

## Atomic and nuclear physics

X-ray physics

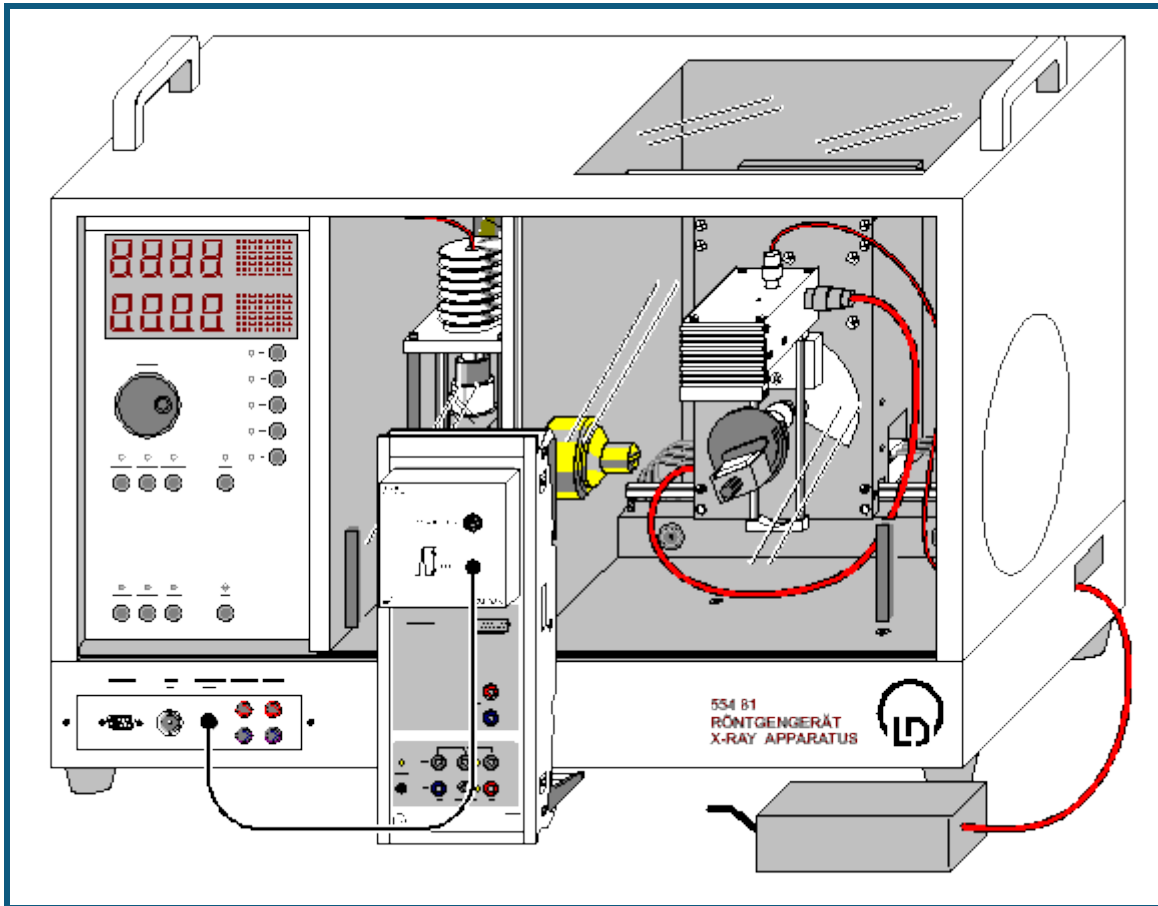
*X-ray energy spectroscopy*


Investigation of the characteristic spectra as a function of the element's atomic number: L-lines

### Description from CASSY Lab 2

For loading examples and settings, please use the CASSY Lab 2 help.

## Moseley's law (L-line x-ray fluorescence)



 can also be carried out with [Pocket-CASSY](#)

### Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (BfS 05/07 V/Sch RöV or NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than  $1 \mu\text{Sv/h}$ , which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

When handling heavy metals or allergen substances from the target set, observe their operating instructions.

### Experiment description

X-ray fluorescence occurs when electrons are knocked out of the inner shells of an atom through x-ray radiation. The atom ionized in this way then has a vacancy (electron hole) in a lower shell which previously had been full. These electron holes can be filled with electrons from other, less strongly bound shells of the atom: e.g. the K-shell can be closed by the transition of an electron from the L-shell. Such a transition is connected with the emission of a photon. This radiation has only particular discrete photon energies corresponding to the energy difference of the levels involved, and it is characteristic for every chemical element.

The designations of the characteristic x-ray lines are a combination of the symbol for the electron shell (K, L, M etc.) and a Greek letter ( $\alpha$ ,  $\beta$ ,  $\gamma$ , etc.). The electron shell being referred to is the one which was ionized before the electron

transition. For example, the designation  $K_{\alpha}$ -line describes the transition from the L-shell into the K-shell,  $K_{\beta}$ -line refers to the transition from the M-shell to the K-shell. The  $L_{\alpha}$ - and  $L_{\beta}$ -lines refer to the transitions from the M-shell and the N-shell to the L-shell.

