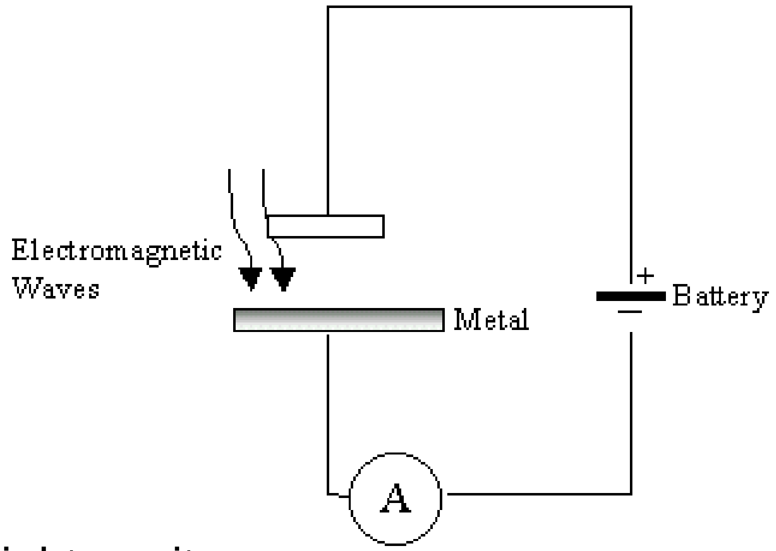
Photoelectric effect

Basic experiment

This is the basic set-up of the photoelectric experimentation. Light is shone on the metal and particles are ejected and the current is measured.



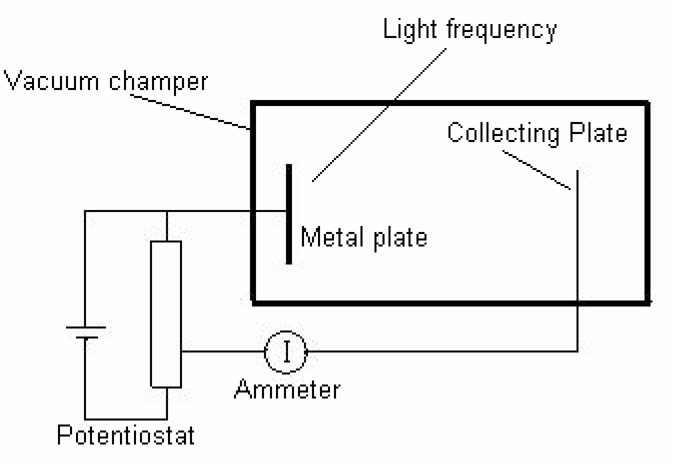
History of photoelectric effect

Metal plate in vacuum irradiated by ultraviolet light, emits charged particle (Hertz 1887), which were subsequently shown to be electrons by (J.J. Thompson1899).

J.J. Thompson identified that ultraviolet light caused **electrons** to be emitted when a metallic surface was exposed to radiation in a vacuum tube.

He also discovered that the **number** and the **speed** of the electrons emitted would be expected to vary with the intensity and the wavelength of the radiation, respectively.

Classical expectations



-Electric field E of light exerts force **F=-eE** on electrons. As intensity of light increases, force Increases so Kinetic energy of ejected electrons Should increase.

-Electrons should be emitted whatever the frequency v of the light, so long as E is sufficiently large.

-For every low intensities, expect a time lag Between light exposure and emission. While electrons absorb enough energy to escape from material.

Actual results

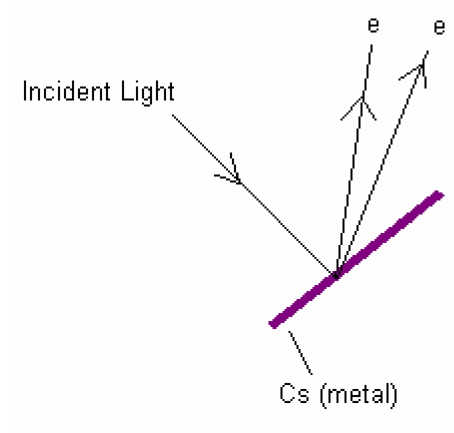
Maximum kinetic energy of ejected electrons is independent of intensity but dependent on v.

FOR V<V0 (i.e. for frequencies below a cut-off frequency) no electrons are emitted .

