Planck constant

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Abstract: The connection to the Planck constant with Wien's displacement law and Kepler's third law. The exact value of Planck's constant for the liquid or solid state of aggregation of matter equals to

$$h = 4*10^{-34} \text{ J*s.}$$

The formula that combines four physical constants - the speed of light - c, Wien's displacement constant - *b,* Planck constant - h and the Boltzmann constant - k

$$3k\textit{b} = hc$$

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Planck's constant

On this physical constant for the first time, said the German physicist Max Planck in 1899. In this article I will try to answer three questions:

1. What is the physical meaning of Planck's constant?
2. How can it be calculated from the actual experimental data?
3. Is it connected with Planck's constant assertion that energy can be transferred only in certain portions - quanta?

Introduction

Reading the contemporary scientific literature, involuntarily pay attention to the fact how difficult and sometimes obscure authors reflect this theme. The story began in the second half of the 19th century, when scientists began to study in detail the processes of thermal radiation tel. To improve the measurement accuracy in these experiments used a special chamber that was allowed to bring the energy absorption factor to unity. The device of the camera is described in detail in various sources and I will not dwell on this, I note only that they can be made from almost any material. It was found that the heat radiation is electromagnetic wave radiation in the infrared range, i.e. at frequencies slightly below the visible spectrum. During experiments it was found that for any particular body temperature IR spectrum of this body has a peak maximum intensity of this radiation. When the temperature rises, this peak shifts towards shorter wavelengths, ie, to higher frequencies of infrared radiation. Charts of this law also has a variety of sources, and I'm not going to paint them. The second rule was already in the present amazing. It was found that various substances at the same temperature has an emission peak at the same frequency. The situation called for a theoretical explanation. Then Plank offers a formula linking the energy and frequency of the radiation:

$$E = hf,$$

where E - energy, f - frequency of the radiation, and h - constant value which was later named after him. Planck and calculated the value of this quantity, which proved to be in his calculations

$$h = 6{,}626*10^{-34}\ J*s\ .$$

Quantitatively, this formula describes the real experimental data did not accurately and then you'll see why, but in terms of a theoretical explanation of the situation is completely untrue, that you will see later, too.

Preparatory part

Next, we recall some of the physical laws that form the basis for our further discussion. The first formula is the kinetic energy of the body, accomplishing a rotational movement in a circular or elliptical path. It is as follows:

$$E = mV^2,$$

those. product weight by the square of the speed with which the body moves in its orbit. V The speed will be calculated by a simple formula:

$$V = 2\pi R/T,$$

where T - the period of revolution, and as R for circular motion is taken radius of rotation, while the elliptical trajectory semi-major axis of the ellipse trajectory. For a single atom of matter, there is one very useful for us formula relating the temperature to the energy of the atom:

$$\mathbf{(1)\qquad mV^2 = 3kt.}$$

Where t - the temperature in degrees Kelvin, and k - Boltzmann constant, which is equal to 1,3807*10-23 J/K. If we take the temperature of one degree, then, in accordance with this formula, the energy of an atom is equal to:

$$(2) \qquad \mathbf{E = 4140*10^{-26}\ J}$$

And this energy will be the same for the lead atom, and for any other element of the aluminum atom or atoms. This is precisely the meaning of the concept "temperature". From the formula (1), valid for solid and liquid physical state of matter, it is clear that the equality of energies for different atoms of different mass at a temperature of 1 degree is achieved only by changing the magnitude of the velocity square, ie the speed with which the atom moves over its circular or elliptical orbit. Therefore, knowing the energy of the atom when one degree and the mass of the atom, expressed in kilograms, we can easily calculate the linear velocity of the atoms at any temperature. How this is done, let us explain a specific example. Take from periodic table of Mendeleev any chemical element, for example - molybdenum. Next we take any point, for example - 1000 degrees Kelvin. Knowing the formula (2) the value of nuclear energy, with 1 degree, we can find the energy of an atom at a temperature taken by us, ie, Multiply this value by 1000. It has turned out:

(3) Energy molybdenum atom in 1000K = $4{,}14*10^{-20}$ J

Now we calculate the value of the mass of an atom of molybdenum, expressed in kilograms. This is done by means of the periodic Mendeleev's table. In the cell of each chemical element, about his serial number, indicated its molar mass. For molybdenum is 95.94. It remains to this number divided by Avogadro's number, equal to 6,022*1023 and the result multiplied by 10-3, as in the periodic Mendeleev's table contains the molar mass in grams. It turns out 15,93 *10-26 kg. Further, from formula

$$mV^2 = 4{,}14*10^{-20}\ J$$

calculate the speed and get

$$V = 510\ m/s\ .$$

Then it's time to move on to the next question of the preparatory material. Let us remember about this concept as momentum. This concept was introduced for the bodies of committing circular motion. You can conduct a simple example: take a short tube, pass through her cord, a cord tied to a weight of m, and, holding the cord with one hand and with the other hand to promote a load over your head. Multiplying the speed of movement of cargo by its mass and radius of rotation, we obtain the value of the angular momentum, which is usually denoted by the letter L. That is,

