Qualitative examination of the absorption of X-rays

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/5f607b657e9d5b0003e1e630

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)

Prior knowledge

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

Main principle

X-rays penetrate objects that are impenetrable for visible light. The absorption depends on the thickness and type of the material. This dependence is demonstrated in a qualitative manner on a fluorescent screen with the aid of various different absorption specimens.

Other information (2/2)

Learning objective

The goal of this experiment is to investigate the exat characteristic of X-rays to penetrate matter.

Tasks

- Observe the transmission of X-rays as a function of the material thickness.
- Determine how the atomic number of the elements in a material affects the transmission of X-rays.

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Theory (1/3)

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X-rays are invisible to the human eye. In order to be able to perceive them nonetheless, they are “converted” into visible light by fluorescence and with the aid of certain materials. These substances absorb the X-radiation and enter into an excited state. When they fall back into the ground state, they partly emit this energy. The loss in energy results in a changed wavelength of the emitted light: The wavelength is longer and now in the visible range. Nowadays, mostly zinc sulphide is used as the luminescent agent on the screen. X-rays penetrate objects that are impenetrable for visible light. Visible light is absorbed to a far lower extent. The absorption depends on the thickness and type of the material. While in the past X-rays were even used to check whether a shoe fits well, we now know about the harmful effects of the radiation. At airports, it is used in order to inspect luggage.

When X-rays with the intensity I_0 hit matter of the thickness d, the intensity I of the transmitted radiation is as follows in accordance with the law of absorption:

$\mathrm{I} = \mathrm{I}_0 e^{-\mu(\lambda,\mathrm{Z})\cdot \mathrm{d}}$ (1)

Theory (2/3)

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I: Intensity of the radiation behind the absorber; I_0: initial intensity of the radiation

μ: linear absorption coefficient; d: thickness of the material

Equation (1) directly shows that the intensity of the radiation behind the absorber also depends on the thickness of the absorber. The linear absorption coefficient $\mu[\mathrm{cm}^{-1}]$ depends on the wavelength λ of the radiation as well as on the atomic number Z of the absorbing matter. Since the absorption of the absorbing matter is proportional, often the so-called mass absorption coefficient $\mu/\rho[\mathrm{cm}^2/\mathrm{g}]$ is used, with ρ as the density of the absorber.

Here, however, absorption due to pair production can be excluded, since the X-rays do not have the required energy level. As a result, the absorption coefficient for X-rays consists of two parts:

$\mu = \tau + \sigma$

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Theory (3/3)

τ: absorption coefficient of the photoelectric effect; σ: scattering coefficient

In the wavelength range that is used for this experiment, the photoelectric effect dominates ($\tau > \sigma$). The absorption for this case can be described with the following empirical relationship:

$\frac{\tau}{\rho} \approx \frac{\mu}{\rho} = \mathrm{k}(\lambda^3 \cdot \mathrm{Z}^3)$ (2)

In accordance with (2), the absorption capacity drastically increases when the wavelength λ increases as well as when the atomic number Z of the absorber increases.

The following processes are responsible for the attenuation:

- photoelectric effect
- scattering
- pair production

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Equipment

Position	Material	Item No.	Quantity
1	XR 4.0 expert unit, 35 kV	09057-99	1
2	XR4 X-ray Plug-in Cu tube	09057-51	1
3	XR 4.0 X-ray imaging upgrade set	09155-88	1

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Setup and procedure

Setup

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- If a goniometer is installed in the experiment chamber, it should be removed if possible.
- Install the optical bench and position the fluorescent screen in its holder on the optical bench as far to the right as possible. In order to position the various objects in front of the fluorescent screen in a stable manner, we recommend using the object stages.

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Procedure (1/4)

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- For task 1, position the aluminium specimens of different thicknesses next to each other in front of the screen. Close and lock the door. Then, activate the X-radiation. Observe the result on the fluorescent screen. You can also place the specimens on top of each other. Repeat this with the Plexiglas plates.
- For task 2, the comparison of different materials, such as acrylic glass and mineral glas is very interesting. Interchange the materials repeatedly and observe the result.

Procedure (2/4)

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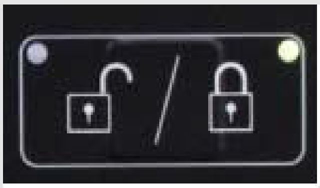
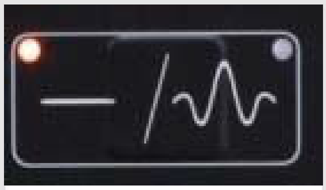
Position the object directly in front of the fluorescent screen, or at a distance from the screen, right in the beam path. If it is positioned at a distance from the screen, it will be magnified but at the same time it will also lose sharpness. You will obtain a high-contrast image with maximum anode voltage (35 kV) and maximum anode current (1.0 mA).

