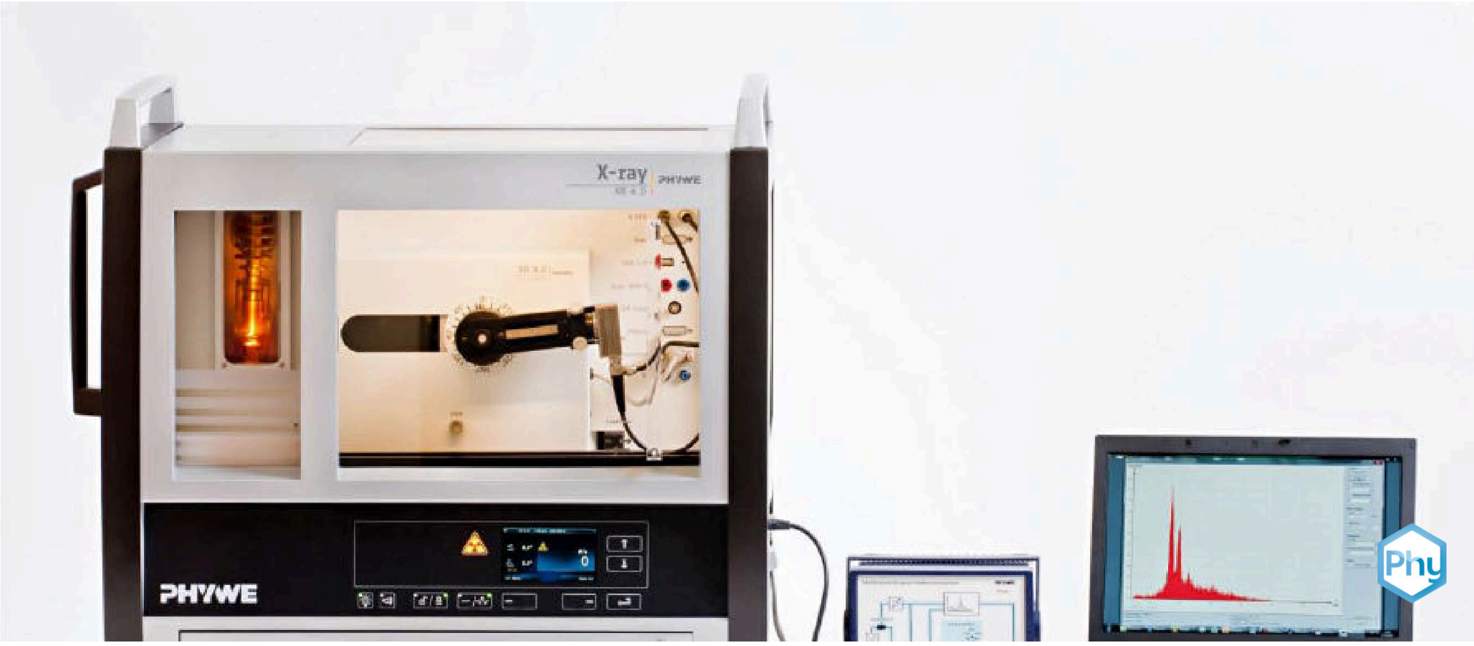
Duane-Hunt displacement law



Physics > Modern Physics > Production & use of X-rays

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/5f948db48217cc000342e1f9

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General information

Application

Setup

Most applications of X rays are based on their ability to pass through matter. Since this ability is dependent on the density of the matter, imaging of the interior of objects and even peaple becomes possible. This has wide usage in fields such as medicine or security.

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Other information (1/2)

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Prior knowledge

The prior knowledge for this experiment is found in the Theory section.

Main principle

X-ray spectra of an X-ray tube are measured in an energydispersive manner with a semiconductor detector and with various anode voltages. Duane and Hunt’s law of displacement is verified with the aid of the maximum energy of the bremsspectrums.

Other information (2/2)

Learning objective

The goal of this experiment is to get to investigate the Duane and Hunt's displacement law.

Tasks

1. Record the X-ray spectrum that is emitted by the tungsten anode for various anode voltages U_A
2. Calculate the minimum wavelength of the photons based on the maximum energy of the bremsspectrums.
3. Represent the relationship between the anode voltage and the minimum wavelength of the bremsspectrums graphically.

