TRIP ALONG THE ACOUSTICS

As always, when we first met the subject, it seemed that everything there was trivial, everything had already been studied, and, in fact, there was nothing to learn there. But rather quickly, starting to delve into it, you understand that you do not understand anything, and the main desire in this period is to give up everything and find another occupation. The state of mind in the second stage is very difficult, and it lasts for years.

The state of mind in the second stage is very difficult, and it lasts for years. The second stage ends with the sensation that something seems to be becoming understandable. But the number of unknown all the time increases. Such is the algorithm for comprehending any field of knowledge.

The subject in which I got stuck 45 years ago is the acoustics of solid materials. I did not enter it smoothly, learning first the basics, but abruptly, as I enter the water. But as a teacher of the main branch of this part of physics - seismic exploration. It happened not because of my will, but because of the circumstances.

In 1973, a full-time teacher had to leave for Moscow for six months to retrain, and all the scientists in the department refused to teach this discipline. And so, I, who had prior experience with hydroacoustic devices on ships of the Northern fleet, felt that this experience will be enough for me to quickly learn the principles of seismic exploration, and accepted the offer to read this material.

The first problem I encountered was the lack of laboratory work in the seismic survey course. They were not in the Leningrad mining institute (at the Department of Geophysics), nor at the Leningrad State University, and not in any other educational or research institution, either in our country or in other countries. And when I appealed to the leading seismic scientists to share with me the idea of some laboratory work, they met this request with great surprise. Say, the subject of seismic exploration is so simple and logical that it does not require laboratory study.

And indeed, as I later became convinced, the idea of seismic prospecting is so simple that it can be invented by people who have no education at all. In fact, the emergence of a field of elastic oscillations, directed into the earth’s strata as a result of a shock impact on it, by virtue of its obviousness does not require any proof. In the same way, the very fact of the reflection of this (probing) field from geological objects located in the Earth’s depth does not require proof.

That is, there are conditions that imply the implementation of the principle of radiolocation.

It so happened that by the time I began my teaching activities, I somehow formed some hobbies of my own, which help me very often. First, it is the history of the development of physics. Analyzing the delusions and findings of previous generations of scientists, we find analogies with today's problems.

And secondly, recently (at that time) Kuhn’s book translated into Russian [1] about the methodology of the development of scientific knowledge. From Kuhn I learned that the evidence, not supported experimentally, is a path to a dead end, and that axioms are not something that does not require proof (because there is simply no such thing), but something that cannot be proved.

And so I decided to put the acoustics labs , but I give to students something simple as a basis for seismic exploration. And so I decided to put the acoustics labs , but to give to students something simple as a basis for seismic exploration.

It seemed that very simple to determine the speed of propagation of a probe pulse in samples of a geometrically regular shape. Before giving to students, I myself measured the speed of sound in several plates of varying thickness from durable rocks, using standard ultrasound equipment.

To my surprise, the average speed in the plates of the same material is changed as their thickness changed. This was my first misunderstanding.

And I remembered that at all the conferences that I attended at that time, this question arosed. Constantly there were fierce disputes about how to measure the speed correctly.

But the moment of registration of the beginning of the signal is the only metrologically correct measurement of speed, which is possible in acoustics ...

Well, it may be coming up with something simpler. For example, to look the decrease in the field amplitude when the geophone is removed of the impact point. There should be no surprises here.

I had a thick sheet of glass 2 by 2 meters. Nothing more homogeneous than glass, it is impossible to think up. The fact that the plot of the amplitude I versus the removal of the geophone from the impact point l is approximately similar to the graph (a, shown in Figure 1, was not in doubt.

But in fact, the graph turned out to be geometrically similar to the dependence (b.

