Determination of the Ratio of the Number of Recoil Electrons to the Number of Photoelectrons by Experimentally Measured Ratio of the Intensities of Characteristic Fluorescent Radiation and Uncoherently Scattered X-Ray or Gamma Radiation, Explanation of the Results Obtained

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Abstract. Work presents the results of the theoretical and experimental analysiges of different forms of interaction of the photons of the ionizing emission s by substances, in particular, photo effect and the Compton scattering of these photons. Using the author developed a new method of determining the ratio of the number of Compton electrons to the number of photoelectrons for the first time obtained the experimental results for molybdenum and tungsten. Analysis of the results showed that there are significant discrepancies between previous theoretical calculations and experimental data. The new results of the measured simultaneously relations of sections for the heavy atoms with the aid of the method developed by the author, and the old measurements of these relations for the light atoms with the aid of the Wilson cloud chamber, with their comparison with the theoretical calculations, show that for the X-ray and gamma emissions of the range of energies in question, is observed the significant (by an order and more) unidirectional difference. The possibility of explaining these divergences by fundamentally new view on the states of electron in the atom is shown. The possibility to explain the divergences by the presence of the free state of electron in the atom is shown.

1. Introduction

The measurement of electronic fluxes in the substances is urgent both for checking the validity of the theory of interaction of the light quanta with the substance and for solving different applied problems. However, since the methods of the energy-dispersion registration of the recoil electrons and photoelectrons, for example with the aid of the Wilson cloud chamber, or electronic spectroscopy [1-4], in the condensed media are problematic, then tasks in the development of new experimental methods to the foreground leave.

In this work is examined possibility, to use as the information source about the given phenomena, flows of the characteristic and scattered by substance primary of emissions. It is shown that the ratio of the mass coefficient of the section of the incoherent scattering of primary emission to the mass photoelectric absorption coefficient of primary emission can be determined throughout the experimentally measured ratios of the intensities of characteristic and incoherently scattered of emissions in the substance.
2. Known experimental substantiation of theory

The first experiments on the detection of recoil electrons with scattering and gamma X-rays in air were executed with the aid of the Wilson cloud chamber 1. The results of measurements are given in the table 1.

Table 1. The experimental data of the ratios of the intensities of the recoil electrons and photoelectrons and respectively their sections.

| №  | Wavelength (Å) | Energy (keV) | Nc/Npe | σ/τ |
|----|----------------|--------------|--------|-----|
| 1  | 0,71           | 17,49        | 0,10   | 0,27|
| 2  | 0,44           | 28,23        | 0,90   | 1,20|
| 3  | 0,29           | 42,83        | 2,70   | 3,80|
| 4  | 0,20           | 62,21        | 9,0    | 10,0|
| 5  | 0,17           | 73,06        | 17,0   | 17,0|
| 6  | 0,13           | 95,55        | 72,0   | 32,0|

Here Nc/Npe – the ratio of the number of recoil electrons to the number of photoelectrons, σ/τ - the ratio of the coefficient of the section of the incoherent scattering of primary emission, to the photoelectric absorption coefficient of primary emission. Moreover it is assumed that Nc/Npe = σ/τ. It is obvious that to use this method as the methods of electronic spectroscopy in the solids, especially in the metals, is problematic. Actual, against the background “electron gas” in the depth of conductor, to isolate and to distinguish photoelectrons and recoil electrons, it is practically impossible.

In the figure 1 for the comparison they are shown: experimental curved and theoretical curved calculated on the basis of model [5] taking into account the influence of scattering on the bound electrons of atoms.

![Figure 1](image)

Figure 1. Experimental -○ and theoretical -Δ the dependence of the ratio of the number of recoil electrons to the number of photoelectrons on the energy of primary emission.

As is evident, the divergence between the curves composes order and more. It is understandable that it is not sufficient for the agreement of theory and experience, experimental data.

