Information Brochure

Formulation and Confirmation of Theory:

ORIGIN OF EARTH: ACCRETION TRIGGERED BY THE IMPULSE MAGNETIC FIELD

Operačný program VZDELÁVANIE

Agentúra
Ministerstva školstva, vedy, výskumu a športu SR
pre štrukturálne fondy EÚ

Európska únia
Európsky sociálny fond

Modern Education for the Knowledge Society/Funding is provided in part by the European Union.

Demand oriented project number ITMS – 26140230006 „Formulation and Confirmation of the Theory of Earth Origin by Accretion in Cooperation with Internationally Recognized Experts" is solved at the Geophysical Institute of the Slovak Academy of Science within the call for proposals OPV-2010/4.2/03-SORO

Introduction

The physics curriculum the primary and secondary schools in the Slovak Republic have been following is long on encyclopedic information but short on integrating the isolated bits of knowledge into a coherent whole. In fact, instruction in all branches of science suffers from a similar deficiency. And, of course, the unavoidable nexus between physics and mathematics makes physics one of the least favorite subjects to study. Perhaps the teachers themselves, empowered by the newly adopted legislation, could make the necessary changes and improvements. This places new demands on the personality of each teacher and on his or her inventiveness and creativity. In the past, it was mostly the development of creativity on the part of students that had been emphasized. Loosening the grip of the traditional teaching methods, the Ministry of Education has begun challenging teachers to seek novel didactic approaches that would make classroom instruction more attractive and the subject matter more accessible. The teacher's creativity, it is expected, would compel students to ponder the less obvious relationships and grasp the big picture on their own. A task of gigantic proportions and an unrealistic completion date—immediately. We are presenting an example that may serve as a motivating lesson in the innovative and interdisciplinary physics instruction. Our example combines physical theory with laboratory experiment; it also incorporates both the established and the up-to-date facts taken from a number of branches within physics and disciplines outside physics. Namely, it combines electricity, magnetism, gravitation, astronomy, geophysics, and geology. A teacher of physics could hardly wish for a more instructive demonstration of the research methods employed in sciences. The example we refer to involves a new theory of the origin of planets. Slovak scientists have proposed this theory and have confirmed its plausibility experimentally. The laboratory apparatus they made use of was fabricated in Slovakia. We shall briefly outline the main ideas of the theory and show some of the results of the experimental work.

Origin of the Solar System: Evolution of Hypotheses

Cosmogony is the science of the origin of the Solar System and of the bodies the system contains. (Cosmogony should not be confused with cosmology—the science of the origin, evolution, and structure of the universe.)

The question of the origin of Earth and the planets had been tormenting humanity for millennia. Just about every ancient nation (or tribe) had invented its own fanciful explanation of how the world came into being. With the development of science, the observational facts found their way into the notions of the once fairy-tale-like cosmogonies. The endeavor of justifying the existence of the world acquired more solid foundations. The first appearance of the term "Solar System" (1704), influenced by the Isaac Newton's theory of gravitation, has marked the general acceptance of the idea of heliocentrism. With the Sun assuming the central position within the family of the planets, and holding the family together, came also the idea of a common origin of the family members. According to the suggestion made by G. L. Leclerc de Buffon (1749), the Sun once collided with a comet. This event was supposed to lead to the formation of fiery debris that cooled off and coalesced into individual planets. I. Kant (1755) proposed that the stars, the Sun, and eventually the planets formed as a result of the gradual collapse of the primordial gaseous nebula. In P. S. Laplace's view (1796), the cooling and rotating protosolar nebula spun off rings of material that consolidated into planets. The cooling planets spun off their own sets of rings that became the moons. The hypothesis put forth by T. C. Chamberlin and F. R. Moulton (1901) bears a distant resemblance to the Buffon's hypothesis. Tidal interaction between the Sun and a star passing close to the Sun resulted in the ejection of material from the Sun. Some of the ejected mass fell back, some condensed into small bodies for which Chamberlin and Moulton coined the term "planetesimals." Over time, the tidally created planetesimals collided with each other and formed larger assemblages—planets, comets, and asteroids. The theory is weak—likelihood of an encounter of the Sun with a star drifting through the galaxy is virtually nil. Also, the dynamics of the ejected material, if such an encounter did take place, would not conform to the requirements of planetary formation. The Chamberlin-Moulton hypothesis sank into oblivion but the concepts of planetesimals and of collisions of planetesimals have been retained. The current ideas of planetary accretion are largely due to O. Y. Schmidt (1944) and V. S. Safronov (1972).