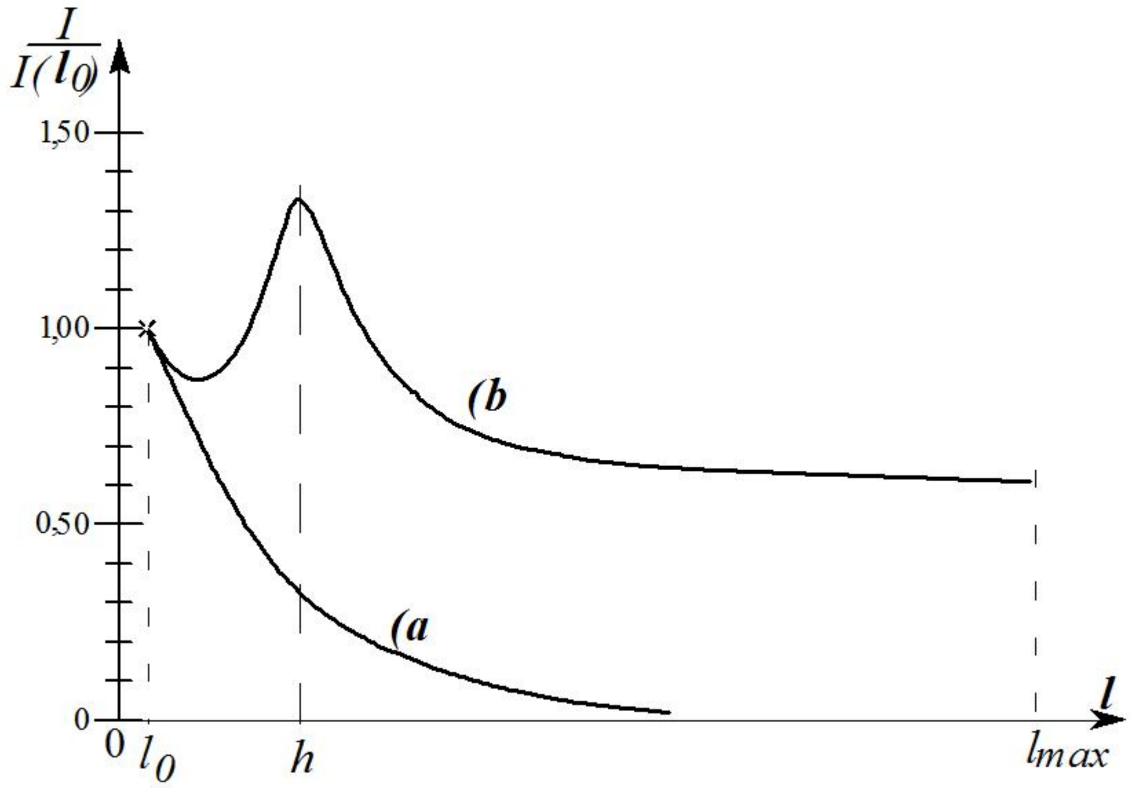

Fig. 1

At the very beginning everything, it seems, was happening as expected. First, the signal decreases with distance from the point of impact. But further, when the seismic receiver approaches the value of *l*, approximately equal to h, the signal suddenly begins to increase significantly, reaching a value exceeding the amplitude value at the point of impact. After that, it still decreases with increasing *l*, but ... with further removal of the geophone from the point of impact, the decrease in the signal is very slight.

I did not know how to explain to students that for some value of *l*, the amplitude of the signal does not decrease with distance from the point of impact, but increases! And how to explain that with a further increase in *l*, the decrease in the signal almost stops?

One of my students saw this effect, and a pilgrimage began to the lab. Everyone wanted to see how the signal increases with distance from the point of impact.

All this lasted until 1977, when I was instructed to make the equipment, which allows me to determine the attenuation of the signal in the rock layer, in the so-called direct roof in the coal mine. Direct roofing is the rock layer that lies directly above the coal seam. When extracting a coal seam, beneath this rock layer are mechanisms extracting coal (combine, conveyor and lining), as well as miners involved in the extraction of coal.

The number of miners dying during the sudden collapse of the immediate roof is very high throughout the world. And it was necessary to find signs of this collapse, so that it ceased to be sudden.

In theory, if there are no cracks in the immediate roof, it should not collapse. And the number of cracks in the rock layer, also from general considerations, should be related to the damping of the elastic field in it.

For the experimental verification of this logical line, an apparatus was manufactured, which makes it possible to estimate the damping of the field of elastic oscillations in the rock layer. When planning these measurements, it was necessary to first understand what frequency of the probing signal is optimal. Oddly enough, there was no information in the literature about this. In order to obtain this information, a generator of a sinusoidal signal was designed, the frequency of which could vary from 20 Hz to 20 KHz. This entire range was divided into several dozen frequency intervals, and in each of these intervals, the attenuation of the elastic field was measured. The radiation and reception of the field of elastic oscillations were carried out at a fixed distance *l* with the help of two identical piezoceramic transducers.