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Theory (1/2)

Due to the voltage U_A between the anode and cathode, the electrons are accelerated from the cathode towards the anode. At the cathode, the electrons have the energy:

$E = e \cdot U_A$ (1)

Due to interactions with the atoms of the anode material, the electrons gradually lose their kinetic energy, which is converted into a continuous X-ray spectrum (bremsspectrum). If the kinetic energy is lost in one step, X-rays with a maximum energy E_{max} and a minimum wavelength λ_{min} are generated. In 1915, the American physicists Duane and Hunt found that the product of the accelerating voltage, and of the minimum wavelength, is constant:

$U_A \cdot \lambda_{min} = 1.25 \cdot 10^{-6}\,\mathrm{Vm}$ (2)

Theory (2/2)

The energy equation

\mathrm{E}_{\mathrm{max}}=e\cdot\mathrm{U}_{\mathrm{A}}=\mathrm{h}\cdot\mathrm{f}_{\mathrm{m
{\lambda_{\mathrm{min}}} (3)

leads to

\lambda_{\mathrm{min}}=1.24\cdot 10^{-6}\cdot\frac{1}{\mathrm{U}_{\mathrm{A}}}\ \mathrm{Vm}
(4)

for the shortest wavelength of the X-ray photons.

Planck's quantum of action	h = 6.626\cdot 10^{-34} Js
Speed of light in vacuum	\mathrm{c}=2.998\cdot
Elementary charge	e=1.602\cdot 10^{-19}\,\mathrm{As}

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Equipment

Position	Material	Item No.	Quantity
1	XR 4.0 expert unit, 35 kV	09057-99	1
2	XR 4.0 X-ray goniometer	09057-10	1
3	XR4 X-ray plug-in W tube	09057-81	1
4	PHYWE Multichannel Analyser (MCA)	13727-99	1
5	XR 4.0 X-ray energy detector (XRED)	09058-30	1
6	measure Software multi channel analyser	14452-61	1
7	XR 4.0 XRED cable, 2 m	09058-35	1
8	Screened cable, BNC, l = 750 mm	07542-11	1
9	XR 4.0 X-ray Diaphragm tube d = 1 mm	09057-01	1
10	XR 4.0 X-ray Diaphragm tube d = 5 mm	09057-03	1

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Setup and Procedure

Setup (1/2)

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- Screw the adapter ring onto the inlet tube of the energy detector and connect the signal and supply cables to the corresponding ports of the detector with the aid of the right-angle plugs.
- Connect the signal and supply cables to the corresponding ports in the experiment chamber of the X-ray unit. In Figure 1, the port for the signal cable is marked in red and the port for the supply cable is marked in green. Connect the external X RED ports of the x-ray unit (see Fig. 2) to the multi-channel analyser (MCA). Connect the signal cable to the “Input” port and the supply cable to the “X-Ray Energy Det.” port of the MCA.

Fig. 1: Connectors in the experiment chamber

Fig. 2: Connection of the multi-channel analyser

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Setup (2/2)

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- Secure the energy detector in the holder of the swivel arm of the goniometer. Lay the two cables with sufficient length so that the goniometer can be swivelled freely over the entire range.
- Connect the multi-channel analyser and computer with the aid of the USB cable.
- Insert the tube with the 2-mm-aperture.
- Bring the goniometer block and the detector to their respective end positions on the left. Bring the detector to the 90° position in the 2:1 coupling mode (Fig. 3).

Fig. 3: Goniometer set-up

Procedure (1/4)

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- Bring the goniometer block and the detector to their respective end positions on the right.
- Insert the tube with the 1mm-aperture into the exit tube of the X-ray tube.
- With the X-ray unit switched on and the door locked, bring the detector to the 0° position. Then, shift the detector by some tenths degree out of the zero position in order to reduce the total rate.
- Operating data of the tungsten X-ray tube: Select an anode voltage U_A = 25 kV and an anode current I_A = 0.02 mA and confirm these values by pressing the "Enter" button.
- Switch on the X-radiation

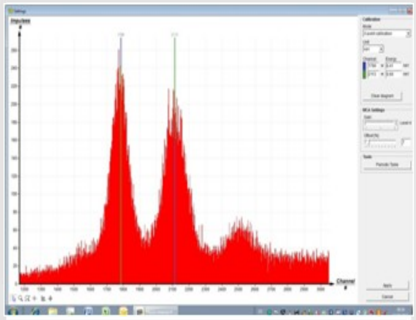

Fig. 4: calibration of the multi-channel analyser

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Procedure (2/4)

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- In the MEASURE program, select “Multi channel analyser” under “Gauge”. Then, select “Settings and calibration”. After the “Calibrate” button has been clicked, a spectrum can be measured. The counting rate should be < 300 c/s. Energy calibration settings: - 2-point calibration, - Unit = keV, Gain = 2 – Set the offset so that low-energy noise signals will be suppressed (usually a few per cent are sufficient), See Fig 4.
- Measuring time: 5 minutes. Use the timer of the X-ray unit.
- Make the two coloured calibration lines congruent with the line centres of the two characteristic X-ray lines. The corresponding energy values (see e.g. P2544705) $\mathrm{E(L_3M_5/L_3M_4)}$ = 8,41keV and $\mathrm{E(L_2N_4)}$ = 9,69 keV are entered into the corresponding fields, depending on the colour. (Note: Since a separation of the lines $\mathrm{L_3M_4}$ and $\mathrm{L_3M_5}$ Lines is not possible, the mean value of both lines is entered as the energy of the line).
- Name and save the calibration.

