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GEOPHYSICS

Subjects:
1. Methodological basis
2. Earth in the structure of the Universe

Lecture notes

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Methodological foundations of the course are considered: the alternation of paradigms, simulation as a method of cognition, problems of model objectivity, the notion of systems and laws, as well as the position of the Solar System and the Earth in the structure of the Metagalaxy. The concepts on the structure of the Universe are stated.

The lectures are intended for students of geophysics and geology Specialization 657200— Hydrometeorology. The new material and the system approach to its interpretation can also be interesting and useful for lecturers and students of other specializations.

PREFACE

The synopses of the lectures on the discipline "Geophysics" consist of three booklets, each of them including two basic subjects:

I. Subject 1 — The methodological basis.
   Subject 2 — Earth in the structure of the Universe.
II. Subject 3 — Physical models of the Earth.
   Subject 4 — Geophysical fields.
III. Subject 5 — Space and time in the sciences on the Earth.
   Subject 6 — The interaction between the external geospheres.

Their contents meet the contemporary requirements of Teaching Standard of the Education Ministry of Russian Federation for Specialization 657200— Hydrometeorology.

With regard to the RF Government reformation (March, 2004) and the reorganization of the Education Ministry into the Science Ministry, creation of new Standards for education is expected, which also affects the discipline "Geophysics". Probably, the new requirements for teaching Geophysics, being more universal, will give to the course the Weltanschauung orientation and add to its fundamentality.

Proposals made by the RSHU on the improvement of teaching the Geophysics discipline were taken into account in these synopses. The proposals are concentrating on essential role of methodological foundations, system ideology in presentation of the material, and orientation to the scrutiny of the principles and mechanism of the geospheres interaction. First of all, it concerns the upper envelopes of the Earth as the main object for both practical and scientific professional activity of meteorologists, hydrologists, oceanologists, and ecologists. Also considered in the course is a new geosphere — noosphere — as a field around the Earth.

The section on every subject is provided with questions and problems for self-control and a list of regnired and further reading for students'.

INTRODUCTION

“Geophysics” is one of the education disciplines being taught in the RSHU for specialization 657200 — Hydrometeorology. In accordance with the Standard of the Higher Professional Education, the programme of the course presupposes the acquaintance of the students with general information about the Earth as a planet of the Solar System, its physical fields, geological processes and phenomena, problems of interaction between the solid, liquid, gaseous envelopes of the Earth, and methods of geophysical investigations.

The word *physics*. Thus, in general understanding, it is a science about the simplest properties of the substance. In this or approximately this way it is written in higher-school textbooks and manuals on physics.

Therefore, for Specialization 657200— Hydrometeorology, the term Geophysics can be understood as the science about the nature of the Earth.

Earth is a celestial body. Earth is a product of the Universe, and its development obeys the laws of the Universe. The structural elements of the Earth also are not isolated from each other. Being the autonomous creations, they are aggregated into a whole, whose name is the planet Earth.

But the wholeness is formed as a system and reveals itself in the interaction of the parts, of which the system consists.

Thus, in our course the Earth is considered as a cosmic and geological system. Hence, further in the text, both the term “geophysics” and the term “geology” will be used. To adopt such approach to the problem, it is necessary to begin with considering the methodology of this discipline.

Subject 1. The Methodological Basis

Methodology is a system of methods and rules applicable to research or work in a given science or art (Chambers 20th Century Dictionary).

"Whoever undertakes to set himself up as a judge of Truth and Knowledge is shipwrecked by the laughter of the gods."
Albert Einstein

1.1. The Change of Paradigms

The paradigm is a complex of opinions that determine the direction and way of scientific thinking at a given stage of its development.

Analysis of the history of science reveals that its development is determined and controlled by the scientific revolutions, which originate as a product of the change of paradigms, i.e., predominant Weltanschauungs.

Geology went through two paradigms. Now, we are entering the third paradigm, after the second revolution. Before we start discussing these events, we first of all try to formalize the idea of the science development through the change of paradigms.

In their constructions, the official philosophy and science on science continue to rest on the concept of the exponential law of the evolution of our knowledge. Parametrizing this idea, we can write:

$$I = I_o e^{\lambda t},$$

where I is scientific information at the moment t; I_o is initial information; λ is a constant characterizing the rate of growth of our knowledge, i.e., accumulation of information over time (Fig. 1.1).

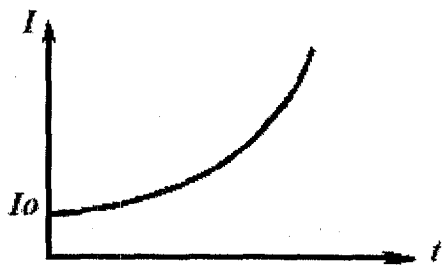

Figure 1.1. Exponential law of science development. I stands for information; t stands for time

It is easy to notice that exploiting the exponential law as a description of the evolution of our knowledge is connected with no less than three principal difficulties:

- There are no abrupt changes and points of discontinuity on the graph. Thus, exponential law is not able to describe the scientific revolutions.
- The value of I grows over t when λ = const. And if $t = 0$, we obtain $I = I_o$ ($I_o > 0$). In other words, a certain initial information had already existed before science came into being. It is natural, but the uniqueness of the beginning leads to pure logicism that contradicts to the Gödel's Theorem of Incompleteness.
- The gradient dI/dt grows catastrophically over t. In practice, it corresponds not to the change of paradigms but informational explosion, i.e., the demolition of science.

To exclude the third difficulty, the most evident at first glance, the scienfists proposed to use the logistic function as the law of scientific development:

$$I = (I_1 - I_0) / (1 + e^{a + bt}) + I_0,$$

where a and b ($b < 0$) are constants (Fig. 1.2).

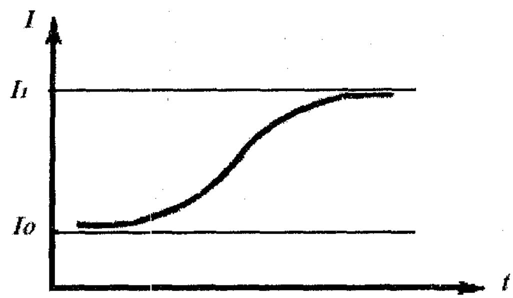

Figure 1.2. Logistic law of science development:
I_o is the lower asymptote, I_1 is the upper asymptote

Indeed, in this case the gradient dI/dt first grows and then decreases; therefore, the option of informational explosion is excluded. However, having eliminated one drawback, we get another and more serious problem: The information growth, or the development of science, which is the same, is bound to a limit of I_1.

Investigating the kinematics of the informational spiral, the author managed to describe the process of science development in the form of a series of logistic functions (Fig. 1.3). It allows, on the one hand, to avoid the above-mentioned difficulties, and on the other hand, to pose additional questions which new for geology and geophysics. Without solving these questions, both geology and geophysics cannot develop as up-to-date sciences.

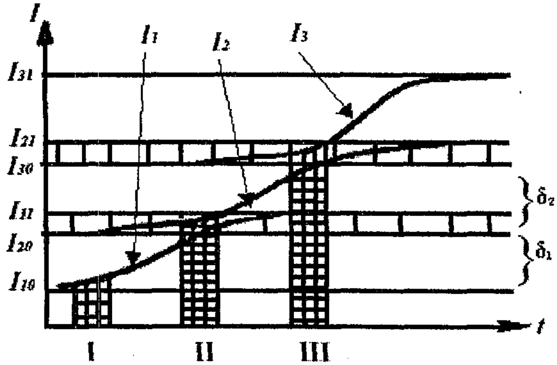

Figure 1.3. The law of transfinite development of science with the main paradigms (the set of logistic functions).

I_1, I_2, I_3 are the first (initial), the second, and the third paradigms, respectively;

I_{11}, I_{21}, I_{31} are the limit values of information that can be obtained from I_1, I_2, I_3, respectively

The cross-hatched areas are revolutionary periods. Area I is the epoch of the Renaissance (commencement of the I_1 activity), area II is the epoch of the end of the 18th and the early 19th centuries — the Enlightenment (commencement of the I_2 activity), and area III is the end of the 20th century (commencement of the I_3 activity).

The peculiar feature of these revolutionary periods is the coexistence and the struggle of two world outlooks: old and new paradigms. In this struggle, the new paradigm is to necessarily oust the old one, so the gradient dI/dt within the confines of old logistic function decreases and approaches zero; on the contrary, the gradient of new logistic function increases. The old and new ideas are irreconcilable; hence the discontinuities of the total logistic function. Theoretically, a previous paradigm can be exploited without any limitation of time, but in practice this time is restricted by the life span of the human generation that exploited this paradigm last of all.

Every new paradigm is born in the depths of the old one. Theoretically, its roots go back to the very remote past. However, in practice it appears as if all of a sudden like a small jump δ_i detaching the lower asymptote of the given logistic function $I_i(t)$ from the lower asymptote of the next logistic function.

The proposed scheme (Fig. 1.3) excellently corresponds to the fundamental Gödel's Incompleteness Theorem. We give this theorem in interpretation of Prof. Yury I. Manin:

For comprehension of the full truth, it is necessary to have a transfinite series of creative acts (acts of belief) and we do not prove the truth of these acts, we can only guess them right.

The acts of belief are postulates that can be considered as paradigms, i.e., as a whole complex of the ideas accepted to be true. In Fig. 1.3, these are the lower asymptotes. Gödel's Incompleteness Theorem states that every such act is finite. In Fig. 1.3, these finitenesses are represented by upper asymptotes. The theorem also states that the number of these acts and the number of their alternations is infinite. Only two such alternations are shown in Fig. 1.3, although we can draw as much of them as we like.

Science evolves, and the fact of its evolution is shown in Fig. 1.3 as the growth of value of functions $I_i(t)$ being theoretically unlimited.

Without concentrating on Gödel's proof, we will only consider, very briefly, the consequence of the theorem that concerns the bound of the deductive system of drawing conclusions. The theorem states that there is no deductibility being non-contradictory for all transfinite set of the logistic curves (Uspensky, 1980). We denote the whole complex of logistic curves $I(t)$ (Fig. 1.3), where the lower asymptote of every next curve is situated under the upper asymptote of the previous curve, as transfinitude.

Thus, according to Gödel's Theorem, the deductive system is consistent, i.e., non-contradictory only on intervals: $I_{10} - I_{11}$, $I_{20} - I_{21}$, $I_{30} - I_{31}$, and so on. The existence of upper limitations I_{11}, I_{21}, I_{31}, ... makes the deductive system incomplete. Therefore, every paradigm being non-contradictory is necessarily incomplete.

Now, with the help of transfinitude (Fig. 1.3), we will briefly consider the sequence of changing of paradigms in geology and geophysics as a basis for the mechanism of their development.

The first logistic curve of transfinitude corresponds to the epoch of the Renaissance. This paradigm originated from the Biblical insights. Its gist was briefly explained in the works of Andrey Vistelius (1980) and Alexander Pavlov (1990). Geological deduction of this paradigm has never been specially investigated. The purport of the approach to geological investigations was plainly axiomatic and ideology was clear enough but not so simple as is presented sometimes by orthodox atheists. This approach implies that our world is created by the Divine Reason according to strict mathematical laws while the humans are bestowed a part of this reason. Therefore, they are able to reveal these laws and comprehend the structure of the world. If they were able to construct a non-contradictory theory of formation of our world, this theory could be a deduction over geology; therefore, all geological laws could be derived mathematically.

However, there was no geology, in the sense we understand this term nowadays, during the life of the first paradigm (I_1 in Fig. 1.3). The deductive foundations of geology were formed later by such titans as Mikolaj Kopernik, Tycho Brahe, Johann Kepler, Galileo Galilei, René Descartes, Isaac Newton, Gottfried Leibniz. Thus, we can see that axiomatic approach to science was established by the outstanding scholars of authority of that time, mainly of physical, mathematical, and philosophic orientation. Nevertheless, along with the prevalent ideology, the inductive system of cognition appeared and began to develop (Georg Agricola, Nicolaus Steno), which afterwards determined the generation of a new paradigm to investigate the world in the 18th–19th centuries. For geology, it was the creation of the second descriptive paradigm, related to such names as Mikhail Lomonosov in Russia, James Hutton in Scotland, Abraham Werner in Saxony, Charles Lyell in England, Georges Cuvier and Alexandre Brongniart in France, and others.

Geology, at this stage of its development, wasn't concerned with the philosophical problems and the search for the beginning of all beginnings. It was most clearly manifested by James Hutton, who believed that the Earth lived and developed in accordance with common physical laws. The Earth is a machine and all geological phenomena can be explained through the natural agents that the geologist is able to observe. The second paradigm and special attention to the genetic trend of geological works affected the development of geology in a very productive way.

The second, or descriptive, paradigm was based on the ideology of heliocentric conception; therefore, its deduction was more or less invariant with regard to diverse cosmogonical theories (from Pierre Laplace's hypothesis to 'cold' hypothesis by Otto Schmidt and contemporary ideas on 'hot' formation of the Earth). Without any claim on strictness and completeness, it is possible to formulate three statements that modern geologists, one way or another, use in their work as cardinal axioms:

- The geological development of the Earth is an evolutionary and at the same time step-wise process.
- This process is generated by the internal energy sources: gravitational, thermal, and others.

- The only external energy source is the Sun that controls the exogenic processes on the Earth.

The logical apparatus of the deduction for the descriptive paradigm is sophisticated enough; it is based on the classical logic, classical physics, and thermodynamics. Until recently, axiomatics of the second paradigm and its logical deductive apparatus were in agreement with the factual data and were suitable for geologists as satisfactory to their demands. The known facts remain to be valid today as well. However, the postulates themselves are found to be insufficient, because it becomes impossible to answer serious questions on their basis — in particular, to explain the cyclic recurrence of different scales in the development of the Earth (magmatic, metallogenic, biospheric, tectonic, and some others). Thus, one can say that the old axiomatics has served its time and now we are on the verge of creating a new axiomatics.

It would be proper to recollect here the opinion of the outstanding physicist of the 19th century Ludwig Boltzmann. He understood the mission of the modern science not as gathering the empirical facts and their further estimation from the standpoint of already-known laws, but as an adjustment to our thinking, ideas, and concepts with the obtained empirical data. Today it is clear to most scientists that it is essentially easier to make measurements than to comprehend what was measured.

The principal provisions of new axiomatics were for the first time formulated in the works of Alexander Pavlov and Azariy Barenbaum (1991). These are as follows:

- The geological development of the Earth is caused by the influx of the energy from outside.
- The Earth receives this energy not continuously but by certain fixed amounts (quanta).
- These energetic quanta emerge during the Solar System's passing through the jet flows of the Galaxy.
- The periodicity of the energetic quanta emergencies corresponds to the periodicity of the Solar System's passing through the jet flows of the Galaxy.

These postulates are the basis for a new paradigm in geology, quantum paradigm that allows us to abandon the heliocentric concept on geological development of the Earth for the Galacentric ideology. The Galacentric ideology is based on the concept of open system not only for the Earth and the Solar System, but also for the Galaxy.

1.2. The Principle of Actualism

Actualism is a form of interpretation of geological processes of the past by means of comparing the geological phenomena of the past epochs of the evolution of the Earth with the processes of the present.

There are plenty of books and articles written about actualism. And this very fact shows that the concept of actualism is not only sophisticated but also very important. It concerns the foundations of the geology as a science. It is necessary to notice that during the past years, the question about the foundations of the science ceased to be only philosophical, it became very particular and requiring a clear and precise answer. Geology (in our educational program, it is called geophysics) is a science about the structure of the Earth, its origin, and development. So it is necessary to determine what truths are the foundations for geology. Regretfully, the modern geology can propose only the ideas of actualism. However, the principle of actualism is not an up-to-date concept. The degree of contemporaneity of the principle of actualism depends on the manner how it interprets the geological space–time system.

Thus, the principle of actualism cannot be used as a method without precise space–time notions.

The ideas of actualism appeared as early as at the epoch of Renaissance (the 16th–18th centuries) and in one or another form can be found in the works of Leonardo da Vinci, Nicolaus Steno, George de Buffon, James Hutton, and Russian scientist Mikhail Lomonosov. But in the most complete form, the notions of actualism were formulated by Charles Lyell in his 3-volume work "*Principles of Geology*" (1830–1833). Charles Lyell made the development of the Earth to be intelligible by determining three cardinal principles.

