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# Compton scattering measurement with Laue-geometry spectrometer

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## Abstract

When A.H. Compton discovered "Compton scattering", a broadening of scattered X-ray peak was also captured. Now, the broadening is used for studies of electronic states of atoms. In high energy beamline BL08W, a Laue-geometry wave dispersive spectrometer is installed for Compton scattering measurement. In the practice, we will measure one-dimensional projections of electron momentum density distribution of a single crystal.

## Introduction to Compton scattering

Compton scattering is a phenomenon of inelastic scattering of a photon on a free or weekly bounded electron. During this process photon is transferring a part of his energy to the electron, which is knocked out from the atom. To fulfill this condition energy of the photon must be significantly bigger than the binding energy of the electron. Therefore the hard X-rays (high-energy synchrotron radiation) or γ-rays (radioactive isotopes) are the most commonly used sources of photons in Compton spectroscopy.

Scattered photon energy can be calculated using quantum approach to the energy and momentum conservation rules. In the simplest case, when scattering of a photon on electron at rest is considered this energy ($\hbar\omega_0'$) is equal to:

$$\hbar\omega_0' = \frac{\hbar\omega}{1 + \frac{\hbar\omega}{m_0c^2}(1 - \cos\theta)} \tag{1}$$

where $\hbar\omega$ is an incident photon energy, $m_0c^2 = 511keV$ is electron rest mass and $\theta$ is a scattering angle. This means that in the spectrum of scattered photons two lines will be observed. The one of energy $\hbar\omega$ corresponding to elastically scattered photons (without energy transfer) and the lower energy $\hbar\omega_0'$ corresponding to the inelastically scattered photons.

But the electrons in matter are never at rest. When electron is considered as a moving object, the energy of scattered photons ($\hbar\omega'$ ) can be expressed as:

$$\hbar\omega' = \frac{1}{1+\frac{\hbar\omega}{E}(1-\cos\theta)}\left(\hbar\omega + \frac{\hbar c^2}{E}p_z K\right) \tag{2}$$

where $E$ is an electron energy. As can be easily observed an additional term appears (compared to the equation 1) that is dependent from the electron momentum $z$ component ($p_z$), where $z$ axis is specially chosen to be a scattering vector ($\vec{K}$) direction. Scattered photon energy is not constant anymore and the spectral shape of its line is broadened due to the Doppler effect from the moving electrons and is usually called the Compton profile $J(p_z)$ (Fig. 1).

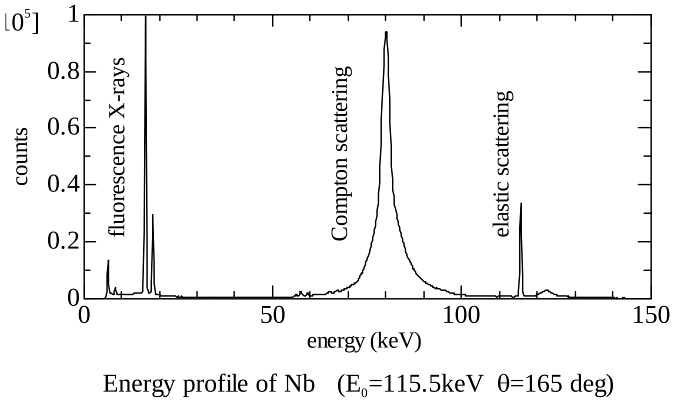

Fig. 1. X-ray energy spectrum from Nb measured by Ge-SSD with a scattering angle of 165 degrees. The incident X-ray energy is 115.5 keV at elastic peak and the Compton scattered X-ray line at 80 keV is broadened by Doppler shift in collision between the photons and moving electrons.

Electron energy and momentum are strictly connected with a state of this electron in atom (band structure). Therefore it is easily to conclude that the Compton scattering on a different materials (different atoms and band structures) will give the different shape of a Compton peak. This shape is directly connected with an electron momentum density distribution $\rho(\vec{p})$:

$$J(p_z) = \iint \rho(\vec{p}) dp_x dp_y \tag{3}$$

and is schematically shown on Fig. 2.

