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PROPOSED BY PLANCK IN PHYSICS ON THE BASIS OF THE
PRINCIPLE OF CONSISTENCY

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METHODOLOGY FOR SOLVING THE RADIATION PROBLEM PROPOSED BY PLANCK IN PHYSICS ON THE BASIS OF THE PRINCIPLE OF CONSISTENCY

Abstract: The article describes issues based on a method of forming the solution of the radiation problem by Planck in physics on the basis of the principle of consistency. The principle of consistency, along with serving as a methodological principle in pedagogical and didactic research, plays an important role in the spectral distribution of energy in thermal radiation in physics and its effective assimilation by students at the required level. The method of demonstrating the results given by the laws of Ray-Jeans, Vin, and Planck for small frequencies using the universal computer algebra system Mathematica is presented.

Keywords: Methods of teaching physics, Planck energy, the principle of consistency, Mathematica universal computer system, Vin's law of displacement, classical and quantum physics.

It is known that in order to bring up the next generation as perfect human beings who can meet today's requirements, to improve the quality of their teaching, it is necessary to strengthen the connection between the theory of teaching physics at different stages. At the same time, improving the training of well-educated and well-rounded teachers is one of the important tasks facing the system of continuing education. [11]

In the training of future physics teachers of the highest category requires students to have a deep knowledge and understanding of the scientific basis of the course of physics in general secondary and secondary special institutions, the sequence of teaching physics at different stages. However, this issue has not been adequately addressed in pedagogical universities. Most students find it difficult to apply the knowledge they have acquired from higher education physics courses to teaching physics in general secondary and secondary special institutions. The reason is that they do not have a clear idea of the extent to which the theories being taught are explained in terms of the stages of teaching.

Now we will consider in detail the solution of the problem of thermal radiation of black bodies in the case of analysis of historical views of high scientific and methodological significance, including the work of Max Planck. We note that the ratio of temperatures in the events under study is related to their thermodynamics.

Given the large number of sources on how Max Planck's theory of thermal radiation came to the forefront of quantum theory, we will explain how the
problems were solved in his own scientific work [1]. However, M. Planck's report "Theory of Distribution of Normal Spectral Radiation Energy" at the meeting of the Prussian Academy of Sciences on December 14, 1900 [2], published in 1901 "On the law of distribution of energy in the normal spectrum", later published in 1943. We will focus on the basic information presented in the article “History of the Discovery of the Quantum of Motion” [3].

M. Planck began his article, published in 1943, with the words: "With the advent of the elementary quantum of motion and the beginning of a new era in physics, one final article among next-generation physicists I feel (according to the data I remember)”. He then described the work done on thermal radiation, and said that in 1860 Kirchhoff's "hollow cavity bounded by walls arbitrarily absorbing and returning on all sides to the surface of a stationary state of temperature T, which is common to all bodies for irradiation due to irreversible processes over time. This is the state of radiation that occurs in a vacuum lined with black walls with such a temperature. Such a radiation corresponds to a known distribution of the energy spectrum at certain frequencies. 

Hence, the so-called normal distribution of energy is a universal function in which no temperature depends on any material, only the temperature T and the frequency $\nu$. However, the simpler the law of nature on the belief formed from this, the more interested I became in the search for this function, which depended on its being so powerful.

In my opinion, a direct way to achieve this goal is the electromagnetic theory of light created by Maxwell, who achieved his last victory in the work of Hertz a few years before this period. So I imagined a cavity that generates, radiates, and absorbs energy from electrical vibrations, and since its properties as such an object depend on nothing, it is as simple as possible to have a linear resonator with a specific $n$ frequency and a slow extinction associated only with radiation. I took the oscillator.

I hoped that the result of applying Maxwell's theory to any initial state obtained in an arbitrary round of this system would be a process in which the irreversible, hollow radiation of radiation, which is a stationary state of thermodynamic equilibrium, has an energy distribution in the radiation of a black body.

Accordingly, I began my research by irradiating with the absorption of resonant electric waves [4]. At the same time, I predicted that the interaction between the excitatory electromagnetic wave and the oscillator that absorbs and emits energy is an irreversible process. However, in the general round, such a prediction is found to be erroneous, and L. Boltsman immediately showed that such an error would occur. This is because the whole process goes well both in the
right direction and in the opposite direction. For this, it is only necessary to change
the sign of the voltage of the magnetic field to the opposite sign, while maintaining
the signs of the electric field voltages at some point in time. In this case, the energy
emitted as concentric spherical waves is absorbed by the oscillator from the
excitation energy in the form of such spherical waves and returned in the opposite
direction. So, in similar situations, there can be no question of irreversible
processes.