- All the processes altering the appearance of the Earth are constant over the time. It is the *principle of monotony.*
- The forces defining the formation of the Earth act slowly, but continually. It is the *principle of continuity.*
- The slight alterations acting continually during long time lead to considerable alterations without additional catastrophes. It is the *principle of summation.*

Thus, Charles Lyell promulgated the concept of uniformitarianism in its final form that explains the features of the Earth's crust by means of natural processes over geological time. Uniformitarianism posits that natural processes existing through long periods of geological time and acting in the same manner and with essentially the same intensity as at present are sufficient to account for all geological alterations.

In spite of all shortcomings and mistakes that are unavoidable in the process of cognition of nature, the concept of uniformitarianism is based on the idea *"today as always and always as today"* that performed an exceptional and progressive role in geology. Uniformitarianism received its further substantiation and development in the works of Russian scientists Alexander Arkhangelsky, Nikolai Strakhov, and others.

When it became clear that *"today is not absolutely the same as always"*, the principles of Charles Lyell were transformed to the modern formula: *"the present is a clue to the cognition of the past"*. Nowadays, this formula is considered to be the gist of the method of actualism.

However, this formula by itself gives not much. It only shows that to accept the uniformitarian reconstructions is not enough. These allow us only somehow to orient ourselves in the geological history of the Earth, but do not allow one to reproduce authentically the geological events, authentically in the sense of reconstructing the observed geological structures without variants.

To avoid the cardinal mistake that is usual for many geologists, it is necessary to draw the line between the actualism as a principle and the actualism as a method. The principle is, generally speaking, a postulate. And it is impossible to discuss whether to accept it or not. We have to accept it, because the refusal of this postulate is a fruitless declaration giving us nothing. As far as the geological processes are concerned, we search for the analogues of the present in the past. And the discussion about actualism as a principle reminds us of the discussion on parallel lines in Euclidean geometry. Actualism as amethod is an algorithm in our specific geological activity. Probably, it would be more correct to speak not about a method, but about methods, because in applied geology these methods, although having a common basis, are nevertheless different enough. There are various schemes of description of sequences of operations necessary for methodical realization of the principle of actualism, but all these schemes are very imperfect. To my mind, all difficulties associated with the creation of these schemes are caused by the situation that the space–time problem of geology is not resolved till now. Therefore, the solution of the problem of "space–time" remains asan urgent problem for modern geology.

We can approach nearer to the solution of the problem of "space–time" in geology only by resolving specific geological problems. At the present time, development of the "space–time" basis of geology proposes at least five groups of these problems:

- Investigation of the physical sense and properties of the geological "space–time".

• Investigation of the stability of space and time scales and their relationship.

• Synchronization of the geological clocks.

• Development of principle of actualism on the space–time geological basis.

• Further elaboration of the foundations of the geohistorical method (the development of actualism as a method).

1.3. Simulation as a Method of Investigation.

Consider a game. There are many different objects of the interior in a room: furniture, pictures, vases, and so on. The players survey the room for about a minute. Each player must enumerate all items of the interior that he or she can remember. At first sight, it is a game to check the attention and memory. But in reality, the description of what was seen is more than only an exercise for these capabilities. Enumerating the items of the furniture, the players reproduce in their mind the room interior by creating the most subjective and private images. In this way the player simulates the room. And the listeners to the enumeration create their own subjective and private images, i.e., they also simulate the room. This play quite precisely illustrates the process of cognition of the world around.

Cognition by way of simulation.

In its most general sense, a simulated model provides a framework for organizing or structuring a study of the natural phenomena. The word *model* is akin to the word *mode*. In mathematical statistics, *mode* is the most frequent value in a statistical array. Let the price of garments be its indication. We can state that only a few people, who are very rich, can afford haute couture and only a few people, who are very poor, wear the rags. And what is worn by most people makes a mode of fashion, i.e., norm.

Nobody can produce an absolutely exact copy of the real world. For this, it is necessary to comprehend all the diversities of the real world's traits, while having such a copy is senseless. To comprehend the world around, it is enough to have certain schemes or even the grotesque, cartooned pictures. Therefore, instead of the originals we can use ersatz as an imitation of the real world. Astonishingly, very often the more caricatural and simplified the imitation, the better the reproduction of the object's gist, hence more useful for science.

Ersatz substitutes the original.

The procedure of constructing ersatz is *simulation*. What is the mechanism of this procedure? Nobody knows it exactly, although everybody can simulate. It can be said that the ability of simulation is our natural gift. Is it possible to improve this ability? Yes, it is possible indeed, like many other of our skills. To do it, it is necessary at first to determine the basic stages of simulation. Approximately, they are the following:

observation → determining the model → abstracting →
→ formalization → simulation → testing

Observation is a process of obtaining information. It can be the glance of a child, the work of a modern telescope, a book, someone's story, and so on.

Determining the model is the decomposition of the informational signal into the portions and selection of its strongest component, which can be juxtaposed with making an *impression*.

Abstracting is a transformation of a model to any generalized image. The loss of association with the real object stipulates the transition to a new area of the informational field, to a realm of certain symbols.

Formalization is binding the abstraction to a certain form. It is the creation of a symbol.

Simulation is constructing some structures from symbols, copying the real object or phenomenon, producing its ersatz that demonstrates the *essential* part of the original informational signal.

Testing is the comparison of a model with real object and making a decision concerning what to do next: Accept the model, improve it, or reject it.

Of course, the given scheme is conventional enough, since it splits a single whole that cannot be split because it has neither beginning nor. To be able to observe and see, one needs to possess some a priori knowledge. The level of our knowledge grows as a result of the accumulation of experience, advance in education, and so on. For example, we arrive to the outcrop of the rocks at a steep seashore or at a river valley. Everybody perceives here his or her own. A common person can see a cliff, an artist can see a certain pattern of colours, and only a geologist can see the alternation of the rock layers and conditions of their bedding.

However, to recognize the rocks one should understand the meaning of special terms, know their classification and, of course, distinguish the sand from clay, limestone, or marble; the knowledge of many other things is also needed. In other words, to be able of seeing nature, it is necessary to operate with abstractions (in our case, in the form of classificatory symbols) and at least have the primitive model perception in the form of such notions as bed, boundary, thickness, and so on. All this information is given at geological faculties of universities.

Let's exercise the geological theme on a very simple example that must be understandable to everybody who remembers a little the school programme on natural history and geography. We pick up a rock specimen, which the well-known geological classificatory indications allow one to recognize as quartz. At once we find ourselves in the sphere of abstraction: A particular specimen is labeled with a generalized term used for all types of quartz. Then we investigate this abstraction on the basis of a logical scheme, also abstract, that must correspond to certain requirements. For the sake of convenience, in their practical work geologists often use, instead of the word quartz, the symbol Q, or the chemical formula of silicon dioxide SiO_2.

Symbols Q and SiO_2, like the word quartz itself, both are formalization of an abstract notion. Symbolism of Q is not identical to symbolism of SiO_2. The first designation is just a substitution of the word quartz by the capital letter Q, whereas the designation SiO_2 is not a mere substitution. SiO_2 is a model itself, the one that uses chemical symbols. The model SiO_2 represents our notions on the properties and genesis of this specimen as a representative of a certain class of chemical compounds. The real specimen of quartz that we are holding in our hands differs essentially from pure silicon dioxide: It is characterized by the presence of admixtures, structural defects, and other special features. Thus, from the example with quartz we can conclude that symbolism of the models may be naught, i.e., not bearing any content (like the designation Q), or based on the models of another origin (designation SiO_2). The latter cannot be considered as naught.

A written formula of a chemical reaction with quartz is a model of a real process. Abstracted quartz participates in this reaction — not our real one. Although, in principle, our specimen can work in such reaction.

The chemical reaction is a product of our definite theoretical notions formed as a result of generalization of our experience and some a priori knowledge. Following the example with quartz, we can construct many different models: social, professional, and so on. Despite this, it is clear that *the beginning and the end of a model are rather vague notions to define.*

The fixation of the beginning and the end is always conventional and determined by the specifics of practical purpose.

Analysis of the process of cognition reveals that we usually operate with two levels of simulation: *conceptual* and *working.*

The *conceptual model* is a basic scheme reflecting our very approximate and, as a rule, intuitive concepts about real object or phenomenon. Conceptual models, being the mental image of a natural phenomenon, are based on the observations and serve for expressing some segment of the real world in an idealized form. In essence, it is only a hypothesis that determines the type and direction of all our further work. It defines the circle of parameters and the type of their relationship. These parameters are to be measured and the expected results estimated. Without such model, it is impossible to start working because it will be unclear *what, how and for what purpose to measure, how to estimate the volume of the whole work, what precision is necessary,* and so on. For a well-developed conceptual model, we obtain the final result faster and with better quality. Very often, especially in the process of scientific explorations, specialists work with several models simultaneously. Then, after estimation of the correspondence of models to the results of observations or experiments, some of the models are rejected, while the others can be corrected. There is an essential difference between the engineering and scientific work. Engineers exploit ready and revised models; scientists create models.

The conceptual models can be both qualitative and quantitative. The physical clarity of the conceptual models and clear elaboration of their axiomatics are the matter of principle for most problems concerning the material world, and for these problems it is good to accept the advice of John W. Tukey (Ann. Math. Stat., vol.33, p.13, 1962):

"Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made precise".

This recommendation emphasizes the fundamental implication that the efficiency of understanding the world in general and specific investigations in particular depends on the definition of the problem. The problem definition consists not only and not as much in formulating the problem as of the scheme chosen for its solution, i.e., the conceptual model. The development of this model is a gist of the definition of the problem.

The *working models* are the result of the detailed investigation of the chosen conception. Just these models allow us to find a specific solution either in the form of statements (qualitative models), or in the form of numerical data (quantitative models). For example, the question about whether a region is seismically dangerous may have a qualitative answer "Yes". The confirmation of this answer may be the results of comprehensive geological explorations and the seismic maps made up on the material of the explorations. If in the process of these works the areas of most seismic danger are outlined, then a quantitative estimation can be given. This quantitative answer is confirmed by the exact figures, namely, by the geographical coordinates, dimensions of the areas, seismic records, and so on.

By their form, the conceptual and working models can be classified in different ways. These classifications themselves are models to be determined by the rules of the division and grouping. As an illustration, consider the classification of William C. Krumbein and Franklin A. Graybill (with some author's additions and contractions).

Diagrammatic models. It is a table, scheme, or graph. In geological practice, these models are used very widely, as maps, sections, profiles, and so on.

Deterministic models. These show the cause-and-effect relationship between the parameters, when for measured or defined arguments the functions take certain specified values. These models are usually said to describe the events with absolute memory.

Statistical models. These propose the absolute absence of the cause-and-effect relations, and create ersatz based on the assumption of the existence of the processes without memory. A statistical model is a mathematical expression involving mathematical variables, parameters, constants, and one or more random components due to fluctuations in experimental data.

Statistical models can be derived from deterministic models by including the random components explicitly.

Stochastic models. These describe the object or process in terms of probability, that is, not the event itself, but the probability of its occurrence.

The term *stochastic model* is essentially synonymous with *statistical* model, because each of them contains a random component. A statistical model has one or more random components related to measurement error, equation error, or to the inherent variability of the objects being measured, such as the actual differences in shape, say, of a handful of pebbles. A stochastic model, which may contain similar random effects, has in addition a built-in specific random process that describes the phenomenon on a probability basis. In stochastic models, an investigated phenomenon is exactly determined at any fixed point of time.

Algorithmic models. It is a special type of models. Usually, these suggest guitea quite a complicated description of the behaviour of an object, or a process. This description includes many sequential operations, often implying other models.

Thus, it is possible to agree that the same problem may have solutions based on different models and expressed in different terms. It is useful to recollect here the well-known dictum of Niels Bohr that for the same group of objects, an infinite set of the equally true theories may be created. It remains only to come to an agreement how to estimate their truthfulness. But about that a little later.

The world is perceived by humans through the procedure of simulation. Apparently, this method is the only one at people's disposal. And nowadays this method of cognition has been developed well enough. The following scheme gives the best guarantees:

1. Formulation of the problem. We determine what we actually want.
2. Statement of the problem. Construction of the conceptual model, one or several.
3. Construction of the parametrical base for the model chosen: what should be measured, how to measure, and so on.
4. Field investigations. Observations, measurements.
5. Revision of the model in accordance with the results of field investigations.
6. Exploitation of the model (testing) and decision-making.

In case of positive results, the model is accepted. Otherwise, the procedure of simulation is repeated again. For this reason, the investigators work with several models simultaneously.

The closedness of the procedure of simulation is especially important. Just *closedness* as iteration, as a process with a feedback allows for permanently acquiring the information at qualitative and quantitative levels. Every iterative cycle, from the statement of the problem (item 2) to the testing (item 6), accumulates the information. From cycle to cycle, the quality of information improves, because every iteration takes place with due account of the previous experience and errors.

The scales of these cycles could be very diverse: from the solution of partial problem to the level of paradigm. Here is an example.

In 1829, the outstanding French physicist Dominique F.J. Arago wrote about weather-forming that *"Atmospheric machine for pumping out the water is an irreproachable mechanism and its discontinuous work doesn't present any inconveniences"*. More than 100 years later, Russian academician Vasiliy V. Shuleikin, investigating the physical basis of the climate and weather forecasts, began to develop ideas about the working principles of natural thermal machines. Following Shuleikin, the geologists and geophysicists began to develop the idea of thermal machine. They put forward the idea of Earth's thermal machine as a device with heater and cooler that produces the work.

There is one methodological subtlety having principal importance for the comprehension of the world and its laws. Arago derived his reasoning from his considering the nature phenomena as engineering problems. On the contrary, modern scientists go from the engineering achievements to the natural processes. Each way has its own starting point (prototype). For Arago, it is nature, while for Shuleikin and other modern explorers it is a set of technical devices. I have proposed another form of analogy, where both prototype and analogue are the natural phenomena: There is no need to compare nature with a machine. It is possible to compare various nature elements with each other by the criterion of their resemblance to a thermal machine.

The humans, like dual-faced Janus, look both to nature and to their own creations simultaneously.

The humans borrow the technical ideas from nature. Then they make experiments with them, interpret results, and come back to nature again to take the new and the newest ideas using more and more refined methods.

To acquire the information, humans constantly put it into circulation.

Living creates the living, money make money,
and information makes information.

All this resembles the circular flow, rotation of procedure.

SIMULATION IS A MECHANISM OF INFORMATION CIRCULATION AND ACCUMULATION

1.4. Objectivity and Truthfulness

As we have seen, creation of a model is a procedure exceptionally subjective. Therefore, demanding the objectivity from the model is, at least, not correct. To my mind, the concept of objectivity itself is an ideal that cannot be achieved due to the very essence of the ideal. The reality is sensed through the apparatus of specific parametrical perception and because of this reason the reality is illusive for every observer. *Objectivity exists outside the observer.*

In real life, we can give the estimation to the facts without asking who and how obtained them, and without thinking about so-called mete-wand, standard estimations. However, standard estimations are very important. The people have their own and much different standard estimation, which makes understanding each other very difficult.

Regretfully, even the official science rather often forgets about it. And scientific discussions often debate not the axiomatic base, but the conclusions and estimations of the observations. Consider the well-known discussion between the supporters of inorganic and organic origin of the oil, or the discussion on origin of glacial deposits. There are two viewpoints about the glacial deposits: Are these the result of glaciation, or were they brought by the calved ice? Who is right?

Unfortunately, very often that expert is considered right who is more assertive and due to this circumstance *can make his opinion to be public* or *takes the public opinion for his or her own.*

Estimate now the humour of the famous American physicist Clarence Darrow, who gave such characteristic to the theory:

"The theory is an intellectual cathedral erected for the God's Glory and giving the complete satisfaction to both the architect and an onlooker. I am not going to proclaim that the theory is the reflection of reality. The word 'reality' frightens me, I suspect the philosophers know exactly what this word means while I don't know, so I can say something that could hurt them. Nevertheless I am not ashamed to say that theory is a beautiful construction, because the beauty is a matter of taste. So here I am not afraid of philosophers".

All quoted above certainly concerns models as well. Models are intellectual constructions too and if they are not the cathedrals then at least they are the buildings for production activity and/or living in.

Darrow's understanding of the factual difficulty of the real world was very deeply-felt. That is why he always regarded the definition of theory with great seriousness, although not without a tinge of joke. It is difficult to say better or not to agree that *theory is a cultic construction for performance of intellectual necessities of life.* This Aesopic-languaged definition reproduces the modern requirements to any theory or model that were long ago formulated by Albert Einstein as principles of *internal perfection and external justification.*

The internal perfection is the beauty. The *minimum of antecedents* and *maximum of consequences* are the most important features for scientific beauty. We can estimate the beauty or internal perfection of a theory or a model by these quantitative characteristics.