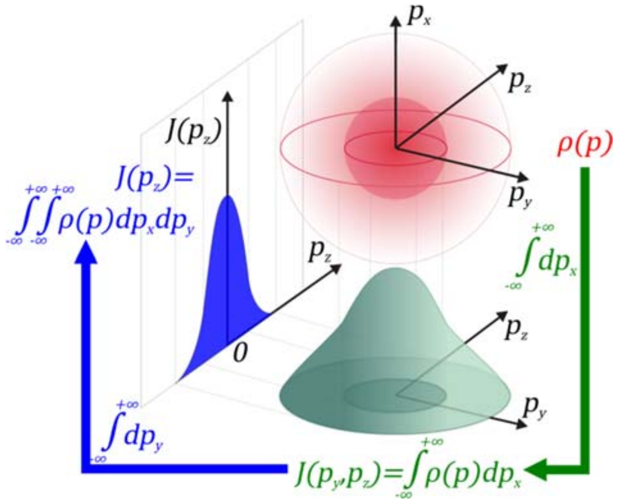

Fig. 2. Schematic drawn of the relationships between the 3D electron momentum density distribution $\rho(\vec{p})$ its 2D projection $J(p_x, p_y)$ and 1D projection $J(p_z)$ (Compton profile).

Electron momentum density distribution is anisotropic. This anisotropy comes from the anisotropic electron wave functions and the influence of a crystal potential. For this reason Compton profiles measured along the different crystal orientations are slightly different. In order to get the full 3D (or 2D) electron momentum density one needs to measure an adequate number of directional Compton profiles and use one of the reconstruction methods (eg. Direct Fourier transformation method or maximum entropy method). The more Compton profiles measured the better reconstruction results are usually obtained.

## Compton experiment

Most of the Compton experiments require high incident photon energy especially for heavy materials study. The only beamline in SPring-8 that can provide this is the BL08W station with the multipole wiggler as a source of high energy X-rays (110 – 300 keV). The main equipment on this station is a high resolution Cauchois-type Compton spectrometer dedicated for Compton scattering measurements (Fig. 3).

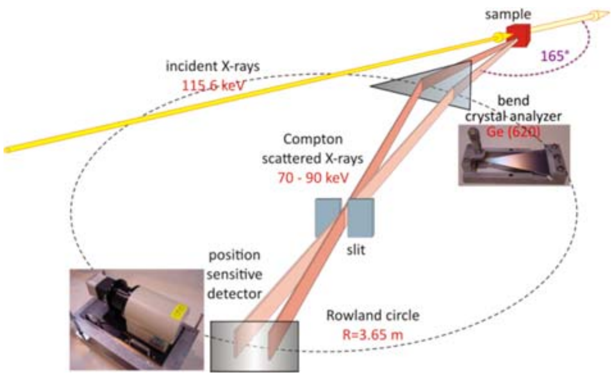

Fig. 3. High energy (115.6 keV synchrotron radiation) and high resolution (0.10 a.u.) Cauchois-type X-ray Compton spectrometer at SPring-8 (beamline BL08W)

## Practice

In the beamline practice (BL08W), we will measure a series of directional Compton profiles for vanadium crystal (cubic) along the crystallographic directions between [100] and [110]. The aim of this experiment is to observe Compton profile anisotropy (differences between the measured Compton profiles) and reconstruct the 2D electron momentum density distribution in the [100]-[110] plane using direct Fourier transformation program widely used on the BL08W.

## Literature

[1] "X-ray Compton Scattering", eds M. J. Cooper et al., Oxford University Press, 2004

[2] "Compton Scattering: Tool for the Investigation of Electron Momentum Distribution", ed. B. Williams, McGraw-Hill International Book Co., 1977