Therefore, in order to follow the path defined in the theory of thermal
radiation, it became necessary to include the possibility of changing the signs of
spherical wave processes, as well as all the strengths of the magnetic field, which
accumulate in such a separate and never-occurring concentric round in nature. I
solved this problem by proposing the “natural radiation” hypothesis [6]. Its content
is that some harmonic partial oscillations that cause a wave of thermal radiation to
occur due to the addition are not completely coherent. Based on this hypothesis, I
obtained the laws of radiation processes in a closed cavity with definite special
frequencies and linear oscillators that slowly fade. I first solved the problem for a
hollow circle with such an oscillator in the center. The reason is that the
differential equation written for the process is easily integrated. I then solved the
problem in a general round for a situation where there are a large number of
oscillators of an arbitrary type for an arbitrary cavity. These studies have shown
that the interaction of the oscillator with the radiation that excites it is an
irreversible process at all times. Its meaning is that the initial phase and time
fluctuations of the radiation intensity are corrected and flattened over time. As a
result, a steady state occurs at the very end, so that the specific frequency is equal
to $\nu$ and the oscillator energy $U = \frac{c^2}{\nu^2} K$, has a very small extinction decrement of
any type.

The meaning of this equation, which has served me invaluable, is that the
energy of a forced oscillator according to this equation depends only on the $K$,
intensity of the radiation and its frequency to $\nu$, but not on any of its other
properties.

We note that the process of equilibrium radiation is one of the irreversible
processes in thermodynamics and that M. Planck made a great contribution to the
discovery of this state. We will continue to look at the development path of the
ideas outlined in the article we reviewed. The law of normal distribution of energy,
discovered in 1896 by V. Vin [5]. Its accuracy was confirmed by the results of
measurements at that time (1899) on its own peculiarities. Overall, everything
seemed to fall into place.
However, not long after that, first O. Lumer and E. Pringsheim, then F. Pashen in their experiments found some deviations from Vinn's law of distribution at large wavelengths with increasing accuracy of measurements. After that, M. Plank described his work in this case as follows:

"However, an event took place that led to a sharp turn in this work. At a meeting of the German Physical Society on October 19, 1900, F. Karlbaum described the results of his work with G. Rubens on energy measurement in the field of very large wavelengths.

After that, M. Plank explained the issue of finding a basis for the law, which he opened. In this section, he notes that "there remains an issue that is very important in theory: it has been a very difficult issue to give a proper basis for the law."

The reason is that in this case the problem is to theoretically derive the expression for the entropy of the oscillator ... ".

Planck successfully solved this problem by switching from a thermodynamic view of entropy to a statistical view, using Boltzmann's formula that connects entropy $S$ with probability $W$.

He predicted that the $S_N$ entropy of a system consisting of $N$ resonator and full vibration energy $U_N$ is equal $S_N = k \ln W + \text{const}$.

A proportional coefficient was determined by expression $k$, but this coefficient was not entered by Boltzmann himself (by entering this coefficient, Planck immediately determined it by $k$ [7]). Since Planck has to show energy $U$ not in the form of a continuous, infinitely divisible quantity to find the probability $W$, but in the type of discrete estimates consisting of finitely uniform section $U_N = P\varepsilon$

used a fundamental prediction of the type.

In this way, for resonators, or for harmonic oscillators, the discreteness of energy - the idea of the quantization of energy - first appears. Planck calculated the probability $W$ and found the approximate entropy $S = S_N / N$ as a function of the ratio of the average energy $U / \varepsilon$ of a resonator corresponding to the expression $U_N = P\varepsilon$, and calculated the magnitude

$$ S = k \left[ \left( 1 + \frac{U}{\varepsilon} \right) \ln \left( 1 + \frac{U}{\varepsilon} \right) - \frac{U}{\varepsilon} \ln \frac{U}{\varepsilon} \right] $$

and $\varepsilon$ for the element $U = U_N / N$ of energy.

On the other hand, $y$ Vinn’s law of displacement

$$ S = f \left( \frac{U}{\varepsilon} \right) $$
showed that it is possible to specify the type.

This expression is denoted by an arbitrary constant through $f$, a comparison of the last two expressions written for $S$ shows that the formula $\varepsilon = h\omega$ takes place.

