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Faculty of Physics

Laboratory III

Laboratory Report

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Measurement Setup and Preparations

Setup

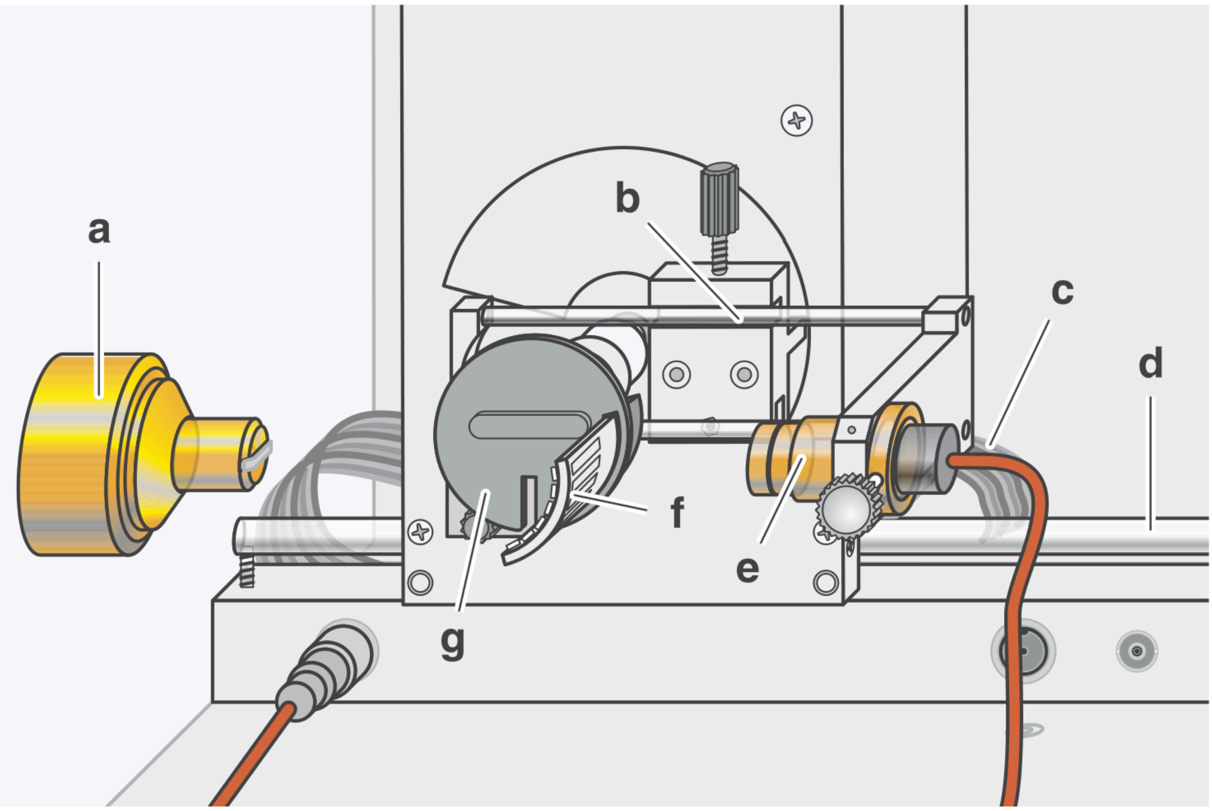

Figure 1: Measurement Setup with following compenents: (a) collimator mount, (b) sensor holder, (c) flat ribbon cable, (d) goniometer guide rods, (e) sensor mount, (f) insertion edge of absorber set 1, and (g) goniometer target holder.

