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one another only by the amplitude of vibration.

It can be concluded from the above investigation that the phase of the modulation of light from an interferometric modulator retains a practically constant value along the cross section of a beam of light obtained by reflection from one vibration zone of the piezo-electric mirror. This property of the interferometric modulator must be considered as an important advantage over the Kerr cell and diffraction modulators.

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X-RAY MONOCHROMATOR FOR ULTRASOFT RADIATION WITH THE RECORDING OF THE ABSOLUTE NUMBER OF QUANTA

A. P. Lukirskii, M. A. Rumsh, and L. A. Smirnov

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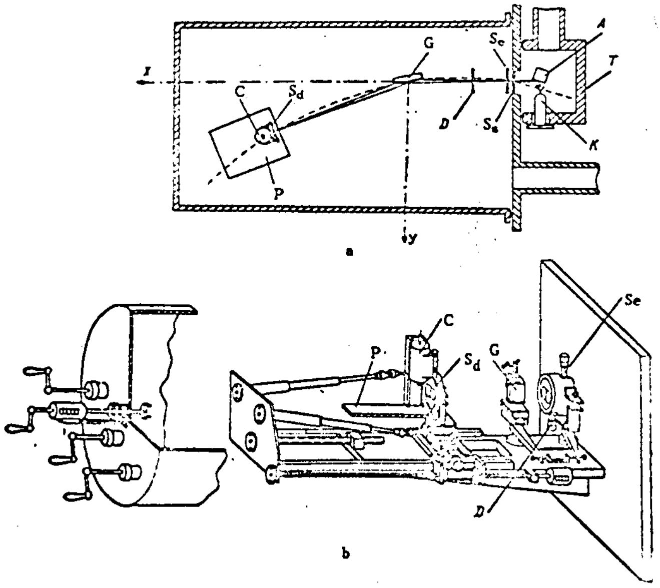
The construction of a diffraction-grating, vacuum, x-ray monochromator for the spectral region from 15 to 120 A is described. Methods of adjusting the monochromator and methods of obtaining electronic regulation of the monochromatic radiation are presented. A method for the absolute counting of the number of quanta with the aid of a Geiger counter is developed.

THE MONOCHROMATOR

The monochromator to be described is designed for the study of the efficiency of various radiation detectors. A focusing diffraction grating* is used as the dispersive element in the apparatus. The source of radiation is a demountable x-ray tube which makes it possible to obtain a series of characteristic lines without breaking the vacuum. A drawing of the monochromator is shown in Fig. 1,a. The entrance slit S_e is placed on the Rowland circle between the x-ray tube and the diffraction grating, and the diaphragm D is set near the grating. The monochromatic radiation is selected by the detector slit S_d, behind which the radiation detector is located. The Geiger counter is placed between the detector slit and the detector to be studied and with the aid of special accessories can be removed from the beam without breaking the vacuum, thus allowing the radiation to fall on the other detector. The detector slit and the detectors are mounted on the platform P, which can be translated, without breaking the vacuum, in two mutually perpendicular directions, thus making it possible to place the detector slit at different points of the Rowland circle. The platform with the radiation detectors can be rotated about an axis coincident with the detector slit, also with-



S_s : 5 mm^2

Fig. 1. Construction of the x-ray monochromator. S_e—entrance slit; D—diaphragm; G—grating; S_d—detector slit; C—Geiger counter; P—platform; S_s—separator slit; T—x-ray tube; A—anode; K—cathode.

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*The grating, made in GOI (State Optical Institute) and ruled on glass, has 600 lines/mm and a radius of curvature of 1 meter. The grazing angle of incidence of rays on the grating is equal to 2.5°.