The $h$ in this formula is found to be a constant $b$ that has a unit of motion previously introduced by Planck. The expression written for $S$ is the average energy of one resonator when $\varepsilon = h\omega$ is set to:

$$U = \frac{h\nu}{e^{h\nu/kT} - 1}.$$ 

Planck showed that the volumetric density of the energy of equilibrium radiation, which belongs to one unit of the frequency range, is calculated according to the following formula:

$$u_v = \frac{8\pi\nu^2}{c^3}U.$$ 

The formula $u_v = \frac{8\pi\nu^2}{c^3} \frac{h\nu}{e^{h\nu/kT} - 1}$, which is the last appearance of the Planck formula, is obtained.

If we consider the ratios $\frac{cu_v}{4\pi} = E_v$ and $\frac{cE_v}{\lambda^2} = E_{\lambda}$, then the semi-empirical law of spectral distribution introduced by Planck in the autumn of 1900 we have the formula $E_{\lambda} = \frac{c_1}{\lambda^2} \frac{1}{e^{c_2/\lambda kT} - 1}$.

This is $c_1 = 2hc^2$, $c_2 = hc/k$. in the formula. By comparing the experimental data with the constants $h$ and $k$, Planck obtained the following values

$$h = 6,55 \times 10^{-27} \text{ эрг-сек}.$$ 
$$k = 1,346 \times 10^{-16} \text{ эрг/град}.$$ 

and calculated the amount of elementary electric charge from them [5].

The result is a value that is close to the currently accepted value $e = 4,6910^{-10} \text{ CGSE}$ [4].

On December 14, 1900, Planck proposed new and important results for the science of physics in a statement at a meeting of the German Physical Society. The concept of energy quantum emerged in the form of a discrete portion of energy. However, Planck himself first used the term “element of energy” and later began to use the term “energy quanta”. Planck's resonators only have multiple times the energy of the whole number. From this they derived and absorbed the energy of this whole number of times. This means that the absorption jumps with the emission of electromagnetic radiation, and therefore it is completely contrary to the laws of classical electrodynamics. However, the discreteness of the energy turned out to be related to the constant $h$, which is a quantum of motion.
As a peculiar feature of Max Planck's views we mention the following case: he considered the discreteness of energy to be related to the properties of matter, in his theory the energy of resonators was quantized, but radiation was considered a continuous phenomenon similar to electromagnetic waves. At the same time, Planck did not consider the exact question of the elementary act of the emission of electromagnetic energy by the absorption of certain portions equal to it. He was primarily interested in solving the problem of the spectral distribution of the energy of equilibrium radiation.

One example can be given of the importance of the spectral distribution of energy in thermal radiation in physics. Almost all libraries of mathematical programming languages, which are now widely used by researchers, have special sections on Planck's formula and related problems. For example, the Mathematica universal computer system has a special type of section called PlanckRadiationLaw, which can be used to solve a large number of problems.

As a result of the calculation on PlanckRadiationLaw[Quantity[5000, "Kelvins"], Quantity[500, "Nanometers"]], we obtain a value of $2.27261 \times 10^{14}$ W/(m² * sr) for the approximate radiant energy.

![Figure 1.](image)

The result of demonstrating the results of Rayleigh-Jeans, Vin and Planck's laws for small frequencies using this computer system is given in Figure 1. It clearly shows that at low frequencies Rayleigh-Jeans law and Planck's law give the same results, or that there is no difference between classical and quantum laws.

If, on the basis of our experiments, we fully form the above ideas in students, they will form scientific and methodological ideas about radiation. This in turn serves to better understand the concepts of thermal radiation in quantum physics.

The scientist, who studied the methods of teaching probability-statistical ideas and concepts in the course of theoretical physics at the university based on the principle of consistency, said: He explains that the principle of consistency in the teaching of physics is in many ways similar to the principle of compatibility. "Because according to this principle, any newly developed theory must, when
certain conditions are met, result from the experimentally confirmed results of the previous theory" [8].

The principle of consistency serves as a methodological principle in pedagogical and didactic research. Summarizing these points, the consistency can be described as follows. Consistency in teaching represents the link between the stages of development of knowledge, skills and abilities. The knowledge gained in the first stage of training is preserved and used in the acquisition of new knowledge in the next stage. If students have the skills to apply consistency in the study of physics, they will be able to effectively formulate basic concepts, laws and theories of physics in students at different stages of teaching.

This, in turn, does not lead to the full mastery of physics teaching materials, but also allows them to master the physics course in higher education in the future. It also leads to a spiraling growth of students 'knowledge of physics.

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