There is no time lag. However rate of ejection of electrons depends on the light intensity

Summary

In 1905 A. Einstein show that when light strikes a metallic surface it causes the ejection of electrons his findings are as follows:



1- No electrons are ejected until the frequency of the light becomes larger then a certain value. This minimum frequency is called threshold frequency.

2- At light frequencies higher than the threshold frequency the electrons are ejected with extra kinetic energy, this extra kinetic energy is independent of the light intensity but is directly proportional to the light frequency.

3- When the light frequency of the incident light is higher than the threshold frequency the current flowing (i.e. number of electrons ejected) is dependent only on the light intensity.

Einstein explained his results by assuming that light behaves as though it were a stream of particles these light "particles" or quanta are called photons and the energy of each quantum is proportional to its frequency**. E=hv**

And so light or radiation energy in general is also quantized. When photon strikes the metallic surface it give its energy to one of the electrons causing it ejection. A photon of light frequency ($\therefore$ high energy) ejects an electron and gives it extra kinetic energy. The number of ejected electrons (current) is proportional to the number of photons, i.e. proportional to the light intensity. If a photon is of low frequency its energy may not be enough to cause the ejection of an electron. Violet light, for example, will cause potassium to eject electrons, but no amount of red light (which has a lower frequency) has any effect.

$$K.E = hv - hv_0$$ (h Planck's constant universal constant of nature 6.63*10↑-34Js))

$$K.E = hv - W$$ (W is work function: minimum energy needed for electron to escape from metal (depends on material, but usually 2-5eV)

Milikan's Disbelief

Robert Milikan, an American experimental physicist would not except Einstein's theory of energy as quanta.

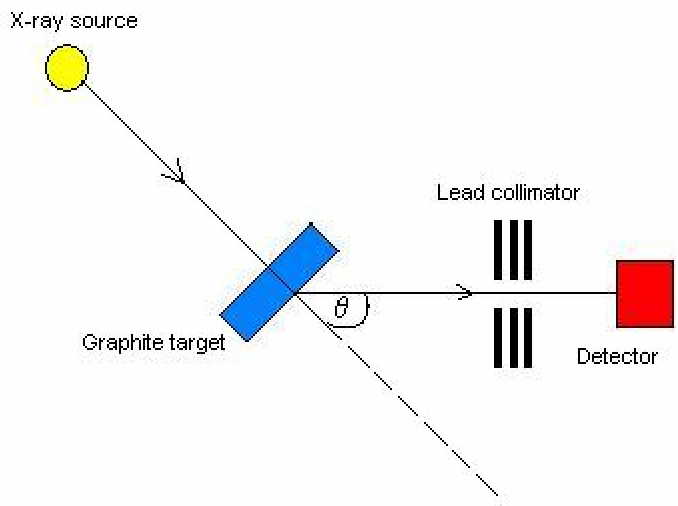
He thought it was an attack on the wave theory of light. Also, if Einstein was right, there was a completely new way to measure planck's constant.

He spent ten years of his life (1906-1916) working on the photoelectric effect trying to disprove Einstein.

He even devised techniques for scraping clean the metal surface inside the vacuum tube. To his disappointment, he actual confirmed Einstein's work with his results and measured Planck's constant with 0.5% error. He did however earn a Nobel Prize for his series of experiments.

Compton effect

In1922 Arthur Compton studied scattering of X-rays with a definite wavelength from free electrons of a graphite target. Note the difference between photoelectric effect and Compton effect. The former (photoelectric effect) deals with ejection of bound electrons from the surface of a metal, the later (Compton effect) deals with scattering of light from almost free inside metal.