What came out of this is shown in Fig.2.

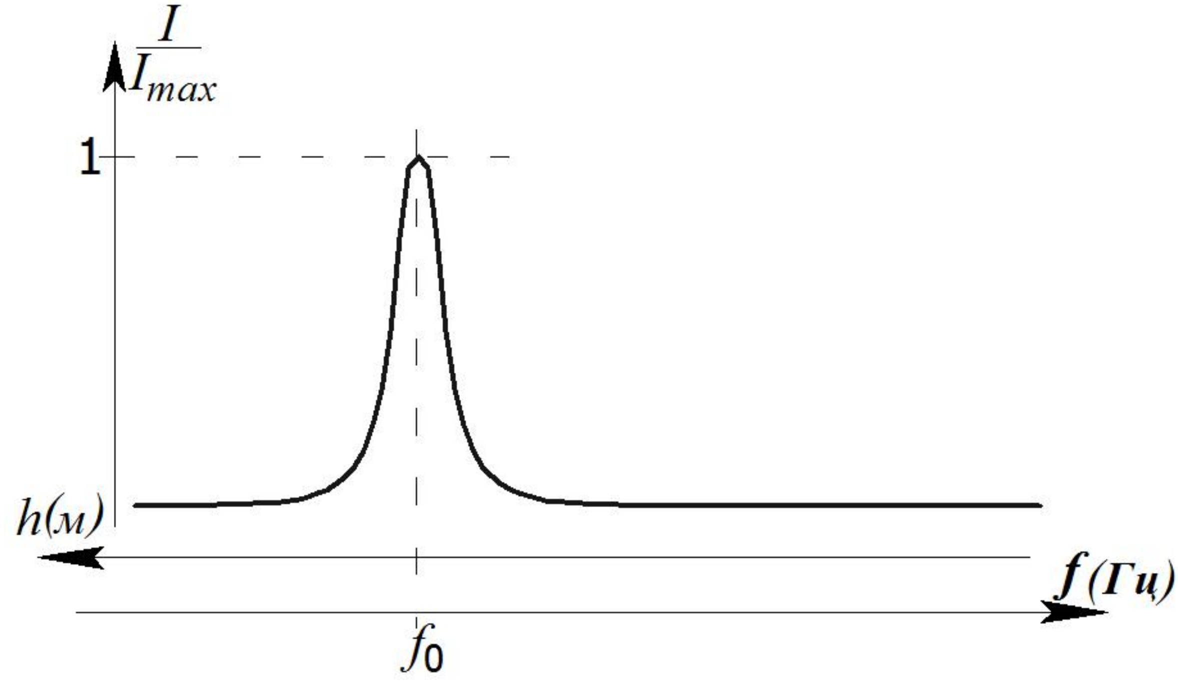

Fig. 2

I/Imax – signal amplitude in relative units.

Fortunately for me, by that time I had knowledge in the field of radio engineering, and I knew what means such dependence of amplitude on frequency .

I met geometrically similar dependencies in the works on mining, and they were explained by the fact that at some frequency there is an anomalously high value of the stressed state of rocks.

I treat this statement with suspicion, because the stress state of rocks, around which all the efforts of mining science are combined, does not have its own standard in the Chamber of Measures and Scales, and therefore cannot be assessed by any measurements.

As follows from the course of theoretical radio engineering [3], if the graph of the amplitude characteristic of any device versus frequency (that is, the spectral characteristic) is geometrically similar to the graph shown in Fig. 2, then this device is an oscillatory system. This statement is easy to prove mathematically, which is done in the book [3].

The *I*(*f*) dependence itself, which has a form geometrically similar to the graph shown in Fig. 2, is a spectral (frequency) image of a single oscillatory process, that is, a damped sinusoidal signal. In other words, having received the graph shown in Fig. 2, I realized that this is a new, previously unknown oscillatory system, the properties of which are possessed, in particular, the rock layer. Let me remind you that the oscillatory system is an object that reacts to a shock by a damped harmonic (sinusoidal) signal.

Immediately, I realized that the frequency of the signal f_0 should be inversely related to the thickness of the rock layer h and therefore another I-h axis $I(h)$ can be drawn on the $I(f)$ graph, as shown in Fig.2.

