# Atomic and nuclear physics

X-ray physics

*Compton effect at X-rays*

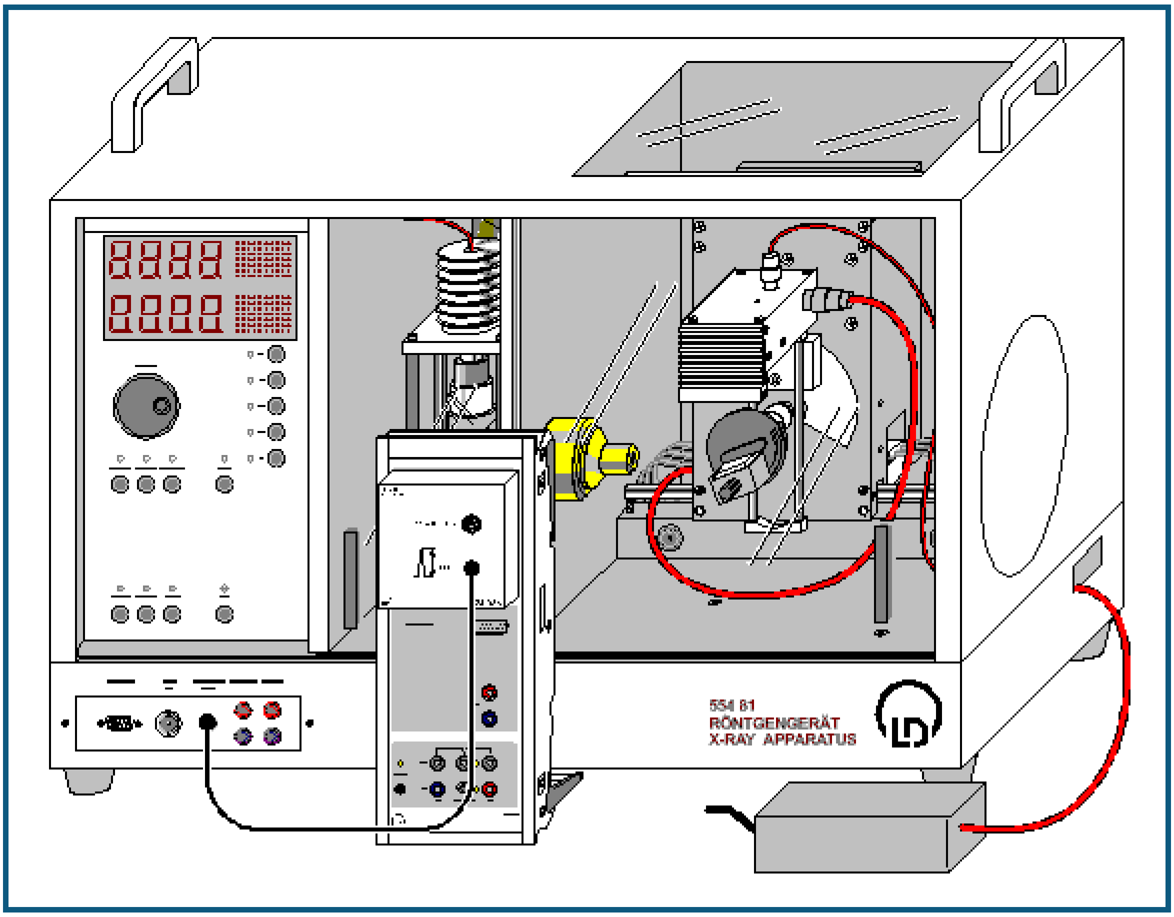
## Compton effect: Measurement the energy of the scattered photons as a function of the scattering angle

**Description from CASSY Lab 2**

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

CASSY Lab 2 (2013-06-07)

## Compton effect on X-rays




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 µSv/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.

### Experiment description

When X-rays pass through matter, part of them is scattered. According to classical physics, the frequency of the radiation should not be changed by the scattering process. However, in 1923 the American physicist A.H. Compton observed that the frequency was reduced in some of the scattered X-rays.

In order to explain this phenomenon, the entire scattering process has to be treated in terms of quantum physics, and the X-rays have to be considered, for example, according to the particle aspect. Moreover, it is assumed that the scattering electron are free, which is a good approximation for the outer atomic electron shells at energies in the range of X-rays. Thus, in a scattering process, a photon with the frequency $\nu_1$, i.e. with the energy $E_1 = h \cdot \nu_1$, hits a free electron at rest with the rest mass $m_0$. The photon is scattered by the angle $\vartheta$.

