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Fig. 1

Figure 1: Fig. 1

Abstract

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PHYSICS

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PHOTOEFFECT FROM METALLIC CATHODES IN THE WAVELENGTH RANGE FROM 1.39 TO 13.3 Å

(Presented by Academician A. A. Lebedev on 11 VI 1960)

Using the method developed earlier (^{1},^{2}), we investigated the dependence of the quantum yield $\varkappa$ on the grazing angle θ for W-, Ni-, and Be-photocathodes in the wavelength interval from 1.39 to 13.3 Å. The experimental results showed a sharp increase in the quantum yield with decreasing grazing angle. In the region of not very small angles this dependence is well approximated by the expression $\operatorname{cosec}\theta$. Figure 1 presents the dependence of $\varkappa\sin\theta$ on θ in the case of a Ni photocathode for all the wavelengths used. For the other photocathodes (W and Be), analogous dependences are observed. All the curves in the region of not very small angles have a horizontal course. If one takes into account that, in the interval of angles, the quantities $\varkappa\sin\theta$ and $\sin\theta$ change by ~ 10 times, then the approximation should be considered good. In the region of very small angles (up to 3°) the rapid drop of the curves is explained by total external reflection of the x-ray radiation. On all the curves there is a tendency toward a decrease in the value of $\alpha\sin\theta$ as the angle is reduced from $10 \div 15^\circ$ to $2 \div 3^\circ$.

Fig. 1

To explain the observations, let us assume that as a result of absorption of radiant energy in the metal, in the absorption region "free" electrons appear, moving with a velocity sufficient to overcome the work function. In a layer dx (see Fig. 2), the energy absorbed per second is

$$dE = I\frac{\mu}{\sin\theta}\,dx \qquad \left(I = N_0\frac{hc}{\lambda}\,[1 - R(\theta)]e^{-\mu x/\sin\theta}\right),$$

which leads to the formation of $dn = dE/\varepsilon$ "free" electrons.

The following notation has been introduced: θ is the grazing angle, defined with respect to the mean surface; submicroscopic irregularities of the polished surface

Fig. 2

Figure 2: Fig. 2

affect only total external reflection, the coefficient of which $R(\theta) = 0$ everywhere except at very small angles; μ—coeff-

coefficient of linear attenuation of X-rays; $I_0 = N_0 \frac{hc}{\lambda}$—the intensity of the incident beam; N_0—the number of quanta incident per second; h—Planck' s constant; c—the speed of light; λ—wavelength. ε—the average energy expended in creating one "free" electron; this energy is greater than the kinetic energy of such an electron, since it includes the heat arising when a quantum is transformed into a "free" electron, as well as the part of the absorbed energy that leaves the metal in the form of fluorescent radiation.

Fig. 2

Assuming, as is done in the theory of secondary emission (³), that on emergence from a depth x the electron flux decreases according to an exponential law with linear attenuation coefficient α, and integrating with respect to α from 0 to ∞, for the quantum yield $\varkappa$, equal to η/N_0, we obtain:

$$\varkappa = \frac{hc}{\varepsilon\alpha}\,\frac{\mu}{\lambda}\,[1 - R(\theta)]\,\operatorname{cosec}\theta\,\frac{\alpha}{\alpha + \mu/\sin\theta}. \tag{1}$$

As is known, for X-rays $R(\theta) = 0$ everywhere, with the exception of very small θ, where total external reflection occurs. Therefore, for very small angles $[1 - R(\theta)] = 1$. According to Becker (⁴), and also Parch and Hallwachs (⁵), α is of the order of 10^6 cm^{-1}, and calculations from Jonsson' s tables (⁶), even for $\lambda = 10$ Å and W, show that the values of μ do not exceed $2 \cdot 10^4$ cm^{-1}. Consequently, the factor

$$\frac{\alpha}{\alpha + \mu/\sin\theta}$$

differs little from 1. Thus, excluding the region of small angles, formula (1) may be rewritten in the form

$$\varkappa = \frac{hc}{\varepsilon\alpha}\,\frac{\mu}{\lambda}\,\operatorname{cosec}\theta. \tag{2}$$

Formula (2), valid for $\theta \gtrsim 10$–15°, does indeed indicate the proportionality of $\varkappa$ and $\operatorname{cosec}\theta$ observed experimentally. The observed tendency toward a decrease of $\varkappa \sin\theta$ is explained more accurately by formula (1), the last factor of which, owing to the approach of $\mu/\sin\theta$ to α, becomes less than 1.