Procedure (3/4)

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Measurement of X-ray spectra

In order to verify Duane and Hunt's displacement law, X-ray spectra are measured with various accelerating voltages between 8 keV < $\mathrm{U_A}$ < 30 keV.

- The goniometer block with the inserted LiF-crystal is at the left stop. Use the parameters that were also used for the energy calibration.
- Use the parameters that were also used for the energy calibration.
- The counting rates should be $\approx$ 300 c/s. This can be achieved by varying the anode current and by shifting the detector some tenths degree out of its zero position.

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Procedure (4/4)

- The measuring time is approximately 3 minutes/spectrum.
- In order to simplify the evaluation of the measurement curves, switch from the bar display to the curve display. To do so, click “Display options” and then “Interpolation and straight lines”.
- Use the “Survey function in order to determine the bremsspectrums.

Evaluation

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Task 1

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Figure 5a and 5b show the X-ray spectra of tungsten for two different accelerating voltages. In Figure 6a, the accelerating voltage is $U_A = 9\,\mathrm{kV}$. Since the energy of the L-level of tungsten is approximately 10 keV, it is impossible to generate any characteristic L-lines with this accelerating voltage.

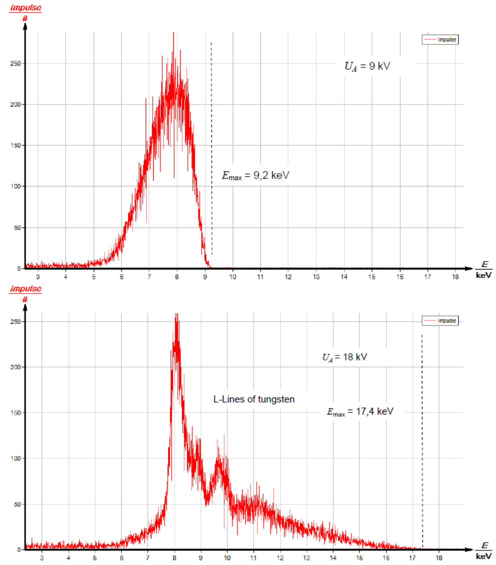

Fig. 5: W-X-ray spectrum with accelerating voltages of a: $U_A = 9\,\mathrm{kV}$ and b: $U_A = 18\,\mathrm{kV}$

Task 2

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A	B	C
U_A / kV	E_{max} / keV	λ_{min} / pm
30	29	42,8
27	26,1	47,5
24	23	53,9
21	20,1	61,7
18	17,4	71,3
15	14,7	84,4
12	12	103,3
9	9,2	134, 8

Table 1: Minimum wavelengths of the X-ray photons as a function of the anode voltage

Table 1 below shows the evaluation of the measurement series. Column A includes the anode voltage values U_A. Column B shows the maximum energy E_{max} of the associated bremsspectrums. Column C shows the λ_{min} values that have been calculated in accordance with (3) and with the equivalent $1\,\mathrm{eV} = 1.6021 \cdot 10^{-19}\,\mathrm{J}$

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Task 3

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Figure 6 shows the curve of the function $\lambda_{min} = f(1/U_A)$ with the values of the table. The gradient of the regression line that is also shown is $\approx 1.2 \cdot 10^{-6}$ Vm and is in accordance with Duane and Hunt's displacement law.

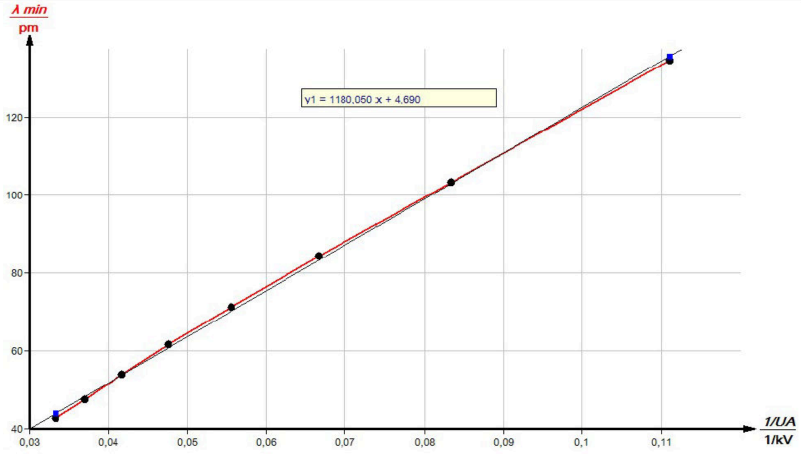

Fig. 6: λ_{min} of the photons as a function of $1/U_A$

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