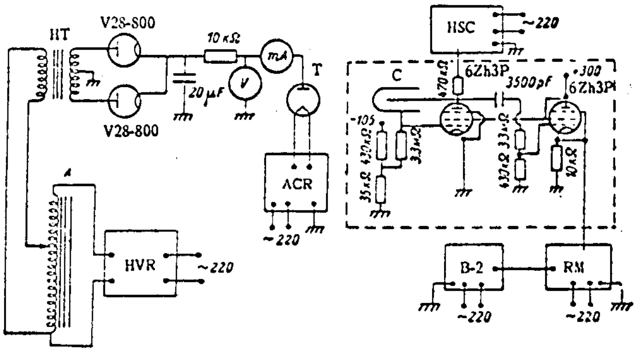

Fig. 2. Block diagram of the x-ray tube supply and Geiger counter recording circuit. HVR—high-voltage regulator; A—autotransformer; HT—high-voltage transformer; V28-800—kenotron; V—electrostatic kilovoltmeter; mA—milliammeter; T—x-ray tube; ACR—anode current regulator; C—Geiger counter; HSC—high-voltage supply for counter; RM—counting-rate meter; B-2—scaling circuit of a B-2 radiometer. The section within the dotted outline is located in the vacuum chamber of the monochromator.

out breaking the vacuum. Such motion is necessary to point the detectors toward the diffraction grating. The monochromator is enclosed in a vacuum chamber. Between the x-ray tube and the vacuum chamber of the monochromator is placed the separator slit S, of area 5 mm^2, through which radiation from the tube passes into the monochromator. The volumes of the x-ray tube and the monochromator are pumped out by separate diffusion pumps, which are equipped with stainless steel oil baffles and liquid-oxygen traps. This pumping system permits vacuums of 5×10^{-7} and 2×10^{-5} mm Hg in the x-ray tube and monochromator chamber, respectively. Such a high vacuum in the x-ray tube is necessary to obtain characteristic lines in the ultrasoft radiation region that are stable in time. The vacuum chamber of the monochromator is connected with apparatus for filling the Geiger counter. Construction details of the monochromator are shown in Fig. 1,b.

For tube

10^{-7} mmHg
(necessary)

X-RAY TUBE SUPPLY CIRCUIT AND RECORDING CIRCUIT

Circuits for electronic stabilization of the anode current of the x-ray tube and of the high voltage were used in order to stabilize the radiation intensity with time. A block diagram of the x-ray tube supply is presented in Fig. 2. Regulation of the anode current was carried out by means of a regulator analogous to the one in the URS-501 instrument[1] except that in our regulator the range of emission currents was considerably wider (from 20 μa to 150 ma). Regulation of the high voltage was accomplished using a magnetic-amplifier stabilizer which was controlled by the rectified voltage from a separate rectifier. This rectifier was fed by the same alternating potential as was the transformer of the high-voltage apparatus. The high-voltage regulator had a stabilization coefficient of about 30. The remaining parts of the supply circuit are seen in the block diagram.

The recording and supply circuit for the Geiger counter is also presented in Fig. 2. In order to obtain a good "plateau" a forced-quenching circuit of the Neher-Harper type[2] was used. Impulses from the quenching circuit proceeded to the counting-rate meter, in the first stage of which they changed sign, and then to the scaling circuit of a B-2 radiometer.

detector
Geiger
Counter

ADJUSTMENT OF MONOCHROMATOR

In adjusting the apparatus with the curved grating operating at grazing incidence it is necessary to establish strict parallelism between the entrance and detector slits and the rulings of the grating. Deviation of the slits from the required position in planes perpendicular to the direction of the beam is particularly inadmissable. The entrance slit, diffraction grating, and detector slit were mounted on cones, which were inserted in conical sockets. The conditions of manufacture were such that the axes of the conical sockets were strictly parallel to one another. All three cones were made to be interchangeable, and, in addition, a fourth socket was placed on the table of an autocollimator. The slits and the grating were mounted in turn in this socket. By clamping a small plane-parallel glass plate to the jaws of a slit (or by holding it between the jaws), parallelism of the slit and its axis of rotation was established. Precise setting of the distances between slits and grating (the distances between axes of the cones were precisely measured) was insured by coincidence of the slits with the axes of the conical bearings; this coincidence was set with the aid of a microscope. Each slit was placed in such a way that its position did not change as a result of rotation in its conical socket.