Preparations

- Carefully align the guide rod while inserting the collimator into the collimator mount (a).
- Secure the goniometer onto the guide rods (d) before connecting the flat ribbon cable (c) for control.
- After removing the protective cap, install the window counter tube into the sensor mount (e) and plug its cable into the GM-tube socket in the experimental area.
- Remove the goniometer's target holder (g) to lift off the target table.
- Slide the insertion edge of absorber set 1 (f) into the quarter-circle groove of the target holder until it clicks into place.
- Swap out the sensor holder with X-ray energy detector for the holder equipped with the window counter tube.
- Reinstall the target holder carrying absorber set 1.
- Press the "Zero" button to set target and sensor to their null positions.
- Verify (and adjust if needed) the zero position of both the blank aperture in the absorber set and the sensor (see "Setting the measurement zero position" in the X-ray manual).
- Finally, slide the goniometer to position the collimator at 5 cm from the blank aperture, then slide the sensor holder (b) to set 5 cm between aperture and sensor slit. = Dependence of attenuation on absorber thickness

Experiment 1: Attenuation of X-Ray Radiation

Objectives

- Investigate the attenuation of X-ray intensity as a function of absorber thickness and material.
- Verify Lambert's law of exponential attenuation.
- Demonstrate the wavelength dependence of the attenuation coefficient.

Theory

When a narrow beam of X-rays of initial count rate R_0 passes through an absorber of thickness x, the transmitted count rate R satisfies

$$T = \frac{R}{R_0} \quad \text{where} \quad T(x) = e^{-\mu x} \quad \rightarrow \quad \texttt{ln}\, T = -\mu x$$

where μ is the linear attenuation coefficient.

Setup

1. Mount the collimator and goniometer on the X-ray tube as shown in Fig. 1.
2. Insert the Geiger–Müller detector in the sensor arm and connect via "GM Tube".
3. Align the target (absorber holder) and detector so that the slit-to-target and target-to-detector distances are each ≈ 5 cm.
4. Zero-position both arms with the "Zero" button.

Attenuation vs. Absorber Thickness

Without zirconium filter

1. Set tube voltage $U = 21$ kV, emission current $I = 0.05$ mA, measurement time $\Delta t = 100$ s.
2. Set absorber angles corresponding to the corresponding thicknesses, press **Scan**, wait Δt, then read count rate R via **Replay**.
3. Record in Table 1.

d / mm	R / s^{-1}
0	1618
0.5	787.4
1	403.5
1.5	226.4
2	49.1
2.5	30.55
3	16.11

Table 1: Some Caption

With zirconium filter

1. Mount Zr filter, set $I = 0.15$ mA, $\Delta t = 200$ s.
2. Repeat step 1.1 at the same angles.
3. Record in Table 2.

d / mm	R / s^{-1}
0	775.1
0.5	337
1	149.8
1.5	72.1
2	33.85
2.5	18.6
3	7.85

Table 2: Some caption

Data Analysis

- Compute transmission: $T(d) = \frac{R(d)}{R(0)}$.
- Plot $T(d)$ vs d and $\ln T(d)$ vs d.
- Fit $\ln T(d) = -\mu d$ to extract μ for both unfiltered and filtered cases.

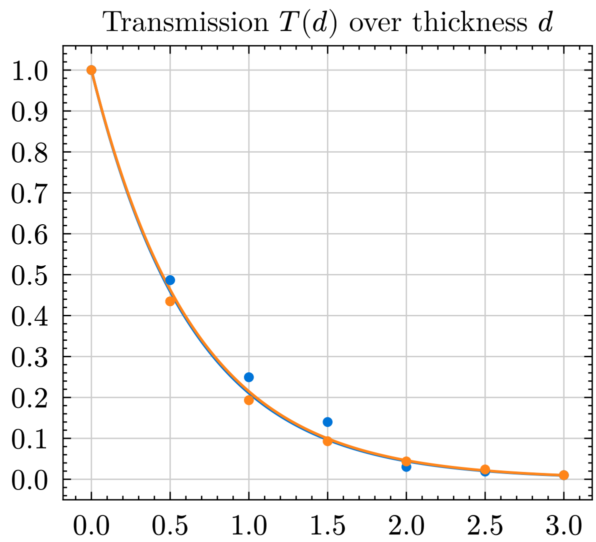

Figure 2:

