Phys 231 Sp 2026

Lecture 4

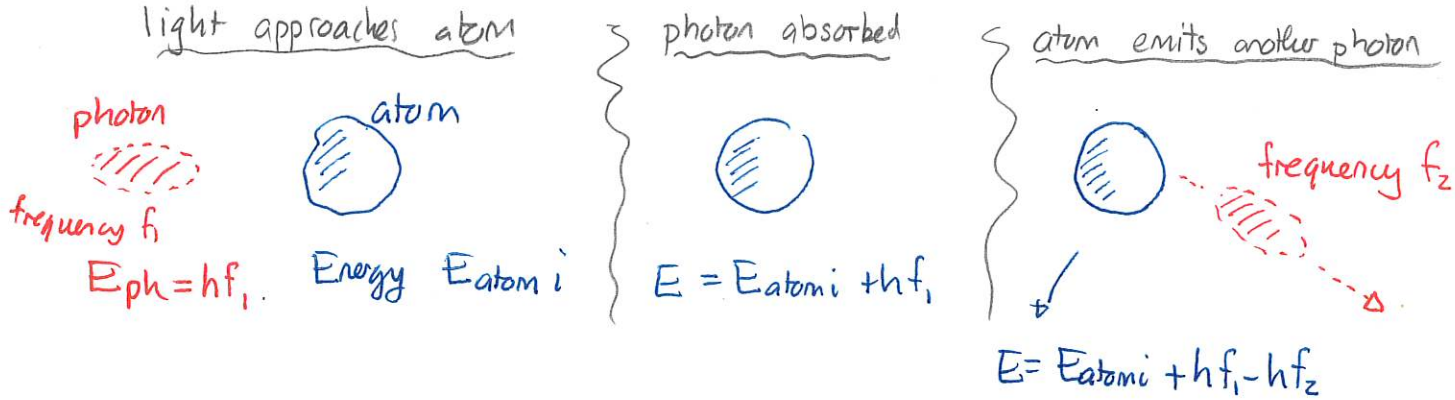
Thurs: Seminar 12:30 Wubben 160

Fri: Read 3.1 → 3.3, Appendix H.

Mon: HW 2

Quantized electromagnetic interactions

We have seen that certain phenomena that involve interactions between light can be explained by assuming that the light has a particle nature. Then the model for interaction is, for example



At all points the basic rules of energy conservation apply.

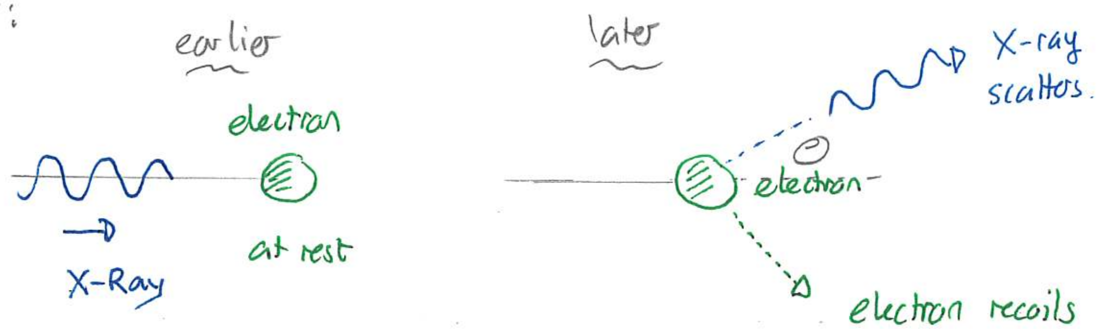
Quiz 1 80%

DEMO: Down Conversion Video

This type of process is frequently used in optics that requires single photons.

Compton effect.

We can bombard matter with high energy photons and observe the resulting scattering process. Historically this was done with X-rays and the first such experiments were performed in 1923 by A. H. Compton. He bombarded electrons with X-rays and observed the scattered X-rays. We might expect:



The interesting observation was:

> The wavelength of the scattered X-ray was different to the wavelength of the incident X-ray. The difference depends on the scattering angle θ

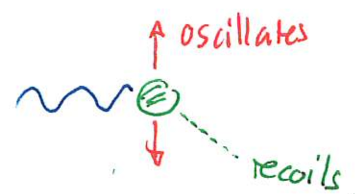
There is a possible explanation using classical mechanics and electromagnetism.

① The incident electromagnetic wave (for the X-ray) causes

* the electron to oscillate

  AND

* the electron to recoil

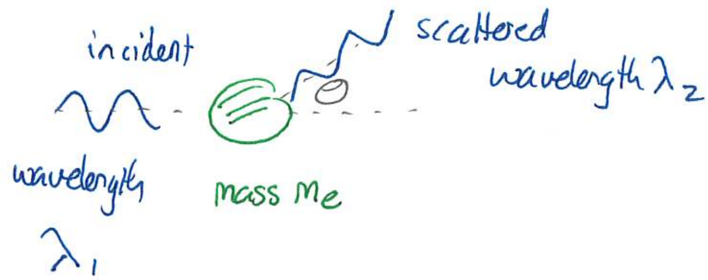


② the electron oscillates at the same frequency as the incident X-ray. Electromagnetism predicts that it emits radiation. If the electron did not recoil, the frequency of emitted radiation would equal that of the incident.

③ classical electromagnetism predicts that the incident X-ray and scattered X-ray each have momentum. Total momentum can only be conserved if the electron has momentum after the interaction. So the electron recoils.

