Формула Планка (6) указывает на присутствие фотонного излучения во Вселенной во все времена её космологического движения (за исключением эпохи Планка). На планковское время из (3) и (4) следует равенство $\frac{U_{\varepsilon PL}}{v_{PL}} = h$, что отвечает (2). В выражении (6) $U_{\varepsilon PL}$ – доля полной планковской энергии $U_{PL} = \left(\frac{h \cdot c^5}{G}\right)^n = 10^9$ Дж. Эпиграф принят согласно работе [4, с. 35].

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Uncertainties relation and micro particles diffraction

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Аннотация

Показано, что для объяснения экспериментальных результатов по дифракции микрочастиц не требуется использовать концепцию волн де Бройля. Эти результаты описываются на основе соотношения неопределенностей Гейзенберга. В качестве примеров рассматриваются известные результаты экспериментов Дэвиссона и Джермера по дифракции электронов и Резерфорда по рассеянию α -частиц.

Ключевые слова: Соотношение неопределенностей Гейзенберга, эксперименты Дэвиссона и Джермера, дифракция электронов, рассеяние альфа-частиц.

Abstract

It was shown that for explanation of experimental results on diffraction of micro particles it does not need to use the de Broglie wave's concept. Such the results can be described with the aid of the Heisenberg uncertainties relation. As for examples the known results of experiments conducted by C. Davisson and L. H. Germer on diffraction of electrons and by Rutherford on α particles scattering are considered.

Keywords: quantum number, electron diffraction, α -particles scattering, diffraction lattice, de Broglie waves.

Introduction

According to one of the Bohr's postulates regarding to the stationary states of electron in hydrogen atom it takes place the expression

$$pr = n\hbar, n = 1, 2, 3, \dots,$$

where $p = mv$ – electron impulse (m – mass, v – velocity), r – orbit radius, $\hbar = h/2\pi$, h – Planck's constant, n – quantum number.

This expression is consequence of the interaction of the electron with the atom nuclear. At falling of a micro particles beam upon a crystal structure it takes place the interaction between every particle and atoms of the structure. This interaction must have a

quantum character as well. As the result of this interaction there arise uncertainties of the particle impulse and its coordinate which Heisenberg described by the expression [1]

$$\Delta p_x \cdot \Delta x \sim h,$$

where Δp_x – uncertainty of impulse, Δx – uncertainty of coordinate.

However in another work [2] he noticed that “it takes place

$$\Delta p_x \cdot \Delta x \sim nh,$$

where n denotes a quantum number of corresponding state”.

But he does not use this expression in analysis of experiments on micro particles diffraction. Following to Heisenberg and Bohr the uncertainties relation can be written as

$$\Delta p_x \cdot \Delta x = nh, \quad n = 0, 1, 2, \dots, \quad (1)$$

where quantum number n is the uncertainty index.

Experiments of C. Davisson and L. H. Germer on diffraction of electrons

The relation (1) gives a possibility to explain experiments on electrons diffraction that been realized by American physics C. Davisson and L. H. Germer [3] without of attraction of the de Broglie waves concept. The installation scheme for carrying out of the first series of experiments is shown in fig. 1.

Fig.1. Scheme of the installation for the first series of experiments.

A beam of electrons from an electron gun (1) normally falls upon {111} side of a nickel crystal (2). The lattice constant of this layer is $d = 2.15 \cdot 10^{-8}$ cm. The electrons been reflected from the upper atom layer get to a detector representing some Faraday cup (3) that was tied with a galvanometer for measuring of electron current. The detector can be shifted in the plane of the falling beam for changing the θ angle. It was determined the dependence of current from θ angle at the given accelerating voltage of the electron gun.

The scheme of reflection of electrons from the crystal lattice is presented in fig. 2. Let some electron of the falling beam has an impulse p , and a reflected electron – impulse p_1 . For describing of the process of electrons reflection the relation (1) in which $\Delta x = d$ will be used.

Fig.2. Scheme of reflection of electrons in the first series of experiments.

Believing this process of an elastic character, and by absolute value $p = p_1$ the equality (1) can be written in the form of

$$\Delta p_x \cdot d = \frac{\Delta p_x}{p} p d = \sin \theta p d = nh.$$

From this expression it can be derived

$$\sin \theta = \frac{nh}{pd}. \quad (2)$$

The electron impulse p been defined by the expression for energy

$$\frac{p^2}{2m} = eU,$$

is tied with the accelerating voltage of the electron gun by the relation

$$p = \sqrt{2meU}, \quad (3)$$

where m and e are correspondently mass and electron charge. Since $\sin \theta \leq 1$ then from (2) and (3) it follows

$$n \leq \frac{d\sqrt{2meU_m}}{h} = 1,245,$$

where $U_m = 68$ V is the maximum accelerating voltage been used in the first series of experiments. Then the whole number n can accept unique value $n = 1$. This means that the diffraction maximum at every value of voltage may be only one. In fig. 3 there is presented the original diagrams “electron current – reflection angle” been obtained in the experiments. The reflection angle is counted from the vertical axes on which the arrow shows the direction of falling of the electron beam. Under every diagram it is pointed the voltage at which it was obtained. The angle values been shown

Fig.3. Experimental diagrams “electron current – reflection angle”.

in diagrams were determined by (2), they with a great accuracy coincide with the experimentally measured angle values.

The second series of experiments were conducted along the Wolf-Bragg scheme. The electron beam fell upon the crystal surface under angle of slide α , and in this case the reflection takes place in the region of interatomic layer as it is shown in fig. 4.

Fig.4. Scheme of electrons reflection in the second series of experiments.