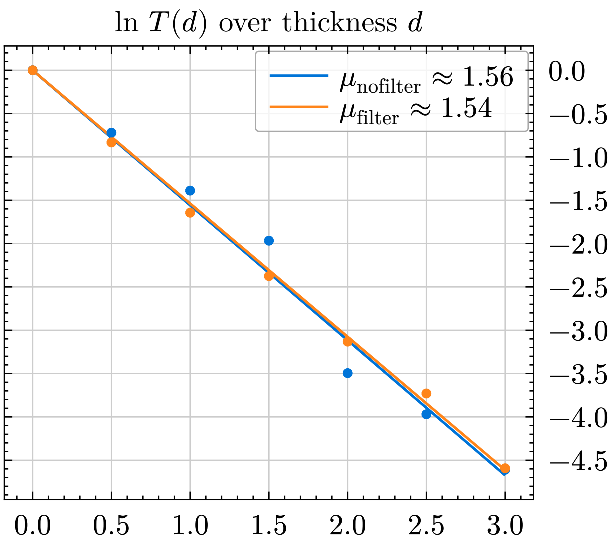

Figure 3:

Dependence of attenuation on the absorber material

Without zirconium filter

Some text

Absorber	Z	$\frac{I}{\text{mA}}$	$\frac{\Delta t}{\text{s}}$	$\frac{R}{\text{hz}}$	T	$\frac{\mu}{\text{cm}^{-1}}$
leer	0	0.02	30	89550	1	0
C	6	0.02	30	85050	0.95	17
Al	13	0.02	30	54150	0.605	168
Fe	26	1	300	7355	0.082	833
Cu	29	1	300	15.55	0	2886
Zr	40	1	300	181.8	0.002	2067
Ag	47	1	300	56.65	0.001	2455

Table 3: Some caption

With a zirconium filter

some Text

Absorber	Z	$\frac{I}{\text{mA}}$	$\frac{\Delta t}{\text{s}}$	$\frac{R}{\text{hz}}$	T	$\frac{\mu}{\text{cm}^{-1}}$
leer	0	0.02	30	36915	1	0
C	6	0.02	30	34730	0.941	20
Al	13	0.02	30	19545	0.529	212
Fe	26	1	300	2585	0.07	886
Cu	29	1	300	5.7	0	2925
Zr	40	1	300	107.3	0.003	1947
Ag	47	1	300	12.05	0	2676

Table 4: Some caption

Data Analysis

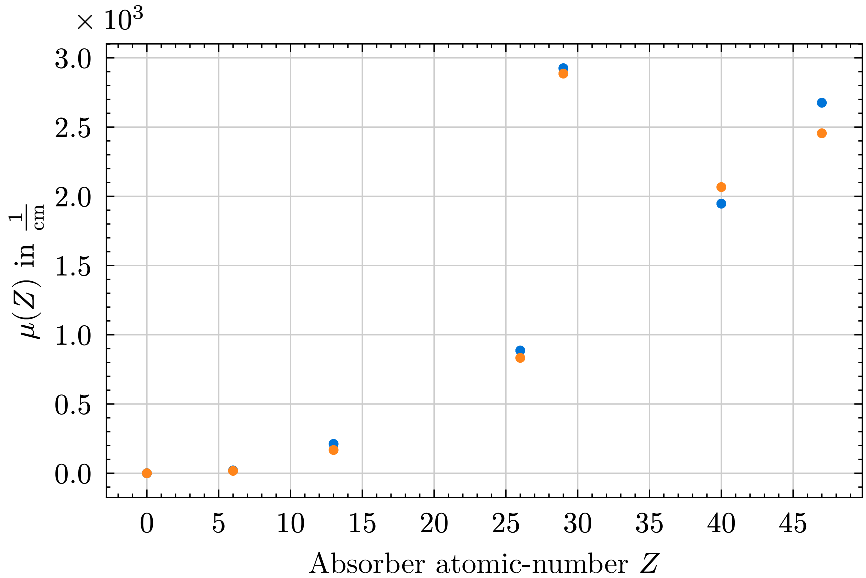

Figure 4: Linear attenuation coefficient μ as a function of the absorber's atomic number Z