In the adjustment of the slits the autocollimator was set up such that its optic axis was perpendicular to the axis of rotation of the conical bearing. After this the adjustable stage with the grating was placed in the conical socket on the autocollimator. The diffraction grating was made so that its rulings were parallel to the boundary surfaces of the glass block. By fastening plane-parallel plates to these end surfaces and to the rule surface of the grating, strict parallelism was established between the rulings and the axis of rotation of the cone by means of the autocollimator. The remaining steps of the adjustment (coincidence of the ruled surface and the axis of rotation of the cone, setting of the necessary angle of incidence of rays on the grating, adjustment of the separator slit, and adjustment of the x-ray tube) were carried out in the monochromator with the use of a light beam.

In order to illustrate the operation of the monochromator, Fig. 3 presents the characteristic K-series lines of fluorine, oxygen, carbon, boron, and beryllium, which have wavelengths of 18.3, 23.6, 44, 67, and 113 A, respectively. These lines were obtained using LiF, MgO, aquadag, boron, and beryllium applied to the surface of the anode in the form of fine powder suspended in alcohol (with the exception of MgO, which was obtained by the combustion of Mg). The use of powders insures stability of the radiation with time because of the poor heat contact between the powder and the anode and the low heat conductivity, which leads to heating of the powder by the electron beam. Hot surfaces are coated to a considerably smaller degree with carbon which results from the decomposition of residual organic vapors (diffusion pump oil, etc.) in the electron beam.

The characteristic lines are obtained by measuring the intensity during translation of the counter along the y-coordinate for fixed values of the x-coordinate corresponding to calculated values for the wavelength at the "center of gravity" of the lines (see Fig. 1,a). As can

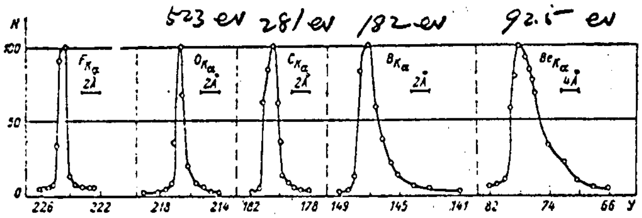

Fig. 3. Characteristic K-series lines of fluorine, oxygen, carbon, boron, and beryllium. N—intensity in relative units; y—translation of detector in y-direction (1 division equals 0.1 mm).

be seen from Fig. 3, the characteristic lines have background. The considerable excess in intensity of the lines over the magnitude of the background attests to the favorable operation of the grating and correct adjustment.

DETERMINATION OF THE ABSOLUTE NUMBER OF QUANTA IN THE MONOCHROMATIC BEAM

The use of the Geiger counter for recording ultrasoft x-radiation is known in the literature.[3,4] With special recording circuits it is possible to exclude the main deficiencies in the operation of counters which there are in the cited works and to use counters for absolute measurements of intensity. Two drawbacks which have been met in previously used counters are poor counting characteristics ("plateau"), which, moreover, shift with time along the voltage scale ("plateau drift"), and absorption in the "dead region" of the counter which cannot be taken into account.

In order to determine the absolute number of quanta with a counter it is necessary to satisfy the following conditions: (1) the counter must have a good "plateau" (i.e., a relatively small number of spurious counts); (2) there must be no "dead region;" (3) it is necessary to know the amount of absorption in the counter window, the absorption coefficient of the counter gas, and also the "dead time" of the counter is needed in order to introduce corrections for "missed counts."

The construction of the counter used by us is shown in Fig. 4. As can be seen from the diagram, the window 9 was glued over the slit in the frame 7. This frame was connected to the casing of the counter 1 through the rubber gasket 8. The possibility of removing the frame with the window made it easy to glue on the window and to determine its transmissivity. In order to do this the frame and window were mounted in the vertical slider of the monochromator in place of the Geiger counter and could then be moved into and out of the beam. Another radiation detector (e.g., photomultiplier of the Allen type[5]) was attached to the platform, and with it measurements were made of the transmissivity for the characteristic lines O_k, C_k, B_k, and Be_k. Results of the measurements are given in the Table.