Hypotheses of planetary formation tend to suffer from the lack of completeness. For instance, the compositional non-uniformity among the planets of the Solar System is not fully understood. It is evident that the gravitational attraction of the central star (the Sun) plays the decisive role here, but the details remain to be elucidated. Dynamical circumstances also pose problems. Tilts of the planetary rotational axes relative to the respective orbital planes vary widely. The axis of Uranus is tilted by 97.8°; that of Mercury is hardly tilted at all. Mercury is particularly puzzling. Due to the unique 3:2 spin-orbit resonance, Mercury rotates three times (period of rotation 58.7 days) for every two revolutions around the Sun (period of revolution 88 days). All the planets revolve and rotate in the prograde sense except Venus, whose rotation is retrograde. The distribution of the angular momentum is also difficult to explain. The magnitude of the orbital angular momentum of Jupiter is more than 20-fold larger than the magnitude of the rotational angular momentum of the Sun. The Sun represents 99.9% of the mass of the Solar System, yet only about 1% of the system's angular momentum resides in the Sun (Carroll and Ostlie, 1996).

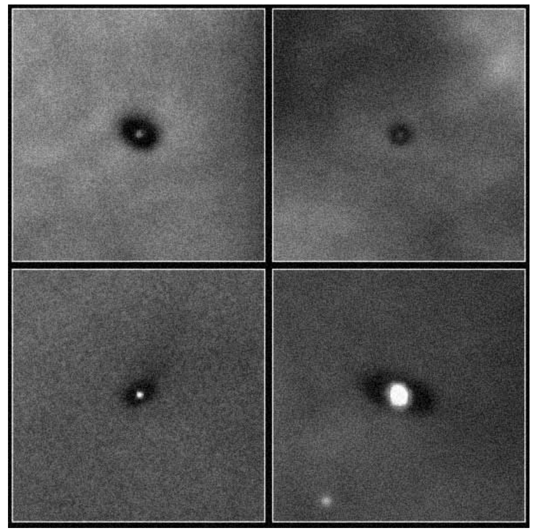


Fig. 1. Protoplanetary disks. M. J. McCoughean (MPIA), C. R. O'Dell (Rice University), NASA

Simultaneous emergence of the Sun and other entities comprising the Solar System from the primordial dust and gas nebula is at the core of the contemporary notions of the origin of the planets. The eighteenth-century philosophers and naturalists, Buffon, Kant, and Laplace, are credited with the initial formulation of the nebular origin of our planetary abode. While the Solar System has been in existence for over 4.5×10^9 years, its genesis was probably quite fast. The kernels of planets likely came into being as the result of collisions of grains of metal compounds and silicates with diameters smaller than about a millimeter. The originally hot nebula gradually cooled and morphed into a rotating disk (Fig. 1). The drop in temperature permitted the colliding particles to stick together and form larger aggregates. These objects, visualized as granules and chondrules, began exert gravitational attraction. Drawing smaller grains, they grew larger and larger. Passing the phase of intermediate-sized planetesimals, they reached the planetary dimensions. The duration of the early stage of planetary formation perhaps did not exceed 10^5 years; the stage was almost certainly over in 10^7 years. The period of the Late Heavy Bombardment, when objects from the asteroid belt rained on the inner Solar System, occurred about 4.0×10^9 years ago; this period may have lasted several hundred million years. Craters on the Moon and Mercury provide the evidence. After the heavy bombardment ended, about 3.8×10^9 years ago, the Solar System settled into the form and shape we are familiar with.

Magnetism: The Triggering Mechanism of Planetary Formation

Gravitational attraction is the natural mechanism of planetary accretion. The actual accretion, as it happened four and half billion years ago, was perhaps speeded up or triggered by the action of the forces of magnetism or electromagnetism. As is well known, these forces are present whenever electric charges are in motion (Fig. 2a).