From formula (2), in addition to the angular dependence, follows the dependence of $\varkappa$ on λ. If one assumes that the product ε and α does not change in passing from one wavelength to another, the spectral distribution of the quantum yield is specified by the dependence μ/λ on λ.

Table 1*

λ, in Å	W photocathode $\varkappa \cdot 10^2$	W photocathode $\frac{\mu}{\lambda} \cdot 10^{-3}$	W photocathode $\frac{\varkappa}{\mu/\lambda} \cdot 10^6$	Ni photocathode $\varkappa \cdot 10^2$	Ni photocathode $\frac{\mu}{\lambda} \cdot 10^{-3}$	Ni photocathode $\frac{\varkappa}{\mu/\lambda} \cdot 10^5$	Be photocathode $\varkappa \cdot 10^3$	Be photocathode $\frac{\mu}{\lambda}$	Be photocathode $\frac{\varkappa}{\mu/\lambda} \cdot 10^3$
1.389				1.9	1.75	1.08			
1.537	1.8	2.16	8.3	0.3	0.26	1.15	0.78	2.5	3.10
2.743	4.8	4.6	10.4	1.1	0.53	2.07	1.3	5.5	2.36
3.351	5.9	6.0	9.8	1.2	0.94	1.22	2.9	8.1	3.60
5.385	11.0	8.5	13.0	2.5	1.06	2.35	7.7	18.4	4.2
7.111	5.4	7.8	6.9	4.4	2.54	1.73	11.4	30.5	3.74
8.321	7.3	9.5	7.7	5.6	3.08	1.82	14.6	41.5	3.52
9.870	8.1	12.0	6.8	7.0	3.77	1.86	22.5	55.0	4.1
13.33				11.5	5.0	2.30	39.0	92.0	4.2

* The quantum yield $\varkappa$ was measured for the angle $\theta = 10^\circ$.

Table 1 gives the values of $\varkappa$ for W-, Ni-, and Be-cathodes and for all wavelengths. Each value of $\varkappa$ in the table is matched with the quantity μ/λ, where μ was obtained by calculation from Jonsson’ s tables (^{6}), and with the ratio $\frac{\varkappa}{\mu/\lambda}$.

It is seen from the table that, whereas the variation of $\varkappa$ and μ/λ along the spectrum reaches a factor of 40, the ratio $\frac{\varkappa}{\mu/\lambda}$ remains constant to within 50%. Note, for example, that for the wavelengths of Cu $K\alpha$- and Cu $K\beta$-radiation, lying on different sides of the absorption jump in Ni, $\varkappa$ and μ/λ for the Ni cathode change by a factor of 6.3, whereas the value of the ratio $\frac{\varkappa}{\mu/\lambda}$ is practically the same. A certain scatter in the value of the ratio $\frac{\varkappa}{\mu/\lambda}$ is apparently explained by errors in the experiment and in the calculation of μ from Jonsson’ s tables. It is also possible that this scatter is caused by small variations in the product $\alpha\varepsilon$ with change in wavelength. For the Be cathode, the wavelength interval studied is free of absorption jumps. Therefore, in this spectral interval $\mu_{\text{Be}} = c\lambda^3$ (^{6}), and $\mu/\lambda = c\lambda^2$. Consequently, it follows from formula (2) that $\varkappa = k\lambda^2$. Figure 3 gives the dependence of $\lg \varkappa$ on $\lg \lambda$, constructed from the experimental data.

Fig. 3: plot of $\lg \varkappa$ versus $\lg \lambda$

Figure 3: Fig. 3: plot of $\lg \varkappa$ versus $\lg \lambda$

The rectilinear course of this dependence and its slope confirm the validity of the last conclusion.

Fig. 3

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REFERENCES

1. M. A. Rumsh, A. P. Lukirskii, I. A. Karpovich, V. N. Shchemelev, *Pribory i tekhn. eksperimenta*, No. 5, 67 (1960).
2. A. P. Lukirskii, M. A. Rumsh, I. A. Karpovich, *Optika i spektroskopiya*, 9, 683 (1960).
3. H. Bruining, *Die Sekundärelektronenemission fester Körper*, Berlin, 1942.
4. H. M. Terril, *Phys. Rev.*, 22, 161 (1922).
5. A. Partsch, W. Hellwachs, *Ann. Phys.*, 41, 247 (1913).
6. M. A. Blokhin, *Physics of X-Rays*, Moscow, 1953.