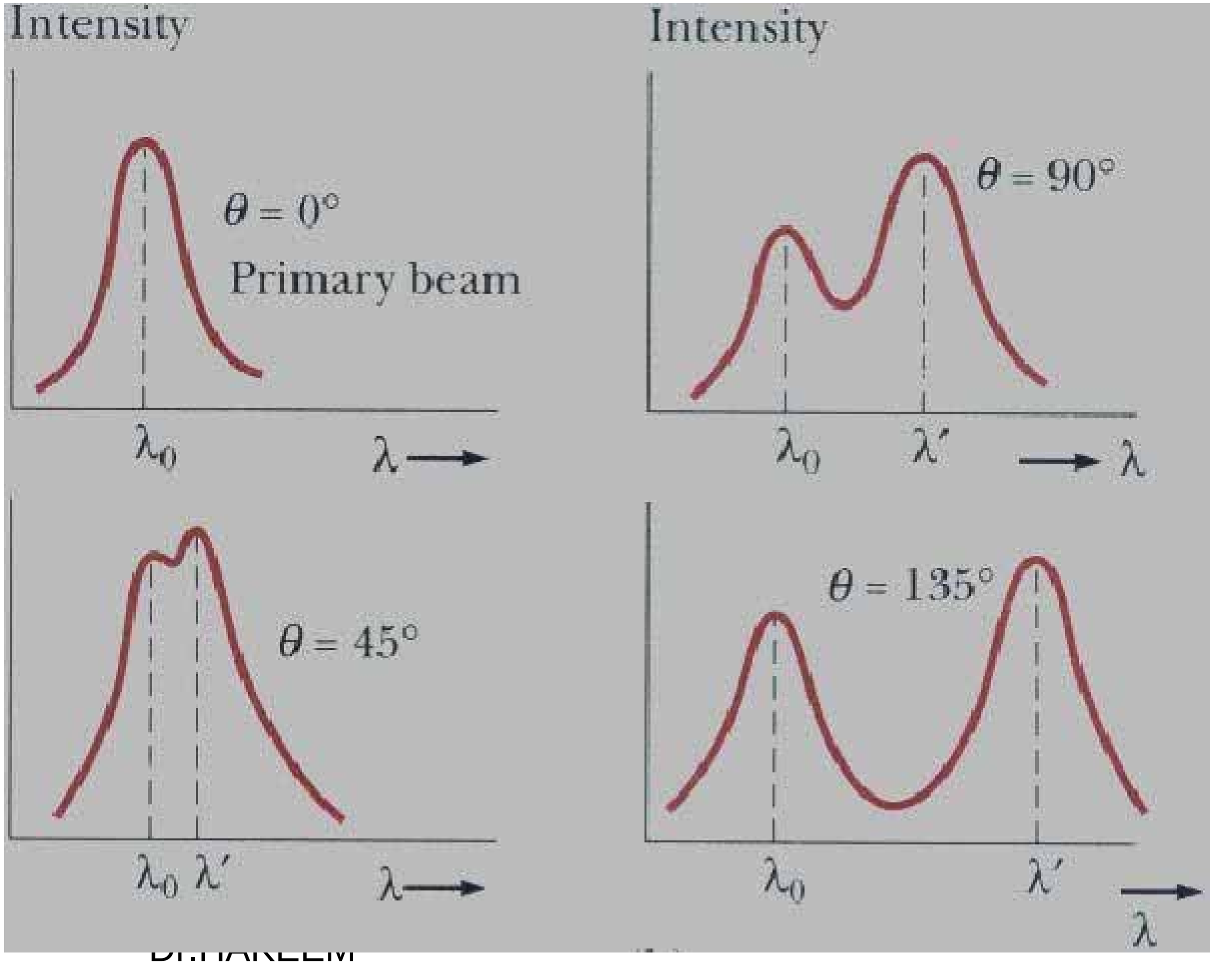


Classical electrodynamics predicts that scattered light arises because emitted light forces electrons to vibrate with light's frequency, and hence to emit light at the same frequency. Therefore, according to classical theory, scattered light must have the same frequency as the incident light.

The presence of additional resonance (at θ = 45,= θ 90 and θ =135) is impossible to explain classically. If however one assume that photons carry not only energy but also momentum, the problem can be reduced to that of elastic collision between two particles.

$$P = \frac{E}{c} = \frac{hv}{c} = \frac{h}{\lambda}$$

$$\lambda' - \lambda_0 = \frac{h}{mc}(1 - \cos\theta)$$



Why there is a peak at the original frequency then? Electrons scatter also from heavy ions, for which the change in the wavelength is negligible.

1922: Arthur Compton (USA) proves that X-rays (EM Waves) have particle like properties (acts like photons)

– Showed that classical theory failed to explain the scattering effect of X rays on to free (not bound, barely bound electrons)

Experiment : shine X ray EM waves on to a surface with “almost” free electrons

– Watch the scattering of light off electron : measure time + wavelength of scattered X-ray