1905-2005 Celebrating 100 years of Einstein's work

Four major papers in 1905: one of them explains the photoelectric effect

A wave of light (with interference effects) is made up of many photons (an ensemble)

Photons have particle-like properties, even though their rest mass is zero

Photons carry momentum/energy associated with the wavelength λ and frequency f

Photons do not interact with each other – the analogy with water waves made up from H_2O is not perfect

What is the photoelectric effect?

A vacuum diode contains a mantle (surface coated with a metal from which it is relatively easy to knock out electrons) and a metal post.

When light hits the surface an electric potential difference between post and mantle is measured.

Electrons (negative charge) are removed from the mantle and collected at the post. Post is charged negatively against the mantle (becomes +).

Some of the energy associated with the light is converted into electric energy
(cf. photovoltaics – solar cells).

Potential difference has little to do with the intensity of the light, but depends strongly on the colour (or wavelength/frequency) of the light.

Within a wave theory this is impossible to understand:

Big intensity means large amplitude for the wave. That should mean more energy (potential difference).

New idea: photons have an energy associated with the frequency of the light. Whether they can knock out electrons, and how much kinetic energy they give the electrons depends on their energy.

More intensity = more photons

Yet, when many infrared-wavelength photons hit a metal – no photoelectrons come out (intensity doesn't help, they can't beat the work function)

True up to some point: low-energy photons can conspire to combine their energy (in high-power lasers).

Quantitative analysis:

Wavelength times frequency = propagation speed

$$\lambda f = c$$

Visible light wavelengths λ: 650 to 400 nm (red to violet)

$$c = 3 \times 10^8 \text{ m/sec}$$

Frequencies *f* in the hundreds of Terahertz range

What is a light wave? Oscillating electric (and magnetic) field.

Photon energies:

$$E = h f$$

h = Planck's constant (to be measured)

Energies are in the electronvolt range:

$$E = eV$$

e=electron charge, V=potential difference in volts; $e=1.6\times10^{-19}$ serves as the conversion factor.

A large part of the photon energy goes into pulling electrons out of the metal – we won't measure the work function, will just observe the linear photovoltage - light frequency relationship.

Work function is an important idea which explains how a battery works (e.g., copper-zinc b.)

In our measurement we go directly for the photovoltage which is possible with a high-impedance voltmeter (electrometer).

Light sources can be LEDs (broad spectrum), lamp with interference filters (narrow bandpass), laser pointers (red and green).

Planck's constant:

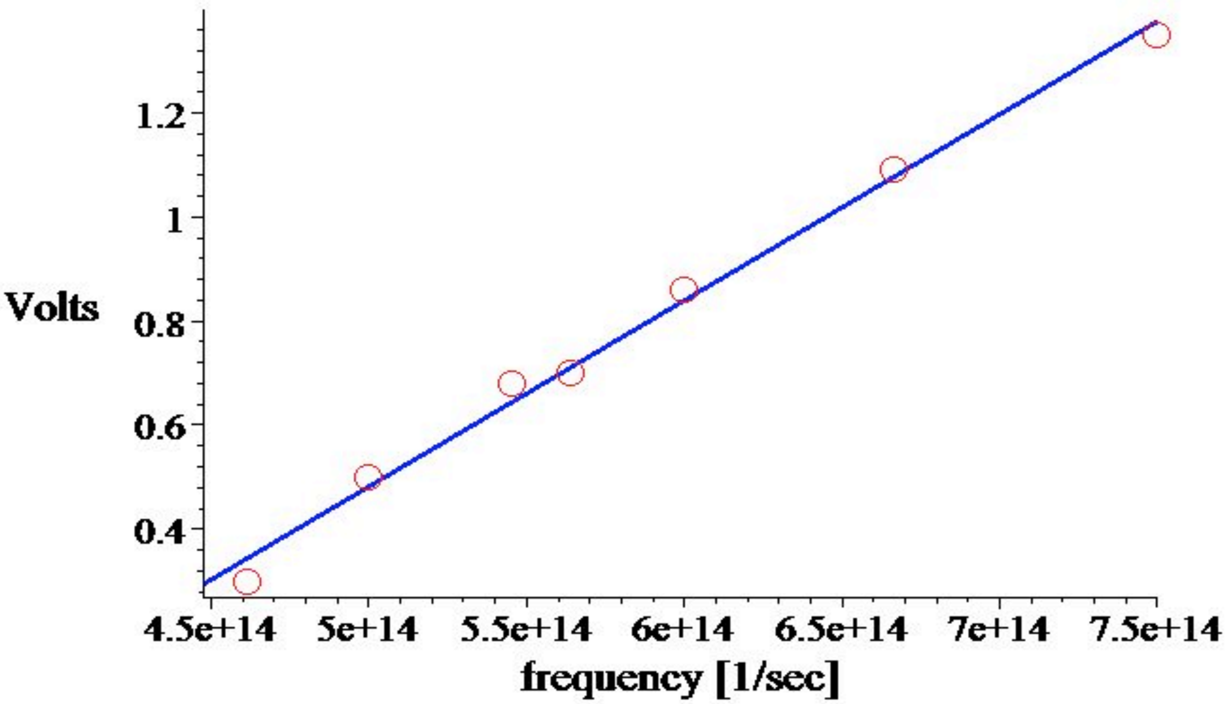
We will test the hypothesis

$$E_\gamma = hf = eV + \text{const(work function)}$$

assuming e as given. If we can fit a linear line to the V versus f data, then the slope will be h/e.
Units: energy = Nm = Joule = Ws = VAs =VC

Planck constant h will come out in Js
A small value because e is small and we divide it by ≈500THz = 500×10^{12} 1/s
It measures action (relevant in modern physics, unit is energy times time: *Et*)

Data (Volts versus frequency):



Fitted a line, read out the slope times e:
Planck constant: h ≈ 5.7E-34 Js
Best value measured? 6.6260693(11) E-34 Js
Scatter in the data is less than this 15% difference:
Systematic effects must be affecting our measurement. How do we find them???