It was established experimentally that the relationship between f_0 and h is as follows:

$$h=k/f_0 \quad (1)$$

Thus, when striking the rock layer, we get as a response a damped oscillatory signal, the frequency of which f_0 is uniquely related to the thickness h of the rock layer. And, therefore, to obtain information on the thickness of the rock layer h, it is only necessary to strike this rock layer and using the device (frequency meter) to obtain the value f_0, and therefore, h.

The fact is that the power of the immediate roof h is the key information when considering the problem of predicting the collapse of the rocks of the immediate roof. But to get this information before it was possible only by drilling from underground workings, from the bottom up, which is almost impossible in the mines. Now this problem has ceased to exist.

However, this is not all. According to Lord Kelvin’s definition, an oscillating system is an object that responds to a shock (pulse) effect by a signal that is a damped sinusoid. Of the known oscillatory systems, the electric oscillatory L-C circuit is most in demand (opened in the 1870s by Lord Kelvin). What I discovered in 1977 is also an oscillatory system, but an elastic oscillatory system (EOS).

The definition of the oscillatory system can be slightly modified. For example, like this: an oscillating system is an object that contains a mechanism for converting a pulse signal into a sinusoidal one. For all known oscillatory systems, this mechanism is known, but not for EOS. And not only unknown, but it is not difficult to prove that it cannot be.

When I started laboratory modeling of the EOS, the most prominent representatives were glass samples. Glass is the most uniform material. And consequently, it does not have any inhomogeneities that could serve as a mechanism for converting a blow into a sinusoid. It turns out that there is a paradox: there is a transformation, but there is no transformation mechanism.

And I began to object to the transfer of equipment made by us to the mine geologists, which, using the physical effect found by us, allows us to estimate the stability of the roof and predict its collapse. I believed that equipment designed to improve the safety of miners should not be based on a physical effect, which cannot be. Because if this equipment suddenly works according to science, then this may contribute not to an increase, but to a decrease in safety.

And only somewhere in the 81st - 82nd year I found a condition under which the physical effect discovered in 1977 may exist. The mechanism for converting a blow into a sinusoid is still unknown to me, and only the condition for the existence of this mechanism is known.

Being several years in a state of constant search for some heterogeneity in a monolithic and homogeneous material, I somehow suddenly realized that we should be interested only in acoustic heterogeneity. But we, in acoustics at the metrologically correct level, cannot determine anything but speed. Therefore, it is necessary to find some differences in the velocity of propagation of the front of elastic oscillations V_{fr}. And they were found. As it turned out, in glass and other objects-resonators (from metals and alloys, from ceramics and rocks) in the border areas, the velocity of propagation of the field of elastic oscillations V_{fr} slows down.

And then it became clear why in the samples of the same material the speed in the plates changed with a change in their thickness.

On fig. 3b) shows how the velocity of propagation of the front inside a single sample varies in thickness h. By changing the thickness of this sample, we change the contribution of the near-surface zones Δh to the value of the average thickness of velocity V.