3. Results obtained by the new method

To a study and to the use of a method of spectral relations devoted many works [6-10], is accumulated the enormous base of the experimentally measured ratios of the intensities of the characteristic and incoherently scattered of X-ray and gamma emissions in different substances. The author obtained the following expression [10]:

\[
y = \frac{J_c}{J_r} = 2\eta \frac{S_k - 1}{S_k} \frac{p_k\tau_{in}}{\sigma_\alpha} \frac{1}{\left[(E_0 / E_i)^3 + 1\right]} \frac{1}{S_k}
\]  

(1)
where: \( \eta \) — the coefficient of yield of fluorescence*; \( \sigma_u \) - mass ratio of the cross section of incoherent scattering of the primary radiation in the sample; \( \alpha \) - the coefficient of anisotropy of the angular distribution of incoherently scattered radiation; \( p_k \) — probability of transition of an atom, excited to the \( K \)- level with emission of a characteristic statistical radiation of \( i \)-line*; \( S_K \) — the value of \( K \) (or \( L \)) is the absorption jump of the element to be analyzed*; \( \tau_m \) — mass coefficient of photoelectric absorption of the primary radiation of the element [m²/kg]; *Dimensionless quantity.

And, from the resulting expression is easy to obtain the desired proportion of the mass ratio of the cross section of incoherent scattering of the primary radiation to mass ratio photoelectric absorption of primary radiation:

\[
\frac{\sigma_u}{\tau_m} = \frac{N_c}{N_n} \times \frac{J_2}{J_1} \times 2 \eta \times \frac{S_K - 1}{S_K} \times \frac{p_k}{\alpha} \times \frac{C}{\left(\frac{E_0}{E_i}\right)^3 + 1}.
\]  

(2)

where the coefficient of anisotropy of the angular distribution of incoherently scattered radiation - \( \alpha \), the angle \( \psi=\varphi=45^\circ \), and therefore the scattering angle \( \theta=90^\circ \) and for energies from 10 Kev to 100 Kev, varies from 0.4 to 0.2; the probability of transition of an atom, excited to the \( K \)-level with emission of a characteristic radiation of \( i \)-line — \( p_k \geq 0.9 \) [11], the fluorescence yield for the \( K \)-series can be calculated by the formula of Stephenson [12]:

\[
\eta = \frac{bZ^4}{1+bZ^4}.
\]  

(3)

where \( Z \) — the atomic number of the element, \( b = 1,127 \times 10^6 \); The obtained expression (2) allows to determine the mass ratio of the cross section of incoherent scattering of the primary radiation to mass ratio photoelectric absorption of primary radiation by the experimentally measured relations of intensities and incoherently scattered characteristic radiation of known energy in a given substance, and hence the desired ratio of the number of recoil electrons to the number of photoelectrons.

For example, the synthesis of a number of experimental data [8], irradiation of Mo(Z=42) of gamma radiation of radionuclide 241 Am \((E_0=60 \text{ Kev})\), the relation \( \frac{J_2}{J_1} = 0.12 \pm 0.03 \), respectively the ratio \( \frac{\sigma_u}{\tau_m} \approx 0.075 \pm 0.02 \). Irradiation of W(Z=74) of gamma radiation of radionuclide 57 Co \((E_0=120 \text{ Kev})\), gives \( \frac{J_2}{J_1} = 0.08 \pm 0.02 \), respectively, the ratio of \( \frac{\sigma_u}{\tau_m} \approx 0.25 \pm 0.02 \).

For the comparison, in the table 2, are cited the data of the corresponding relations, obtained on the basis of the theoretical calculations [13].

**Table 2.** Theoretical data of the ratios of the sections of recoil electrons to the sections of the photoelectrons.

| E(keV) | C (Z=6) | Al (Z=13) | Cu (Z=29) | Sn (Z=50) | PB (Z=82) |
|-------|--------|----------|----------|-----------|-----------|
|       | \( \sigma_u/\tau_m \) | \( \sigma_u/\tau_m \) | \( \sigma_u/\tau_m \) | \( \sigma_u/\tau_m \) | \( \sigma_u/\tau_m \) |
| 5.12  | 0.003  | 0.0001   | -        | -         | -         |
| 10.24 | 0.096  | 0.0030   | 0.000096 | -         | -         |
| 25.60 | 0.184  | 0.092    | 0.000092 | 0.000092  | -         |
| 51.20 | 2.80   | 0.084    | 0.00084  | 0.000084  | 0.000084  |
| 102.4 | 24.67  | 0.587    | 0.0074   | 0.00074   | 0.00074   |
| 256.0 | 190    | 5.70     | 0.180    | 0.0057    | 0.0057    |
From the comparison it follows that the preliminary conclusions about the essential divergence of theoretical and experimental data are confirmed. Moreover, if table 1 presents data for the light atoms, the author for the first time obtained data for the heavy atoms.