Transmissivity of Window

Spectral line (Å)	Transmissivity (%)
O_k (23.3)	88
C_k (44)	92
B_k (67)	80.5
Be_k (113)	55

2 layers
window
0.1μ

A double sheet of $\boxed{\text{celluloid}}$ with a total thickness of about 0.1μ was used as a window. This thin sheet is very weak, and even when glued on a slit of width 0.3 mm it can withstand a pressure difference of only about 150 mm Hg. Therefore we used a special gas filling system allowing the counter to be pumped out together with the monochromator chamber; also the air could be let into both simultaneously. The gas mixture was prepared in a separate tank, from which it was fed into the counter each time after pumping out the apparatus. In the operation of the counter its "plateau" shifted as a result of a change in the composition of the gas. Forced circulation of the mixture was used to speed up the establishment of a "plateau." Experiment showed that forced circulation of the gas stabilizes the operation of the counter, practically eliminating "plateau drift" with time. The copper casing of the counter 1 has two hose connections 6 for filling and forced circulation. The diameter of the cylindrical bore of the casing equals 18 mm.

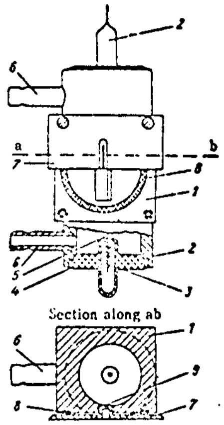

Fig. 4. Construction of Geiger counter. 1—casing (copper); 2—glass insulator; 3—spring; 4—picein; 5—tungsten wire (diameter 0.05 mm); 6—hose connections for filling; 7—frame; 8—rubber gasket; 9—celluloid window.

As the counter gas we used either a mixture of argon and methane (80% A and 20% CH_4) or a mixture of argon and absolute ethyl alcohol (90% A and 10% C_2H_5OH). The use of forced quenching provides an extension of the "plateau" to 250 volts with a slope of about 2% per 100 volts. Consequently, "spurious impulses" could be disregarded.

A study of counter efficiency was carried out by measuring the intensity for different gas pressures. Figure 5 gives curves of counting rate as a function of gas pressure (80% A and 20% CH_4) for K-radiation of Be, B, C, and O. From the graph it is evident that for pressures greater than 80 mm Hg all curves approach "saturation." This attests to the fact that under these conditions total absorption of radiation occurs within the gas of the counter. The absence of a falling off for high pressures indicates that there is no "dead region" in the counter. Extrapolation of the curves into the region of small pressures (anticipating a dependence according to the law $1 - e^{-kp}$, where p is the pressure and k the absorption coefficient) shows that the curves pass through the origin. This indicates that photoelectrons from the window have only a second-order role, which is in agreement with a small absorption and, apparently, a low value of the photoelectric yield in the window. Therefore, the photoeffect in the window was not taken into consideration. Thus in our case many phenomena (the effect of "spurious impulses," the effect of a "dead region") have been reduced to negligibly small quantities. The pressure in the counter is chosen such that practically total absorption of the radiation occurs within the gas. If under these conditions account is taken of absorption in the window and of "missed counts," then the reading of the counter will lead to the absolute number of quanta incident on the window.

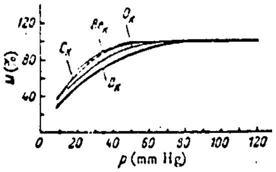

Fig. 5. Dependence of relative counting rate M of Geiger counter on gas pressure p for constant intensity of radiation.

Absorption in the window was determined experimentally.

Correction for "missed counts" was introduced using the equation[2]

$$N_1 = \frac{N}{1 - \tau N},$$

where N_1 is the actual counting rate, N the measured counting rate, and τ the "dead time." The "dead time" was determined experimentally by the method of two sources[6] (as sources we used two radioactive preparations of Co^{60}) and for our counter amounted to about 2.5×10^{-4} sec. It is evident that the maximum counting rate for such a counter is about 500 impulses/sec. For counting a larger number of quanta an attenuator consisting of a series of raster screens with about 30-μ mesh laid one on top of another was placed before the counter. Such an attenuator produces the same attenuation for all wavelengths. A special investigation of the dependence of the counting rate on the point of incidence of the beam in different parts of the attenuator showed that the attenuation was the same in different spots. Calibration of the attenuator was accomplished in the same way that the transmissivity of the counter window was determined. A selection of raster attenuators made it possible to increase the counting rate to 3×10^5 quanta of monochromatic radiation per second. The possible error in determining the absolute number of quanta is estimated to be no more than 10%.