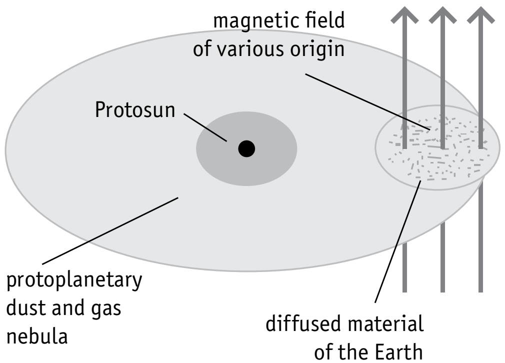


Fig. 2a. Model of Earth creation by accretion. The Earth protocore was created from diffused material in primordial dust and gas nebula with magnetic field of various origin.

Accretion with the assistance of the forces of magnetism is the proposed new mechanism of planetary formation. The idea of magnetic accretion follows from and is backed by a number of confirmed facts.

1. Magnetic fields are present in our galaxy and in the general neighborhood of the Sun.

2. The primordial nebula originated as a consequence of an explosion of a supernova. Plasma (ions and free electrons), the ferromagnetic elements (iron, nickel) and their compounds, and the nonmagnetic materials (silicates and compounds of nonmetallic elements) constituted the three principal components of matter contained in the protoplanetary disk (Fig. 2a).

3. Electric discharges analogous to the terrestrial lightning bolts have been detected in the protoplanetary disks that surround young stars. These discharges testify to the existence of impulse electric currents. Such currents generate impulse magnetic fields capable of transient or even permanent magnetization of particles in the vicinity of the electric discharge channels (Fig. 2b).

4. The spacecraft traveling through the Solar System's outer reaches (Pioneer 11, Voyager 1, and Voyager 2) detected showers of relativistic electrons (i. e., electrons moving with speeds approaching the speed of light).

5. Chondrites, the oldest types of meteorites, contain ferromagnetic grains magnetized to saturation. Strong fields are required to achieve saturation. It is likely that chondrites were formed still in the protoplanetary cloud. The material that went into the formation of chondrites was probably in a melted state, then it underwent abrupt cooling. Cooling took place in the gravity-free environment, thus chondrules acquired spherical shapes. Conditions of flash melting and flash cooling in the presence of strong magnetic fields occur in the immediate surrounding of the discharge channels.

6. The Earth's core is divided into a solid inner core, composed primarily of iron and nickel, and a less dense outer core, also composed of nickel and iron with admixed lighter elements. A much less dense mantle composed almost exclusively of silicates surrounds and envelopes the core.

7. Earth itself possesses magnetic field. The field originates in the outer core; the mechanism of generating and maintaining this field is not fully understood.

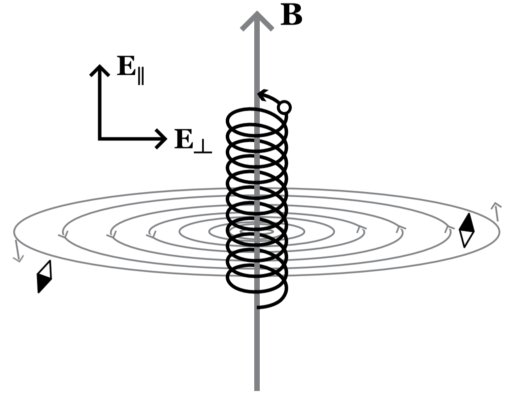


Fig. 2b. Physical principle of impulse magnetic field. The electron moving along the magnetic lines of force (B) generates the linear electric current (E) by its rotational movement. This current generates the circle magnetic field which magnetizes the ferromagnetic planetesimals.

The particles that entered into the process of accretion had the same composition as the rocks making up the present-day Earth. Heavy ferromagnetic or paramagnetic materials formed a certain fraction of the particles; light diamagnetic silicates formed the remainder. Strong discharge currents instantly set up correspondingly strong magnetic fields. These fields brought about almost instant magnetization of the nearby ferromagnetic particles or planetesimals. The magnetized particles were attracted toward the axis of the discharge current. The discharge would cease before the particles managed to reach the respective axis. Particles collided and, if magnetized, stuck together. The clusters that were created in this manner retained the magnetic moments of the constituent particles. As a consequence of the conservation of angular momentum, they also developed rotational motions (Figs. 2c through 2e).

