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PHYSICAL EXPERIMENT IN UNIVERSITY EDUCATION

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The role of physical experiment in modern university education is discussed. The principles of organization of a training and research physical practical work for the lower years students at faculty of nonlinear processes of the Saratov university are stated. The concrete examples of experimental researches are cited.

Introduction

Exactly 40 years ago the academician P.L. Kapitsa spoke at the General meeting of the Academy of Sciences of the USSR with a report, which gave the title to a famous book «Experiment. Theory. Practice» [1]. The work is well known to physicists - its main idea is comparison of theoretical and practical physics development in the USSR. As the editor of «The Journal of Theoretical and Practical Physics» P.L. Kapitsa estimated relation of articles on experimental physics to articles on theoretical physics as 1:4 or 1:3. Work of great scientists - naturalists, who made a large contribution to development of modern natural science, was making invariably in an intimate connection with theory and experiment. Harmonious development of theory and experiment «is absolutely necessary in all fields of natural science». Still the famous lord Kelvin compared theory with millstones, and data of experiment with grain. Much as millstones whirled by themselves - it would be nothing useful. But quality of flour is determined by quality of grain that is why «high quality of experiment is a necessary condition not only for forming an advanced theory, but also for getting practical results». It is hard to determine the mentioned relation of theoretical and experimental works today, and the idea of high quality of physical experiment, its role nowadays and teaching to this art, is urgent today.

In our opinion, preservation and development of the experiment on location is an important element of the correct formation of a modern natural picture of the world in the mind of the student. For a first year student (a physicist) experiment begins with a physical practical work and connected with a course of general physics. It should be noted, that organization of physical education at the University begins with its base - the course of physics, being understood in a broad sense: a course of lectures, seminars, laboratories, demonstrational experiments, manuals and so on.

Unfortunately it should be noted, that the role of physical experiment does not often get due attention in modern manuals. Courses of general physics undergo an excessive «theorization» - statement of fundamental classical experiments «disappears» from the pages of training aids, and some of them changed radically established conceptions in physics. For science the most valuable experiments were those ones, results of which contradicted theoretical expectations, though many experiments were organized «under the direction» of one or another, sometimes hypothetical, but always theoretical scheme, in the context of which they wanted to understand experimental facts. Just such experiments played a decisive role in the picture of the modern natural science. Side by side with simplicity and clearness of an idea (sometimes just «witty») these experiments were notable for striking, even for today, resolution. Estimations on the Mickelson - Morley experiment are usually traditionally given as an example from a chrestomathy [2]. And some years before the very «sensitive» experiment, results of the skilful experimentalist Rowland (1878) on direct verification of the Maxwell's idea about magnetic field of a moving charge (paragraph 770 of «The Treatise about electricity» [3]) were published. The idea of the experiment is simple - the magnetic field of a rotating charged ebonite disk should be determined. What can be surprising for a modern student here? Of course, experimental art - the value of the found magnetic field was equal to 10^5 (!) of the earth magnetic field value. This is an extremely hard experiment even for today, but it is difficult to find a description of the measuring method. There are some other similar examples. We can observe the same situation with modern experiments. But when explaining some effects, their enclosure was rather convincing. (For example, when studying resonance - the application of the Mössbaur effect for measuring of fantastically little effects of changing frequency when studying «gravitational violet shift» of the photon in experiments of Paund and Rebka). It seems to us, that the student of nowadays should know about such unique investigations. An educated specialist should get even «a grain» of art and culture of organization of great experiments in the university lecture-room. The usage of the adjective «great» is quite justified - many of the experiments have a «Nobel» character.

Leading university centers pay serious attention to a new approach in creation of training laboratories, corresponding to «the spirit of modern physical investigations» [4-8]. They should provide interest for the student in researches in the physical laboratory, but it is not so easy, as he is «charmed» by the computer technology, which is fascinating and seems all-powerful to him. The practical work is only «ideologically» connected with the course of lectures; its principal task is not verification of «correct» laws, and mainly mastering of measuring techniques, analysis of reasons of experimental results difference, correcting of experiments. All this is directed to overcome «intellectual sterility» of the student. Organization of an effective process of studies in the physical laboratory demands changing technology of the accepted method: creation of multifunctional module facilities with elements of automation of measuring, autonomous composition of elements on such facility to extend the number of being executed exercises, that provides a «storing» system of collection of experimental data. The essential moment is the intensification process of organization of the work at the sacrifice of time saving on usual «routine» procedures (replacement of the facility and mastering of a new one, exception of ineffective measurements, unjustified prolonged «theoretical» test). At the same time it is necessary to take into consideration the natural law of «distribution of students over energies» in depending on their creative abilities, desire and ability to work with the equipment. Equally with a modern «arrangement» of organization of works it is expedient to use «out-of-date» tasks (warmth, sound and so on): the student would not possess some scientific erudition without fundamental studying «the classics». After having carried out experimental investigations by the student, the crucial stage is analysis and processing, showing sufficient erudition, of the received data, usage of a computer to model and demonstrate visually the results.