In conclusion we wish to express our thanks to A. A. Lebedev for discussions and his interest in this work.

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MEASUREMENT OF THE PHOTOELECTRIC YIELD FOR ULTRASOFT X-RADIATION

A. P. Lukirskii, M. A. Rumsh, and L. A. Smirnov

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A method for measuring the photoelectric yield for ultrasoft x-radiation is described. The method is based on a system devised for absolute counting of very small numbers of photoelectrons using an electron multiplier and for absolute counting of quanta using a Geiger counter. Results of measurement of the photoelectric yield for a series of metals and nonmetals are presented.

INTRODUCTION

Study of the photoelectric yield under the action of short wavelength ultraviolet light and ultrasoft x-radiation is of interest from the point of view of both theory and application. Some works[1,2] have indicated the possibility of using photomultipliers of the Allen type for the absolute measurement of intensity in these spectral regions.

The external photoeffect for short wavelength ultraviolet light has been investigated many times.[3-8] In the contiguous, ultrasoft x-ray region this problem has until now been discussed in only a few works.[9-12] In these works only the relative photoelectric efficiency of a series of metals for polychromatic radiation was determined. The lack of detailed quantitative studies of the photoelectric yield is explained by the experimental difficulties connected with (1) the necessity of either obtaining powerful monochromatic beams or else measuring very weak photocurrents, and (2) the determination of the absolute intensity of beams causing the photoemission. These difficulties are relatively easy to overcome when working in the short wavelength ultraviolet part of the spectrum since discharge in a capillary (Lyman source[13]) is sufficiently stable and provides the necessary intensity of the monochromatized beam to allow measurement of the photocurrent by the usual electrometric methods. In this case measurement of the absolute intensity is made using sensitive detectors which have been calibrated relative to an intense source of thermal radiation.

In this work a photomultiplier of the Allen type[1] operating in a system for counting separate photoelectrons was used for the measurement of the photocurrents. The possibility of counting separate electrons enabled us to use a special x-ray tube of relatively low power as a radiation source. We used the characteristic K-series radiations of the elements oxygen, carbon, boron, and beryllium, which have wavelengths of 23.6, 44, 67, and 113 A, respectively.

A monochromator with a curved diffraction grating was used for monochromatization of the radiation. Measurements of the intensity of the monochromatic radiation were made with a specially constructed Geiger counter, for which the operating conditions that make it possible to determine the absolute number of quanta passing through the detector slit were found experimentally. The construction of the monochromator* made the following operations possible without breaking the vacuum: isolation of different monochromatic lines by the detector slit; placing of either the Geiger counter or the photomultiplier behind the detector slit; and small shifts of the counter or photomultiplier relative to the selected monochromatic beam.

The x-ray tube supplies (i.e., high-voltage and filament supplies) were regulated by special electronic stabilizers, which in combination with the high vacuum in the x-ray tube (5×10^{-7} mm Hg) kept the monochromatic radiation sufficiently constant during the measurement time. The width of the monochromator slit was chosen such that the isolated spectral interval amounted to 1 A.

MEASUREMENT OF THE PHOTOCURRENT

An Allen-type multiplier was used to record the photoelectrons. These multipliers possess a comparatively stable amplification factor, very low background, and also permit air to be let into the apparatus. Electron multipliers with dynodes of a Cu-Be alloy[14] were used in this work.

The photocathode was mounted in the first dynode in such a way that it practically duplicated the form of the plane middle part of the dynode. The angle of incidence of the beam on the photocathode was equal to about 60°.