The requirement of beauty allows us to draw a clear demarcation line between the hypothesis and the theory. Both hypotheses and theories show a good agreement with the observations and experiments that allows us to forecast the future and reconstruct the past. However, hypotheses the theories have different number of antecedents and consequences. Only a hypothesis with minimum antecedents and maximum consequences could be considered a theory. Of course, it remains a theory only till the moment of the appearance of a new, more beautiful intellectual construction.

Recently, additional requirement has arisen, about the *falsifiability* that probes the theories for being scientific. *A scientific theory can be at* *the same time scientific and non-scientific.* It is not difficult to understand this paradox.

Having minimum antecedents and maximum consequences is the necessary condition for a hypothesis to be a theory, but it is not sufficient. The theory is dead if it explains everything we know today but nothing more. In this case, the theory formally closes the idea of research and augmentation of our knowledge, hence our experience as well, which does not allow to advance our comprehension of the world around. If in explaining all known facts and observations the theory allows us to make the risky prognoses and steps to the unknown, then the theory is scientific — only in this case. A really scientific theory states new tasks and problems, and makes the process of knowledge to be ongoing.

When analyzing what we can consider as theories, we a re concern ed about their *verification.* It is nothing else than the agreement of the theory with the observations and experiment.

Suppose an experiment (observation) is consistent with a theory. This fact gives to the theory the right of life, although no more. And certainly it does not mean that the theory is true. It is not excluded that tomorrow somebody will find new data that disprove this theory. According to the remark of the American physicist Richard P. Feynman, science is permanently concerned with the denial of itself. And it is absolutely normal. Developing this theme further, he affirms that the experiment must be clean, i.e., must represent the reality correctly, without any distortions. So the question on the *truthfulness of experiment* is raised here. It brings to mind the adage *"Who are you to judge?"*

In search of the truth, we ourselves are catching our own tail. Consider some examples.

- Everybody can watch the sunrise and the sunset, i.e., the motion of the Sun. The Moon also appears on the horizon, moves across the sky and then disappears. The observations show the movement of the celestial bodies around the Earth. During the ages, the people believed in it. According to this theory, the ships laid their courses and always arrived to the seaport B from the seaport A successfully. However, later it became known that the remarkable geocentric theory of the Universe structure is only kinematical and its agreement with observations and experiments doesn't represent the real motion of the Solar System bodies. The geocentric theory was not based on the dynamical laws of motion. There was no gravitation law to take into account. Only in the 16th century the heliocentric system of the Universe replaced the geocentric system.

• Another illustration, at first seeming very simple. There is a graph in Fig. 1.4, showing the possible dependence of oil content in the soil,

DISTANCE from the derrick

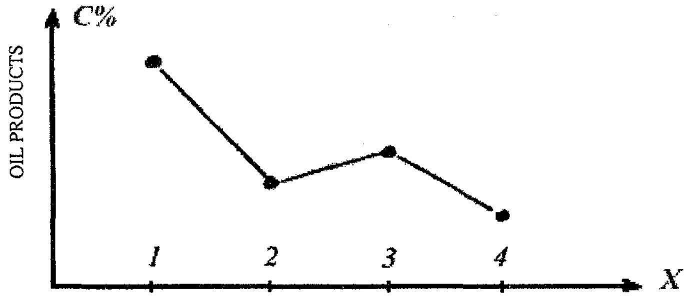

Figure 1.4. The illustration of the linear interpretation of observations. 1, 2, 3, and 4 are the points of observations.

along the direction X, some distance away from the oil derrick. Along the X axis, samples of the soil were taken and then analyzed for the total content of oil. The points on the graph exactly correspond to the results of laboratory analyses. Constructing the graph, we assume that the relation between the variables X and C is linear within the point-to-point intervals. Having assumed the dependence to be linear, *we fall within the realm of the belief*. We don't know, which it is indeed. In reality, the situation may be very different. The graph $C = C(X)$ may be not piecewise linear, but have any convex or concave configuration; it is also possible that between the points of observations $C = 0$. In the last case, the oil products were not accumulated along these intervals.

But what is the truth? Only God knows it. It is impossible to give the exact answer. We can say that the points on the graph reflect the real facts within the accuracy of the topographic base and the precision of chemical analyses, made in accordance with certain chemical methods. By using another method of analytical chemistry, we could obtain another value of the oil content. On the graph, we can see only some random variables. So the truth remains elusive. There are many examples of this kind.

We may quote the response of Professor James L. B. Smith to the newspaper article about his finding of the Coelacanth Latimeria.

In 1836, Louis Agassiz discovered a fossil fish and called it Coelacanthus (from Greek *koilos* — hollow, space; *akantha* — spine). The discovery was important, because this species spanned a "missing link" in the story of evolution: It gave rise to amphibians, terrestrial reptiles, birds, and mammals. Coelacanths were found in the sedimentary layers from the Devonian till the end of Cretaceous period and were never met in younger layers. Until quite recent time, these observations encouraged the scientists to affirm that coelacanths disappeared by the end of the Mesozoic era. Yet this statement was unknown to the inhabitants of the Comoro Islands and Madagascar who caught this fish and ate it with great pleasure under the name "gombessa".

The first living coelacanth known to the scholars was by chance netted near the South-Eastern coast of Africa, not far from East London, in 1938. The second "scientific" coelacanth was found by Prof. Smith near the Comoro Islands only 14 years later, in 1952. The "living fossil" caused a great sensation as the sole survivor of a line of development that otherwise became extinct.

Very convincingly, this discovery demonstrates that in geology, all the timing based on the palaeontological findings gives only the event boundaries and can be considerably shifted along the astronomical time axis. So the truthfulness of this timing is also event-dependent.

Prof. Smith strove to find and catch the Coelacanth during 14 years and certainly understood the fundamental significance of his discovery.

There was an interesting dialogue between Smith and the editor of an East London newspaper. The editor asked whether the Professor was sure that the East London exemplar (the first that was netted in 1938) really was Coelacanth. Smith dryly answered: — *No.*
The editor exclaimed:

— *No! How could you say then?..*
— *I didn't say so,* — Smith remarked. — *I have said, and I keep saying that as far as I can rely on my knowledge, experience and observations, I can judge that it is a real Coelacanth.*
To the next question of the editor: — *What is the difference?* — Smith answered:
—*If you show me a flower and tell me its colour is blue then I'll answer I should say it is blue, instead of definite "Yes".*

I hope you felt the subtlety. There are neither any absolutes nor any assertiveness. "Yes" or "No", but *always under some conditions.*

So we are moving along a certain circle. To prove the truthfulness of a statement, we use definite criteria, primary standards, whose correctness we should also prove. And so on, without an end.

The way out of this situation is the only one:

It is necessary to accept something as the truth without any proofs and preliminary conditions.

Recollect the scene of the talk of Berlioz and Voland from Bulgakov's *"The Master and Margarita"*:[*]

— *Bear in mind that Jesus did exist.*

— *You see, Professor,* — Berlioz responded with forced smile, — *we respect your great learning, but on this question we hold to different point of view.*

— *There's no need for any points of view,* — the strange professor replied, — *he simply existed, that's all.*

— *But there is need for some proof* … — Berlioz began.

— *There's no need for any proofs,* — replied the professor…

Well, it is all about the religion as you may remark. And I'll answer to this:

— *With science, it is the same thing* ...

In conclusion to the theme of this section, we'll discuss the problem of *proofs*.

Science knows a notion of the *legislative truth* or the *truth by convention*. Actually, it relates to the *invention of a truth*. The process of invention takes place in accordance with the clear and well-defined scheme that the mathematicians call *proof*. It is a principal notion in mathematics. Special literature gives a detailed and rigorous description of the proof procedure. This procedure includes such elements as axiomatics, logic, and function of the separation of the proven statement (see *Section 1.1*).

The method of obtaining the legislative truths represents, accurately enough, the modern concept of the algorithm as a procedural prescription:

- For every algorithm, it is necessary to indicate an alphabet of initial data, so that all possible initial data are the words in this alphabet.
- It is necessary to create the alphabet of the results. All the results are words in this alphabet.

Thus, before you obtain a new truth, you have to discuss the deduction and your own doctrine on your world outlook with your opponents, and gain their agreement to your statements. After that, your opponents must not debate your inferences. Certainly they may examine your process of deduction to check whether you made any mistakes, but no more. Your inference will be a *new truth*, although invented. And this

[*] Michael Bulgakov. *"The Master and Margarita"*, Penquin Books, 1997.

truth remains truth even if somebody cannot understand it, or dislikes it, or considers this truth too fantastic. It is the truth by convention.

In everyday life, the ideology of proving looks outwardly different. Using the same arguments, you can prove the validity of your truth to one person and cannot prove it to another. Why can it be so? The key to this puzzle is the difference between the Weltanschauung and the deduction system of your opponent and your own. To accept your arguments and understand the validity of your truth, your opponent needs to accept your Weltanschauung and deduction system beforehand. So first you need to change the belief of your opponent. There is an English proverb: *"When in Rome do as Romans do"...*

To close the reasoning on the objectivity and trustfulness, I'll give a quotation from a monograph on geology:

...in reality, a considerable part of geology is a fruit of our imagination. When we say "The observation shows the Earth has a dense nucleus with a radius of 3,400 km", *this means that on the basis of a great number of estimations, mainly, the data on the seismic waves propagation time, we can surmise that the Earth has a nucleus. But nobody saw the Earth nucleus, neither did anybody see an electron.*

Also nobody saw tropopause, stratopause, and a great number of other things. Our truths are *ours* indeed. As a matter of fact, they are only *our interpretations* made with the aid of certain deductions.

1.5. The Systems and the Laws

By the term *system* is meant some degree of order, certain logic of relations between the objects, phenomena, or elements of a set that we consider as a whole. Mendeleev's Periodic Table of Elements is the classical illustration of system.

Due to the peculiarities of human mind and its predilection for the harmony, the humans strive for the systematic perception of the world around based on subconscious cause-and-effect postulates. It is the determinism that is the basis of any religion — the idea about God as a prime cause of all reality. Even elaborating the ideology of stochastic or random events and processes, the people created the probability theory and mathematical statistics, constructed the equations and criteria, and so on, which represents a certain logic and rules, i.e., attributes of the system.

Various classifications of the natural objects and processes are also examples of systematization. The systematization depends on the aims and tasks set. The classification of rocks is a good example of the approach to systematization. The geologists investigating the structure of the Earth and the origin and distribution of mineral resources divide the rocks according to their genesis into three groups:

- Magmatic rocks (granite, basalt, gabbro, etc.)
- Sedimentary rocks (sand and sandstone, clay, limestone, etc.)
- Metamorphic rocks (gneiss, schist, marble, etc.)

Each of these groups has many subgroups featured with their own chemical and mineralogical composition, structure, texture, and other attributes.

Engineering geology investigates other parameters of the rocks, i.e., ultimate strength, water permeability, creep strength, and so on. All these properties are essential for various construction works when hydroelectric plants, enterprises, and houses are being built. And for these tasks, another classification system was created:

- Solid rocks
- Soft rocks
- Pressed rocks
- Incoherent rocks

There are no genetic types in this classification. Other parameters are essential here. So one group can include granite, gneiss, schist, sandstone, or even limestone with strong cement.

Examples with different classifications of the rocks help us comprehend the following questions:

- Do the systems objectively exist in the nature, so that the humans only discover them?
- Or maybe there are no systems in nature, and humans fabricate them to make the procedure of understanding the world easier?

It is not easy to answer these questions. The answer may be ambiguous. Look at Fig. 1.5. There are lots of spots on the picture: White ones are the snow and black ones are the ground. At first, you can see only chaos of the spots. Then, after you have found an order or, more exactly, constructed it in your mind, you will see the face of Jesus Christ. And then it will be impossible for you to return to the chaos in the picture. You will continue to see the face of Jesus Christ. It will be so despite any picture rotation. The image of Jesus Christ is fixed in your memory.

Figure 1.5. A photograph of thawing snow (from the book "Models in Geography")

I brought this photo to the lecture hall and showed it to my students. About 20% of them at once saw the face. Most of the students needed some time to find the image. Approximately 10% of my audience spent much time but could see nothing except chaos.

Everybody has seen the clouds in the sky, scrutinized the frost designs on the window-pane, combinations of different spots, and so on. You remember that you could find there animals (real or fantastic), trees, flowers, figures of people, different faces. Nobody drew these images. You fancied them yourselves. But why can you see only familiar images? Certainly because you cannot imagine anything else. You cannot think about things that are not existing in your own memory or memory of other people. We can make inventions only according to our ideas and notions that are in our mind. We take all we can imagine from our own memory or memory of our ancestors.

The system is an embodiment of the idea of integrity. Talking or thinking about natural systems, we mean only their integrity, realized through an interaction. This integrity is constructed in our mind and can represent some features of reality. The quality of such representation is determined by ourselves, although our own ideas about the real absolute are quite vague. Reaching the absolute is only making a copy that we are unable to make. A skilful painter can produce replicas of the canvases of Shishkin, Repin, Rembrandt, Cézanne, but even the most outstanding painter cannot create the absolute of a landscape or human face. The most outstanding painter is only a copyist, maybe the greatest among the other people, but a copyist anyway. The man is no more perfect than God. And this is the truth.

Recollect the story of creating the model of atom. During many centuries, an atom was considered indivisible and this model was accepted as truthful. Then, however, Joseph Thomson (1903), Ernest Rutherford (1911), Niels Bohr (1913) created more and more complicated models of atom. Is there an end or not? Is the model of atom, which at the moment rules over the science development, so flawless and perfect?

Man always created the systems as theoretical constructions. But a system boom began in the 1970s. All scientific circles started talking about systems, system approach, and system analysis. Why did it so happen? Probably, the hour of the system methodology struck when specialists understood that it had become necessary to construct systems not spontaneously, but strictly following certain rules. And these rules began to be formed.

There is an Oriental parable telling about three blind men who could not come to an agreement about what an elephant looks like. The first man was convinced that the elephant resembled a snake, because he could put his arms on its trunk only. The second was sure that the elephant was like a broom, as he kept its tail. The third argued that the elephant reminded him of a pillar: He touched the elephant's leg. Certainly they all were wrong, and the reason of their mistakes is easy to understand. Each blind man could only rely on his own sensuous experience that helped him recognize only a part of the animal (leg, tail, or trunk). Besides, their opinions rested on the wrong premise that the elephant must resemble only something alreadyknown to them.

This simple parable raises and illustrates at least two cardinal issues of scientific cognition: about the integrity of the object to be investigated and about the validity of our notion on this object.

At present, there are many conceptual definitions of a system, and all of them, in the methodological sense, can be reduced to the identity:

systematism ≡ integrity

The process of cognition is essentially a controversial one. It is procedurally connected with seemingly irresolvable paradox: To cognize means to decompose, to decompose again, and… to continue the decomposition. Yet nobody can say where is a limit when we need to terminate this process, which means the refusal of the idea of integrity, the loss of wholeness.

The real depth of this paradox hides, as one can suppose, in the law of spontaneous information growth. There are many examples supporting this assertion. Consider the situation a little more thoroughly. All the history of science consists of periods of its spontaneous differentiation, i.e., the number of scientific disciplines increases constantly. The same process takes place in religions. Consider the Christianity. It originated from the single indivisible doctrine brought in by the Messiah. But nowadays, there are many branches of Christianity: Orthodoxy, Catholicism, Protestantism, and so on. The Cross is a sign common for all these religious fractions. However, they differ from each other. And the process of divergence of religious views continues spontaneously, by itself and without any special efforts.

To gather the sprawling-away knowledge into a single whole, great efforts are needed, great energy expenditures, and even great sacrifices. The idea of monotheism — the only God (not the chief of gods, like Ra or Zeus or Odin, but just single God) was inculcated long enough and not without difficulties. The new Physics and Mathematics trying to collect a single whole from all previous achievements in diverse branches of the sciences had also to walk a very hard way of their coming into being.

The author supposes that system methodology appeared as an idea to create the principles and, if possible, the apparatus for reconciling the contradictions of the cognition process:

• *How it is possible to decompose without destroying the single whole*

• *How it is possible to control the process of natural differentiation while preserving the single whole*

The integrity of the object, from the viewpoint of system ideology, consists of its internal and external connections, which lets us consider the object as a complex set. This set allows for essentially different decompositions provided that the object is non-additive relative to these decompositions.

