Modern Physics

Compton Effect

$$\lambda_{scattered} - \lambda_{source} = \frac{h}{mc}(1 - \cos\theta)$$

Problem 1.- Why is the Compton experiment done with x-rays and electrons? Why not scattering visible photons off protons?

To answer this question, calculate the shift of green light (wavelength=532nm) when scattered at 90º off a proton. The result will make it obvious why this is not a good idea.

Solution: Let us find the shift in wavelength for the example proposed:

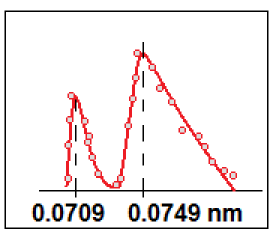
$$\Delta\lambda = \frac{\text{h}}{mc}(1 - \cos\theta) = \frac{6.62\times10^{-34}\,Js}{1.67\times10^{-27}\,kg\times3\times10^{8}\,m/s}(1 - \cos 90^\circ) = 1.3\times10^{-15}\,m$$

The shift is 1.3 femtometer, so it is insignificant compared to the 532 nanometers of the incident wavelength. You would need at least 6 significant figures when measuring the wavelength to detect the shift.

Problem 2.- In the Compton experiment why are un-shifted peaks present in the scattered radiation?

Solution: In the Compton experiment when a photon is scattered by a strongly bound electron the electron doesn't absorb energy, so the photon is scattered un-shifted. The shifting in wavelength occurs because the electron absorbs energy.

Problem 2a.- Look at the picture below. It is part of a scattering spectrum taken at 135º with a source of λ=70.9 pm.



a) Why is the first peak not shifted?
b) Calculate the mass of the scattering target that produces the second peak.

Solution:

a) The first peak is due to scattering the photons off heavy masses. That is, scattering off electrons that are strongly bound to the nucleus, so they behave as having a large mass, giving a negligible shift.

b) From the graph we determine $\Delta\lambda = 4$ pm and the mass of the target is:

$$\Delta\lambda = \frac{h}{mc}(1-\cos\theta) \rightarrow m = \frac{h}{c\Delta\lambda}(1-\cos\theta) =$$

$$= \frac{6.62\times10^{-34}\,Js}{4\times10^{-12}\,m(3\times10^{8}\,m/s)}(1-\cos 135^{\circ}) = \mathbf{9.4\times10^{-31}\ kg}$$

Problem 3.- A scientific instrument measures the difference in frequency of two light sources. Calculate the difference observed when light of 0.0729 nm wavelength is compared to light from the same source but scattered off electrons at 120º.

Solution: We can calculate the difference in wavelength between the two photons using the Compton equation:

$$\lambda_{scattered} - \lambda_{source} = \frac{h}{mc}(1-\cos\theta) = \frac{6.62\times10^{-34}\,Js}{(9.1\times10^{-31}\,kg)(3\times10^{8}\,m/s)}(1-\cos 120^{\circ}) = 0.0036\text{nm}$$

So the wavelength of the scattered photon will be: $\lambda_{scattered} = 0.0764$ nm

But if the instrument measures difference in frequency we need to find:

$$f_{source} - f_{scattered} = \frac{c}{\lambda_{source}} - \frac{c}{\lambda_{scattered}} = \frac{3\times10^{8}\,m/s}{0.0729\times10^{-9}\,m} - \frac{3\times10^{8}\,m/s}{0.0765\times10^{-9}\,m} = \mathbf{2.0\times10^{17}\ Hz}$$