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COMPTON SCATTERING NOT WELL VERIFIED

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ABSTRACT. Compton scattering cannot yet be said to have been verified beyond any doubt. The only verification experiment performed is still the original experiment of A.H.Compton from 1922. To date, there is not another experiment done to corroborate the 1922 findings. There are modern experiments done in the laboratories of today's universities to verify Compton scattering with γ-ray sources from radionuclides where the energies of the rays are measured with NaI scintillation detectors or germanium detectors. Such experiments are shown to be invalid as the result that shows clear agreement with the theory is all due to the calibration of the detectors and nothing besides. Furthermore, a verification that the inverse of energy $1/E$ varying linearly with $(1 - \cos\theta)$ is insufficient as a verification of the full Compton scattering formula for wavelength changes. A proper verification requires verifying the wavelength formula where the wavelength is measured directly.

1. INTRODUCTION

In 1922, A.H. Compton published a paper [1] that proposed a quantum theory explaining the scattering of x-rays and γ-rays when they strike matter. It was known that the original ray scattered with a modified ray and an unmodified ray. The unmodified ray has the same wavelength as the original ray while the modified ray has its wavelength increased depending on the scattering angle. Such a change in wavelength and frequency could not be explained with the classical electromagnetic wave theory. The proposed particle theory of light gives the relation between the increase in wavelength with scattering angle :

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

λ being the wavelength of the original ray, h the planck constant, m the rest mass of the electron, c the light speed, θ the angle the scattered ray makes with the initial direction of the ray. The premise of his theory is based on the relativistic mechanics of special relativity with two postulates for the photon particle model of light:

Key words and phrases. Compton scattering, gamma rays, x-rays, detector, special relativity.

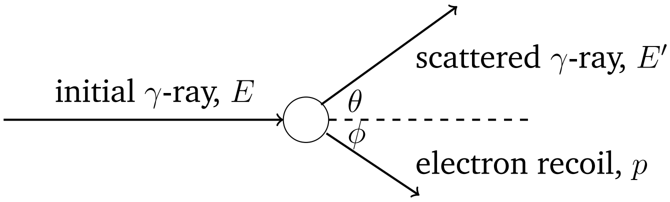

FIGURE 1. Compton scattering of γ-ray by an electron; E, E' are the particle energies, p the recoil momentum of the electron.

(1) The energy E of a photon of light of frequency ν is: $E = h\nu$; h being the Planck constant.
(2) The relation between the photon energy E and momentum p is: $E = pc$; c being the constant speed of light.

A verification of Compton scattering does not only verify the photon model of light, but it will also be a verification of special relativity. We will examine the experimental evidence available to date for Compton scattering.

2. Derivation Of Compton Scattering Formula

Figure 1 illustrates a typical situation. Compton scattering assumes that the photon is *'scattered'* by electrons when the light radiation strikes matter. As it is assumed matter does not have electrons within the nucleus of atoms, the scattering may be best assumed to be a collision of particles, that of the light photon and a free electron; the electron is assumed to be at rest. The direction of the photon will change with the scattered photon losing some energy to the electron. It will be shown the the scattered photon would have its wavelength increased (photon energy decreased) with an amount depending on the scattering angle. The derivation of the Compton scattering formula is simple and is found in nearly all introductory university physics textbooks. It is given here in order to highlight a certain subtlety that is almost never mentioned concerning the Compton scattering formula.

From energy conservation we have:

$$E = E' + \sqrt{p^2c^2 + m^2c^4} - mc^2 \tag{1}$$

m being the rest mass of the electron, p its recoil momentum, c the light speed. As the momentum of the photon is given by : $p = \frac{E}{c}$, we have from momentum conservation:

$$\begin{aligned}\frac{E}{c} &= \frac{E'}{c}\cos\theta + p\cos\phi \\ 0 &= \frac{E'}{c}\sin\theta - p\sin\phi\end{aligned} \tag{2}$$

Eliminating ϕ from the equations (2) above:

$$p^2c^2 = E^2 - 2EE'\cos\theta + E'^2 \tag{3}$$

Squaring equation (1):

$$p^2c^2 = (E - E')^2 + 2mc^2(E - E') \tag{4}$$

Subtracting (4) from (3):

$$EE'(1 - \cos\theta) - mc^2(E - E') = 0 \tag{5}$$

which reduces to:

$$\frac{1}{E'} - \frac{1}{E} = \frac{1}{mc^2}(1 - \cos\theta) \tag{6}$$

Equation (6) is the formula for the energy for Compton scattering. If we include the postulate for the energy of a photon as: $E = h\nu = \frac{hc}{\lambda}$ and substituting $\frac{hc}{\lambda}$ for energy in (6), we have:

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{mc}(1 - \cos\theta) \tag{7}$$

This is the formula that gives the change in wavelength as a function of scattering angle in Compton scattering. It should be noted that relation (7) implies (6), but not the reverse.