$$L = mVR.$$

Pull the cord through a tube down, we reduce the radius of rotation. At the same time the rotational speed of the load will increase and its kinetic energy is increased by the value of the work you perform, pulling the cord to reduce the radius. However, multiplying the weight of the load on the new values of speed and radius, we get the same value that we got before we reduced the radius of rotation. This is the law of conservation of momentum. Back in the 17th century by Kepler in his second law proved that the law is observed and for the satellites moving around the planets in elliptical orbits. When approaching the planet satellite velocity increases and the removal from it decreases. This product mVR remains unchanged. The same applies to the planets moving around the sun. Along the way, remember, and Kepler's third law. You may ask - why? Then, in this article you will see something that is not written in any scientific source - the formula of Kepler's third law of motion of the planets in the microcosm. And now about the fact that most of the third law. The official interpretation of it sounds pretty flowery "squares periods proportional to the cubes of the semimajor axes of the planets around the Sun, their elliptical orbits." Each planet has two individual parameter - the distance to the sun and the time during which it makes one complete revolution around the sun, ie, treatment period. So, if the distance to build a cube, and then divide the result for the period, erected in the square, we get some kind of value we denote it by the letter C. And if you make the above mathematical operations with parameters of any other planet, you get the same magnitude - C. A little later, on the basis of Kepler's third law, Newton deduced the law of gravity, and even 100 years later Cavendish calculated true value of the gravitational constant - G. Only after this became clear the true meaning of this most constant - C. It was found that this encrypted value of the mass of the Sun, expressed in units of length cubed, divided by time squared. Simply put, knowing the distance of the planet from the Sun and the period of treatment it is possible to calculate the mass of the sun. Skipping simple mathematical transformations, said the conversion factor is

$$4\pi^2/G.$$

Therefore, we have the formula, with analogue of which we meet again:

$$\mathbf{(4)\ 4\pi^2R^3/T^2G = M\ sun\ (kg)}$$

Main part

Now we can move on to the main. We will understand the dimension of Planck's constant. From the directory, we see that the value of the Planck constant

$$h = 6{,}626*10^{-34}\ J*s\ .$$

For those rusty physics, recall that this is equivalent to the dimension of the dimension

$$kg*m^2/s.$$

This is the dimension of angular momentum

$$mVR.$$

Now take the formula of atomic energy

$$E = mV^2$$

and Planck's formula

$$E = hf.$$

For a single atom of any substance at a predetermined temperature value of these energies must match. Considering that inverse frequency radiation period, i.e.

$$f = 1/T,$$

and speed

$$V = 2\pi R/T,$$

where R - radius of rotation of the atom, we can write:

$$m4\pi^2R^2/T^2 = h/T.$$

Hence we see that Planck's constant is not angular momentum in its pure form, but differs from it by the factor 2π. Here we have identified its true essence. It remains only to calculate it. Before we ourselves begin to calculate it, let's see how others do it. Looking into the laboratory work on this topic, we will see that in most cases the Planck constant calculating formulas of the photoelectric effect. But the laws of the photoelectric effect were discovered much later than the Planck deduced the constant. Therefore, look for another law. He is. This is Wien's law, which opened in 1893. The essence of this law is simple. As we have said, at a certain temperature heated body is infrared radiation intensity of the peak at a certain frequency. So, if you multiply the value of the temperature wave infrared radiation corresponding to this peak, you get a certain quantity. If we take another body temperature, the emission peak will correspond to a different wavelength. But here, when multiplying these quantities to get the same result. Vin figured this constant and expressed his law in a formula:

$$\textbf{(5)}\ \lambda t = 2{,}898 * 10^{-3}\ \text{m*deg K}$$

Here λ - length infrared radiation in meters, and t - temperature in degrees Kelvin. The law in its significance can be equated to Kepler's laws. Now, looking at the heated body through a spectroscope and determining the wavelength at which the emission peak is observed, it is possible according to the formula of Wien remotely determine the temperature of the body. On this principle work all pyrometers and thermal imagers. Although there is not so simple. Peak radiation shows that most of the atoms in a heated body radiates exactly this wavelength, ie, have precisely this point. A light on the right and left of the peak indicates that the body has a "subcooled" or "overheated" atoms. In the real world there is even a little "hump" of the radiation. Therefore, modern pyrometers measure the radiation intensity at several points of the spectrum, and then the results are integrated, which makes it possible to get the most accurate results. But back to our questions. Knowing the one hand, from the formula (1), the temperature corresponds to a kinetic energy of the atom via constant factor 3k, and on the other hand, the product temperature at a wavelength in the Wien's law also constant expanding square of the velocity in the formula of the kinetic energy of the atom into factors we we can write:

$$m4\pi^2R^2\lambda/T^2 = \text{constant.}$$

In the left half of the equation m - constant, then everything else on the left side

$$4\pi^2R^2\lambda/T^2\ \ – \text{constant.}$$

Now compare this expression with Kepler's third law (4). Here, of course, we are not talking about the sun's gravitational charge, however, in this expression, the value is encrypted certain charge, the nature and properties of which are very interesting. But this topic is worthy of a separate article, so we will continue our. We calculate the value of Planck's constant on the example of molybdenum atoms, which we have taken as an example. As we have found the formula of Planck's constant

$$h = 2\pi mVR.$$

We have already calculated the mass of molybdenum atoms and the speed of its motion along its trajectory. It remains only to calculate the radius of rotation. How to do it? It will help us to Wien's law. Knowing the value of molybdenum temperature = 1000 degrees, we are using the formula (5) can easily calculate the wavelength λ, which will

$$\lambda = 2{,}898 * 10^{-6} \text{ m}.$$

Knowing that infrared waves propagate through space at the speed of light - with, we simple formula

$$T = \lambda / c$$

We calculate the frequency of an atom of molybdenum radiation at a temperature of 1000 degrees. And get this period

$$T = 0{,}00966 * 10^{-12} \text{ s}.$$

But this is the frequency that generates a molybdenum atom, moving along their rotational orbit. We have already calculated the speed of movement V = 510 m/s, and now know the speed and T. It remains only a simple formula

$$V = 2\pi R/T$$

calculate the radius of rotation R. Turns

$$R = 0{,}7845 * 10^{-12} \text{ m}.$$

And now we can only calculate the value of Planck's constant, ie, multiply values

$$\text{mass of the atom } (15{,}93*10^{-26} \text{ kg}),$$

$$\text{velocity } (510 \text{ m/sec }),$$

$$\text{rotation radius } (0{,}7845*10^{-12} \text{ m})$$

and twice the value of "pi". Get

$$4*10^{-34} \text{ J*s} .$$

Either you find reference value

$$6{,}626*10^{-34} \text{ J*s}$$

You yourself by this technique can calculate the value of Planck's constant for all atoms of chemical elements at any temperature that does not exceed the evaporation temperature. In all cases, the value is obtained

$$4*10^{-34} \text{ J*s},$$

but not

$$6{,}626*10^{-34} \text{ J*s}.$$

But, best of all, to answer to this question was given by Planck himself. Let in the formula

$$E = hf$$

We substitute our value of its constant and radiation frequency at 1000 degrees calculated by us on the basis of Wien's law, which is hundreds of times rechecked and passed all experimental tests. Given that the frequency is the reciprocal of the period, i.e.

$$f = 1/T,$$

We calculate the energy of the atom of molybdenum at 1000 degrees. Get

$$4*10^{-34}/0{,}00966*10^{-12} = 4{,}14*10^{-20} \text{ J.}$$

Now compare the results with others obtained by the independent claim, which authenticity is not in doubt (3). These results are the same, that is the best proof. And we will answer the last question - whether the Planck formula irrefutable proof that the quanta of energy is transferred only? Sometimes you read in serious sources such explanation - Now, you see, at a frequency of 1 Hz, we have a certain energy value, and at a frequency of 2 Hz, it will be a multiple of the value of Planck's constant. This is the quantum. Lord! The frequency may be 0.15 Hz, 2.25 Hz or any other. The frequency is an inverse function of the wavelength of electromagnetic radiation and the speed of light through the associated feature type

$$y = 1/x.$$

The graph of this function does not allow any quantization. And now for the quanta in general. In physics, there are laws, expressed in formulas, where there are indivisible whole number. For example, the electrochemical equivalent is calculated using the formula weight atoms /k, where k - is an integer equal to the valence of the chemical elements. The integers are present in parallel connection of capacitors in the calculation of total system capacity. Since energy is the same. The simplest example - the transition of a substance in a gaseous state, where there is clearly a quantum in the form of 2. Interesting and Balmer series and some other ratio. But by Planck's formula is not irrelevant. By the way, Planck was of the same opinion.

Conclusion

If the discovery of the Wien's displacement law can be compared in importance with the laws of Kepler, the discovery of Planck can be compared with the discovery of the law of gravity. He turned a faceless continued Wines in constant having the dimension and the physical meaning. Proving that the liquid or solid state of aggregation of matter, atoms of all elements at any temperature is maintained momentum, Planck made a great discovery, which allowed for new insights into the physical world around us. I will conclude with an interesting formula derived from the above and combining four physical constants - the speed of light - c, Wien's displacement constant - *b*, Planck's constant - h and the Boltzmann constant - k.

$$\mathbf{3k}\boldsymbol{b} = \mathbf{hc} \qquad \mathbf{(6)}$$

https://youtu.be/VEjP7BdZWLY