The problem of parameters, additive and non-additive, arises here. The gist of additivity is the following:

• For additive parameters, say, a_i, the following condition is valid:

$$A = \Sigma a_i$$

This means that the sum of values of properties of separate elements of the object is equal to the value of the property of the whole object (A). For example, one kilo of apples is equal to the sum of the mass a_i of all the apples from this one-kilo pack. Instead of mass, we may deal with weight; it doesn't change the situation, which implies the absence of interaction between the masses or weights of the separate apples. It is better and much more exact to say that this interaction is not fixed at the level of our interests. Thus, the set of apples, if their masses or weights are considered, cannot be a system.

• For non-additive parameter, say, b_i, this condition is not valid:

$$B \neq \Sigma\, b_i$$

This means that the sum of values b_i of properties of separate elements of the object is not equal to the value B of the property of the whole object. As an example, we may again take that pack of apples, but now consider the temperature of each apple. It is a non-additive parameter: Suppose our set consists of 5 apples and the temperature of every apple is 10°C. It is natural to conclude that the temperature of the whole set is also 10°C, but not 50°C as the condition of additivity would require. So it is indeed, because as far as the temperature is concerned, the interaction takes place among the apples and also between the apples and the environment. Thus, by the temperature variable, this pack of apples is a system.

Functioning of the object and its development manifests itself just through the communicational connections. Therefore, the communicational connections, which we have defined through interaction, determine the integrity and systematic character of the object. Thus, to succeed in constructing the system in its modern understanding, it is necessary to take as components such elements of the object that are non-additive, i.e., the sum of their properties is not equal to the property of the whole object.

Humans create intellectual images of the real world: empirical observations give rise to the whole chain of notions already known. The interaction between various connections determined by these notions destroys the bulk of the minor-importance associations (information noise) and creates one specific image based on the main notion. This image is always abstract and subjective due to its being derived from selected information only, i.e., from the information useful for solving the problem formulated.

The system approach is a methodological principle that implies the endeavour for discovery of the internal essence of an object, but doesn't give any single formal apparatus to study this object. In each particular case, methods of formalization and solution can essentially vary and depend only on the problem, which the investigator is interested in. However, the system approach puts forward a number of requirements:

- Precise definition of the object boundaries
- Determination and analysis of the system-forming connections and the ways of their functioning
- Choosing the mechanism that describes the existence of the object, its evolution, and reproduction

The implementation of these requirement allows us to construct a model of the object. This model, being only a theoretical and as a rule very abstract scheme, reflects the reality in an abstract and conventional form. Nevertheless, it facilitates the perception of reality and gives the opportunity to predict and control it. We perceive the objective reality in a subjective way and this subjectivity can be either "immanent" (we inherited it from our ancestors) or "acquired" (accepted from the existing knowledge). Any intellectual representation of the complicated natural objects (their complication is determined by the problem set in accordance with the general gnostical principles) is no more than a conventional scheme, which can satisfy us only until the moment when the approximation accuracy of this representation does not suffice and we have to create a new model.

Thus, to both questions raised by the parable telling about the wholeness of the object of our investigation and about the truthfulness of our notions on this object, the science answers by representing the nature objects through various models whose approximation to reality is the best with regard to their internal perfection and external correctness. This means that the objectively conventional character of any model, including system models, must not prevent them from internal logic, consistency, accurate use of language at their construction, and correct parametric representation proven by the experiment.

SYSTEMS ARE INVENTED BY HUMANS.
HUMANS CANNOT INVENT WHAT IS NOT EXISTING.
ONLY THE MEMORY OF HUMANS INVENTS.

Now consider physical laws. In general, what do they mean? Do they exist in nature by themselves and humans only discover them? Or maybe man invents them as well as systems, supposing that a certain order and expediency are characteristic for nature, and by inventing laws they find only what they have searched for? It is hard to disagree with Richard L. Gregory who, investigating the perception of the world around us, came to a conclusion that *we not only believe to what we can see, but to some extent we also can see to what we believe.*

Well, one should like to ask, to what extent? Where is the limit of our belief? It is not difficult to understand that this question touches the deep layers of our investigation of interrelation of humans and nature.

We often talk about the objective and the subjective, opposing and juxtaposing them. We should agree with the opinion of Satprem, who wrote that it is not correct to oppose the objective and subjective. To him, the subjective is a higher and at the same time, only

a preparatory stage of the objectiveness, and our excellent 20th century is no better than the stone age as far as psychology is concerned... there are horizons of perfection, harmony, and beauty before us — compared with them, our most wonderful discoveries are similar to crude half-finished products of an apprentice.

The intellect is not the instrument of our cognition, but only the organizer of our knowledge.
The knowledge comes from the other source (Satprem).

From this statement, a conclusion follows — at first glance, a paradoxical one — that the intrusion of our mind inevitably leads to errors. Probably due to this reason, *the history of science is a history of our delusions.*

It is appropriate here to recollect the principle of uncertainty of Werner Heisenberg. According to it, any observation or measurement of parameters that does not affect these parameters is impossible. And if our mind is only the instrument organizing the information, then it is impossible to ignore the principle of Heisenberg in this procedure.

Our mind cannot leave reality undistorted.
Our mind is a great deceiver.

This deceiver is smart enough. It can disguise the ignorance pretending to be the knowledge, substituting the truth with falsehood, to which we promptly get accustomed. Here it is an example.

The energy responsible for ground water movement is provided by the gravitation force. Due to gravitation, water moves from areas where the water table is high to zones where the water table is the lowest. Ground waters, as well as oil and gas, migrate through the pores in rocks and sediments, forming the so-called discrete flow. The structure of this subterranean flow is hidden underground. We can neither measure it nor represent it in a geometrical form. However, we can measure the total cross-section of the rock, or layer (ω) which the subterranean flow passes as a set of different separate streamlets. And we can measure the flow rate (Q), i.e., the quantity of water or another liquid, passing through this cross-section per minute (see Fig. 1.6).

Dividing the flow rate Q by the area of the total cross-section, we obtain the velocity of the continuous flow (V). It is a filtrated flow, and velocity V is the velocity of filtration. But such flow is only imaginary and does not exist in reality. We have substituted a real cross-sections with small holes due to the cavities with a cross-section of an imaginary tube, and a real flow consisting of numerous streamlets — with a unified continuous flow in fictitious filtrating medium with fictitious value of hydraulic resistance (K), characterizing permeability of the medium.

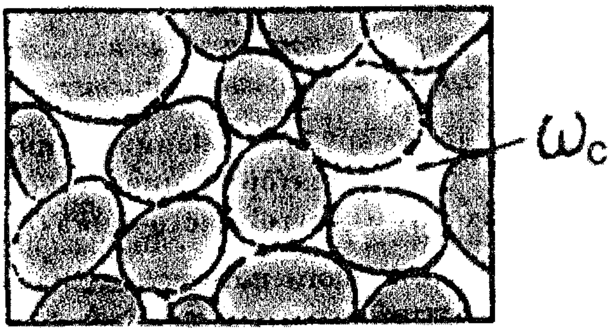

Figure 1.6. The scheme explaining the concept of filtration flow. ω_c is the area of cavities through which the water rills, ω is the total area of the cross-section (both cavities and mineral grains). $\omega_c < \omega$. The area of mineral grains, as waterproof part, is shaded.

The modern concepts of ground water movement were formulated in the middle of the 19th century. Henry Darcy, a French engineer who studied the water supply of the town of Dijon in France, formulated a law that now bears his name and is basic to understanding of ground water movement. Darcy found that if permeability remains uniform, the velocity of ground water increases as the slope of the water table increases. The water table slope, known as the hydraulic gradient, is determined by dividing the vertical difference between the recharge and discharge points (a quantity known as the head) by the length of flow between these points. Darcy detected a linear dependence between the velocity of water flow and the hydraulic gradient, which can be expressed by the following formula:

$$V = K \cdot \Delta H / \Delta X,$$

where V stands for velocity, ΔH for the head, ΔX for the length of the flow, and K represents the coefficient that accounts for permeability of the material. This formula is called the law of Darcy or the law of filtration.

The whole modern theory of movement of ground waters is based on this law, i.e., on the concept of an imaginary flow that does not exist in reality. It is possible to say then that the law of filtration is a fiction, tremendous bluff.

But the most surprising thing is that this bluff gives method to solve many practical problems. It agrees well enough with the results of observations and experiments, although this agreement is not absolutely perfect, a certain discrepancy in velocities is registered.

Thus we can see that our great deceiver, i.e., mind, is really smart.

As a result of the consideration of our attitude to the laws of nature, it can be said that

IF THE MIND IS THE ORGANIZER OF INFORMATION, THEN THE LAWS ARE THE MOST COMMON PRODUCT OF THIS ORGANIZER.

QUIZ

1. Explain the gist of Gödel's theorem.
2. What is the gist of the quantum paradigm for the course of Geophysics?
3. What is the difference between uniformitarianism and actualism?
4. What is the gist of the rotation of informatiom?

5. Tell about the principle of falsifiability for scientific theories.

6. What is the difference between laws and dogmata?

What do they have in common?

7. Formulate and disclose the sense of the principal requirements to objectivity of models (by Albert Einstein).

8. What is a legislative truth?

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There is no logical way to the discovery of these elemental laws.
There is only the way of intuition,
which is helped by a feeling for the order
lying behind the appearance.

Albert Einstein

2.1. The Universe

On the question "The Universe — what is it?" it is better to say nothing. But if you need an answer you may say that the Universe is everything around us. However, this answer is also not definitive. Many other questions arise: about the dimensions of the Universe, about its nature and structure, age, and so on.

The article of the Great Soviet Encyclopaedia says: *"The Universe is a whole world, without any limits in time and space, with infinitely varied forms that the substance takes on during its development. The Universe exists objectively and independently from the consciousness of the humans investigating it. The Universe contains a gigantic set of celestial bodies, many of them have dimensions that are much more than the Earth, sometimes in many million times"* (vol. 5, p.1315, M., 1971).

According to this canonized definition, the Universe is infinite, i.e., has no beginning. The material bodies that constitute the Universe are located in infinite space and the materiality of this space is not to be discussed. Here, it is very important to underline that our notion about the Universe and its structure is the extrapolated Universe. We identify it with the Metagalaxy accessible for our investigation. At present, the concept of Metagalaxy cannot be considered as well developed. In fact, the Metagalaxy is the whole cosmos, or only its part that is available for instrumental survey. The concept of the Metagalaxy's infinity in time and space is an institutional and a rather artificial postulate.

The contemporary estimations of the age of the Metagalaxy give about 15–18 milliard years. Before answering the questions: *How were these estimations obtained* and *Which physical processes are behind the them*, we need to consider some characteristics of the Universe or, more exactly, only the Metagalaxy, i.e., the part of the Universe, available for the survey.

At the present stage of the Universe evolution, its substance is clustering mainly in the stars. However, the stars fill up only about 10^{-25} of the whole volume of the Universe (without the nuclei of Galaxies). The stars' formation from the condensing interstellar matter is a secret not revealed till now. The everlasting process of hydrogen transformation into heavier elements, mainly helium, can indicate the irreversible character of the evolution of the Universe.

The astronomers of the 18th–19th centuries considered the interstellar medium as absolute vacuum. But at the beginning of the 20th century, the German astronomer Johannes F. Hartmann proved that the interstellar medium is filled up with very rarefied gas. The modern achievements of astrophysics allowed to obtain the quite comprehensive knowledge on the density and chemical composition of the interstellar gas, though only for those zones of cosmos that are situated at a comparatively short distance from the Earth. The distribution of the interstellar gas is very irregular. There are both high-density areas (ten times more than the average density), named clouds, and the areas of scattered gas molecules. A perfectly regular global alteration of the average density is also observed. Around the plane of our Galaxy, the average density is about $(5\text{–}8)\cdot 10^{-25}$ g/cm^3 and it decreases rapidly along the direction to the periphery of the Galaxy. Although of a very low density, the interstellar medium is not vacuum.

We can consider a medium as vacuum only if the length of the free path of a particle within it is greater than the dimension of the volume of this medium. The average value $(5\text{–}8)\cdot 10^{-25}$ g/cm^3 is related to the layer with thickness about 200 parsec and the mean free path of a particle in it is estimated as 10^{15} cm ($3\cdot 10^{-4}$ parsec). Thus, the central part of our Galaxy cannot be considered as vacuum and the interstellar gas here should be considered as a compressible medium — continuum, to which the laws of gas dynamics are applied. This interstellar gas can propagate the waves and is involved into complex turbulent movements.

Hydrogen and helium are the dominant chemical elements of the interstellar gas, which is close to the chemistry of the atmospheres of the Sun and other stars. Recently, however, essential differences were found, mainly in the content of magnesium, manganese, chlorine, and carbon compounds. Interstellar gas contains the chemical elements in the form of atoms and ions. There are molecules as well, but only in modicums, about 10^{-7} % of the content of the atoms of hydrogen. Among these molecules, the carbon compounds are discovered, such as CH, CH^+, CN. There are also molecules of hydrogen, whose proportion varies on a large scale (from several tens to 10^{-7} and less).

Besides the gas, the interstellar medium contains the so-called interstellar dust. Its distribution in interstellar space is extremely uneven. The dust consists of microscopic particles less than 1 μm in size. These are represented with graphite, silicates, minute fragments of dirty ice and others, usually elongated in shape and oriented in approximately the same direction under the influence of the weak magnetic field. The temperature of the interstellar medium is very low, about several Kelvin degrees.

While the interstellar medium cannot be treated as an empty space, the intergalactic medium is significantly more rarefied. The average density of all the Universe together with invisible crowns of galaxies is estimated as 10^{-26} g/cm^3, that is, by a degree lower than the average density of the interstellar medium. In literature, other values can be found, e.g., 10^{-29} g/cm^3.

The present-day observations show that the interstellar medium is so transparent that it practically doesn't weaken the luminosity of the galaxies scattered in it. If this is the case, the density of the interstellar medium cannot be greater than 10^{-31}–10^{-32} g/cm^3.

Before the formulation of the general relativity theory, the Universe was considered as an integral object in a stationary state, always being eternal and invariable. All events inside the Universe were considered local, unable to cause any overall alterations, and the Universe was considered as a set of actual worlds with no beginning and no end. Its centre is everywhere and the surface is nowhere.

However, in 1922–24, the outstanding Russian scientist Alexander Friedman proposed a model describing the geometry and evolution of the Universe substance. In accordance with this model, the Universe is not a stationary system, it can either increase or decrease. At first, even Albert Einstein could not believe it.

Five years later, in 1929, the American astronomer Edwin Hubble discovered that the spectral lines of nearly all galaxies he observed (except for those situated most closely to our planet) are shifted to the red part of spectrum. He explained this situation with phenomenon of the Doppler effect.

Recollect the gist of the Doppler effect. If an object sends the light signal with the velocity C and wave length λ and the object itself holds fixed position in relation to the observer, or moves with a velocity $V<<C$, then the observed wave length is equal to the actual wave length, i.e., λ. But if the object and the observer move in opposite directions with considerably high relative velocity V, then the observer will measure the length of the wave with an increment of $\Delta\lambda$, that shifts the object's light spectrum to the long-wave red section.

Suppose the distance between the observer and the object at the moment of signal emitting by the object is equal to $L_0 = C\Delta t$, where C is the signal propagation velocity and Δt is the period of time that the signal needs to reach the observer.

Then let the distance between the observer and the object at the moment of the signal receipt be equal to $(L_0 + \Delta L)$, where $\Delta L = V\Delta t$. For

n, the number of the wave lengths between the object and observer, we can write

$$n = L_0/\lambda = (L_0 + \Delta L)/(\lambda + \Delta\lambda).$$

From this, we can obtain the expression:

$$(L_0 + \Delta L)/L_0 = (\lambda + \Delta\lambda)/\lambda,$$

and therefore

$$V/C = \Delta\lambda/\lambda \tag{2.1}$$

Hubble has shown that the value of the ratio $\Delta\lambda/\lambda$ depends on the galaxy spectrum and increases proportionally with r, the distance to the galaxy. As $C = \text{const}$, we can write

$$C(\Delta\lambda/\lambda) = Hr, \tag{2.2}$$

where H is a coefficient of proportionality called Hubble's constant.

In astronomy, the last expression is accepted as a law, verified by reiterative observations. But we should remember that the formula derived from (2.1) and (2.2)

$$V = Hr \tag{2.3}$$

is correct only *under the assumption* that the nature of the red shift is explained *only through the Doppler effect.* Formula (2.3) works until another explanation is found for the phenomenon of the red shift. Here it is possible to feel the difference between the *measurement* and the explanation of the *result of measurement.*

From (2.3), the result follows that captures the imagination: *The farther from the Earth a galaxy is situated the faster it moves away.* The value of the Hubble constant H is repeatedly updated. At present, specialists use different estimations of H, mainly 55 km/sec·megaparsec or 75 km/sec·megaparsec. This means that for every megaparsec, the velocity of the galaxy's moving away increases by 55 or 75 km/sec.

