(This is a part of the book The Concept of Reality.pdf)

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The Compton Effect

At the scattering of X-rays on electrons, two effects are observed, which do not seem to be in accordance with the assumption that light is only a wave.

1. The wave-length of the scattered radiation is greater than the wave-length of the incoming radiation.
2. The scattering angle distribution is asymmetrical with respect to the forward and backward direction.

In 1922, Arthur Compton described the scattering of X-rays on graphite as impact process of light-particles and electrons.

He derived the measured, on the scattering angle ϑ dependent difference between the wavelength λ_2 of the scattered and the wavelength λ_1 of the incoming radiation

$$\lambda_2 - \lambda_1 = \lambda_C (1 - \cos\vartheta) \qquad (\lambda_C \text{ Compton wave-length of the electron})$$

under the assumption that light particles are scattered on electron particles.

The difference between the Compton Effect and the Photoelectric Effect, seen from the conventional viewpoint, is that at PE the photon is absorbed, i.e. its total energy is passed to the electron, whereas at CE the photon is deflected and loses only a part of its energy.

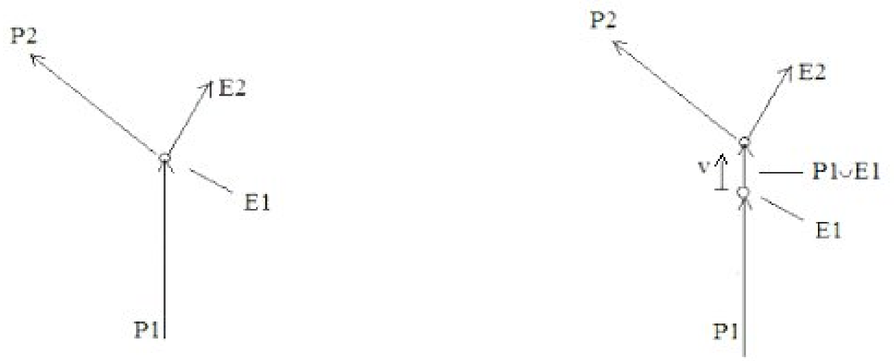
From our viewpoint, the difference between the two effects consists in the fact that at PE both waves form a persistent superposition, whereas at CE they separate again.

Therefore, seen in this way, the scattering process photon-electron proceeds in two steps:

A: The photon hits a resting electron. Both waves form a superposition.

B: The two waves separate again.

In the following outline, to the left the scattering seen as particle impact, to the right our two-step variant:



(S3)

$P1 \cup E1$ denotes the short-time state where both waves are united.

Thus the whole process can be described as follows:

The resting electron E1 unites with the photon P1. Hence it turns into E_+. ($E_+ = P1 \cup E1$). E_+ moves with velocity v. E_+ emits the photon P2 and turns into the electron E2.

Let us denote the laboratory system as the reference frame S. Now let us look at the scattering process from a reference frame S', which moves with velocity v relative to S, and with respect to which E_+ is at rest. (Thus E1' moves with -v relative to S'.)

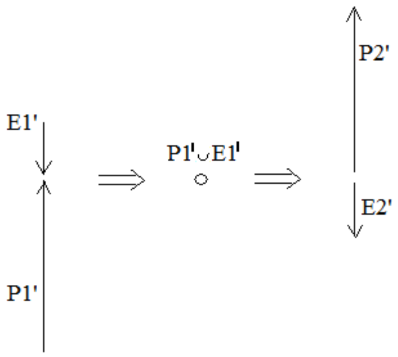
An electron moving at v possesses a de Broglie wave-length

$$\lambda_B = \lambda_C \frac{c}{v} k \qquad (\lambda_C \text{ ... Compton wave-length of the electron, } k = \sqrt{1-\frac{v^2}{c^2}})$$

Therefore with respect to S' applies:

(1) The wave-length of E1' is $\lambda_C \frac{c}{v} k$.

We remain in S'. We look at first at the case where both waves separate exactly along the straight line on which P1' was moving towards E1' :



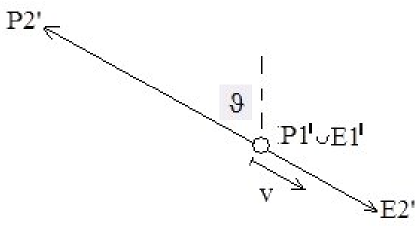
(S4)

Obviously, in this case, the separation process SP(0°) represents the inverse of the uniting process UP, and this leads to

$$P2' = P1' \quad \text{und} \quad E2' = E1'.$$

Thus E2' moves with velocity -v with respect to S'. (exactly as E1' before); in the usual description, P2' would be just an *unscattered* photon.