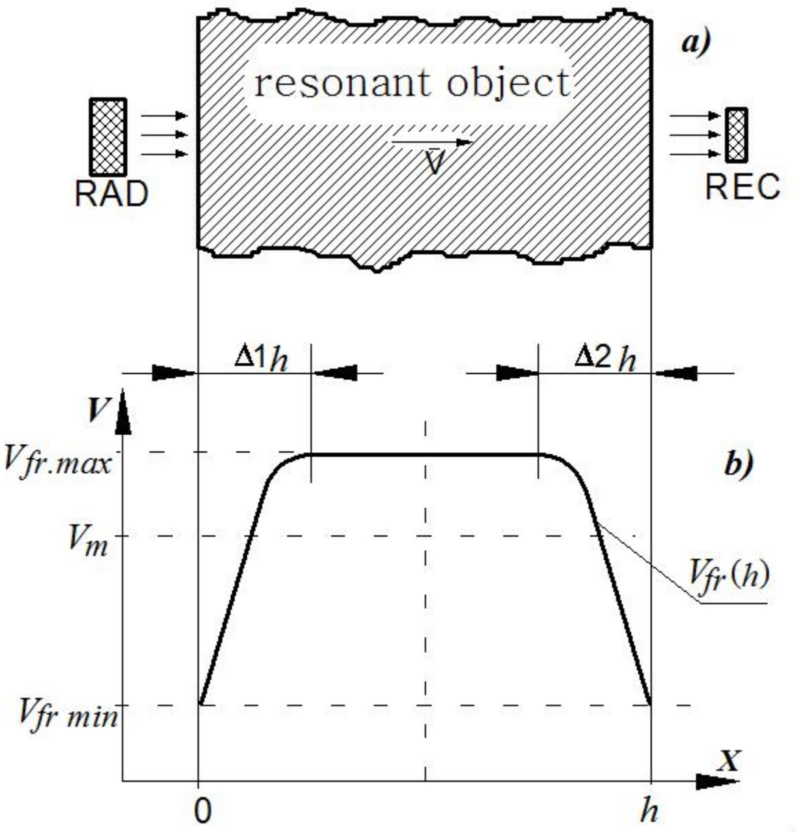

Fig. 3

RAD and REC - respectively, a piezo-ceramic emitter and receiver.

Later it became known that not all samples of solid media are resonators. And plexiglas samples are not resonators. When exposed to it by acoustic pulse, its own oscillatory process is not formed. But at the same time, the speed V_{fr} in Plexiglas samples is constant and the same at all points.

But on the other hand, the speed itself cannot change without external influence.

A lot of time passed until I realized that in order to get the dependence shown in Figure 3, it is not at all necessary for the speed to vary in magnitude. It would be enough for her to change only in the direction.

Suppose that the velocity vector near the boundaries is bent. We do not define the actual speed, but only its projection on the *X* axis! And there is enough experimental datas that support this model.

First, if the velocity vector changes its direction in the zones *Dh*, then, with normal (perpendicular) sounding of the resonator plate, the tangential field component arises. And this is well confirmed by the observation of the effect of acoustic resonance absorption (ARA), [4].

Secondly, a gradual decrease in the V_{fr} speed in the border areas is indeed a condition for the formation of EOS, and this is proved by the fact that if you create such *Dh* zones in plexiglass or air or water, then the objects of these materials will also have the properties of resonators [5].

EOS detection highlights another problem. The fact is that any measurement in the field of acoustics implies a seismic receiver. And it is necessary that this geophone does not contain its own EOS. This problem is known in radio engineering when we are forced to investigate an oscillating circuit with the help of an apparatus (oscilloscope) that has its own oscillating circuit in the input circuit. At the same time, the natural frequency of the circuit under study will change, and it is not always possible to take this into account.

So, all existing seismic receivers incorporate their own EOS. First, it is a metal case. Secondly, the sensitive elements themselves possess the properties of EOS. Either this is piezoelectric ceramics, or a coil on spring hangers. This is very easy to verify. For this, a seismic receiver should be struck with a short blow (drop a small steel ball on its body). The resulting electrical signal will have the appearance of a long harmonic signal. The task was solved by creating a special seismic receiver for spectral-acoustic measurements [6], in which the piezofilm, which is not a resonator, serves as a sensitive element, and the plexiglass is the body.

I Still have not said what is the coefficient *k* with the dimension of speed in expression (1).

Purely empirically, it turned out that the value of this coefficient is 2500m / s with an error not exceeding 10% for all rocks. At first it caused a shock. The fact is that according to the data published in various handbooks on the physical properties of rocks [7], all rocks are characterized by very different velocities. And even the same rocks have different speeds depending on the field. Then I began to measure the speed of propagation of the front of elastic oscillations in samples of approximately the same geometry.

So, I claim that round samples with a diameter of approximately 80mm and a thickness of approximately 20mm of all major rocks (both terrigenous and carbonate) have a velocity of propagation of the elastic vibration front V_{fr}, approximately 5000m/s. That is, $k = 0.5\ V_{fr}$ or $k = 2500$m/s. And until now, when I have to give reports on the physics of the field of elastic oscillations in rocks, the listeners categorically object to this. Well, as you know, changing stereotypes in thinking is not a task for the faint of heart.

So, the expression (1) would be correctly written in the following form:

$$h=V_{fr}/2f_0=5000/2f_0 \quad (1)$$

Taking into account the effect discovered in 1977, it can be said that the earth's strata by acoustic properties is a aggregate of oscillatory systems. Most often, these oscillatory systems are more or less plane-parallel extended layers-resonators. These objects, as it turned out, have very peculiar properties. With short impact on them, an oscillatory process arises in them, shown in Fig.4.