Hubble's Law makes it possible to conclude that the cause for the galaxies "runaway" might be a great explosion — "The Big Bang" that gave a launch to the modern Universe, which originated from a piece of substance, initially small enough. The Hubble coefficient is a constant characterizing the velocity of the enlargement of the cosmic space. This enlargement is isotropic, and the Hubble law is correct for observations made at any point of the Universe. Based on the Hubble constant, it is possible to estimate the age of the Universe. Really, if the velocity of enlargement is 55 km/sec for every megaparsec ($3.08 \cdot 10^{19}$ km), then the age of the Universe is

$$t = 3.08 \cdot 10^{19} / 55 \doteq 5.6 \cdot 10^{17} \text{ sec} = 17 \cdot 10^{9} \text{ years (17 milliard years)}$$

Obviously, the calculated age of the Universe depends on the choice of the Hubble constant value: the greater it is, the "younger" the Universe. The first estimation of the Hubble constant H was 540 km/sec·megaparsec and therefore, the age of the Universe was estimated as 2.5 milliard years.

In 1963, new extraordinarily powerful sources of radiation, *quasars* (the term is a contraction of "quasi-star") were discovered. Their radiation was detected by radio, optic, X-ray, infrared, and ultraviolet telescopes. For quasars, enormous red shifts are those characteristics that also confirm the theory of the enlargement of the Universe.

In 1965, Robert Wilson and Arno Penzias, employees of the Bell Telephone Company, who experimented with the antenna receiver of satellite signals, detected a faint radio-frequency emission that came with even intensity from all the areas of the sky. Nearly simultaneously, Princeton astronomers headed by Robert H. Dicke, when working with the "Big Bang" problem (the idea was proposed by George Gamov in the 1940s), applied the important and simple thermodynamic law:

If something (like gas) is expanding, then its temperature must decrease.

In accordance with this law, the enlargement of the Universe must be accompanied with a temperature drop. According to the estimations, two hours after the explosion the temperature of the Universe should be 10^8 K; in 100 years less than 10^6 K, and 17 milliard years later, i.e., today, about 3K.

Objects with such temperature emit radio waves with λ from 1 mm to 100 cm. The Antenna of the Bell Telephone Company was tuned to $\lambda = 7.53$ cm. After numerous experiments and observations, experts came to the conclusion that this all-round radio noise is residual. It is a background radiation of the Universe formed as a result of the "Big Bang". The most surprising peculiarity of this background radiation is its isotropy.

Isotropy of movement (in our case, the movement of radio waves) means the isotropy of real space and, consequently, its homogeneity.

Although the physical gist of the space isotropy is not yet clear enough, the relict radiation begins to be considered as the new cosmic ether, i.e., as an ideal reference system. Assigning to ether any special properties is not necessary. Ether as a medium doesn't prevent the relativity of the movement and the rest. These are ordinary uniformly-propagating electromagnetic waves.

Within the framework of classical physics, by analogy with the air vibrations due to a sound impulse, the movement of electromagnetic waves was compared with the vibration of a substance (ether). At present, after abandoning the classical ether theory, the electromagnetic field is considered as a new original kind of matter and this matter can fulfil the role of classical ether for all other forms of movement. The directions and velocities for different objects of the Universe are estimated in relation to this new ether.

The discovery of the relict radiation is the event of great importance that can be compared with the Hubble's discovery of the red shift in the spectra of galaxies.

In conclusion, it should be pointed out that all contemporary experiments and observations confirm that our Universe is not a stationary system. It originated about $17–18 \cdot 10^9$ years ago — probably, after a great explosion. And the process of its enlargement continues.

2.2. Stars, Galaxies, Supersystems of Galaxies

As was mentioned above, in modern Universe the substance is concentrated in stars. A star, what is it? Everybody knows this. It is enough to look at the night sky. A poet wrote: *"...there is nothing simpler than a star..."*

Humans managed to examine the sky with aided eye only in 1609 when Galileo Galilei created his first telescope. But long ago, looking at the sky, the people could distinguish stars from planets. The planets look travelling among the practically unmoving stars. (The word *planet* is Greek for wanderer). Besides, the planets seem brighter due to their close proximity to the Earth and their reflecting the sunlight.

In contrast to the planets, stars are seen in the night sky as bright shining motionless points fixed in the firmament. But nowadays, due to the modern scientific achievements, we know that it is only an illusion. Stars, like other celestial bodies, also move in cosmic space, but owing to their colossal remoteness we perceive them motionless. Investigations of stars' spectra have shown that stars consist of a high-temperature gas. The Soviet astronomer Iosif S. Shklovsky wrote:

"A star is a gaseous sphere being in an equilibrium state..., the overwhelming majority of stars don't change their properties during enormous periods of time".

But stars, like people, are born, live, and die. Their life cycle has not been explained properly till now. It is not our purpose to discuss this problem here. All information about it can be found in the literature from the list recommended.

A star appears as a blob of substance of the Universe collapsing under the action of the gravitation forces. Intensive compression causes heating of the substance with the result that its density and temperature reach the critical values giving rise to the thermonuclear reaction, which raises the pressure and temperature more and more. The primary blob becomes a gaseous sphere (being in balanced state as to temperature and pressure) that is named a star. The internal energy of the star is caused mainly by the reaction of the transformation of hydrogen nuclei into helium nuclei. As the quantity of hydrogen decreases, the central zone of the star begins to shrink, which leads to a new temperature increase. The internal structure of the star is essentially rearranged. The star swells, while its nucleus continues to shrink. The external layers of the star may come off forming gaseous nebulae.

But at the moment when the nuclear fuel comes to an end, the star begin to cool down. The internal pressure drops down and the star's nucleus shrinks quite rapidly. This situation can lead to one of three events:

- Origination of a white dwarf
- Origination of a neutron star
- Origination of a black hole

These are the final products of the evolution of stars.

White dwarfs. At present, they are enough well. Their dimensions correspond to the dimensions of the Earth. The mass of their nuclei is no more than 1.4 M_S (M_S is the mass of the Sun equal to $1.98 \cdot 10^{30}$ kg). The average density is about 10^9 kg/m^3.

Neutron stars. Their masses are 1.4–2.0 M_S, or sometimes about 3.0 M_S. There is no more precise estimation so far. The neutron stars shrinkage is stronger than the white dwarfs'. Their average density is about 10^{18} kg/m^3. Their diameter is about 20–30 km. The density of 10^{18} kg/m^3 corresponds to the density of atomic nuclei. Electrons, being pressed into atomic nuclei, unite with protons and as the result, neutrons are generated. Such atomic nuclei become unstable, and break down. Some scientists conjecture that unlike ordinary stars and white dwarfs, neutron stars are not gaseous spheres: They are liquid spheres with superfluidity. This neutron liquid is confined within an iron sphere as a crystalline crust. The process of a powerful and rapid compression causes powerful heating in these stars and, consequently, a colossal increase of their luminosity, up to 10^{10} of the Sun luminosity. Sun's light flash does not last long (several weeks). Then the luminosity falls and the star gradually becomes invisible. Its matter, enriched with the heavy elements, dissipates in the middle plane of Galaxy under the influence of the gravitation forces.

The remnants of these stars can combine to produce a new star. Observations confirm that the new stars are richer in the heavy elements than parental stars.

Black holes. Theory shows that if the mass of the nucleus at the decay of the star is greater than 3 M_S, then nothing can prevent its collapse. Thes so-called gravitational collapse occurs, resulting in the generation of nuclei of very small dimensions and very high density. Simultaneously, the gravitation forces increase enormously, so that even light is absorbed by the newly-generated nucleus; hence the name "black hole". *It is only a hypothesis.* The black holes have not been discovered till now. However, the candidates for black holes have been determined. These are double stars in the constellations of Cygnus and the Large Magellanic Cloud. Of these double stars, one star is invisible. If the mass of the invisible star exceeds the mass of its visible companion, then the invisible star should be visible too. But once that it remains invisible despite of the fact that its mass is greater than 3 M_S, this unordinary star might be a black hole.

The total number of the stars in the visible zone of the Universe is estimated as 10^{20}. Most often, these are the stars with lesser mass and lesser luminosity than the Sun; however, their internal structure is nearly of the same type as of the Sun. Bright giants stars are rare enough. The white dwarfs take about 1% of the total number, neutron stars, about 0.01%, and, apparently, black holes cannot take more than 0.1%. In the early 1970s, the theoretical possibility of the emergence of the primary black holes in the Universe and their partial survival till now was proven by Stephen Hawking. Black holes were considered as the product of the "Big Bang". There are hypotheses that the background radiation is caused by the volatilization of these black holes and that their number can amount to only 300 primary black holes per cubic light-year (if all the black holes are inside the Galaxies).

Galaxies. These are gigantic star clusters. They became known as long ago as in the second half of the 18th century after the investigation of the English astronomer William Herschel, the first who detected in the sky a large circle with great number of these star clusters. When approaching this circle from any direction, the number of the stars increases and reaches its maximum at the very circle. It is our Galaxy.

The hypothesis of William Herschel was proven only after the other cosmic objects, outside our Galaxy, had been found.

Our Galaxy is not a single stellar system in the Universe. There are multitudes of them in the Universe and in principle they have much in common. However, to admit this fact the astronomers had to toil up a slow and difficult path. By analogy with the other galaxies that resemble ours in their stellar structure, we can assume that our Galaxy has a spiral shape.

In 1953, the supersystem of galaxies was discovered by the French astronomer Gerard de Vaucouleur. It comprises numerous bright galaxies, in a way similar to our Galaxy's comprising the stars. The supersystem is strongly compressed in the direction normal to its plane, which indicates the rotation of the supersystem around its axis; it resembles a disk with a diameter equal to 30 megaparsec. Our Galaxy is situated not far from its border, i.e., at 2–4 megaparsec. The centre of the supersystem is located in the constellation of Virgo that may be considered as a nucleus of the supersystem of galaxies.

The supersystem does not include weak galaxies; presumably, these compose their own supersystem. Thus, the supersystem of galaxies cannot be considered as a Metagalaxy. Nevertheless, it is an important element of the Universe.

The constellation of Virgo recently drew attention of astronomers in connection with the effect of the so-called *gravitational lens* predicted by Albert Einstein. The gist of this phenomenon is that a powerful gravitational field can so strongly change the direction of a light ray that an optical illusion appears and we can see a doubled or even manifold image of one object. This phenomenon was first observed in 1979. Later, another 5 gravitational lenses were found. In 1986, with a 4-meter optical telescope, the astronomers of Princeton University discovered the presence of a utterly gigantic invisible mass in close proximity to the constellation of Virgo, with the gravitation equal to gravitation of thousand large galaxies. The evidence on the existence of a new object is the double image of a very distant quasar located at the very edge of the Metagalaxy. The angular distance between these two images is about 2.5' (Fig. 2.1). Specialists believe that this discovery can turn upside down all our understanding of the Universe.

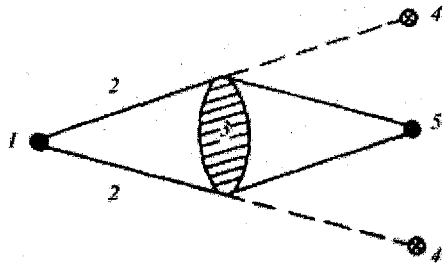

Figure 2.1. Illustration on the effect of gravitational lens. 1 is the Earth; 2 is the trajectory of the light rays; 3 is the gravitational lens; 4 is the visible position of quasar; 5 is the real position of quasar.

In conclusion, we can affirm that the Universe is the combination of the different celestial groups. The stars compose numerous clusters that are constituent parts of the galaxies. The galaxies, in their turn, are united into supersystems, of which the Metagalaxy is constructed. It is quite possible that in future, Metagalaxy will happen to be not a single one, but now it is considered as the greatest structural cell of the Universe.

It is not excluded that one of the fundamental properties of Nature is its aptitude for *fractalizing*, i.e., recurrent grouping the objects similar in size and properties into an object of a meta level, which is observed in a wide range of natural phenomena. This idea is advocated by the mathematician Benoît Mandelbrot who proposed the term *fractal* for the objects whose structure is the same, or approximately the same, at any scale. Mandelbrot argues that such apparently disparate things as shape of coastal lines and river basins, clustering of galaxies, blood vessels and lungs, plants and trees; even the snowflake and stock market prices can be considered as fractals (recurrent structures). Examples of geometrical fractals are shown in Fig. 2.2. Each of them is named after its author and can be described by a graceful mathematical formula implying the dependence on the iteration step *n*. There is true inner beauty in these constructions.

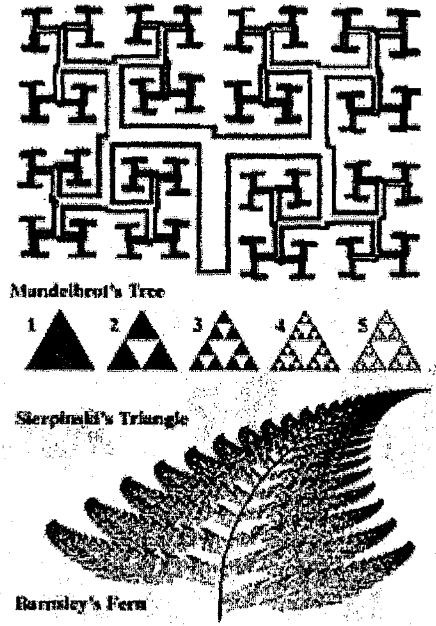

Figure 2.2. Examples of fractals. From top down: Mandelbrot's tree, Sierpinski's trianle (given in progress), Barnsley's fern

If this hypothesis works, then we will see this type of structuring on the Earth.

2.3. The Structure of Our Galaxy

Our own Galaxy, the Milky Way, is relatively well studied. It is a typical star system with the mass equal to 10^{12} of mass of the Sun. It is in the state of quasi-dynamic equilibrium. Its evolutionary stability is maintained by the intermingling of the stars during their movement in the general gravitational field of the system.

The Galaxy looks like a flattened disk with an equatorial plane of symmetry and an axis of symmetry normal to this plane and located in its centre. The Galaxy has no clear-cut border; to a certain degree, this border is conventional and its contour is assumed according to the purpose of the exploration. The scheme of our Galaxy is given in Fig. 2.3.

The maximum star density (the number of stars per cubic parsec) falls into the central parts of the Galaxy, where it is equal to several stars per cubic parsec. If we put the border of the Galaxy at the area of the density no less than $1 \cdot 10^{-3}$ stars per cubic parsec, then the diameter of the Galaxy will be about 30 kiloparsec, and the thickness about 2.5 kiloparsec. The Sun is located almost exactly on the plane of symmetry and at a distance of about 10 kiloparsec, or 2/3 of the Galaxy radius, from the centre of the Galaxy. The number of stars in our Galaxy is estimated as being about 10^{11} (or 100 milliard "Suns").

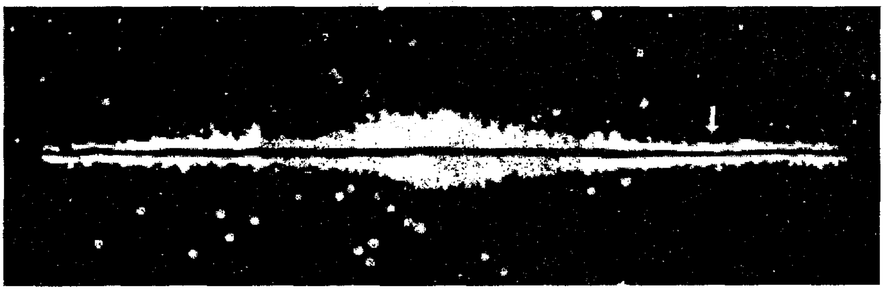

Figure 2.3. Modern notions about our Galaxy. It is shown as a side view. The black line corresponds to the equatorial plane. The arrow points at the location of the Sun.

The Galaxy has an intricate interior structure. There are various collective objects there, such as double stars or star clusters containing ten to 2,000 stars (Fig. 2.4).

Spherical star clusters uniting hundreds of thousands, or millions, stars are very large objects of the Galaxy. They are situated symmetrically in relation to the centre of the Galaxy.