Zero effect:

$R_{\text{zero}} = 0.174$ hz

Experiment 2: Bragg Reflection

Objectives

- Investigate the Bragg reflection of Mo K-characteristic X-rays on a NaCl single crystal.
- Determine the wavelengths of the Kα and Kβ lines up to third order diffraction.
- Confirm Bragg's law and the wave nature of X-radiation.

Theory

When X-rays hit parallel crystal planes spaced by distance d, constructive interference occurs at angles θ satisfying Bragg's law:

$$n \sin\theta = n\frac{\lambda}{2d}$$

where n is the diffraction order and λ is the wavelength.

Apparatus

- X-ray tube with collimator mount and goniometer guide rods.
- Geiger–Müller detector in the sensor mount.
- NaCl single crystal fixed on the crystal stage.
- Distances: collimator–crystal ≈ 5 cm; crystal–detector ≈ 6 cm.

Procedure

1. Connect PC via USB, start the "X-ray Device" software, select automatic scan mode.
2. Set parameters: tube voltage $U = 35$kV, current $I = 1.00$ mA, measurement time $\Delta t = 10$ s, angle step $\Delta\beta = 0.1°$; press COUPLED; set scan range $\beta_{\text{min}} = 2.5°$, $\beta_{\text{max}} = 30°$.
3. Start scan to record the spectrum; save data with F2.
4. Identify peak angles θ for Kα and Kβ lines at orders $n = 1, 2, 3$ and record in tables.
5. Calculate wavelengths via $\lambda = 2d\sin\theta$ using $d = 282.01$ pm.

Results

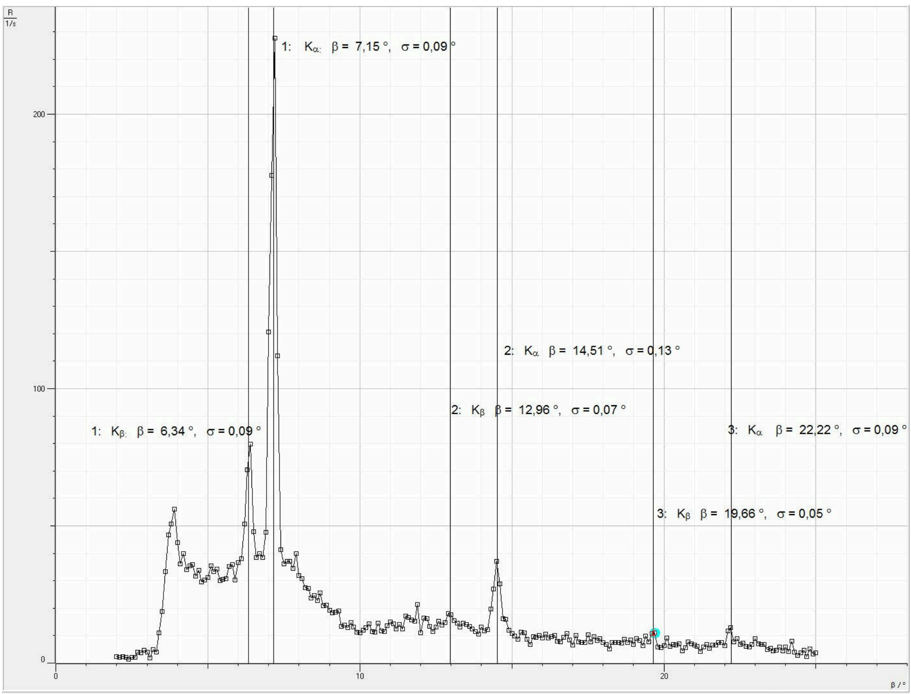

Figure 5: Some Caption

Conclusions

Measured wavelengths agree with literature and validate Bragg's law and the wave character of X-rays.