For the energies  $E$  of the characteristic lines Moseley discovered in 1913 the following law

$$\sqrt{\frac{E}{Ry}} = (Z - \sigma) \sqrt{\frac{1}{n_1^2} - \frac{1}{n_2^2}}$$

with the atomic number  $Z$ , the screening constant  $\sigma$ , the constant  $Ry = m_e e^4 / 8 \epsilon_0^2 h^2 = 13.6 \text{ eV}$  and the main quantum numbers  $n_1$  and  $n_2$  for the electron shells involved ( $n_1 < n_2$ ).

In the experiment the energies of the  $L_{\alpha}$  and  $L_{\beta}$ -lines for Ag, In, Sn, W, Au and Pb are determined, Moseley's law is confirmed and the screening constants  $\sigma_{\alpha}$  and  $\sigma_{\beta}$  are determined. The fine structure of the lines, e.g.  $L_{\alpha 1}$  and  $L_{\alpha 2}$ , cannot be resolved in this experiment. Therefore they appear in the spectrum as a single ( $L_{\alpha}$ ) line.

### Equipment list


1	<a href="#">Sensor-CASSY</a>	524 010 or 524 013
1	<a href="#">CASSY Lab 2</a>	524 220
1	<a href="#">MCA box</a>	524 058
1	X-ray apparatus with x-ray tube Mo	554 801 or 554 811
1	Target set for L-line fluorescence	554 846
1	X-ray energy detector	559 938
1	HF cable, 1 m	501 02
1	PC with Windows XP/Vista/7/8	

### Experiment setup (see drawing)

- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR button and set the sensor angle with the rotary adjuster ADJUST manually to  $90^{\circ}$
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Press the TARGET button and adjust the target angle manually using the rotary button ADJUST to  $45^{\circ}$ .
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

### Carrying out the experiment

#### ■ Load settings

- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use)
- Place the first target (Ag) from the target set for L-lines fluorescence onto the target table
- Set the tube high voltage  $U = 35 \text{ kV}$ , emission current  $I = 1.00 \text{ mA}$  and switch the high voltage on
- Start the spectrum recording with 
- Then record spectra for the other targets (In, Sn, W, Au and Pb) in the target set for L-lines fluorescence.

### Energy calibration

The energy calibration of the spectra is made using the  $L_{\alpha}$ -line of tungsten (W) and the  $K_{\alpha}$ -line of silver (Ag).

- Open in the [Settings EA](#) (right mouse button) the [Energy calibration](#), select **Global for all spectra of this input** and enter on the right-hand side the energies of the W  $L_{\alpha}$ -line (8.40 keV) and of the Ag  $K_{\alpha}$ -line (22.17 keV).
- In the context menu of the diagram select [Calculate peak center](#), mark the W  $L_{\alpha}$ -line (largest peak in the 4th spectrum) and enter the result in the left-hand side of the [Energy calibration](#) (e.g. with drag & drop from the status line)
- Then determine the center of the Ag  $K_{\alpha}$  line (1st spectrum) and also enter it on the left-hand side
- Switch the display to energy (e.g. with Drag & Drop of  $E_A$  into the diagram)

## Evaluation

As the atomic number  $Z$  increases, the energy of the characteristic lines also increases and so does the separation between the  $\alpha$ - and the  $\beta$ -components in the L spectral series. For the heavier elements, in addition to the  $L_\alpha$  and  $L_\beta$ -components, the relatively small  $L_1$  and  $L_\gamma$ -components can also be demonstrated with the x-ray energy detector. For a quantitative analysis, the energies of the individual lines can be determined:

- Select spectrum in the diagram
- In the context menu choose Set [Marker → Vertical line](#) and mark approximately the positions of the  $L_\alpha$  and  $L_\beta$ -line with two [vertical lines](#). Because for the elements silver, indium and tin the  $L_\alpha$ -line and  $L_\beta$ -line are not resolved, they will be treated in the evaluation as a single line.
- In the context menu of the diagram select [Fit Function → Gaussians of equal width](#) and mark the area of the desired peak (also mark sufficient background!)
- Read the determined peak positions from the status line and enter them together with the atomic numbers  $Z$  of Ag ( $Z=47$ ), In ( $Z=49$ ), Sn ( $Z=50$ ), W ( $Z=74$ ), Au ( $Z=79$ ) and Pb ( $Z=82$ ) into the **Energy** diagram (click with mouse) (e.g. by drag & drop from the status line)

For each line, the expression  $\sqrt{E/Ry}$  is automatically calculated and plotted in the **Moseley** diagram as a function of the atomic number  $Z$ . The same applies to the screening constants  $\sigma_\alpha$  and  $\sigma_\beta$  and the **Screening** diagram.

In the **Moseley** diagram, by means of a [Best-fit straight line](#) for  $L_\alpha$  and  $L_\beta$ , the linear relationship in Moseley's law can be confirmed.

In the **Screening** diagram, the very different dependence of the atomic screening constants for the  $L_\alpha$ -lines and  $L_\beta$ -lines of the atomic number  $Z$  indicates the differences in structure of the sublevels in the M-shell and the L-shell. It is remarkable that the atomic screening constant for the  $L_\alpha$ -lines has a value of  $\approx 7$ . This means that the screening is provided by the seven electrons remaining in the L-shell after ionization. This again indicates that the p-orbitals and s-orbitals (L-shell or K-shell respectively) have such a form that the two electrons in the K-shell are ineffective at screening the  $L_\alpha$ -transition.