The Soviet academician Victor Ambartsumyan has discovered the collective objects, later called the star associations. These are the "nests" consisting of 2–3 tens of gigantic stars. Such star associations occupy the space of tens and hundreds cubic parsec and beside the gigantic stars forming their basis contain also star-dwarfs and stars with medium luminosity.

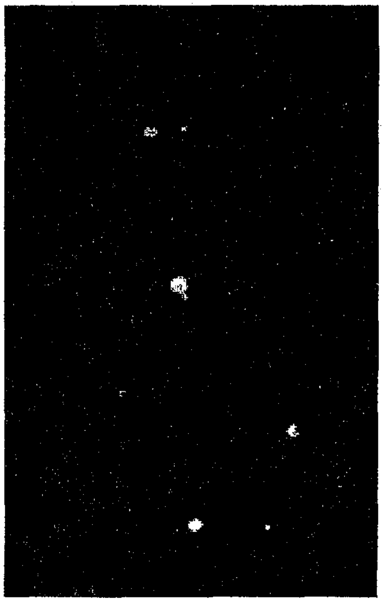

Figure 2.4. The Pleiades star cluster (about 500 light years away).

The conspicuous Pleiades in the constellation of Taurus, one of the nearest galactic star clusters, are commonly spoken of as seven-starred, though only six are visible by the naked eye. The cluster also contains over 100 small stars. The light of some of the stars can be seen reflected from dust clouds in their vicinity (R. Kippenhan, 1990)

Evolution of galaxies stimulates the processes of old stars destruction in the galaxy nuclei, where the star density is the highest. The gas-and-dust products of the destruction are accumulated in the galaxy centre and make up a rapidly-rotating system.

When the accumulated material ceases to be kept by gravitational field of the nucleus, it detaches from the disk and scatters in the galaxy forming whirled flows, the so-called *spirals of Archimedes.*

The substance eruption from the nucleus of our Galaxy began more than 5 milliard years ago. During the last 3.6 milliard years, the average outflow of the substance is 8.8 Sun masses per year.

Besides the flows whirled into the spirals of Archimedes, there is another kind of flows, the so-called *logarithmic spirals.* The logarithmic spirals are the result of action of the Galaxy electromagnetic field.

Our Galaxy has four logarithmic spirals originating from four different points of the central disc.

The composition of the substance ejected from the central part of the Galaxy is close to the composition of the Sun. By two diverging fan-shaped flows, this substance spreads along the Galaxy plane, where it condenses to gas and dust clouds, comets, and stars. The processes of gas condensation and star formation are most intensive in the areas of the intersection of the spirals of Archimedes and logarithmic spirals, where the Galaxy electromagnetic field partially traps and carries away the ionized gas and dust particles of the jet flows. The zones of accumulation of the ionized gas and dust particles are the main places of the stars formation.

With the rotation of the Galaxy, these places change their location moving along the spirals.

The objects formed in the zones of the ionized gas and dust particles accumulation develop in different ways. Some of these objects continue their movement in radial direction and in about10^8 years leave the visible borders of the Galaxy. The others, formed mainly of the gas and dust of the logarithmic spirals, inherit the tangential direction movement and remain in the Galaxy. After condensation, they take their own orbits. Our Sun is one of such objects.

2.4. The Solar System

The Solar System is the Sun and all objects that are situated in its gravitational field. These are 9 planets and their 34 satellites, numerous comets, and asteroids. All the planets, except for Mercury and Pluto, rotate around the Sun in one direction in the orbits close to circular. The planes of these orbits practically coincide (with an accuracy of several degrees). Numerous precise measurements allowed to determine that the orbits of planets are not circles but ellipses. The orbits of Mercury and Pluto have the maximum eccentricity and a noticeable slope to the average plane of orbits of other planets. The planets, except for Venus and Uranus, rotate around their axes in the direction coinciding with the direction of the rotation around the Sun. Venus rotates in the opposite direction, while the rotation axis of Uranus lies nearly in the plane of the orbit of its rotation around the Sun. Table 2.1 displays the main information on the Solar System.

Table 2.1. General Characteristics of Solar System

Sun Planets Moon	Average Radius, km	Average Distance to The Sun, Million km	Period of revolution along the orbit	Number of satellites	Mass, kg
Sun	695,000	-	275 million years	9 planets	$1.98 \cdot 10^{30}$
Internal planets					
Mercury	2,440	57.9	88 earthdays	0	$3.28 \cdot 10^{23}$
Venus	6,129	108.2	224.7 "	0	$4.83 \cdot 10^{24}$
Earth	6,378	149.6	365.26 "	1	$5.98 \cdot 10^{24}$
Mars	3,387	227.9	687 "	2	$6.37 \cdot 10^{23}$
External planets					
Jupiter	71,400	778.3	11.86 years	13	$1.90 \cdot 10^{27}$
Saturn	60,000	1,427	29.46 "	11	$5.67 \cdot 10^{26}$
Uranus	25,900	2,870	84.01 "	5 (15)*	$8.80 \cdot 10^{25}$
Neptune	24,750	4,497	164.8 "	2	$1.03 \cdot 10^{26}$
Pluto	2,900	5,900	247.7 "	0	$6 \cdot 10^{23}$
Moon	1,740	-	29.5 earthdays	-	$7.34 \cdot 10^{22}$

* In addition to 5 known satellites, the cosmic station Voyager-2 discovered another 10 small satellites in 1986.

All the figures presented in Table 2.1 are not constants. They characterize our ever-changing world, built with definite regularity, only with a certain degree of accuracy. The quantitative estimation of the degree of these changes is rather difficult to obtain. For example, the velocity of the present-day Moon's movement off the Earth, measured by means of laser engineering, equals 3.8 cm/year, while analysis and interpretation of observations of lunar eclipses during historical periods gave 4.0 cm/year. The forecast of estimation of this value, for both the future and the past data, depends on our theoretical assumptions and on our viewpoint on the origin of the Moon, its age, structure, and so on.

Thus, the Solar System is varying in its parameters; however, the general regularities in its structure and activity are detected. There is a principal peculiarity in the discovery of the mysteries of the Universe. The classics of science deliberately idealized the real world around and only in this way they could find its fundamental laws. Getting rid of the details, sometimes knowing nothing about them, they could see the gist. Using modern terminology, we may say that they created fundamental model of the world phenomena and processes. They sought ideal analogues for nature. Nowadays, it is known that the more complicated a real systems is, the more considerable simplifications are applied when creating a model. An outstanding Soviet physicist Yakov I. Frenkel wrote about this peculiarity of human knowledge, that the investigator *"is like a-cartoonist.... The good theory of an intricate system must be the good caricature of this system, exaggerating certain most typical characteristics; at the same time, it must ignore all other features that are not essential"*.

So the genius of classics of science consists in their ability to sort out the most characteristic features of the intricate natural phenomena.

Now, after preliminary comments, it is possible to speak about the main laws of the Solar System structure and the processes going on there.

All these laws were obtained on the basis of empirical materials; therefore, they in fact are inductive rules. The first rule reveals some order, a systematization in the disposition of planets, i.e., describes the spatial structure of the Solar System. It is the so-called Titius-Bode law

$$r = 0.4 + 0.3 \cdot 2^n,$$

where r is the distance to the Sun, measured in astronomical units (AU). The exponent n has an individual value for every planet.

Planet	n
Mercury	$-\infty$
Venus	0
Earth	1
Mars	2
Jupiter	4
Saturn	5
Uranus	6
Neptune	6.63
Pluto	7

There are some eye-catching exceptions in this regularity:

- n = 3 doesn't correspond to a planet. However, at the distance r = 0.4 + 0.3·103 = 2.8 AU a belt of asteroids exists as a set of par-ticles and bodies with the sizes up to several hundred kilometers. The total mass of this asteroid belt is about 0.1% of the Earth mass. It may be considered either as an aggregation of the matter not yet having been formed into a planet, or as the product of destruction of a planet body (or maybe several bodies) existing before.

• For the planet Neptune, located between Uranus and Pluto (r = 30.06 AU), the exponent n is a non-integer number, i.e., $n = 6.63$.

• Mercury is also an exception, because its n is $-\infty$.

Enumerating the planets, putting Mercury and Neptune aside, as Venus is 1, Earth is 2, Mars is 3, and so on, we can rewrite the Titius-Bode rule in the following form:

$$r = 0.4 + 0.3 \cdot 2^{n-1},$$

where the second addend is a term of geometrical progression.

If we want to calculate the distance r not from the Sun, but from Mercury, i.e., shifting the coordinate origin to 0.4 AU from the Sun, we may use the formula

$$r = 0.3 \cdot 2^{n-1}.$$

It is a geometrical progression law that can be considered as fundamental for the Solar System structure, but only with some exceptions. The combination of the words "fundamental" and "exceptions" has the legal right to be. (Recollect the opinion of Yakov I. Frenkel that the models of the most intricate natural systems are the most caricatural.) In fact, there are many exceptions. These are exceptions in the direction of rotation of planets, in the forms of orbits, in the slope of the axis and the plane of their orbits, in the directions of their revolutions, and so on. And they are also the characteristics, though qualitative, of the Solar System's spatial structure.

Thus, the constitution of the Solar System is characterized by certain regularities that determine a certain arrangement in the location of planets and their orientation in space. But there always are some exceptions in this arrangement. Probably, it is better not to speak that the regularity exists, but *as though* it exists, or more correct, to speak thatregularity exists and at the same time does not exist.

All elements of the Solar System are in permanent movement. Quite naturally, the exploration of the Solar System caused the discovery of kinematic laws, known under the name of Johannes Kepler, who, based on the astronomical observations of Tycho Brahe, created a clear and rigorous mathematical construction. Here it is necessary to underline one methodological circumstance illustrating the logic of scientific search. The heliocentric system created by Mikolaj Kopernik was a scientific theory according to the criteria of that time, i.e., it satisfied the condition of falsifiability (see *Subject 1*). This fact encouraged Tycho Brahe on numerous careful astronomical observations: Brahe refused to accept Kopernik's heliocentric system, tried to refute it, but in the end gathered the material that not only proved the heliocentric system but also composed the base for the creation of laws of Kepler.

The first law. Every planet travels along an elliptic orbit and in one of the focuses of this ellipse the Sun is located.

The second law. The radius vector between the Sun and a planet (a line joining a planet and the Sun) sweeps out the equal areas ΔS during equal periods of time Δt. Actually, we get a kinematic constant for the Solar System:

$$\Delta S/\Delta t = \text{const}.$$

Sometimes, this law is called the law of equal areas.

The third law.

$$R^3/T^2 = \text{const},$$

where R is the average radius of the orbit of a planet calculated as the arithmetic mean of its maximum and minimum distances from the Sun. T is the period of planet revolution around the Sun.

The present-day measurements of the parameters of planet orbits and periods of their revolutions give $R^3/T^2 = 3.35 \cdot 10^{18}$ m^3/sec^2 (with an accuracy to the second decimal digit).

It is easy to see that according to the above-mentioned rule of "being caricatural", the first two laws contradict to the third law simplifying the planets' orbits to the circles. Nevertheless, the laws of Johann Kepler make the kinematic base for the Solar System. These laws are purely kinematic because they describe the movement of planets without any explanation for the causes of their movement. These laws allow us to predict the position of the planet at a given moment, and no more. In this sense, Kepler's kinematic methods based on the heliocentric conception of Kopernik not very much differ from the scheme of Ptolemy based on the geocentric concept, especially as both systems are accurate enough. From the viewpoint of kinematics, both schemes are true, because they differ from each other only in the coordinate system. However, the coordinate system of Kopernik, used by Kepler, gives a simpler and clearer scheme of calculations. This situation illustrates once more that the fact of good coincidence of the theoretic predictions with the observations cannot be the proof of the truthfulness of a scientific concept. This fact only demonstrates the objectivity of the created model and its applicability for the task chosen. We have seen that objectivity doesn't mean the physical truthfulness, in any case in kinematics, where the choice of the coordinate system is determined only by considerations of convenience.

The laws of dynamics are not invariable to the choice of the reference system; therefore, the heliocentric system of Kopernik and laws of Kepler were more appropriate for Isaac Newton's law of universal gravitation.

The *law of inertia* says that a body at rest remains at rest and a body in motion continues to move at a constant velocity V unless acted upon by an external force F. Formally, this law is derived from the second law of Newton (under conditions: $F = 0$ and the acceleration $a = dV/dt = 0$). Nevertheless, the law of inertia was formulated by Newton as postulate of the existence of the inertial system. Furthermore, this law, as a particular case of the law of the impulse conservation, implies the uniformity of the space (the parity of all its points) in any inertial reference system. The laws of impulse conservation, impulse momentum, and energy for closed systems, being the consequence of Newton's second law, assume the isotropy of space and uniformity of time.

I should like to repeat again the well-known fact that the laws of dynamics are correct only for those reference systems where the space is uniform and isotropic and time is uniform. These systems are called inertial.

By simple experiments (pendulum of Foucault, deviation of movement of free-falling body from vertical line, and so on) it was proven that the geocentric system (a system with coordinate axes rigidly connected with the Earth and rotating together with the Earth) in the strict sense is not an inertial system, although all its deviations from inertness are insignificant for most practical applications. However, for the celestial mechanics the adoption of the geocentric reference system becomes criminal. Only the heliocentric system meets the requirements of inertness.

The centre of the heliocentric system is the Sun. Its coordinate axes are directed to stars that move together with the celestial sphere. So they are immovable relative to the Sun (coordinate axes don't take part in the rotation of the Sun).

Newton's law of gravitation rests not only on Kopernik's heliocentric system, but is also closely connected with Kepler's third law. It is useful to show the possible variant of the process of reasoning of Newton.

1. A planet moving evenly in a circular orbit around the Sun develops the centripetal acceleration

$$a = 4\pi^2 R/T^2 .$$

2. Centripetal force acting on the planet in accordance with Newton's second law is

$$F = ma = 4\pi^2 Rm/T^2, \qquad (2.4)$$

where m is an inertial mass of planet.

3. According to third Kepler's law

$$T^2 = R^3/K,$$

where K is a constant.

$$F = 4\pi^2 Km/R^2.$$

4. The coefficient K, according to Kepler, is constant for every planet with any mass and any radius of the orbit. Thus, constant K in the Solar System depends only on the properties of the Sun as the source of the force F. Newton was *the first* who assumed that this force is gravitational force, i.e., that the value of the force F depends only on the value of the Sun's mass. Newton wrote:

$$4\pi^2 K = GM_s,$$

where G is a coefficient of proportionality between the Sun's mass M_s and the value $4\pi^2 K$, determined by the Kepler constant.

5. Further, we can write the formula of Newton's law of gravitation

$$F = GM_s m/R^2.$$

From Formula (2.4), we can obtain the value of the gravitational constant G. We know that $K = 3.35 \cdot 10^{18}$ m^3/sec^2; $M_s = 1.98 \cdot 10^{30}$ kg. Therefore,

$$G = 4\pi^2 K/M_s \approx 0.667 \cdot 10^{-10} \text{ m}^3/(\text{sec}^2 \cdot \text{kg}).$$

Newton's law of gravitation can be obtained using other schemes of reasoning. The scheme considered here illustrates the connection of Newton's law of gravitation with Kepler's laws. This connection was revealed by Isaac Newton.

For the Solar System, the law of gravitation works nearly irreproachably, with one exception. Mercury is the only planet whose calculated orbit noticeably differs from the observations. The general theory of relativity by Albert Einstein allows us to eliminate this exception. The general theory of relativity is created on the basis of Newton's mechanics, just as Newton's mechanics has in its foundation the works of Kopernik, Galilei, and Kepler.

Solving its own problems, the geology most often observes the actions of the gravitational forces, of both earthy and cosmic origin. The importance of the cosmic forces in geological history begins to become understood only nowadays. This understanding comes to us gradually.

At present, we know that the geological processes observed, such as earthquakes, volcanic activity, the work of rivers and seas, and so on are only the consequences of certain general and fundamental laws that rule over the evolution of the Universe. Therefore, the processes observed by geologists, being only the result of the changes that take place in the Universe, do not make the geological history. It means that Newton's mechanics, as the foundation of geology, cannot interpret all its problems. So we need appeal to the space–time problem.

Newton's space and time are independent and absolute. In the gravitation theory of Albert Einstein, the properties of the space and time are not specified once and forever. These properties are determined by the bodies being inside the space and time. Therefore, to develop their science, the geologists must not only comprehend the structure of the Solar System, Galaxy, Metagalaxy, but scrutinize the gist of the laws that determine the evolution of the Universe and clearly understand what laws are observed and what laws can be used in geological investigations.

