EXPERIMENT 5: ABSORPTION OF X-RAYS

Related Topics

Bremsstrahlung, characteristic X-radiation, Bragg scattering, law of absorption, half-value thickness, photoelectric effect, Compton effect, and pair production.

Principle

The polychromatic X-radiation that is emitted by an X-ray tube is filtered in terms of its energy with the aid of a monocrystal. The resulting monochromatic radiation is used as the primary radiation source for examining the absorption behaviour of various metal foils of different thicknesses.

Tasks

- Determine the attenuation of the X-radiation by aluminium and zinc foils of different thicknesses and at two different wavelengths of the primary radiation.
- Determine linear absorption coefficient μ of Al and Zn absorbers for certain wavelength.

Theory and Evaluation

If X-rays with intensity I_0 penetrate matter of the layer thickness d, then the intensity I of the radiation that passes through the matter is:

$$I = I_0 \, e^{-\mu(\lambda,Z)d}$$

The linear absorption coefficient μ [cm-1] is dependent on the wavelength λ (energy) of the X-radiation and on the atomic number Z of the absorber. This relationship enables the direct determination of the absorption coefficient:

$$-\frac{ln\frac{I}{I_0}}{d} = \mu$$

In order to be able to directly compare the absorption behaviour of various materials, it is advantageous to use the so-called half-value thickness $d_{1/2}$. Absorbers of this thickness reduce the intensity of the primary radiation by half.

$$d_{1/2} = 0{,}69\frac{1}{\mu}$$

The following processes are responsible for the absorption:

1. photoelectric effect
2. scattering (Compton effect)
3. pair production

Pair production, however, requires a certain threshold energy that corresponds to twice the amount of the electron rest energy ($2E_0 = 2m_0c^2 = 1.02$ MeV). As a result, the absorption coefficient only comprises two components:

$$\mu = \tau_{photoelectric\ effect} + \sigma_{compton\ scattering}$$

Table 1: Dependence of the absorption on the wavelength

	μ / cm^{-1}	$d_{1/2}$ / cm	μ/ρ / cm^{2}g^{-1}
Al (Z = 13)			
ρ = 2.7 g/cm^{-3}			
λ = 139 pm	112	$6.2 \cdot 10^{-3}$	41.5
λ = 70 pm	14.1	20.4	5.2
Zn (Z = 30)			
ρ = 7.14 g/cm-3			
λ = 139 pm	280	$2.5 \cdot 10^{-3}$	39.2

Equipment

X-ray experiment unit, X-ray goniometer, X-ray plug-in unit with a copper X-ray tube, counter tube, Lithium Floride crystal, X-ray absorption set.

Fig.1: Experimental set-up for determining linear absorbtion coefficient of Al and Zn.

Set-up and Procedure

The absorption set includes aluminium and zinc foils of various different thicknesses. They are fastened to the Geiger-Müller counter tube by pushing them into the diaphragm that is installed in front of the counter tube. Manually select two different glancing angles for which the intensity is determined first without an absorber (I_0) and then with an absorber (I). In the case of copper, suitable angular positions are, for example, 20.4° (K_β line) and approximately 22.7° (K_α line)(You can search for the peaks between 18° and 25°). Then, note down the corresponding pulse rates without an absorber and with the zinc and aluminium absorber of the "absorption set for X-rays". In order to vary the thickness of the absorbers, it is also possible to use two foils at the same time.

In order to keep the relative errors of the measurement values as small as possible, the measurement should be performed up to an intensity of I ≥ 1000 pulses^{-1}.

- Connect the X-ray unit via USB cable to the USB port of your computer.
- Start the "measure" program. A virtual X-ray unit will be displayed on the screen.
- You can control the X-ray unit by clicking the various features on and under the virtual X-ray unit. Alternatively, you can also change the parameters at the real X-ray unit. The program will automatically adopt the settings.
- Click the experiment chamber to change the parameters for the experiment.
- If you click the X-ray tube, you can change the voltage and current of the X-ray tube.
- Start the measurement by clicking the red circle:
- After the measurement, send all data to measure.
- At the end of this manual a short introduction to the evaluation of the resulting spectra is given.

	I	I_0	μ (cm^{-1})	$d_{1/2}$ (cm)	$\mu_{theo.}$ (cm^{-1})	$d_{1/2_{theo.}}$ (cm)
d=0.08mm Al (K_β)					14.1	20.4
d=0.08mm Al (K_α)					112	0.0062
d=0.08mm Zn (K_β)					-	-
d=0.08mm Zn (K_α)					280	0.0025