4. Explanation of results. Conclusions
The author for the first time determined the ratios of the number of recoil electrons to the number of photoelectrons according to the experimentally measured ratios of the intensities of characteristic and incoherently scattered gamma radiation taking into account matrix effect on the atoms of molybdenum and tungsten. The new results of the measured simultaneously relations of sections for the heavy atoms with the aid of the method developed by the author, and the old measurements of these relations for the light atoms with the aid of the Wilson cloud chamber, with their comparison with the theoretical calculations, show that for the X-ray and gamma emissions of the range of energies in question, is observed the significant (by an order and more) unidirectional difference. Consequently, the theoretically calculated values of the sections of incoherent scattering are substantially understated, and the values of the sections of photo effect are on the contrary, overstated. In modern atomic physics, an electron is taken in the bound state with binding energy $E_n$, where the quantum number $n$ can vary from 1 to $\infty$ and $E_{\infty} = 0$, that is, the electron becomes free. Any transition from one bound state to another $E_2 \rightarrow E_1$ can be represented as $E_2 \rightarrow E_{\infty} \rightarrow E_1$, i.e., through the free state. Since the transition time cannot be zero (violated the laws of conservation) $\Delta t_f > 0$, i.e., for some time, the electron will be free. The contemporary theory of atom, is based on quantum mechanics and for describing the atom solves the steady-state. The interaction of the electron with the light (x-ray or gamma radiation) are considered as quantum effects, while the interaction of the electron with the nucleus is considered from the standpoint of continuum theory, as the motion of a particle in a continuous and stationary Central field Fig. 2.

![Figure 2. Scattering photons on the electron of the atom: a) – coherent scattering; b) – incoherent scattering.](image)

But if we this interaction also consider as the result of the single collision events of electron (and consequently also of nucleus) with the quanta of their joint electromagnetic field, then picture principally will change Fig. 3.
Let us examine Compton scattering and photo effect with the aid of Feynman's diagrams Fig. 4, 5.

Compton scattering occurs on the free electron, photo effect only on the bound electron. The part of the time - $t_f$ electron will be found in the free state, while the part of the time - $t_b$ in the bound state. Therefore the section of incoherent scattering $\sigma_n \sim t_f/T$, whereas the section of photo effect $\sigma_{pe} \sim t_b/T$, where $T$ the period of revolution of electron, $t_f + t_b = T$. By this is explained this large understating of the section of incoherent scattering in the theory, in which the electron in orbit is received as that as always connected and the section of photo effect respectively significantly is overstated.

As can be seen from figure Compton scattering consists of two points of the elementary reports of absorption and scattering of photon by electron. To elementary process corresponds duration $\tau_{e.m.} \sim 10^{-20}$ c, consequently $\Delta t_b = 2\tau_{e.m.}$ and $t_b = N_2 \tau_{e.m.}$, where $\Delta t_b$ – the time of the duration of one report of interaction, $N$ – the number of units of interaction, moreover $N \sim F \sim Z$ (Z - number of protons in the nucleus).

Accordingly $t_f = T - t_b = T - N_2 \tau_{e.m.}$. But then in the first approximation, mass photoelectric absorption coefficient $\tau_m = (t_f/T) \tau_m^* = (N_2 \tau_{e.m.}/T) \tau_m^*$, whereas the mass coefficient of the section of the incoherent
scattering \( \sigma_n = (t/T) \sigma_n^* \) consequently their relation \( \frac{\sigma_n}{\tau_m} = \frac{(T - N^2 \tau_{el.m})}{T} \) \( \frac{\sigma_n^*}{\tau_m} \).

For example period \( k \) the orbit of hydrogen \( T \approx 0.15 \times 10^{-15} \text{s} \), the relation \( \frac{\sigma_n}{\tau_m} \approx (7.5 \times 10^3/ N) \left( \frac{\sigma_n^*}{\tau_m} \right)^* \).

Here value with the asterisk \( (\tau_{el.m}^*, \sigma_n^*, \left( \frac{\sigma_n}{\tau_m} \right)^*) \) determined by theory.

So to the author in the new atom model is explained the divergence between the experimentally and theoretically specific relations of the corresponding values by an order and more.

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