3. Is Compton Scattering Well Verified?

A verification of Compton scattering not only would be a vindication of the photon model of light, it would also be a vindication of special relativity. In view of of the fact that modern physics is now founded on relativistic mechanics with the photon model being a cornerstone of quantum physics, the experimental verification of Compton scattering should not be taken lightly. A.H.Compton published his experiment [2] (1923) to verify his formula for the change in wavelength of the scattered X-ray. The wavelength was measured directly with a Bragg spectrometer for scattering angles of 45°, 90° 135°. The experiment found the measured wavelengths to agree exactly with the predicted values from his formula:

> *The experiments have been performed using a single wave-length, $\lambda = 0.711A$. In this case we find for the modified ray a change in wave-length which increases with the angle of scattering exactly in the manner as described by Eq.(1).*

Though the experiment does constitute a valid verification of Compton scattering, there has not been other experiment performed since 1923 to corroborate his findings. The present situation where the only experimental confirmation being that of the original 1922 experiment of A.H.Compton is not satisfactory; there should be more recent experiment to corroborate the original findings. It cannot yet be said that Compton scattering is verified beyond any doubt.

4. Modern Experiments With Gamma Rays And Detectors

There may be a misunderstanding in the physics community that Compton scattering has been well verified in the modern university laboratories of today. Experiments that have purportedly verified Compton scattering make use of a γ-ray source from a radionuclide, e.g. Cesium ^{137}Cs. The energy of the scattered γ-ray is measured with a detector, usually a NaI scintillation detector or a semiconductor germanium detector. The idea of the experimental verification is to verify relation (6), that the inverse of the energy of the scattered γ-ray pulse varies linearly as $(1 - \cos\theta)$. Full experimental data [4], [3] are available showing very clearly agreement with the Compton scattering energy relation. It will be shown that such experiments using γ-ray detectors are not valid as a verification of Compton scattering, not even for the lesser energy relation (6).

There is a subtle point in Compton scattering that is almost always left unmentioned in the textbooks. As we have shown above, the Compton energy relation (6) is derived without the photon energy postulate :$E = h\nu$; the derivation relies only on the relativistic energy-momentum relation together with the energy-momentum relation for a massless particle :$E = pc$. Even if such experiments do verify Compton scattering, it does not verify Compton scattering as a full photon model of light radiation; the energy relation of Compton scattering does not imply that the photon energy is given by $E = h\nu$. Such an experiment would only be an experimental verification of the relativistic energy relation of special relativity as well as the photon particle obeying the energy-momentum relation for a massless particle: $E = pc$. A proper verification of the Compton photon model must be an experiment which verifies formula (7) which shows the change in wavelength with scattering angles. Such an experiment must directly measure the wavelength of the scattered radiation for various scattering angles. An experiment that measures the scattered energy alone is insufficient.

It can easily be shown that experiments using energy detectors to measure the scattered γ-ray are invalid as verification of Compton scattering. Let's replace the γ-ray detector with a hypothetical detector. This detector takes the γ-ray input, transfers its energy to an electron from rest giving it a velocity v. The velocity v is measured directly through a *'time-of-flight'* measurement. For every scattering angle for the scattered ray pulse, we can now calculate its kinetic energy. But there is now a duality dilemma. Should we use the classical kinetic energy formula $\frac{1}{2}m_e v^2$ or the relativistic formula $(\gamma - 1)m_e c^2$?

The fact that the there is a choice involved to influence and to decide on the outcome of the experiment incontrovertibly nullifies the validity of the experiment.

There is a simple reason why such experiments using γ-ray detectors show data in full agreement with Compton scattering. It is all in the calibration of the detectors. All such detectors rely on the interaction of γ-ray with matter. The energy *'pulse'* deposits its energy on the detector material a pulse at a time. The detector is also a counter for γ-decay. The energy pulse would give rise to a corresponding electrical pulse from freed electrons or electron-hole pairs in semiconductors that would be the input for the electronic circuitry of the detector system. Such an initial electrical pulse would be amplified and analyzed with a Multi Channel Analyzer (MCA) which displays the γ-ray input as a γ-ray spectrum in the computer monitors. All such detector systems need to map an amplified voltage to energy; this mapping is what is meant by calibration of detectors. A detector calibration means there are assumptions about the physics behind the working of the detectors. The calibration parameters are all with the computer software that come with a particular make of detectors. For energy scale, it is the relativistic energy formula that is used, never the classical energy formula. So it is not a surprise that the modern experiments shown to the undergraduates show a clear confirmation of special relativity through the Compton scattering experiments. All of this is the result of detector calibration and nothing else.

5. Conclusion

The present situation concerning the experimental verification of Compton scattering is not satisfactory. The only experiment done so far is still the original experiment of A.H.Compton of 1922; there has not been any other experiment done to corroborate this 1922 experiment. In the Universities today, experiments have been done to verify Compton scattering using γ-ray sources from radionuclides and energy detectors to measure the energy of the scattered rays. But such experiments are not valid as their results are not independent nor unbiased. The working of the detectors are dependent on the manner of calibration of the detectors. The only way now to put to rest any doubt over the validity of Compton scattering is to do a proper experiment with x-ray where the wavelengths of the scattered rays are directly and precisely measured for a sufficient range of scattering angles. To date, no such experiment has been carried out. This leaves doubts as to how well verified the photon model of light really is.

References

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