The measuring was conducted at the same angle α to the crystal surface, at that the electron current was measured in depending on the electron gun voltage. It is seen from the picture that

$$\sin \alpha = \frac{\Delta p_x}{2p},$$

since as $p_1 = p$ owing to the elastic character of interaction. Then the relation (1) gives

$$\sin \alpha = \frac{nh}{2pd}. \quad (4)$$

The maxima values of current been obtained at the appointed values of accelerating voltage U_m must correspond to the whole numbers n . Expressing the electron impulse p from (3) and substituting it into (4), the expression for number n that corresponds to the maximum of current can be found as

$$n = \frac{2d \sin \alpha \sqrt{2me}}{h} \sqrt{U_m}. \quad (5)$$

The original dependence of electron current I on accelerating voltage U been obtained for $\alpha = 80^\circ$ at the distance between atom layers $d = 2.03 \cdot 10^{-8}$ cm is presented in fig.5.

Fig.5. Dependence of electron current on voltage.

But as it is follows from the stated table 1 the numbers n been calculated by (5) and presented in row 2 are not the whole numbers.

Table 1

Values of quantum number n

1	U_m, V	64	133	210	328	445	576
2	$n(U)$	2.6	3.7	4.7	5.9	6.8	7.8
3	$n(U_m + \Delta U)$	3,00	4,04	4,94	6,07	7,00	7,93

This discrepancy arises owing to the extra potential difference that takes place in the surficial region of the nickel crystal. In accordance with the known tabular data this potential difference is equal to $\Delta U = 22$ V. Row 3 of the table gives the values $n(U_m + \Delta U)$ that were calculated by

$$n = \frac{2d \sin \alpha \sqrt{2me}}{h} \sqrt{U_m + \Delta U}.$$

The small differences n from the whole numbers are determined by inevitable experimental errors.

The E. Rutherford scattering of α particles

E. Rutherford had described the experiments on the α particles scattering owing to which it had been established the planetary model of atom [4]. He considered the interaction of some α particle with a single atom along the scheme as it is shown in fig.6.

Fig.6. The scheme of the interaction of a particle with a single atom
1 - α particle, 2 – atom.

The angle θ of the α particle deviation from the initial motion in depending on perpendicular distance s from atom is determined by formula [5]

$$\text{Ctg } \frac{\theta}{2} = \frac{m_{\alpha} v^2 s}{2Ze^2}, \quad (6)$$

where m_{α} is mass of the particle, v its velocity on entering the atom, Ze is the nuclear charge, e is the elementary charge. But in the experiments the α particles beam was transmitted through a thin gold foil which practically was by a diffraction lattice.

The α particles source is the mix of isotopes of radium with the average energy 6.5 MeV. The α particles beam fell normally upon surface of the foil with the lattice constant $d = 4.7 \cdot 10^{-8}$ cm. Fig.7 presents the scheme of scattering for angles $\theta \leq 90^\circ$.

Fig.7. Scheme of α particles scattering for angles $\theta \leq 90^\circ$.

Let $\mathbf{p}$ and $\mathbf{p}_1$ are correspondingly impulses of falling and scattering α particle. Believing that the interaction is of elastic character and by absolute values $p = p_1$ on the basis of (1) for the scattering angle θ it will be

$$\sin \theta = \frac{nh}{pd} = \frac{nh}{m_{\alpha} v d}, \quad n = 0, 1, 2, \dots, n_0. \quad (7)$$

As

$$\sin \theta \leq 1,$$

then the maximum value of number n at $m_{\alpha} = 0.66 \cdot 10^{-23}$ g and velocity $v = 1.75 \cdot 10^9$ cm/c will be

$$n_0 = \frac{m_{\alpha} v d}{h} = 8.2 \cdot 10^4.$$

For the scattering angles $\theta \geq 90^\circ$ the scheme of scattering is presented in fig. 8.

Fig.8. Scheme of α particles scattering for angles $\theta \geq 90^\circ$.

It is seen from the picture that $\theta_1 = \pi - \theta$, then according to (1)

$$\sin(\pi - \theta) = \frac{n'h}{pd} = \frac{n'h}{m_\alpha v d}, \quad n' = 0, 1, 2, \dots, n_0. \quad (8)$$

At the values of number n' over the range $0 \leq n' \leq n_0$ angle θ_1 lies over the range $0^\circ \leq \theta_1 \leq 90^\circ$, then angle θ will be over the range $180^\circ \geq \theta \geq 90^\circ$. For a comparison of classic and quantum approaches to the process of scattering, fig. 9 presents dependences (6) and (7) over the range $0^\circ \leq \theta \leq 90^\circ$, and fig. 10 - dependences (6) and (8) over the range $0^\circ \leq \theta \leq 180^\circ$. From comparison of these dependences it is seen that both of them describe the process of scattering by similar manner. This was waited because of the correspondence principle which is asserting that with increasing the

Fig.9. Graphs of dependences of the scattering angles over the range $00 \leq \theta \leq 900$

Fig.10. Graphs of dependences of the scattering angles over the range $0^\circ \leq \theta \leq 180^\circ$

mass of a particle its behavior approaches to the classic one. Also, owing to this principle quantum numbers n in the process of diffraction of massive α particles exceed those numbers in the process of diffraction of light electrons.

Conclusion

1. The uncertainty relations in the form (1) gave a possibility to describe the experiments of Davisson and Germer on diffraction of electrons as a whole and do the same relatively the alpha particles scattering without the de Broglie wave's concept.
2. The de Broglie wave's concept represents by itself an analogue of the dualism principle "wave-particle" for light and by fact is a mathematical method been founded upon the variable substitution "impulse-wave length".

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