I have presented the most general information about the planets of the Solar System (see Table 2.1) and given a more detailed account of the laws that determine the structure, kinematics, and dynamics of the planets. Recently, more comprehensive data were obtained about planets, including Venus, Mars, Uranus, and the Moon due to the Russian and American spaceships and cosmic stations. This information can be found in the literature recommended for given theme.

Now we can speak a little about the other bodies of Solar system: asteroids, meteorites, and comets.

Asteroids. The name stems from two Greek words: *aster* — star and *eidos* — kind of. Asteroids are treated as minor planets. They are relatively small bodies. The largest, Ceres, is about 1,000 kilometers in diameter, but most of the 50,000 that have been observed are only about one kilometer across. The smallest asteroids are assumed to be no larger than a sand grain. The total mass of asteroids is estimated to be only one-thousandth that of the Earth, itself being not a large planet. The bulk of asteroids is situated at the 2.3–3.3 AU distance from the Sun and forms so-called asteroid belt between the orbits of Mars and Jupiter. The collisions, and continuous processes of breaking, crushing, or every possible degradations of celestial bodies take place in the asteroid belt. The asteroids differ from each other to a considerable degree by mass, shape, and chemistry. Most of asteroids have an irregular shape, and only Ceres, Pallas, Vesta, and some other large asteroids are close to a spherical form.

By the value of albedo, the asteroids are grouped into C-asteroids (albedo < 0.05) and S-asteroids (albedo > 0.09) — compare with the Earth's albedo, which is about 0.4. The composition of C-asteroids is close to carbonic meteorites, while the composition of S-asteroids is close to ferrous aerolites (see below). C-asteroids dominate in the internal zone of asteroid belt, and S-asteroids in the external zone, so it is possible to speak about some kind of chemical regularity: The composition of asteroids depends on the heliocentric distance. At present, the photometric measurements have shown close resemblance of asteroids and meteorites as per their chemistry. It allows us to consider the asteroids as a source of matter for forming meteorites, and explore the structural, mineral, and chemical properties of asteroids using our knowledge about meteorites that are avail-able for our direct investigations.

Meteorites. Meteorites are the extraterrestial solid bodies, referred to as meteoroids, that survived falling to the Earth surface from interplanetary space. Meteorites, meteoritic stones, bolids, and falling stars are synonyms.

Prior to moon rocks brought back from lunar exploration, meteorites were the only samples of extraterrestial material that could be directly examined. At present, various literature about meteorites has been accumulated. The age of meteorites, except for rare exclusions, is estimated as 4.6 milliard years, i.e., it coincides with the age of the Earth and the Moon.

It enables us to use in our reconstruction of the origin and evolution of the Solar System all information obtained from the investigation of meteorites.

In every meteorite, three main components are determined:

- Siliceous (stony)
- Metallic (nickel-ferrous)
- Sulphides (including troilite FeS. It is a mineral rather ncommon in the Earth)

Other components are of little importance. In total, there are about 70 minerals in meteorites, among them we can find olivine, pyroxenes, plagioclases, and some other rock-forming minerals. Both chemical and mineral compositions of meteorites are essentially poorer than the composition of the Earth crust. The compounds of only four chemical elements O, Fe, Si, Mg form more than 90% of the meteorite mass. However, some minerals occurring in the meteorites are not met on the Earth. The relative frequency of the occurrence of meteorites depends on their composition. Thus, the relative frequency for stone meteorites (aerolites) is 92.7%, for ferrous meteorites it is 5.6%, and for ferrous aerolites 1.3%. Among the aerolites, the chondrites are most abundant, which make up about 82.4%. They contain chondrules (these are small, with fractions of a millimeter to several millimeters of size, round masses of olivine and pyroxene). The substance, from which chondrites were formed, is not much differentiated. That is why specialists assume that chondrites are the product of early, even primary processes that formed the solid bodies of the Solar System.

Comets. They are celestial bodies travelling around the Sun, usually in highly eccentric orbits, and consisting of a central nucleus, the so-called *head*, surrounded by a gaseous envelope that may form one or more luminous *tails* turned away from the Sun. Although a comet may be the brightest object in the night sky, most observed comets are extremely distant objects that may be recognized only with the aid of telescopes. Their origin, composition, and structure have not been studied till now, there are only hypotheses and various concepts. According to the hypothesis proposed by Jan Hendrik Oort in 1950, there is a gigantic comet cloud, consisting of hundreds of millions comets, moving around the Sun in an orbit with a radius of one light year (about $9.46 \cdot 10^{12}$ km). The comets, as we observe them, are the fragments of this cloud that were detached from it as the result of external disturbances and then caught by the gravitational field of the Sun. The period of their revolution around the Sun is usually less than 200 years (for example, for Halley's comet this time is 75–76 years). Some comets have periods of revolution equal to several million years. For now, about 700 comets with diameters of 0.5–75.0 km have been registered. Every year about 5 new comets are registered.

It is assumed that the nuclei of comets consist of ice (75%) and dust, together with stony material (25%). The ice forms the central part of the nucleus while the dust and the stony material form its external layer. Approaching the Sun to a distance of 3 AU (about 450 million km), the comet begins to be heated, which initiates the sublimation of undersurface ice. In such a manner, the tail of comet is formed. Later, under the influence of solar radiation the second tail appears.

Not all astrophysicists agree with the above-stated conception (mainly based on the research by an American astronomer Francis Whipple). Some of them (Prof. Kesarev et al.) are of the opinion that comets are the inner products of the Solar system. The old comets were composed from the protoplanet substance. The new comets are composed, and continue their formation, from the material of the disintegrated planets. That is, in essence the comets are the dwarfish planets that, unlike the large planets, have not the internal, but external activity caused by the influence of the Sun.

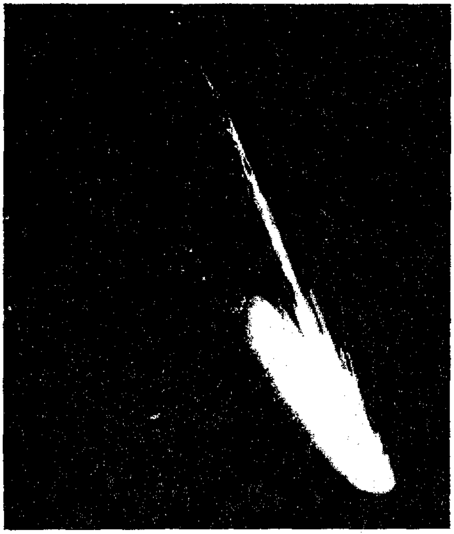

Figure 2.5. Mrkos's comet, 1957.
Dust tail accompanies the gaseous tail (R. Kippenhan, 1990)

Great attention is paid to comets now. Thus, about 900 astronomers from 47 countries took part in the international program on exploration of Halley's comet (1986), eight specially equipped space vehicles were launched: two by USSR, two by Japan, three by the USA and one by European Cosmic Agency. It was a really splendid example of international cooperation. For the first time, the space vehicles were launched to explore a minor celestial body. The photographs of the comet nucleus were made, which are impossible to obtain from the Earth.

2.5. The Earth and Its Planetary Characterization

The Earth surface is too irregular to be easily described by mathematical formulae. However, this difficulty lessens when we resort to the small-scale representation instead of a large-scaleone. In this case, all the peculiarities of the relief are considered for large territories. For example, the average height above the sea level in Europe is 300 m (maximum height: 4,807 m, Mont Blanc), and the average height in Asia is 950 m (maximum height: 8,848 m, Mount Everest, also known as

Chomolungma). The lengths of European and Asian coastal lines are 38 and 62 thousand kilometers, respectively.

Thus, after the representation of the elements of the real Earth surface on the map, all minor details of the Earth surface disappear or become imperceptible and we are able to catch the relation between the actual properties (size, relief, and so on) of large territories. Normally, colour is used as symbolic designation of the relief. In this case, the colour range is applied to the considerably simplified Earth surface, for whose shape the necessary geometrical and physical pre-assumptions were made. The character of these assumptions is determined by the problems that are to be solved.

Different geometrical models of the Earth were proposed: sphere, spheroid and geoid.

Sphere. It is a specific geometrical shape whose surface is everywhere at the same distance from its centre. A sphere is a simple and the most perfect shape from the viewpoint of symmetry. For this shape to be gravitationally stable, we need to assume its isotropy as regards density. If we take into account the rotation of this sphere, we have to postulate it as an absolutely solid body, so that the centrifugal forces caused by the rotation cannot disturb its shape and internal structure. All these assumptions are acceptable for the problems related to constructing the geographic coordinate grid and are justified by those positive results that in this case are possible (the simplicity of calculations).

According to the present-day estimations, the radius of this sphere is 6,371.116 km and the density is 5.52 g/cm^3.

Spheroid. A more complicated model of the Earth is a solid geometrical object generated by rotating an ellipse around one of its axes. A spheroid can be produced by rotation of a not solid but viscous and plastic body with its density increasing to its centre. The spheroid, also called the ellipsoid of rotation, has two radii: polar radius R_p and equatorial radius R_e.

In 1946, the ellipsoid of Feodosiy Krasovsky was accepted as standard in the USSR. Its parameters are as follows:

- $R_p = 6{,}356.863$ km
- $R_e = 6{,}378.245$ km
- Polar compression α is $(R_e - R_p)/R_e = 1/298.3$

Calculated on the basis of these parameters, the area of the spheroid surface and its volume are equal to $5.1008 \cdot 10^8$ km^2 and $1.0833 \cdot 10^{12}$ km^3, respectively. The lengths of arcs of meridians and parallels also have been calculated. The model is considered as standard for the estimation of gravitational force on the equator and particular geographic latitudes. These are standards for estimation of the anomalies of the gravitational field of the Earth (see *Section 4*).

Besides the ellipsoid of Krasovsky, there is a standard Earth ellipsoid of the International Astronomical Union accepted in 1976. Its polar compression α is equal to 1/298.257, which is closer to the value α = 1/298.25 calculated on the basis of the data obtained from the satellite stations.

Krasovsky and his assistants specified some other parameters as well. They stated the ellipsoidal form of the equatorial cross-section with the compression ε = 1/30000 and the longitude of the maximum meridian $\lambda = 15°$ to the East from Greenwich. The difference between the polar semi-axes was also found:

$$R_{\text{North}} - R_{\text{South}} \approx 100 \text{ m}.$$

Therefore, from the present-day viewpoint, the shape of the Earth cannot be considered as a spheroid, or even a three-axis ellipsoid. It is a three-axis cardioidal ellipsoid. But this model, although more precise, is too unwieldy and inconvenient for construction of a coordinate grid and for many geophysical calculations. Usually, specialists prefer to work with a spheroid as the model of the Earth.

Geoid. This model is often used for description of the Earth surface. However, in reality the geoid is not a material surface. It is an imaginary surface that coincides with the average level of the ocean and its extension through the continents. Thegeoid is one of the equipotential surfaces of the gravitation field of the Earth, i.e., the surface where the potential energy of the gravitational field is constant. The conception of the geoid will be considered later in *Section 4*.

Other characteristics of the Solar System:

- Average distance from the Earth to the Moon is 384,400 km.
- Length of the Earth orbit is 939,120,000 km.
- Average velocity of the Earth movement along its orbit is 29.765 km/sec.
- From the distance of one AU, the angular diameter of the Sun (average angular diameter) is 31'59.26".
- Angular diameter of the Moon seen from the Earth when at the average distance from the Moon is 31'05.16".
- General precession in longitude during Julian century is 5029.0966" (standard epoch 2000).
- Constant nutation (a slight "nodding" of the Earth in space caused by the interaction of the Sun and Moon gravitation) is 9.2109" (standard epoch 2000).

QUIZ

1. What is the Metagalaxy?
2. Explain why the laws of gas dynamics can be applied to the interstellar medium.
3. From what theoretical assumptions and on the basis of what observations was the Hubble constant obtained?
4. Give the principal description of the origin, life, and death of stars.
5. On what theoretical apprehensions and experimental data was the theory of "The Big Bang" constructed?
6. Give the morphometric characterization of our galaxy. What is generally accepted as its boundaries?
7. What is the gist of the Titius-Bode law? Comment it.
8. Derive the gravitational constant with the help of Kepler's third law.
9. Name the main geometrical models of the Earth, give their characteristics and explain their physical gist.

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GLOSSARY

A

albedo, the ratio of the light reflected by a planet or satellite to that received by it.
algorithm, a set of rules or procedures that must be followed in solving a certain problem.
astronomical unit, a unit of length, equal to the mean distance of the Earth from the Sun: approximately, 149.6 million kilometres or 93 million miles. *Abbreviation*: AU.
axiom, a self-evident truth; a universally accepted principle or rule; a proposition that is accepted without proof for the sake of studying the consequences that follow from it.

C

cardioid, a heart-shaped curve traced by a point on the circumference of a circle rolling on an equal circle. Greek: *cardia* — heart; *cardioid* — heart-shaped.
cc, cubic centimeter
compound, a substance formed when atoms (molecules) of different elements joined together.
continuum, a continuous extent or whole. In mathematics: a set of elements such that between any of two of them there is a third element.

D

deduction, a reasoning from general principles to a particular case.
dogma, belief or set of beliefs put forward and to be accepted as a matter of faith.
Doppler effect, the apparent change of the frequency of a wave (light wave or sound wave), resulting from the relative motion of the source and the observer.

E

ecliptic, the great circle, in which the plane containing the centres of the Earth and the Sun cuts the celestial sphere: Hence, the apparent path of the Sun's annual motion among the fixed stars; it may be considered as the intersection of the plane of the Earth's orbit with the celestial sphere. The plane of ecliptic intersects 12 constellations, known as Zodiac constellations.

equinox, the time when the Sun crosses the plane of the Earth's equator, making night and day of equal length all over the earth, occurring about March 21 (vernal equinox) and September 22 (autumnal equinox). Latin: *aequus* — equal, *nox* — night.
equinoctial, pertaining to the equinoxes, the time of the equinoxes, or to the regions about the equator.
equinoctial line *or* **celestial equator,** the great circle of the celestial sphere, lying in the same plane as the Earth's equator.
equinoctial point, either of the two points in the heavens where the equinoctial line cuts the ecliptic.

F

fractal, geometrical shape made up of shapes, each of which is a reduced-scale replica of the whole (or at least a very close approximation). In wide sense, any object of recurrent structure.

G

galaxy, a large system of stars held together by mutual gravitation and isolated from similar systems by vast regions of space.
glossary, list of technical or special words with explanation of their meaning, usually those occurring in a particular text.
graphite, a very common mineral, soft native carbon, occurring in black to dark-ray masses.

I

induction, a method of logical reasoning which derives or discovers general laws from particular facts or examples.

J

Janus, an ancient Roman dual-faced god of doorways, whose temple was closed in time of peace, usually represented as having one head with two bearded faces back to back, looking in opposite directions.

L

latitude, angular distance of a place north or south of the equator, measured in degrees.
light year, distance traveled by the light in one mean solar year, about $9.46 \cdot 10^{12}$ km; used as a unit for measuring stellar distances.

longitude, angular distance east or west of the Greenwich meridian, measured in degrees.

M

metagalaxy, the whole universe considered as a system of galaxies, including Milky Way; any system of galaxies.
micrometer, a unit in SI of length equal to one millionth (10^{-6}) of a meter.
Symbol: µm or mn. The obsolete name is **micron (mikron)**.
Milky Way, the faintly luminous band stretching across the heavens, composed of innumerable stars too distant to be seen clearly with the naked eye; the galaxy containing the Earth, Sun and all Solar System.

N

nebula (*pl.* **nebulae),** a cloudlike, luminous or dark mass composed of gases and small amounts of dust. Latin for mist, vapour, cloud.
noosphere, the sphere of the mind, the collective memory and intelligence of the human race.
nutation, a fluctuation in the precessional movement of the earth's pole about the pole of the ecliptic. Latin for nodding.

O

olivine, mineral, magnesium iron silicate $(Mg, Fe)_2SiO_4$, an important constituent of the basic igneous rocks.