Now we turn to an arbitrary separation direction ϑ . With respect to S', after the separation P2' and E2' again move away from each other along a straight:



(S5)

Compared with the separation process SP(0°), the separation process SP(ϑ) is only *rotated*, but unchanged in any other respect. Thus it is the *same* process, and the absolute value of the velocity of E2' in S' is therefore again |v|, and the Photon originating from SP(ϑ) is – except for the direction – identical with the one that originates from SP(0°).

Combined with what has been said just before, it follows:

(2) With respect to S' holds: Except for the direction, the light waves P1' and P2' are identical.

Thus $\lambda_{P1'} = \lambda_{P2'}$ for all scattering angles ϑ.

At last we need the following:

In S', E1' moves with velocity -v. E_+ is at rest.

Now the question is: E_+ is the superposition state of the two waves P1' and E1'. If E_+ is at rest, what follows with respect to P1?

The de Broglie wave-length of the electron: $\lambda_B = \lambda_C \frac{c}{v} k$ is a relativistic phenomenon: Due to the Lorentz transformation of an in-phase oscillation to a system moving with velocity v, the phase coincidence is canceled and a phase-wave with just this wave-length emerges. If the movement generated in this way should disappear, then this phase-shift must be annulled.

Let us look at the short-time superposition E_+ of the waves representing P1' und E1':

According to (1), E1' is represented by (f_e ... frequency of the resting electron)

$$\cos 2\pi \left(t \, f_e \frac{1}{k} + x \frac{1}{\lambda_C} \frac{v}{c} \frac{1}{k} \right) = \cos 2\pi \left(t \, f_e \frac{1}{k} + x \frac{1}{\lambda_B} \right)$$

P1' is represented by

$$\cos 2\pi \left(t \, f_{P1'} - x \frac{1}{\lambda_{P1'}} \right)$$

If we now set the wave-length of P1' equal to the one of E1':

$$\lambda_{P1'} = \lambda_B = \lambda_C \frac{c}{v} k$$

then, according to the identity

$$2 \cos a \cos b = \cos(a + b) + \cos(a - b)$$

we obtain, as the result of E1' ∗ P1', *two waves* (in the same way as at the Photoelectric Effect):

In the first wave, the x-term disappears, which means that the phase shift is in fact canceled and that, therefore, the velocity of E_+ is indeed equal to 0.

The second wave would move, seen from S, opposed to the direction of the incoming photon, but at the same time its frequency would be reduced compared to the frequency of the electron E1 that rests in S, which would be impossible. As in the Photo Effect, also here this second possibility is inapplicable.

Thus we can state:

(3) With respect to the reference frame S', the incoming photon P1' possesses the wave-length

$$\lambda_{P1'} = \lambda_B = \lambda_C \frac{c}{v} k$$

Now we must just transform from S' back to the laboratory system S.

In order to calculate the wave-lengths of P1 and P2, we need the relativistic Doppler Effect with respect to an arbitrary angle ϑ, which has the following form:

$$\lambda' = \lambda \left(1 - \frac{v}{c} \cos \vartheta\right) \frac{1}{k}$$

In our case is $\lambda_{P1} = \lambda_{P1'} \left(1 - \frac{v}{c}\right) \frac{1}{k}$

and, because of (2) $$\lambda_{P2} = \lambda_{P1'} \left(1 - \frac{v}{c}\cos\vartheta\right)\frac{1}{k}$$

From this follows $$\lambda_{P2} - \lambda_{P1} = \lambda_{P1'} \frac{1}{k}\frac{v}{c}(1 - \cos\vartheta).$$

If we now insert the value of $\lambda_{P1'}$ from (3), we get to

$$\lambda_{P2} - \lambda_{P1} = \lambda_C (1 - \cos\vartheta)$$

and this is the desired result.

What about the asymmetry of the distribution of the scattering angles?

In S', all scattering angles are equiprobable, which means: equally distributed between 0 and 2π. For the laboratory system S follows then the observed, with the frequency of the incoming photons increasing asymmetry of the distribution of the scattering angles.

Thus also in the description of the scattering of high frequency light on electrons it was possible, without any physical resources and prerequisites, only based on the assumption that both light and electron are waves, to derive the correct result. Since this result is given here in the form of a wave-length difference, it was – other than at the Photo Effect – never necessary to change over to the usual "mechanical" description. We did not even need to mention the concepts energy and mass.

As could be seen, symmetry assumptions were applied. However they did not serve, as usual, for substantiating conservation laws, but for the assumption that, with respect to S', only the propagation direction of the two waves changes after they have separated, whereas in every other respect they remain identical.

Everything which was said at the end of the previous section, applies identically or analogously also here. Therefore, a summary or a commentary is superfluous.

Thus we have described the two experiments, by which the wave-particle dualism was brought into physics, solely by wave superpositions. The assumption of light particles could be dispensed with.