Assuming energy and momentum conservation, Compton calculated the energy $E_2$ of the scattered radiation and obtained

$$E_2 = E_1 \Bigg/ \left(1 + \frac{E_1}{m_0 c^2}\left(1 - \cos\vartheta\right)\right).$$

In the experiment, Compton's investigations are repeated on a scattering body made of acrylic glass. The results are compared with the above equation. The spectrum is recorded by means of the X-ray energy detector.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | X-ray apparatus with x-ray tube Mo | 554 801 or 554 811 |
| 1 | Compton accessory X-ray II | 554 8371 or 554 837 |
| 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)

- Put the Zr filter (from the scope of delivery of the X-ray apparatus) onto the beam entrance side of the circular collimator (from the scope of delivery of the Compton accessory X-ray II)
- Mount the circular collimator in the collimator mount of the X-ray apparatus
- 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 key and, using the ADJUST knob, adjust a sensor angle of 150° manually. If necessary, push the goniometer to the right
- Adjust the distance between the X-ray energy detector and the axis of rotation so that the detector housing just does not cover the X-ray beam at this sensor angle
- Then push the goniometer to the left so that the detector housing just does not touch the circular collimator (approx. 8 cm distance between the circular collimator and the axis of rotation)
- 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.

### Experiment preparation

- 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)

For an accurate measurement of the small energy shifts, it has to be taken into account that the calibration of the X-ray energy detector undergoes a slight shift at high counting rates. Therefore it is sensible to restrict the counting rates to 200 /s.

Estimating the counting rate in the scattering arrangement:

- Put the acrylic glass scattering body on the target stage, and clamp it
- Press the TARGET pushbutton, and, using the ADJUST knob, adjust the target angle manually to 20°
- Set the tube high voltage U = 35 kV, emission current I = 1.00 mA and switch the high voltage on
- Start the spectrum recording with
- Vary the sensor angle slowly between 150° and 30° each time reading the total counting rate above on the right in the CASSY Lab window
- Reduce the emission current if the total counting rate clearly exceeds 200 /s

Adjusting the counting rate of the primary beam:

- Remove the target holder with the target stage, and take the sensor into the 0° position
- Put the absorption screen onto the circular collimator, and align it carefully (the screws should point upwards and downwards, respectively)
- Reduce the emission current to 0.1 mA, and switch the high voltage on

- Start the spectrum recording with
- In steps of 0.1° look for the sensor angle at which the total counting rate is only slightly greater than the counting rates measured in the scattering arrangement (if necessary, change the emission current slightly)

If no or only a small counting rate is measured:

- Check the alignment of the absorption screen (with the screws pointing upwards and downwards, you may try to turn the screen by 180°)

### Carrying out the experiment

The X-rays to be measured produce additional fluorescence X-rays in the housing of the Si-PIN photodiode of the X-ray energy detector, which are also registered. Therefore the Au $L_\alpha$ and the Au $L_\beta$ lines are to be expected in the primary spectrum apart from the Mo $K_\alpha$- and the Mo $K_\beta$ lines. With the help of these lines the energy calibration of the spectra can be carried out.

- Load settings
- Record the primary spectrum (0° position) with
- 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 Au $L_\alpha$-line (9.72 keV) and of the Mo $K_\alpha$-line (17.48 keV).
- In the context menu of the diagram select Calculate peak center, mark the Au $L_\alpha$-line (small peak on the left had side of the Au $L_\beta$ line, which is also small) 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 peak center of the Mo $K_\alpha$-line (high peak) and also enter the result on the left-hand side
- Switch the display to energy (e.g. with Drag & Drop of $E_A$ into the diagram)
- Remove the absorption screen
- Mount the target holder with the target stage on the goniometer
- Put the acrylic glass scattering body on the target stage, and clamp it
- Adjust the emission current I = 1.00 mA (or the emission current determined previously for estimating the counting rate), and switch the high voltage on
- Adjust a target angle of 20° and a sensor angle of 30°
- Record a new spectrum (30° position) with
- Then record further spectra at constant target angle for the sensor angles 60°, 90°, 120° and 150°

### Evaluation

The energy of the scattered radiation decreases with increasing scattering angle. The intensity of the scattered radiation takes its minimum at $\vartheta$ = 90°.

For further evaluation, you can zoom in on the region around the scattered peak and select Calculate Peak Center for each energy-shifted peak. Starting from a scattering angle of $\vartheta$ = 90°, the energy resolution of the detector is sufficient for separating the unshifted peak (elastic scattering from strongly bound electrons) and the shifted peak (inelastic scattering from quasi-free electrons). For the determination of the peak center, only the region of the energy-shifted peak should be marked.

For each peak center, the energy is entered in the **Evaluation** display together with the corresponding scattering angle. The energy can be taken from the status line into the table using the mouse (drag & drop). The angle has to be entered manually in the table.

For a comparison of the measured energies with the energies calculated from energy and momentum conservation, a free fit of the equation

17.48/(1+17.48*(1-cos(x))/A)

can be selected in the **Evaluation** display with the starting value A = 511 (=constant).

The result corresponds to the theoretical curve with the parameters $E_1$ = 17.48 keV and $m_0 \cdot c^2$ = 511 keV, which is in good agreement with the measured values.

When X-rays pass through matter, part of them is scattered and experiences an energy shift (Compton effect). The energy shift can be calculated by describing the scattering process as a collision between an X-ray photon and a free electron at rest and by postulating the conservation of energy and momentum in this process.

### Remark

Alternatively, the comparison between measurement and theory can be carried out as a free fit with the free fit parameter A (the rest mass of the collision partner of the X-ray photon). As a result a value for the parameter A is obtained, which agrees with the "rest mass" of an electron ($m_0 \cdot c^2$ = 511 keV) to a good approximation.