very small—approximately ½ billion years. Considering that the radiogenic heat released during this time is insufficient for heating, Urey and Donn ([5]) put forward a hypothesis of chemical heating of the matter that gave rise to the chondrules. They suppose that, during the accumulation of the parent bodies, chemically unstable compounds entered into their composition in appreciable amounts and subsequently changed into stable ones with the release of energy.

Data on the chemical composition of meteorites play an important role in substantiating the modern view that planets and asteroids formed from a circumsolar gas-dust cloud. Regardless of differences in the assumed course of the process of planet formation, the problem arises of studying the processes of condensation of matter that occurred in such a cloud. As will be shown below, consideration of the condensation of those molecules that form silicates, i.e., refractory substances, opens new possibilities for explaining the origin of chondrules.

Under conditions of practically zero pressure, the primary act of condensation is the formation of a solid particle from the gas phase. In the protoplanetary cloud, condensation of silicate substances proceeded at temperatures much lower than their melting temperatures. This makes it possible to rely on ideas about the process of the emergence of a new phase from a supersaturated solution, recently developed by Z. Ya. Berestneva and V. A. Kargin ([6]). On the basis of extensive experimental material, they showed that in a supersaturated solution there are first formed spherical or shapeless particles having an amorphous structure characteristic of glasses. These particles, naturally, are nonequilibrium and subsequently crystallize at a rate depending on their chemical nature and external conditions (primarily temperature). The emergence of amorphous particles is explained by the fact that, under the conditions of a supersaturated solution, every collision of molecules, atoms, or ions leads to adhesion, while their arrangement in an order corresponding to the crystal lattice does not have time to occur. Further growth of such an amorphous center leads to the formation of a spherical amorphous particle, since the sticking of molecules, atoms, or ions is equally probable in all directions. When the temperature of the supersaturated solution is much lower than the softening temperature of the glassy particles being formed, crystallization of the latter may occur only after a considerable time. Thus, for example, the onset of crystallization of gold particles at room temperature was observed after 3–5 min., of titanium dioxide after 1–2 hours, of aluminum hydroxide after a day following their formation, while silicic-acid globules remained amorphous even after a year.

These ideas are also valid for the formation of a solid phase from the gas phase, i.e., they are applicable to the protoplanetary gas-dust cloud. In this cloud there were molecules of metal and silicon oxides and molecules of silicates. In collisions of this kind, molecules should yield solid particles with high melting temperatures. In light of the data cited, the primary particles of silicates should be amorphous and close to spherical in form.

In the formation of colloidal particles in solutions, the sizes of the primary globules are very small owing to the rapid contamination of the surface of the growing particles by electrolyte impurities present in large amounts in the solution. Under the conditions of the protoplanetary cloud, where this kind of retardation of particle growth is almost absent, their sizes, naturally, should turn out to be very diverse and reach considerable values, which is what we observe in chondrules. Rare cases in which a smaller chondrule is enclosed within a larger one may be explained by the repeated entry of a chondrule (a small one) into a region of the protoplanetary cloud in which condensation is taking place.

The study of chondrules leads to the conclusion ([7]) that their crystallization had already occurred in meteorites. The presence among them of completely or partially glassy chondrules shows that in some cases the crystallization process proves to be extremely slow. This possibility is confirmed by experimental data on the rate of crystallization of colloidal particles of silicic acid at room temperature: for more than a year they remain completely amorphous, and only two years after their formation does a fine electronographic investigation reveal barely noticeable signs of the beginning of crystallization. Taking into account the sharp dependence of the rate of crystallization on temperature, and using data on the crystallization of silicate and other amorphous particles, it can be shown that in meteorites, which spent most of the time at lowered temperatures, crystallization in some cases must have extended over millions and billions of years.

Condensation of gas molecules leading to the formation of amorphous (glassy) chondrules must proceed to a certain extent selectively,

which also explains the fairly homogeneous composition of the substance of chondrules. They contain mainly silicates (olivine and pyroxenes) and aluminosilicates (plagioclase). As for the so-called olivine chondrules, their monomineralITY is probably only apparent, since glass of indeterminate composition is always present in them. During crystallization of an initially amorphous chondrule, the lattice of a particular mineral may at first grow with the displacement of other silicate molecules into the glass. Subsequently, crystallization of other minerals also begins, so that completely crystallized chondrules, apparently, are always polymineral.

The authors believe that the proposed hypothesis on the origin of silicate chondrules removes certain difficulties now encountered in the problem of the origin of meteorites, and therefore deserves further development. In particular, it appears necessary to study the factual data on the composition and structure of chondrules from the standpoint of the considerations set forth above, and also to conduct laboratory investigations of the process of formation of solid particles from the gas phase at low temperatures and pressures.

Institute of Physics of the Earth named after O. Yu. Shmidt and
Institute of Organoelement Compounds
Academy of Sciences of the USSR

Received
19 XI 1956

CITED LITERATURE

[1] A. N. Zavaritskii, Proc. 1st Conference on Cosmogony, Publishing House of the Academy of Sciences of the USSR, 1951.
[2] H. C. Urey, H. Craig, *Geochim. et Cosmochim. Acta*, **4**, Nos. 1–2, 36 (1953).
[3] B. Yu. Levin, *Meteoritics*, issue 11, 47 (1954).
[4] H. C. Urey, *Ap. J.*, Suppl., **1**, 147 (1954).
[5] H. C. Urey, B. Donn, *Ap. J.*, **124**, No. 1, 307 (1956).
[6] Z. Ya. Berestneva, V. A. Kargin, *Uspekhi Khimii*, **24**, No. 3, 249 (1955).
[7] A. N. Zavaritskii, L. G. Kvasha, *Meteorites of the USSR*, Publishing House of the Academy of Sciences of the USSR, 1952.

Note: Figure translations are in progress. See original paper for figures.