

7.1 Quantum Physics. Particle Nature of Light

Blackbody Radiation
Photoelectric Effect

Photons

When light exchanges energy with matter it behaves as a particle - called the photon

The energy of a photon is proportional to the frequency of light

$$E_{\text{photon}} = hf$$

Where h is a universal constant called Planck's Constant

$$h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$$

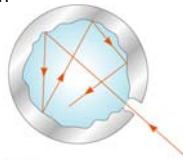
The first evidence for the particle nature of light comes from

Planck's Theory of Black body radiation

Einstein's Theory of the Photoelectric effect.

Thermal Radiation

Blackbody radiation



A container at temperature T in equilibrium with electromagnetic radiation. Light is absorbed and emitted by the walls. At equilibrium the spectrum of the light only depends on the temperature.

Spectrum of Blackbody radiation

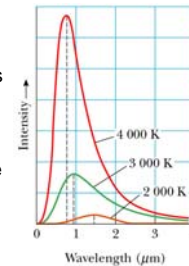
A wide spectrum of wavelengths is produced.

The total intensity increases with temperature

The peak wavelength decreases with temperature
Wien's displacement law

$$\lambda_{\text{max}} T = 0.2898 \times 10^{-2} \text{ mK}$$

The intensity goes down at low wavelengths

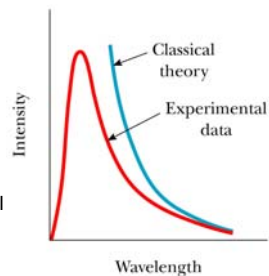


Disagreement with classical theory of light

The classical theory predicts that intensity continues to increase with decreasing wavelength.

"Ultraviolet Catastrophe"

To explain the experimental data Planck proposed the quantum hypothesis.



Planck's constant



Max Planck

Planck proposed that light could only have certain energies

$$E = hf$$

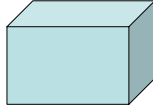
Then the energy of oscillators in the black body could only have certain fixed quantities

$$E = nhf$$

n is an integer. i.e. Energy is Quantized.

A simple analogy

Suppose we have a box that contains light waves with different wavelengths. The energy is contained in "resonators", particles with different



Classical theory predicts that the number of resonators increased with decreasing wavelength. "smaller particles are more numerous"

Planck proposed that in addition the short wavelength particles are more "energetically expensive"

So at short wavelength, they would be hard to produce. This explains the peak in the black body spectrum

Photon Energy

Find the energy of a photon with a wavelength of 500 nm. Use units of electron volts ($1\text{eV} = 1.60 \times 10^{-19}\text{ J}$)

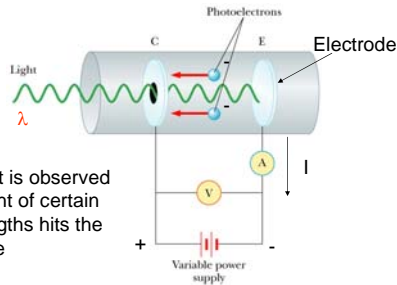
$$E = hf = h \frac{c}{\lambda} = 6.63 \times 10^{-34}\text{ Js} \left(\frac{3 \times 10^8\text{ m/s}}{500 \times 10^{-9}\text{ m}} \right) = 4.0 \times 10^{-19}\text{ J}$$

$$E = 2.5\text{ eV}$$

An electron volt is the energy change in moving an electron across a potential of 1 volt.

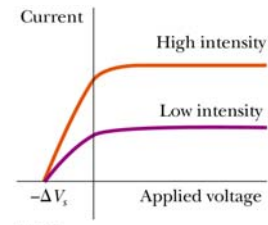
A few electron volts is the energy of electrons in molecules.

Photoelectric effect.



A current is observed when light of certain wavelengths hits the electrode

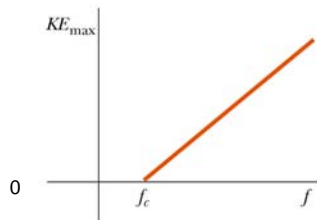
Photoelectric effect



The stopping voltage ΔV_s is a measure of the kinetic energy of the photo electrons.

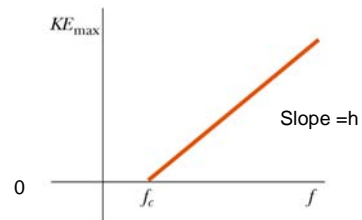
When the ΔV_s is high enough electrons don't reach the electrode C.

Photoelectric Effect



Kinetic energy rises linearly with the frequency of light.

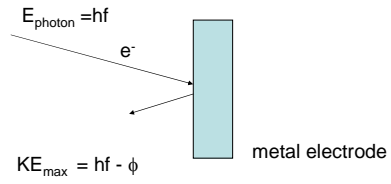
Einstein's explanation



$$KE_{\text{max}} = E_{\text{photon}} - \phi = hf - \phi$$

ϕ is the work function, the potential energy needed to remove the electron from the electrode.

Photon concept



A photon interacts with the electron
The light energy can have only specific values.
Light energy is quantized