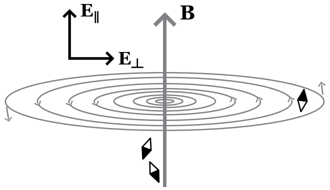
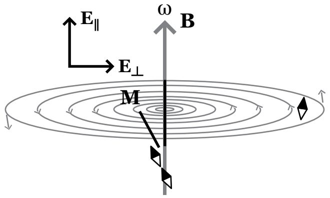


Fig. 2c. Attraction of magnetized particles.



Obr. 2d. Magnetized particles joining.

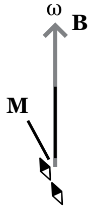


Fig. 2e. Magnetic moment conservation after damping out of the discharge and acquiring of rotation of joined particles as result of their momenta preservation.

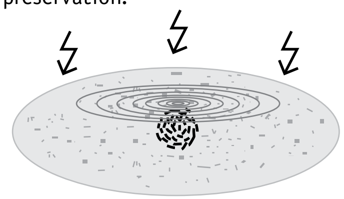


Fig. 2f. Accretion of protocore by multiple discharges.

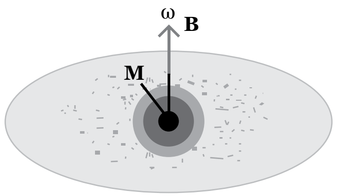


Fig. 2g. Gravitational collapse of silicate particles and the creation of the light cover of core.

The scenario just sketched out gives a sequence of events we consider as the primary impulse toward forming planetary embryos. The process of impulse accretion in the protoplanetary cloud can be sustained as long as the electric discharges take place. Each accretion incident widens the range of sizes of the accreted grains (Fig. 2f). Only the ferromagnetic and perhaps also the paramagnetic particles participate in the process of the impulse accretion. Magnetic field has no effect upon the nonmagnetic silicate particles. When the ferromagnetic planetesimals attain a sufficient mass, their ability to exert sensible gravitational attraction enters the picture. The planetesimals, be it the core of the future Earth or the uncountable numbers of randomly accreted objects, acquire silicate coatings. The coatings may grow and gradually turn into more massive silicate mantles (Fig. 2g). The proposed model (Tunyi et al., 2001, 2002, 2003) justifies the existence of the two most conspicuous characteristics of the planet Earth. The first is the division of the interior into a heavy metallic core and a light silicate mantle (see Item 6 above). The second is the existence of the geomagnetic field (see Item 7). At present, the electric currents in the Earth's outer core are the likely source of the field. In terms of the proposed theory, ferromagnetic and paramagnetic planetesimals magnetized by the external impulse field might have served as the source of the incipient geomagnetic field.

Experiment

To confirm the theory, it is necessary to experimentally verify the basic assumptions and the derived consequences. As the fundamental assumption of the whole theory is magnetization of demagnetized ferromagnetic particles, it was necessary to construct an experimental device that would simulate the conditions described and demonstrated the formation of ferromagnetic aggregates. Such a pulse source of electric current (electric discharge current) was designed and constructed by the authors and the production of magnetized aggregates successfully demonstrated. The figure 3a shows the preparation of a ferromagnetic sample consisting of non compact demagnetized grains before applying the electrical discharge. Discharge takes place in an enclosed space in a highly dilute atmosphere (almost a vacuum). Other figures show an electromagnetic pulse (burst) and its consequences - a cluster of magnetized grains (Fig. 3b,c).

Fig. 3a. Preparation of ferromagnetic samples before applying the electrical discharge.

Fig. 3b. Experimental discharge.

Fig. 3c. Cluster of magnetized samples after the discharge application.

Conclusions

In this contribution a new scenario for the formation of the Earth has been proposed. The existing accretion theories have generally been based on the idea of clustering planetesimals in protoplanetary cloud as a result of collisions and gravitational attraction. Also, the electrostatic attraction of particles has been considered. The basis of the new accretion model is the effect of impulse magnetic fields, which are formed by impulse electrostatic discharges in protoplanetary cloud. A pulsed magnetic field magnetizes the ferromagnetic planetesimals and attracts them to the axis of pulsed electric current, where they cluster together as permanent magnets. The newly created cluster of magnetized ferromagnetic (iron) particles is the germ of Earth's core. When the mass of such a protocore is sufficiently large, gravitational collapse of silicate particles occurs, creating the Earth's mantle. The model is experimentally verifiable and provides an answer to the cause of the two most important physical characteristics of the Earth, namely the existence of the magnetic field and the separation of planet mass to heavy metallic core and light silicate mantle.