Now, close the door and proceed as follows:

- Lock the door with the aid of button 1.
- Activate the X-radiation with button 2.

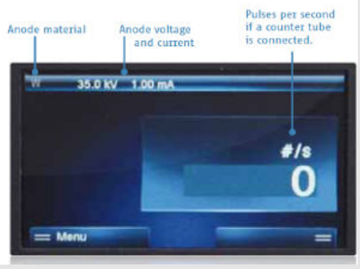


Button 1



Button 2

The display then shows:



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Procedure (3/4)

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Adjusting the anode voltage and current:

- Press the button under “Menu” (display).

- In the following window, select the option “Xray parameters” (use the arrow keys for the selection).
- Select the parameter that you would like to change.
- Confirm your selection with “Enter”.

- Change the current value that is displayed with the aid of the arrow keys.
- Confirm with “Enter”.

The new parameters will now be displayed.

Procedure (4/4)

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Taking a picture with a digital camera:

- Fasten the camera to a slide mount on the optical bench.
- Switch it to night mode and deactivate the flash.
- Either darken the room completely or cover the unit with its cover.
- We recommend starting the camera with the self-timer so that the picture does not blur during the handling of the camera.

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Evaluation

Task 1

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Observation of the transmission of X-rays as a function of the material thickness

As Figures 1 and 2 show, the absorption strongly depends on the material thickness, as it also follows from equation 1.

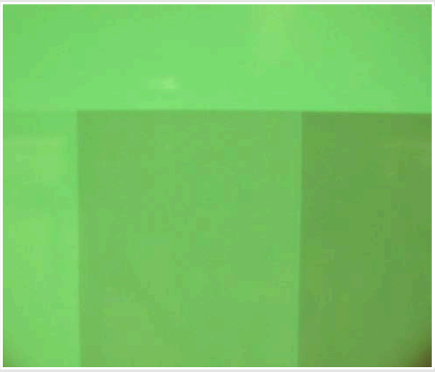

Fig. 1: Plexiglas, from left to right: d = 1 mm, 5 mm and 10 mm (top: no absorber)

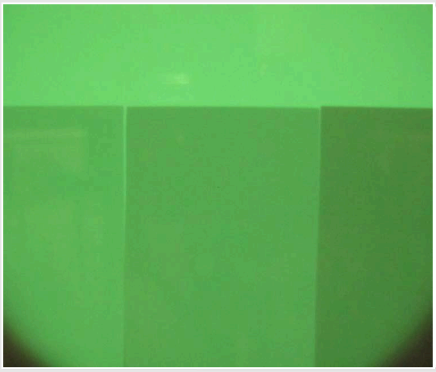

Fig. 2: Aluminium, from left to right: d= 0.3 mm, 0.5 mm and 1 mm.

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Task 2

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Observation of the transmission of X-rays as a function of the atomic number

Acrylic glass vs. mineral glass (Fig. 3):

Since Plexiglas is an organic polymer, it mainly consists of carbon (Z=6), hydrogen (Z=1), and oxygen (Z=8), i.e. of elements with a low atomic number. Mineral glass contains silicon (Z=14) that can be found directly under carbon in the periodic table of elements. It has a higher atomic number, which results in a considerably higher absorption of X-rays in mineral glass.

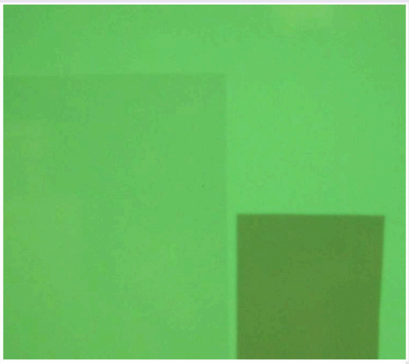

Fig. 3: Plexiglas (left, d = 1 mm) and glass (right, d = 1 mm).

Task 2 (part 2)

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Cardboard/aluminium vs. iron (Fig. 4)

In this case, the difference between the atomic numbers of the two elements (Al: Z = 13; Fe: Z = 26) also has a strong effect. Cardboard consists mainly of organic materials. Compared to metals, the elements that are mainly involved, i.e. carbon (Z = 6), hydrogen (Z = 1), and oxygen (Z = 8), have very low atomic numbers.

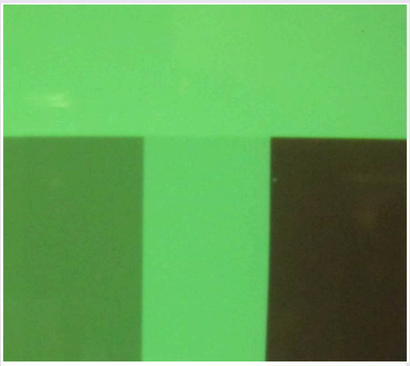

Fig. 5: From left to right: aluminium, cardboard, iron (all of them: d = 1 mm).

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