Experiment 3: Duane–Hunt Law and Planck's Constant

Objectives

- Determine the cutoff wavelength λ_{min} of the Bremsstrahlung continuum as a function of tube voltage U.
- Verify the Duane–Hunt relation $\lambda_{\text{min}} = \frac{hc}{eU}$.
- Extract Planck's constant h from the slope of λ_{min} vs $\frac{1}{U}$.

Theory

Complete conversion of electron kinetic energy into photon energy gives:

$$\lambda_{\text{min}} = \frac{hc}{eU}$$

where e is the elementary charge and c the speed of light.

Apparatus

- Same goniometer and NaCl crystal setup as in Experiment 2.
- "X-ray Device" software with Planck-mode register.
- Geiger–Müller detector.

Procedure

1. For tube voltages $U = 22, 24, 26, 28, 30, 32, 34, 35$ kV at $I = 1.00$ mA, set measurement time and angle range as in Table 1.
2. Perform automatic scans; save each spectrum.
3. In Planck mode, determine λ_{min} for each U.
4. Plot λ_{min} vs. $\frac{1}{U}$ and fit a line through the origin; extract slope A.

Results

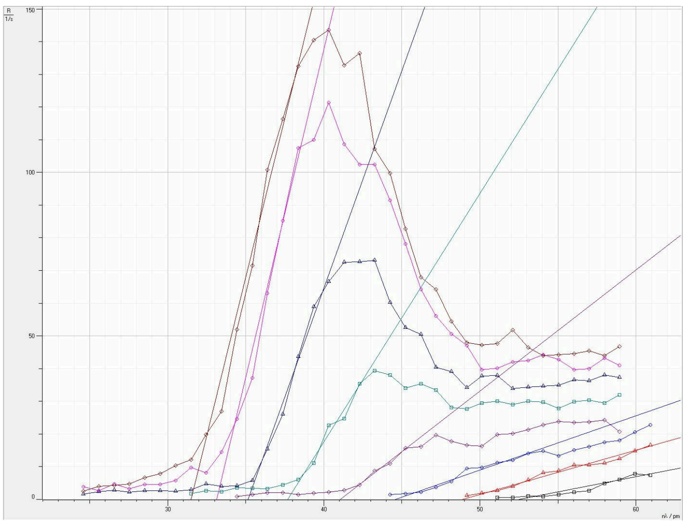

Figure 6: Some Caption

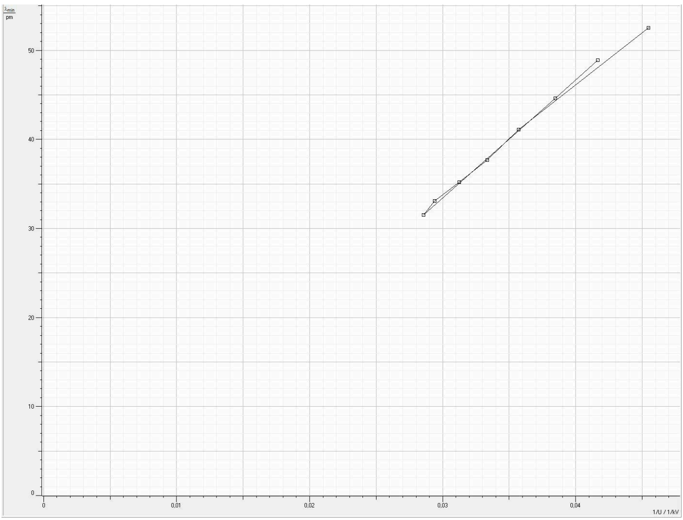

Figure 7: Some Caption

$$A = 1137 \text{ pm kV}$$

Conclusions

The Duane–Hunt law is confirmed, and the measured Planck constant agrees closely with the literature value.

Planks konstant as a wavelenth-voltage factor is about 1240 pm kV