The power supply and recording circuits are shown in Fig. 1. Voltage was supplied to the dynodes through a divider which was connected to a source of regulated voltage, the magnitude of which could be varied between 4100 and 5400 volts

The first resistor of the voltage divider was variable and was placed outside the monochromator so that the voltage between the photocathode and the second dynode could be varied. From the collector of the photomultiplier an impulse passed to a preamplifier, which was placed in the vacuum chamber of the monochromator in the immediate vicinity of the multiplier. The preamplifier consisted of a single stage amplifier and cathode follower. The gain of the preamplifier was equal to 6 for impulses no shorter than 5 μsec. In addition, the preamplifier produced an approximately 4-5 μsec lengthening of impulses arriving from the multiplier. This lengthening was necessary for triggering of the scaling circuit. From the preamplifier an impulse was fed to a wide-band, two-stage amplifier with variable gain (from 0.5 to 50), after which it proceeded to a B-2-radiometer scaling circuit. The "threshold of operation" of the recording apparatus for 5-μsec rectangular impulses fed into the preamplifier and for maximum gain of the wide-band amplifier was equal to 2 mv.

A multiplier with the above described recording circuit registers all photoelectrons under the conditions that (1) all impulses of the multiplier are greater than the "threshold of operation" of the circuit, and (2) all photoelectrons fall on the second dynode of the multiplier. In order to find the conditions under which these requirements are fulfilled the following dependences were investigated:

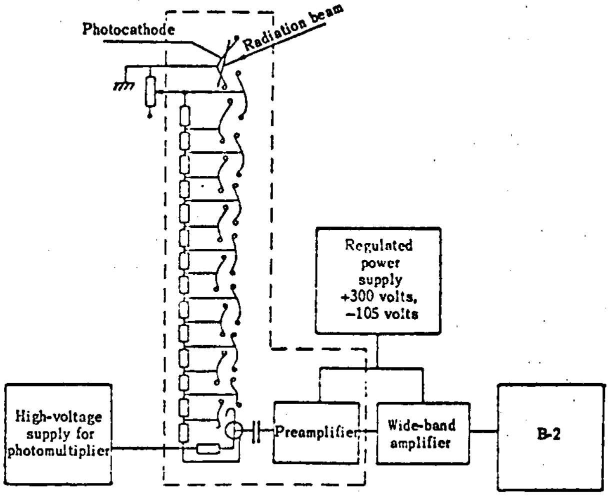

Fig. 1. Block diagram of recording circuit using electron multiplier (part in dotted outline is located within the vacuum chamber of the monochromator).

1. The dependence of the number N of registered impulses on the gain G of the wide-band amplifier was studied for a sufficiently large voltage between the photocathode and the second dynode for x-rays incident on the middle of the photocathode. This dependence is presented in Fig. 2. From the graph it is seen that beginning with a certain value G_0 of the gain, the number of registered impulses ceases to increase (saturation), which verifies that practically all impulses are being counted. Thus, for $G > G_0$ practically all impulses are recorded by the described apparatus.

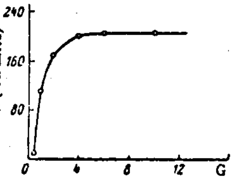

Fig. 2. Dependence of the number of impulses registered by the multiplier on the gain of the wide-band amplifier.

2. The dependence of the number N of registered impulses on the voltage U applied between the photocathode and the second dynode was studied for values of $G > G_0$ and for rays incident on the middle of the photocathode. This dependence was investigated with regard to different wavelengths and for all photocathodes. Figure 3 presents curves corresponding to a Ni photocathode for the extreme wavelengths K_α of O ($\lambda = 23$ A) and K_α of Be ($\lambda = 113$ A).* From the graphs it can be seen that be-

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*The construction and operation of the monochromator and also the technique of measuring the absolute number of quanta are described in the preceding article.

*According to the data of Rudberg,[15] 80% of the photoelectrons arising under the action of carbon K-radiation have energies of 20-30 ev. Such an energy distribution of photoelectrons explains the shape of the curves of Fig. 3, which exhibit a sharp rise as the magnitude of U approaches a value that insures the collection of photoelectrons at the second dynode.

