Teacher notes
Topic E

The Compton effect vs the photoelectric effect.

The Compton and photoelectric effects have common characteristics: in the case of the Compton effect, an incident photon scatters (with an increased wavelength) off an electron at rest causing the electron to recoil. Only part of the photon's energy is transferred to the electron. In the case of the photelectric effect the incident photon is totally absorbed and the electron leaves the metal.

Why is the behavior of the photon different?

To begin with let's show that a free electron cannot absorb a photon.

Suppose that a photon of momentum $p = \frac{h}{\lambda} = \frac{E}{c}$ is incident on an electron at rest and it is absorbed. By momentum conservation, the electron will acquire the momentum of the photon. The total energy before the absorption is $m_e c^2 + pc$. After the absorption it is $\sqrt{\left(m_e c^2\right)^2 + p^2 c^2}$. Energy conservation then demands that:

$$\underbrace{m_e c^2}_{\text{electron rest energy}} + \underbrace{pc}_{\text{photon energy}} = \underbrace{\sqrt{\left(m_e c^2\right)^2 + p^2 c^2}}_{\text{electron total energy}}$$

Squaring gives

$$\left(m_e c^2\right)^2 + 2m_e c^3 p + p^2 c^2 = \left(m_e c^2\right)^2 + p^2 c^2$$

which implies that

$2m_e c^3 p = 0$, i.e. that p = 0 which is impossible.

This is why in the Compton effect the photon is never absorbed but rather scatters off the free electron.

In the photoelectric effect, the electron is never free. It is either part of an atom or subject to forces mainly from the lattice of positive charges. Hence the atom or the lattice can participate in the absorption process providing whatever energy or momentum is required to satisfy conservation of both quantities.

The other difference between the two effects is the energy of the photons involved. In the photoelectric effect the photons are low energy photons, part of the visible or ultraviolet part of the spectrum with a typical wavelength of 10^{-7} m and typical energy 10 eV. By contrast, the Compton effect photons have a typical wavelength of order 10^{-12} m and typical energy 1 MeV.