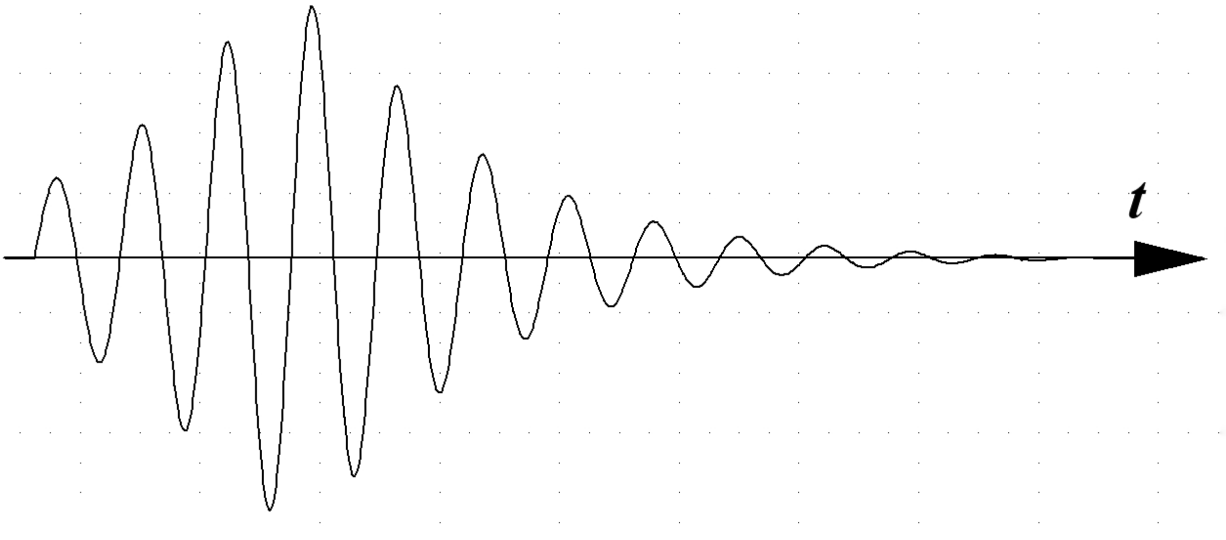

Fig. 4

This wave packet propagates along the rock layer-resonator with minimal attenuation, without going beyond the limits of this rock layer, to the boundary of this layer-resonator. This wave packet propagates along the rock layer-resonator with minimal attenuation, without going beyond the limits of this rock layer, to the boundary of this layer-resonator. There are experimental results (with radiation by means of a vibrating range), where the signal along the rock layer propagated without perceptible attenuation for thousands of kilometers.

The propagation velocity of this signal is half as much as V_{fr}. That is, 2500m/s

Thus, when radiation is emitted into the earth's strata, the seismic signal and the echo signal propagate not across, as claimed by seismic prospecting, but along the bedding, which explains the absence of positive results in the implementation of seismic exploration.

Resolving one after the other misunderstandings allowed us to learn how to solve many problems. The championship among them is prediction of accidents in underground workings at any depth without descent into the mine. So, when geophysicists from Khromtau (Kazakhstan), using our methodology for 12 years, reported this rezult at a conference, a scandal erupted, because everyone present was convinced that this was impossible. This scandal aroused the interest of all owners of neighboring mines, which led to the fact that spectral seismic survey equipment now operates around the clock at all mines in Khromtau. And now, no underground work is carried out in Khromtau without a preliminary survey from the surface using the equipment of the SSP.

Currently, this development is also used in German mines.

The use of the development considered here in mining allows us to eliminate the problem of injury to miners in mines and quarries.

I do not exclude that in due course this development will be applied even in the Russian Federation.

Our second achievement is the development of methods for finding water inflow points. With the help of spectral-seismic exploration seismic equipment (SSP) [9], a method of reliable search for spring water inflow points was created. And now we can say that there are no waterless zones on the Earth.

Thus, the discovery of the EOS in 1977 led to a paradigm shift in acoustics, which is quite consistent with the ideas of the methodology for the development of scientific knowledge. And now acoustics have a chance to develop in accordance with the laws of methodology, and I cannot even imagine that this area of knowledge will still give to humanity.

All the results of research on the problem can be found on my website [10].

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