But the radiation emitted by a moving source will be Doppler-shifted and thus have a different wavelength to the incident X-ray. A detailed analysis gives:

$$\Delta\lambda = \lambda_2 - \lambda_1 = W\frac{\lambda_1}{M_e c^2}(1-\cos\theta)$$



where W is the total energy absorbed by the electron

④ For a <u>given</u> scattering <u>angle θ</u> <u>any wavelength</u> shift is <u>possible</u>

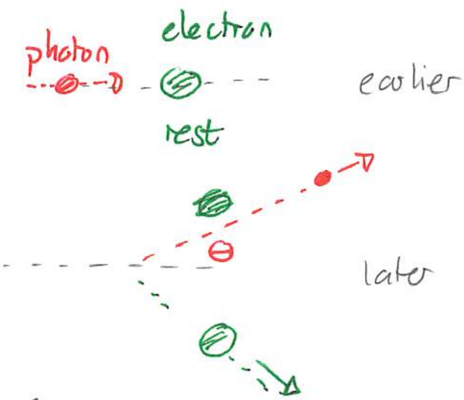
The actual experiment shows that the wavelength shift only depends on the angle and not the intensity.

<u>Compton's explanation</u>

Compton explained the scattering process by using:

* X-rays are a stream of photons, each treated as a particle

* relativistic energy and momentum are conserved.



Note that relativity provides a general relationship between energy and momentum:

$$E^2 = p^2c^2 + m^2c^4$$

and for a photon $m=0 \Rightarrow E = |p|c \Rightarrow \frac{hc}{\lambda} = |p|c \Rightarrow |p| = h/\lambda$

Then, a detailed analysis gives:

$$\boxed{\lambda_2 - \lambda_1 = \frac{h}{m_e c}(1-\cos\theta)}$$

Thus

Using a particle/photon picture of electromagnetic radiation predicts that the change in wavelength only depends on the scattering angle.

DEMO: Compton paper data

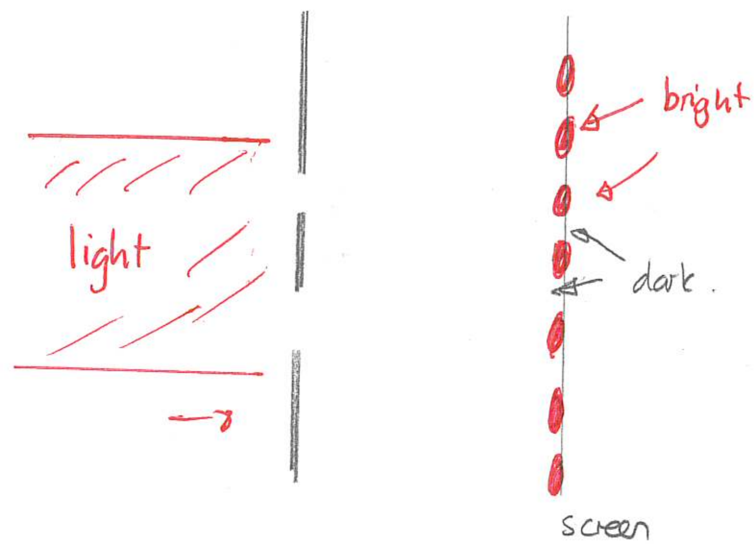
Quiz 2 90%

Photons and interference phenomena

We have seen that certain phenomena involving light and electromagnetic radiation can be explained by assuming that light consists of photons that behave like particles.

However, there are various interference and diffraction phenomena involving light that are well described by assuming light is a wave. For example consider light that is incident on a pair of closely spaced slits

We will observe: an array of bright and dark spots on a distant screen.



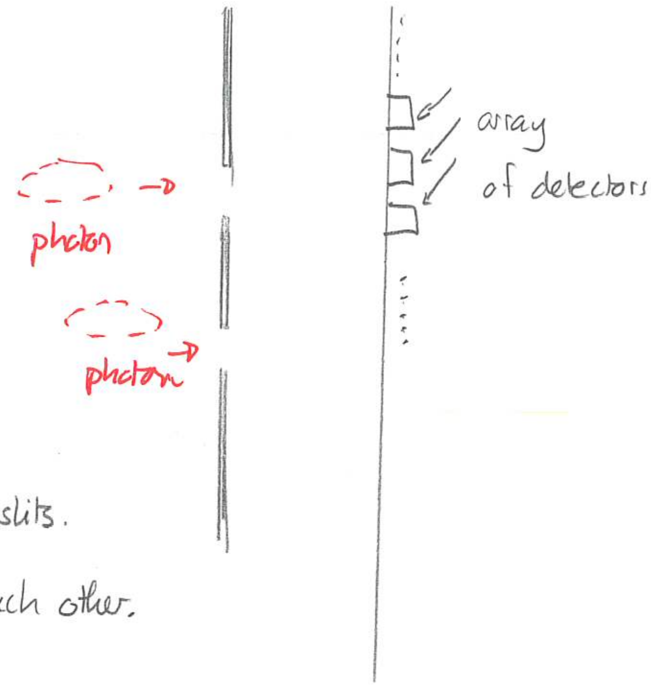
The classical electromagnetic theory desciption of this is

* each slit produces a wave
* these waves overlap and interfere.
* the geometrical configuration of the waves determines where bright and dark fringes appear.

DEMO: Overlapping wave slide

What if we do the same type of experiment with very low intensity light that should be described in terms of photons.

Where would photons arrive at the array of detectors?



When we answer this we should note:

1) the photons are all prepared identically in terms of their direction of propagation before the slits.
2) the photons do not interact with each other.
3) each photon cannot be split.
4) each photon is only detected at a single detector

Quiz 3

We will observe:

1) each photon arrives at one detector (one location)
2) even though photons are prepared identically, their arrival locations will vary statistically.

DEMO: PhET Quantum Wave Interference

- single particles → slits
  → show photons arriving