Training and research physical practical work for the lower years students

The presented «ideology» was established when creating an integrated training and research practical work «Methods, Technology and Informational Provision of the Physical Experiment» at the faculty of nonlinear processes of the Saratov State University (SSU). The main aim of such laboratory is a detailed analysis of the received experimental results, estimation of influencing factors and reliability of the data, that is the training to the foundations of the physical experiment, showing sufficient erudition.

In the practical work there are 15 multifunctional facilities with electronic measuring systems, 110 students of 2 faculties of the SSU: the faculty of nonlinear processes and the faculty of computer sciences and information technologies, take the course during the academic year, 5 training aids have been published [9-13]. The main directions of researches are carried out in the following fields: physical foundations of mechanics (the conservation law, dynamics of the rotary motion, friction forces of different nature, elastic deformations, mechanical oscillations and resonance); oscillations and waves in different mediums, molecular phenomena, thermodynamics and phase transitions, and electromagnetic phenomena.

Taking into account the strategy of education at the faculty of nonlinear processes, based on the ideas of nonlinear dynamics, let us note only some tasks on oscillations and waves, being solved in the physical laboratory. This is, first of all, a vast class of mechanical pendulums with analysis of their characteristic peculiarities, experimental investigation of nonlinear effects and their comparison with different theoretical models [9]. A series of tasks on investigations of waves in different mediums demonstrates the «international» language of the theory of oscillations: waves in bars and strings, sound waves in free space and an acoustical resonator, capillary-gravity waves on the water surface, the study of which already requires a certain experimental skill. Both velocity of sound and velocity of the electromagnetic wave are measured by a widespread standing wave method. To complete the picture let us adduce some results of experimental investigations.

Resonance in mechanical systems

A great role and beauty of the phenomenon of resonance in nature are well known. In the training laboratories this phenomenon is usually studied in a oscillatory contour of the radio range or in systems of microwave frequencies and the optical range. In our practical work resonance is studied on torsional oscillations of the disk of the rotary table, carrying out oscillations in the horizontal plane under the action of two elastic springs, creating a torque moment throughout a thread, enveloping the axis of the pulley of the rotary table [10]. Elastic properties of the springs and the moment of inertia of the rotating system determine the oscillation period of such pendulum. The electronic measuring system allows determining the oscillation period with resolution 0.1ms. To excite forced oscillations in such system and to investigate resonance the pulley of the rotary table is connected with an electric motor, allowing changing the frequency of the forced signal and its amplitude. Dependence of amplitude and, what is more interesting, phase of rotary forced oscillations of the system on frequency of external oscillations are investigated in the work. It is interesting to pay attention, that resonance effects for realized mechanical systems are observed with frequencies about 1 Hertz (!). Results of measurements are presented in Fig. 1. Resonance amplitude characteristics (α - the angle of deflection of the system from the equilibrium position) of the free platform and the platform loaded by a ring are shown in Fig. 1, *a*. Dependences of the amplitude of oscillations α and the phase shift $\Delta\phi$ on the period of external oscillations for one of the systems are shown in Fig. 1, *b*.

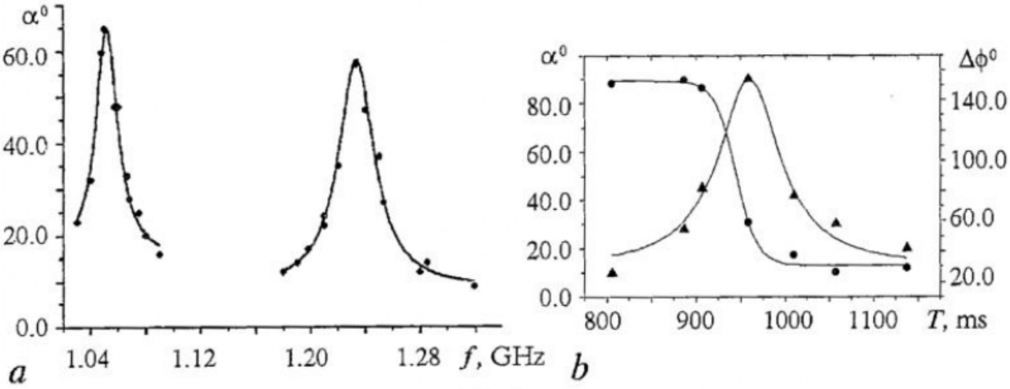

Fig. 1

From received data one can make conclusions about good quality of being investigated mechanical oscillating systems.