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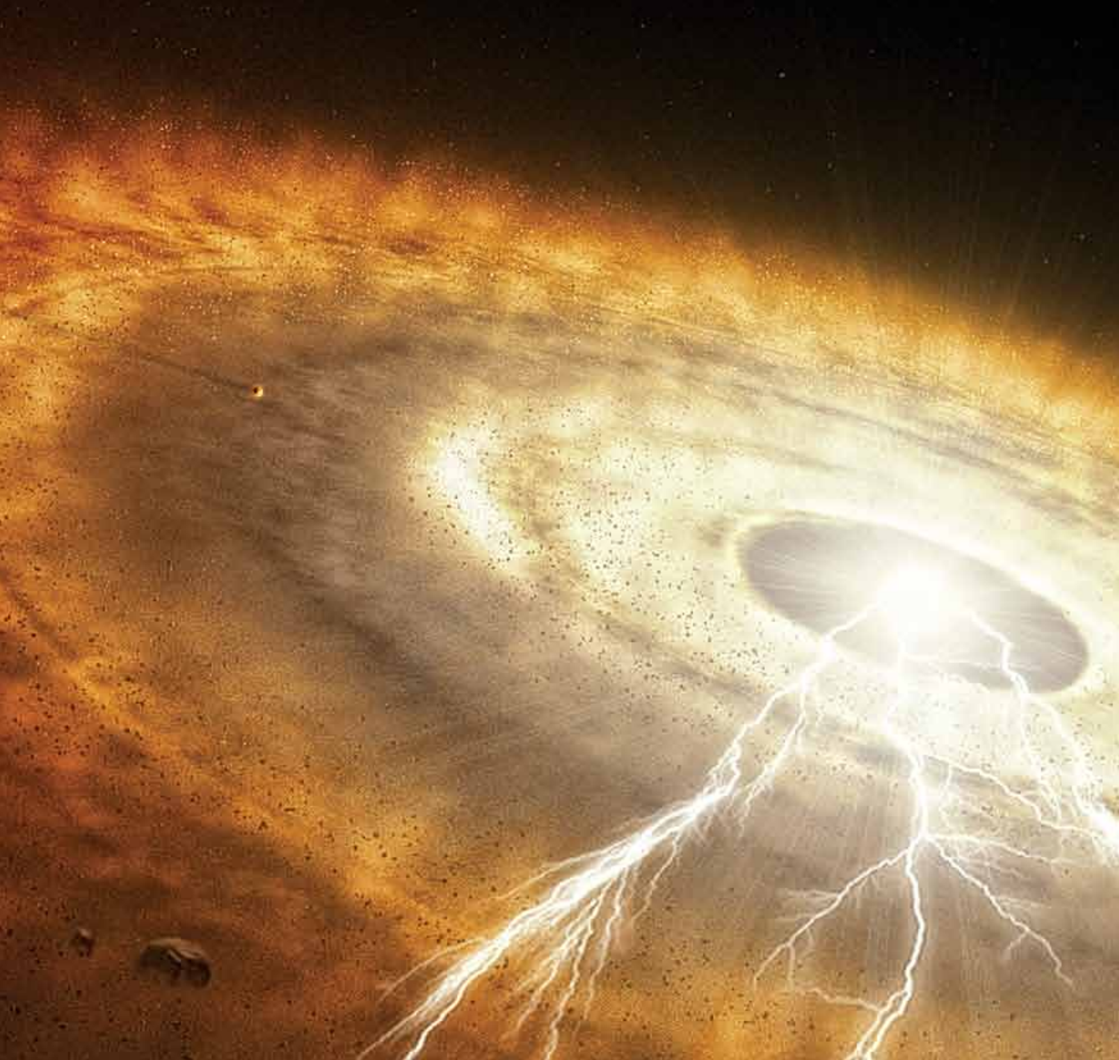

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