P

paradigm, a basic theory, a conceptual framework, within which scientific theories are constructed.
paradox, statement that seems to be absurd or contradictory but is or may be true.
parallax, an apparent change in the position of an object caused by change of position in an observer, i.e., an apparent displacement of an observed object due to the difference between two points of view. In astronomy, the apparent displacement of a celestial body due to its being observed from the surface instead of the center of the Earth (diurnal or geocentric parallax) or due to its being observed from the Earth instead of from the Sun (annual or heliocentric parallax).
parsec (pc), a unit of distance equal to that required to cause a heliocentric parallax of one second of an arc, equivalent to 206,265 times the distance from the Earth to the Sun, or 3.26 light years = $3.08 \cdot 10^{16}$ m.

kiloparsec (kpc), 10^3 pc.
Megaparsec (Mpc), 10^6 pc.
plagioclase, any of feldspar minerals varying in composition from acid albite $NaAlSi_3O_8$ to basic anorthite $CaAl_2Si_2O_8$, found in most igneous rocks.
planet, any of large celestial bodies revolving about the Sun and shining by reflected light. Greek: *planētēs* — wanderer.
precession, the slow motion of the Earth's axis of rotation along the circular cone. The rotation period of this motion is 26,000 years.
pyroxene, a group of minerals of many varieties, silicates of magnesium, iron, calcium, and other elements.

Q

quasar, one of a number of celestial objects, from four to ten milliard light-years distant, that are powerful sources of electromagnetic radiation. Also called quasi-stellar radio source. Abbreviation of *quasi*-star ("as though a star").

S

silica, the dioxide form of silicon, SiO_2.
silicate, any salt derived from the silicic acids or from silica.
sublimation, a process, in which a solid substance changes directly to vapour, without first forming a liquid.

T

Titan, a person of enormous size, strength, might, and influence (in classical mythology, one of the sons of Uranus and Gaea).
troilite, FeS, mineral, scarce on the Earth, is rarely encountered only in pyrrhotine ores.

U

Uniformitarianism, the doctrine stating that geological changes were brought about not by great convulsions but by such actions as may be seen going now, therefore the geological processes of the past epochs are not different from those observed now.

V

verification, the state of being verified; a formal assertion of the truthfulness of something.

Outstanding People

Agassiz, Louis (1807–1873), Swiss naturalist and geologist, the author of the proof to the glacial theory.
Agricola, Georg (1494–1555), German doctor, mineralogist, miner, metallurgist.
Äesop *or* **Asop** (620–560 BC), Greek writer of fables.
Ambartsumyan, Victor Amazaspovich (1908–1996), Soviet astrophysicist, member of Academy of Science of USSR (1953).
Arago, Dominique François (1786–1853), French physicist and astronomer.
Archimedes (287?–212 BC), Greek mathematician, physicist and inventor; discoverer of principles of specific gravity and the lever.
Arkhangelsky, Alexander Dmitrievich (1879–1940), Russian geologist, member of Academy of Science of USSR (1929).
Bohr, Niels Henric David (1885–1962), Danish physicist, Nobel Prize for Physics (1922).
Boltzmann, Ludwig (1844–1906), Austrian physicist.
Brahe, Tycho (1546–1601), Danish astronomer.
Brongniart, Alexandre (1770–1847), French geologist, naturalist, and ceramist.
Buffon, Georges (1707–1788), French naturalist.
Cézanne, Paul (1839–1906), French painter.
Cuvier, Georges (1769–1832), French naturalist.
Darcy, Henry-Philibert-Gaspard (1803–1858), French hydraulic engineer.
Descartes, René (1596–1650), French philosopher and mathematician.
Doppler, Christian (1803–1853), Austrian physicist and mathematician.
Einstein, Albert (1879–1955), German physicist, U.S. citizen since 1940, formulator of the relativity theory; Nobel Prize for Physics (1921).
Euclid (circa 300 B.C.), Greek geometrician and educator in Alexandria.
Foucault, Jean Bernard Leon (1819–1868), French physicist.
Frenkel, Yakov Ilyich (1894–1952), Soviet physicist, corresponding member of Academy of Science of USSR (1929).
Friedman, Alexander Alexandrovich (1888–1925), Russian mathematician, physicist, geophysicist, meteorologist.
Galilei, Galileo (1564–1642), Italian physicist and astronomer.
Gamov, Georgiy (George) Antonovich (1904–1968), Russian physicist and astronomer, worked in the USA.
Gödel, Kurt (1906–1978), Austrian mathematician and logician. Since 1940, worked in USA.
Halley, Edmund (1656–1742), English astronomer and investigator of the Earth magnetism.

Hartmann, Johannes (1865–1936), German geophysicist.
Heisenberg, Werner (1901–1976), German physicist, Nobel Prize (1932).
Herschel, Sir William (Friedrich Wilhelm) (1738–1822), English astronomer, born in Germany.
Hubble, Edwin D. (1889–1953), American astronomer.
Hutton, James (1726–1797), Scottish geologist, chemist, naturalist.
Kepler, Johann (1571–1630), German astronomer.
Kopernik, Mikolaj (1473–1543), Polish astronomer.
Krasovsky, Feodosiy Nikolaevich (1878–1948), Russian geodesist, corresponding member of Academy of Sciences of USSR (1939).
Laplace, Pierre (1749–1827), French astronomer and mathematician.
Leibniz, Gottfried Wilhelm (1646–1716), German philosopher and mathematician.
Lomonosov, Mikhail Vasilievich (1711–1765), Russian scientist, chemist, linguist, poet, and painter.
Lyell, Sir Charles (1797–1875), Scottish geologist.
Mandelbrot, Benoît (1924), Polish-born French mathematician and leading proponent of fractal geometry.
Newton, Sir Isaac (1642–1727), English philosopher and mathematician, formulator of the law of gravitation.
Penzias, Arno (1933), American astrophysicist born in Germany, Nobel Prize for Physics (1978).
Ptolemy (Claudius Ptolemaeus) (90?–160?), Hellenistic mathematician, astronomer and geographer in Alexandria.
Rembrandt Harmensz van Rijn (1606–1669), Dutch painter.
Rutherford, Ernest (1871–1937), English physicist, born in New Zealand, Nobel Prize for Chemistry (1908).
Repin, Iliya Efimovich (1844–1930), Russian painter.
Shishkin, Ivan Ivanovich (1832–1898), Russian painter.
Shuleikin, Vasily Vladimirovich (1895–1979), Russian geophysicist, member of Academy of Science of USSR (1946).
Smith, William (1769–1839), English geologist and engineer.
Steno, Nicolaus (1638–1686), Danish geologist, anatomist.
Strakhov, Nikolai Mikhailovich (1900–1978), Russian geologist, member of Academy of Science of USSR (1953).
Thomson, Sir Joseph John (1856–1940), English physicist, Nobel Prize for Physics (1906).
Vinci, Leonardo da (1452–1519), Italian painter, sculptor, architect, musician, engineer, mathematician, and scientist.
Werner, Abraham Gottlieb (1750–1817), German geologist and mineralogist.
Wilson, Robert Woodrow (1936), American radio astronomer, Nobel Prize for Physics (1978).

VOCABULARY

A

abrupt, резкий, скачкообразный
absolute, абсолют
acceleration, ускорение
accomplish, выполнять, завершать
adage, изречение
addend, слагаемое
adhere, придерживаться
admixture, примесь
adroit, ловкий, искусный
advocate, поддерживать, защищать
aerolite, каменный метеорит
affirm, утверждать
affirmation, утверждение
adjustment, корректировка, приведение в соответствие
alphabet, алфавит
alteration, изменение, перемена
alternation, чередование
ambiguous, неоднозначный
analysis (*pl.* **analyses**)**,** анализ
ancestor, предок, пращур
antecedent, посылка, предпосылка, антецедент
apparently, по-видимому, на вид
appearance, появление, наружность, внешний вид
applicability, применимость
apprehend, понимать
apprentice, подмастерье
aptitude (for), наклонность к чему-либо
arc, дуга
area, площадь, зона
arrow-head, острие стрелки (на чертеже)
aspiration, стремление
assertion, утверждение
asssurance, уверенность, убеждённость
augmentation, увеличение, приращение
authentically, достоверно, аутентично
average, усреднение
axiomatics, аксиоматика
axis (*pl.* **axes**)**,** ось

B

background radiation, фоновое излучение
bang: Big Bang — теория "Большого взрыва"
bed, пласт, слой
bedding, залегание
binomial, двучлен, бином
blob, сгусток
border, граница, край
bound, граница, предел; ограничения
bulk, основная масса

C

calved ice, оторвавшаяся льдина
capability, способность
celestial, небесный, космический
centrifugal, центробежный
centripetal, центростремительный
classific, классификационный
clay, глина
clear-cut, чёткий, резко очерченный, определённый
closedness, замкнутость
coexistence, сосуществование
cognition, познание
coincide, совпадать
coming into being, становление
complex, сложный, составной
compound, соединение, смесь
comprehensive, комплексный, всеобъемлющий; детальный
concave, вогнутый
conceptual, концептуальный
concern, касаться, затрагивать
cone, конус
contemporaneity, современность
consequence, следствие, результат
consistency, логичность; состоятельность
conspicuous, видный, заметный
continuous, непрерывный, сплошной
continuum, сплошная среда
converge, сходиться (к пределу)
convex, выпуклый
cool down, остывать
creep strength, предел ползучести
cross-hatch, штриховать перекрестными штрихами

cross-section, поперечное сечение
crust, кора

D

data (*singl.* **datum**)**,** данные, факты, информация
deal with, рассматривать, иметь дело с
decay, вырождение, разрушение
decomposition, разложение на составляющие
deduce, выводить
definitive, окончательный, полный, точный
delusion, заблуждение, иллюзия
denial, отрицание, опровержение
descriptive, описательный
destruction, разрушение, уничтожение
detach, отторгать(ся), отделять(ся)
detect, обнаруживать
dictum, высказывание, изречение
dioxide, диоксид, двуокись
disclose, показывать, обнаруживать
discontinuity, разрыв непрерывности (функции)
disguise, маскировать
dismemberment, членение, расчленение
disparate, несопоставимый
disposition, расположение
disprove, опровергать, доказывать ложность (ошибочность)
distinguishing feature, отличительный признак
distortion, искажение
diverge, расходиться
diversity, многообразие, разнообразие
dogma (*pl.* **dogmata**)**,** догма
dwarfish, карликовый

E

earthday, земные сутки
eccentricity, эксцентриситет
eclipse, затмение
ejection, извержение, выбрасывание
elemental, природный
eliminate, устранять, исключать
elusive, неуловимый
emergence, появление
endeavour, усилие, старание
enlargement, расширение

enumerate, перечислять, нумеровать
envelope, оболочка
environment, окружение, среда
the environment, окружающая среда
equilibrium, равновесие
equinox, равноденствие
ether, эфир
evince, проявлять, выражать
expediency, целесообразность
extent, объём, пространство; протяженность
extinct, вымерший, исчезнувший

F
facilitate, способствовать, содействовать
factual, фактический
factual data, опытные данные
faint, слабый, тусклый
fan-shaped, веерообразный
feedback, обратная связь
fern, папоротник
firmament, небосвод
fissure, трещина
flow rate, расход потока (жидкости)
fossil, ископаемое, окаменелость
foundations, основания, основы (наук), принципы
fractal, фрактал
fraction, доля, фракция, дробь
framework, структура, каркас, общая схема (деятельности)
functioning, функционирование

G
gamut, гамма
gift, дар, способность
gist, суть, главное, сущность
glaciation, оледенение
gneiss, гнейс
granite, гранит

H
haute couture (*фр.*), "высокая мода", изделия дорогих дизайнеров
head, напор
heaven, небо
heavenly, небесный

I

imperceptible, незаметный, незначительный
implementation, выполнение, осуществление
increment, увеличение, возрастание
indication, признак
inertia, инерция
inertial, инерциальный
inertness, инерциальность, инертность
inference, заключение, вывод
integral, целостный
integrity, целостность
intelligence, ум, интеллект
interference, вмешательство
interior, интерьер
iteration, повторение
irreconcilable, непримиримый
irreproachably, безупречно
irreversible, необратимый

J

jet, струя

L

laws of motion, законы механики
lever, рычаг
limestone, известняк
luminosity, яркость, светимость
luminous, светящийся
luminous emittance, светимость
lustre, блеск

M

magnetism, магнетизм
marble, мрамор
metewand, критерий, мерило
matter, вещество, материя
medium, среда, вещество, материал; средний
minor, мелкий, незначительный
mode, мода
modicum, очень малое количество
monograph, монография
multitude, множество

N

naked eye, невооружённый глаз
nebula (*pl.* **nebulae),** туманность
norm, норма
notion, понятие представление
nowise, никак, никоим образом
nuclear, ядерный, содержащий ядро
nucleus (*pl.* **nuclei),** ядро
number, нумеровать

O

objectivity, объективность
obligatorily, обязательно
obsolete, устаревающий, выходящий из употребления
occur, происходить, случаться
offend, обижать
onlooker, зритель, наблюдатель
option, выбор
orthodox, ортодокс; ортодоксальный
outcrop, обнажение
outwardly, внешне, снаружи

P

parable, притча
paradigm, парадигма
parental, являющийся источником возникновения, “родительский”
path, пробег (частицы), путь
pendulum, маятник
perceive, воспринимать
perception, восприятие
phenomenon (*pl.* **phenomena),** явление
plane, плоскость
posit, класть с основу, постулировать
precipice, обрыв
predominant, господствующий, доминирующий
produce, производить
promulgate, опубликовать, распространять
propagation, распространение
proposition, положение, предложение
provided, при условии
proximity, соседство; сходство
purport, суть, смысл; означать, подразумевать

puzzle, задача, загадка

Q

quotation, цитата
quantum (*pl.* **quanta),** квант

R

radiation, излучение
radius (*pl.* **radii),** радиус
rapid, быстрый
rarefied, разреженный
reason, разум
reasoning, рассуждение, аргументация
rectilinearly, прямолинейно
recurrence, повторяемость
recurrent, повторный
reference system, система отсчёта
refract, преломлять
regularity, закономерность
reiterative, многократный
remnant, остаток, (*мн.*) останки
reproduction, воспроизведение, копия
rest on (upon), опираться на, основываться на
retort, отвечать, возражать
reveal, показывать, обнаруживать
rigorous, строгий, точный
rill, струиться, течь струйками
rock, горная порода
incoherent rocks, рыхлая горная порода
magmatic rock, магматическая горная порода
metamorphic rock, метаморфическая горная порода
pressed rocks, полускальная горная порода
sedimentary rock, осадочная горная порода
soft rocks, мягкая горная порода
solid rock, скальная горная порода

S

sandstone, песчаник
scale, масштаб, шкала
scatter, разбегание
schist, кристаллический сланец
scrutinize, тщательно исследовать, изучать
scrutiny, тщательное изучение, рассмотрение

semi-axis, полуось
sequential, последовательный
set, множество, совокупность, система
shrink, сжиматься, сокращаться
silica, кремнезём
silicon, кремний
simulation, моделирование
slope, наклон
snowflake, снежинка
solution, решение
somehow, как-то
space, пространство; расстояние, промежуток;
космический, пространственный, трёхмерный;
располагать с промежутками (интервалами, на расстоянии друг от друга)
span, интервал, промежуток; заполнять (пробел, промежуток)
species, вид, род
specific gravity, удельный вес, плотность
spectrum (*pl.* **spectra**), спектр
standard, эталон, стандарт; эталонный
statement, утверждение, заявление
steep, крутой
stellar, звёздный
stem (from, out of), происходить, возникать
step-wise, ступенчатый
subjective, субъективный
submit, подчиняться
substance, субстанция, вещество, материя
substantiate, обосновывать
substantiation, обоснование, подтверждение
substitution, замена, замещение
subterranean, подземный
subtlety, тонкость
sunrise, восход солнца
sunset, закат солнца
superfluidity, сверхтекучесть
supporter, сторонник
to be susceptible to, быть подверженным чему-либо
symbolism, символика
synopsis, конспект

T

thaw, таять, таяние
thereby, таким образом, в связи с этим

thickness, толщина, мощность (пласта, слоя)
threshold, порог
tinge, оттенок
toil up, с трудом идти
trait, характерная черта, особенность, свойство
transfinite, бесконечный, безграничный
transfinitude, трансфинита
transverse, поперечный
trap, поглощать, захватывать
traverse, проходить, пересекать
trunk, хобот

U
ultimate strength, предел прочности
uniform, однородный
uniformitarianism, униформизм
uniformity, однородность
uniformly, равномерно
unordinary, необычный
utilization, применение, употребление

V
vague, смутный, неопределённый
vanquish, побеждать
vapour (vapor), пар, газ, газообразное состояние
volatilization, испарение, улетучивание

W
water permeation, водопроницаемость
water table, водная поверхность, уровень грунтовых вод
Weltanschauung *(нем.)*, мировоззрение
wholeness, целостность
withdraw, удаляться
world around, окружающий мир

CONTENTS