At the same time let us note, that such simple oscillating system is a simple and rather precise device to determine moments of inertia of different bodies. It is enough to measure the period of natural oscillations of the free table T_0 and its moment of inertia J_0, the period of oscillations of the loaded table T, the moment of inertia of the table with any figure, placed in an arbitrary way on the disk of the platform, is computed of the relation $J=J_0(T/T_0)^2$. In the table 1 there are found in the experiment and computed moments of inertia of different figures (the moment of the loaded table is J_0=0.0026 kg/m^2 , moments of inertia of figures are presented in the same units).

Table 1

Moments of inertia of different figures

Figure	a Parallelepiped			a Disk		a Ring
Position	Flat-ways	On the «long» side	On the «short» side	In the center of the platform	On the edge	In the center
Experiment	$4.9\cdot10^{-3}$	$4.18\cdot10^{-3}$	$9.65\cdot10^{-4}$	$7\cdot10^{-4}$	$2.1\cdot10^{-3}$	$2.48\cdot10^{-4}$
Calculation	$4.92\cdot10^{-3}$	$4.19\cdot10^{-3}$	$9.65\cdot10^{-4}$	$7.1\cdot10^{-4}$	$2.13\cdot10^{-3}$	$2.5\cdot10^{-4}$

An excellent coincidence attracts attention.

Measurement of velocity of light

We have already spoken above about the «international» language of the theory of waves. It shows itself in methods of investigating waves of different nature. A wide spread measuring technique of the velocity of sound is the standing wave method, as a rule, here conditions of wave reflection are invariable, they are given by the facility construction. By the same method one can investigate, naturally, electromagnetic waves: to determine the velocity of a electromagnetic wave in the free space. Perhaps, first time in his life a first year student has an opportunity to measure «with his own hands» one of the principal «mysterious» physical constants - «velocity of light».

The facility is very simple; its scheme is given in fig. 2.

The source of electromagnetic oscillations is a microwave oscillator in the range of frequencies 1000-2000 MHz. The signal, modulated by a low frequency, went from the signal oscillator to a flat coaxial line, along of which a needle-shaped radio-frequency indicator probe was moving. The signal of the probe was brought to the detector chamber, after which the low-frequency signal was amplified and observed on the screen of the oscillograph. The position of the indicator probe along the shift axis was fixed with the aid of noniuses with resolution to 0.5 mm. The standing wave character was changed easily by the kind of charging of the line: a broken line, a short-circuited or matched line. Length of the measuring line allowed fixing, when the probe moving, some length of waves, in measuring of which one should be especial careful. The signal frequency was determined to tenth parts of a Megahertz on the generator. The result («velocity of light) was determined by these two parameters - signal frequency and wavelength. As we can see, measuring technique is very simple and the art of an experimentalist was in analysis and in provision of conditions of certain measuring of standing wave minimums. In table 2 there are values of velocity of the electromagnetic wave in the air, measured for different conditions of the standing wave.

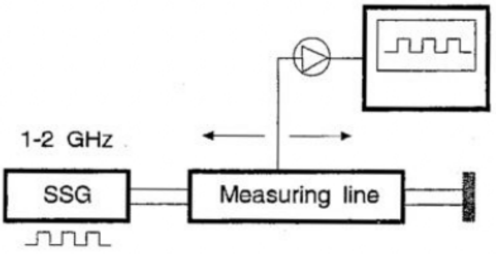

Fig. 2

Table 2

A broken line

f, MHz	1140.7	1217.7	1259.9	1414.1	1689	1807.7
λ, mm	263.23	247.46	238.82	212.25	177.58	165.55
c, 10^8 m/s	3.0027	3.0134	3.009	3.0014	2.9994	2.9927

A circuited line

f, MHz	1200.6	1276.5	1439.4	1518.2	1557.9	1716.7	1796.7
λ, mm	251.30	235.42	209.15	198.57	193.02	175.25	167.35
c, 10^8 m/s	3.0171	3.0052	3.01	3.0148	3.0071	3.0085	3.0068

c - velocity of an electromagnetic wave, f - signal frequency, λ - wavelength.

