USING THE X-RAY SPECTRAL INSTALLATION FOR DETERMINING THE COMPOSITION OF A SUBSTANCE

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Annotation. X-ray spectral analysis of the elemental composition of a substance is based on the excitation of the characteristic X-ray radiation of chemical elements, the release of this radiation and the measurement of its intensity. The characteristic radiation spectrum is individual for each element, and its intensity is a function of the concentration of the element. To determine the composition of a substance, X-ray spectral installations are used to analyze and determine the composition of a substance. The quality of determining the percentage composition of the test substance depends on the elements used in this installation. This article discusses the operation of the X-ray spectral installation and its main components.

Key words: X-ray spectral analysis, X-ray spectral setup.

The X-ray spectrum lies in the wavelength range of 0.01-100 nm, overlapping in the short-wave part with γ-radiation, and in the long-wave part - with the ultraviolet spectrum. In practice, wavelengths in the range of 0.04–1.80 nm are most often used. Within the framework of X-ray spectral analysis, 4 main areas can be distinguished [1]:

- analysis by primary emission spectra;
- analysis by secondary emission spectra;
- analysis by absorption spectra;
- analysis by photo- and Auger-electrons.

With the help of X-ray spectral analysis, it is possible to solve the problems of increasing the rapidity of analysis, developing methods for remote analysis and automatic control of technological processes, and creating new methods for local

analysis. The range of determined concentrations is from 10–4–10–2 to 100%. The error can be brought up to 0.1–0.5%.

Primary X-ray radiation occurs when atoms of a solid body are bombarded by charged elementary particles (electrons, protons) with high energy. The electron receives this energy as a result of acceleration in an electrostatic field of high intensity. As a source of primary X-ray radiation, a deeply evacuated X-ray tube is used, in which a heated cathode filament releases electrons accelerated towards the anode by a voltage of 10–70 kV applied to the tube.

Excitation of X-rays by bombarding a solid with protons and heavier ions is possible by accelerating them to high energies in electrostatic generators or cyclotrons. X-ray sources are also some radioactive isotopes, which either emit X-rays themselves (55Fe, 109Cd), or emit electrons or α-particles (210Po), bombarding which a solid body can produce X-rays.

An electron flying with a speed v, upon impact with a substance, experiences a sharp deceleration, losing its kinetic energy. Most of this energy (p) is spent on interaction with the material of the substance, turning into heat, and the rest of the energy is converted into the energy of electromagnetic radiation, the wavelength of which, depending on the energy of the electron, is determined by

$$\text{the equation } \frac{hc}{\lambda} = \frac{mv^2}{2} - p,$$

where h is where h is Planck's constant, J·s; c is the speed of light in vacuum, nm/s; λ - radiation wavelength, nm; m - particle mass, g.

The appearance of this radiation is connected with the deviation of the flying electron from the initial direction of motion as a result of the impulse of attraction of the positively charged atomic nuclei. According to the laws of electrodynamics, when the trajectory of motion changes, a charged particle loses part of its energy in the form of electromagnetic radiation [2].

Since the deflection angle varies over a wide range (from 0 to 1800) and many electrons change their trajectory many times (Fig. 1.1) before they dissipate all their energy, the radiation will have a continuous set of wavelengths limited from

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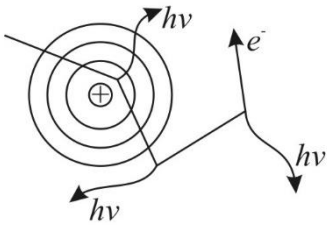

Fig. 1. Scheme of the motion of an electron and the appearance of bremsstrahlung

If p<< mv2/2 and the kinetic energy transforms into electromagnetic radiation upon a single impact, then

$$\frac{hc}{\lambda_{\min}} = \frac{mv^2}{2} = q_e U$$

$$\lambda_{\min} = \frac{hc}{q_e U},$$

where U - is the voltage on the tube, B; q_e - the charge of an electron is 1,602 · 10⁻¹⁹ Kl [3].