ginning with $U = U_0 = 240$ volts, all photoelectrons fall on the second dynode and lead to the appearance of photocurrent impulses. In order to make more precise the conditions under which all photoelectrons are collected at the second dynode, the dependence of the number of impulses N on the point of incidence of rays on the photocathode was studied. This dependence is presented in Fig. 4. From the graph it can be seen that there are regions on the photocathode, considerably larger than the width of the x-ray beam, from which photoelectrons are completely collected by the second dynode. Thus, if the gain of the wide-band amplifier $G > G_0$, the voltage between cathode and second dynode $U > U_0$, and the beam falls at a spot on the photocathode corresponding to the middle of the horizontal part of the curve in Fig. 4, then all electrons will be registered. Possible sources of error may be "miscounts," which depend on the finite length of the impulses, and the natural background of the multiplier. If, however, counting rates of less than 1000 impulses/sec are used, then for impulses 10^{-5} sec long missed counts amount to a fraction of a percent. The natural background of the multiplier, although negligibly small, can easily be measured and taken into account in the final results.

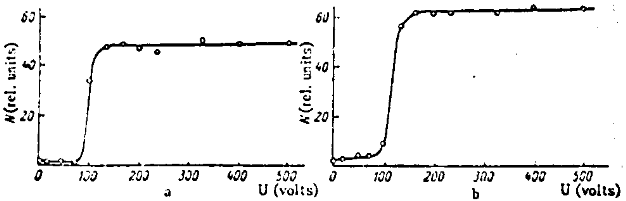

Fig. 3. The dependence of the number of electrons registered by the multiplier on the magnitude of the voltage between the photocathode and the second dynode. a—for Be K-radiation; b—for O K-radiation.

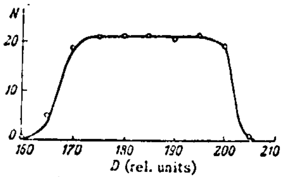

Fig. 4. Dependence of the number of registered electrons N on the point D of incidence of the monochromatic beam on the photocathode. One division corresponds to a translation along the cathode of 0.18 mm; the width of the beam is no more than 1 mm.

Thus, in general, the number of registered impulses equals the number of photoelectrons if we neglect the probability of the appearance of two electrons as a result of the action of a single quantum.

MEASUREMENT OF THE PHOTOELECTRIC YIELD

In the light of the above, measurement of the photoelectric yield in our case amounted to counting with the multiplier the number of photoelectrons arising each second and determining the intensity of the x-ray beam in number of quanta per second using the Geiger counter. Since measurements of photoemission and x-ray intensity were conducted successively in time, they were repeated many times, and average values were used in the calculation of the photoelectric yield. The ratio of the number of impulses recorded by the multiplier in some interval of time to the number of quanta incident on the photocathode for the same interval was taken as the magnitude of the photoelectric yield. The value thus obtained represents the fraction of quanta leading to photoemission from the cathode. This quantity is equal to the photoelectric yield with a precision set by the probability of the appearance of several electrons under the action of a single quantum. For large photoelectric yields this probability is, apparently, considerably different from zero, and the actual value of the quantum yield may prove to be higher than the values determined by us.

Results of measurements for various photocathodes are presented in the Table. It should be noted that the metallic photocathodes which we used were not subjected to outgassing (their surfaces were cleaned with a fine abrasive). The nonmetallic photocathodes were made by vacuum evaporation on a nickel substrate.

Values of Photoelectric Yields of Various Cathodes (%)

Photocathode material	Wavelength of characteristic line (A)			
	523	281	182	92.5 eV
	O_k (23.6)	C_k (44)	B_k (67)	Be_k (113)
Be	0.7	1.1	2.35	2
Ni	2.1	2.3	3.7	4.9
W	3.6	4.0	2.2	0.94
LiF	—	6.0	17.0	61.0
NaF	3.2	12.5	26.0	85.0
CaF_2	15.9	7.1	14.2	25.0
SrF_2	22.0	31.0	27.0	24.0
NaCl	13.5	19.5	13.5	27.0

We must also note that the results obtained should be considered as preliminary since, according to the data of ref. 15 for ultrasoft x-radiation and ref. 9 for short wavelength ultraviolet radiation, a strong dependence of the photoelectric yield on the degree of outgassing of the photocathode surface should be expected. It is very probable that for sputtered layers a dependence of the photoelectric yield on the thickness of the layer should also be observed.

In conclusion, we wish to express our gratitude to A. A. Lebedev for discussions and for his constant interest in this work.

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