The method of a cavity microwave resonator for measuring «c» is methodically very close to the one, stated above, and it is one of modern for determining velocity of light (even the depth of the skin-layer of electromagnetic radiation penetration inside of metal is taken into account in the method). That is why organization of the described work, because of its simplicity and clearness, is very useful for a yesterday's schoolboy, especially as it allows a large creative analysis of mistakes of the experiment. On the facility one could demonstrate and value in quantity the effect of «decelerating» the phase velocity of the electromagnetic wave by a dielectric, placed along the wave propagation channel, and even value dependence of dielectric constant on the signal frequency.

Waves on the water surface

It is interesting to investigate one more type of waves, which, of course, everyone observed more than once - these are waves on the water surface. They are beautiful and usual for us, but these are «especial» waves, as they are similar neither to sound nor to light. As Feiman R. noticed «all difficulties, which only can be in waves, gathered here»[14]. This is one of the most «beautiful» tasks in the theory of waves [15,16]. We can indicate main physical factors, determining existence of the waves, of all variety of waves on water - these are gravity and surface tension. These two effects are compared in a certain field of parameters and these waves are called capillary-gravity. Their characteristic peculiarity is dispersing waves, for which the phase velocity of waves changes with the wavelength. This is a serious research for a student of the first year both in an experimental and theoretical aspects of the phenomenon and, first of all, because of getting to know phase and group velocities. The liquid being investigated is placed in a special container (of organic glass), reminding an irrigation canal. A diaphragm, exciting waves with a certain frequency from a generator, is joined to an edge of the canal. To excite running waves in such canal, the opposite wall is made in the shape of a sloping «bank». A thin probe, submerged a little to the liquid, moves along the canal. Current through the probe depends on depth of its submerging to water, that gives opportunity to observe the wave shape when the probe moves, that is to measure the wavelength. In the measuring scheme we used a dual-beam oscilloscope, on which a reference sine signal, exciting the diaphragm, is observed on a ray and a signal from the probe on another ray. A picture of these two signals, convenient for measuring, can be chosen by means of regulation of parameters of the electrical scheme. Moving the probe along longitudinal coordinates, one gets cophasing or antiphasing position of the signals and determines the wavelength, as a distance between points in a certain phase. Knowing the frequency of the oscilloscope, a phase velocity can be determined easily. Dependence of phase velocity on wavelength for water with temperature 25° C is presented in Fig. 3.

The rated dependence on the relation

$$V_{ph} = (g/k + \sigma k/\rho)^{1/2}$$

is presented by an entire line, here g - gravitational acceleration, σ - coefficient of water surface tension, ρ - density of water, $k=2\pi/\lambda$ - wave number, λ - wavelength. Values of material constants are chosen for the operating temperature. Data of the experiment are given in form of points. Range of operating frequencies is 6-70 Hz when taking down the dependence, the experiment is rather «punctilious», taking into account, that measuring on low frequencies (~10Hz) on usual oscilloscopes is rather difficult. The experiment depends on many «ruses», that is why the present work can be carried out in the form of a course work with large opportunities for independent researches. The received experimental data reflect principal natural properties of capillary-gravity waves in the range of typical wavelength about 1.7 cm, where minimum value of the phase velocity is about 23 cm/s. As for analysis of quantitative coincidence - this is another theme of the research.

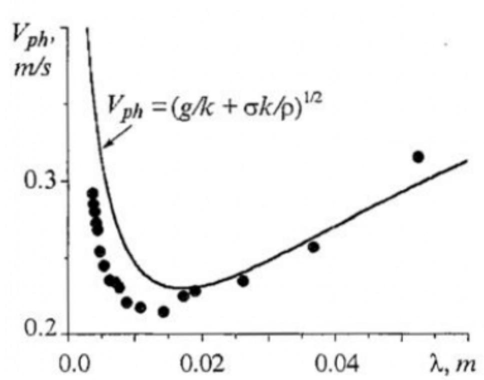

Fig. 3

Conclusion

In the same work some important moments about a role of physical experiment in training of the modern specialist - physics are shown. By the way of illustration stated principles the results of organization of a new training and research physical practical work for the lower years students at faculty of nonlinear processes SSU are given. Different themes of investigations, which the student gets to know in the physical laboratory, show convincingly wealth and breadth of the experiment on location in the surrounding physical world to a young researcher. The knowledge received at this stage, will allow him creatively and with confidence to participate in the program of researches of scientific laboratories of faculty.

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ФИЗИЧЕСКИЙ ЭКСПЕРИМЕНТ В УНИВЕРСИТЕТСКОМ ОБРАЗОВАНИИ

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Обсуждается роль физического эксперимента в современном университетском образовании. Излагаются принципы организации учебно-исследовательского физического практикума для студентов младших курсов на факультете нелинейных процессов Саратовского университета. Приводятся конкретные примеры экспериментальных исследований.

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