After substituting the corresponding values of the Planck constant, the speed of light, the charge of an electron into the formula and converting joules into volt-coulombs (1 J = 1 V · C), we obtain the Duane-Gent formula:

$$\lambda_{\min} = \frac{1240}{U} \ nm.$$

Absorption of x-rays. When X-ray radiation passes through a layer of matter, the radiation intensity weakens as a result of absorption and scattering in accordance with the equation

$$I = I_0 e^{-\mu d},$$

where μ is the linear attenuation coefficient; d is the thickness of the substance layer through which the X-ray beam passed; I is the intensity of the radiation that has passed through the substance; I0 is the intensity of the incident X-ray beam [4].

The linear attenuation coefficient is determined by the sum

$$\mu = \tau + \sigma,$$

where τ is the linear absorption coefficient; σ - linear scattering coefficient. Under real conditions of analysis, τ >> σ, and the total attenuation coefficient is practically determined by $\mu \equiv \tau$.

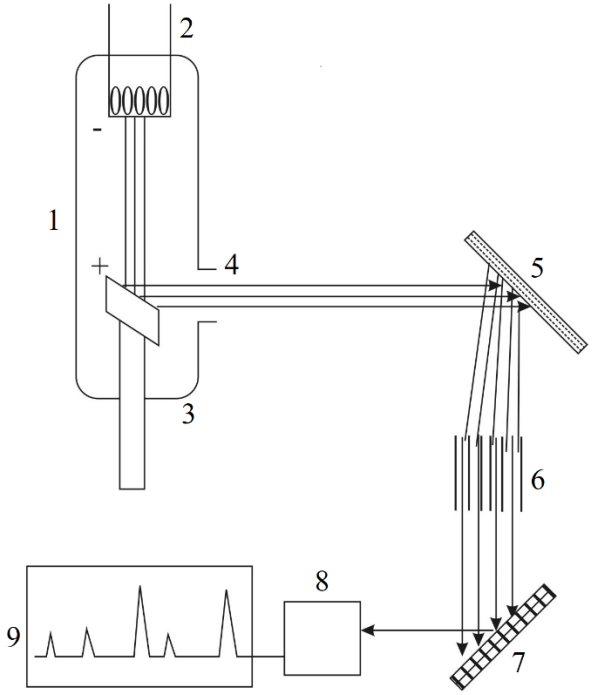

Fig. 1.7. Scheme of the X-ray spectral setup:

1 - x-ray tube; 2 - cathode; 3 - anode; 4 - window; 5 - sample; 6 - collimator Soller; 7 - crystal-analyzer; 8 - detector; 9 - recording device

X-ray tube designed for X-ray fluorescence analysis is characterized by energy efficiency, spectrum purity and radiation stability. The voltage on the tube is 30–60 kV, the vacuum is 10–4–10–6 mm Hg. Art. The tube anode is made of tungsten, molybdenum, copper, chromium, rhenium, etc. A chromium anode is used for the analysis of light elements, and a tungsten anode for heavy elements. The

anode mirror is carefully polished. The tube window is made of ultra-thin beryllium foil.

To create a parallel radiation beam, a collimator is used, consisting of a set of parallel plates made of molybdenum or nickel foil 0.05 mm thick and 100 mm long. The distance between the plates is 0.125–0.5 mm. An increase in the degree of collimation contributes to the formation of sharp lines and an increase in the signal-to-background ratio, despite the overall decrease in intensity. The residual divergence of the beams is (0.1–0.5)o. To decompose X-rays into a spectrum and simultaneously focus them, crystal analyzers made of various materials are used. Wavelengths are recorded within $0.175\ d < \lambda < 1.9\ d$. For example, for quartz - within 0.047–0.596 nm, for lithium fluoride - within 0.050–0.765 nm. X-ray detectors are Geiger counters, proportional and scintillation counters with a photomultiplier. The Geiger counter has good stability and very low background, making it particularly useful for detecting very low concentrations. Also, its advantage is the simplicity of the electronic circuit. Its most serious drawback is the limited pulse count rate. A proportional counter is similar in many ways to a Geiger counter. In scintillation counters, luminescent crystals of phosphorus, cesium iodide or sodium iodide, activated with thallium, convert X-rays into visible light, which in turn is converted by a photomultiplier tube into electrical pulses. The efficiency of scintillation counters is much greater than gas counters, which include proportional counters and Geiger counters, so scintillation counters have found the most widespread use [5].

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