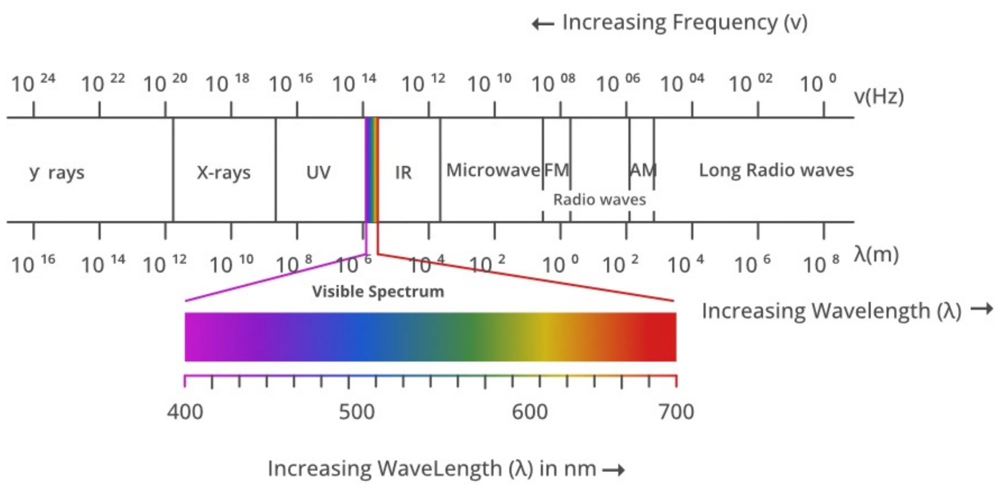
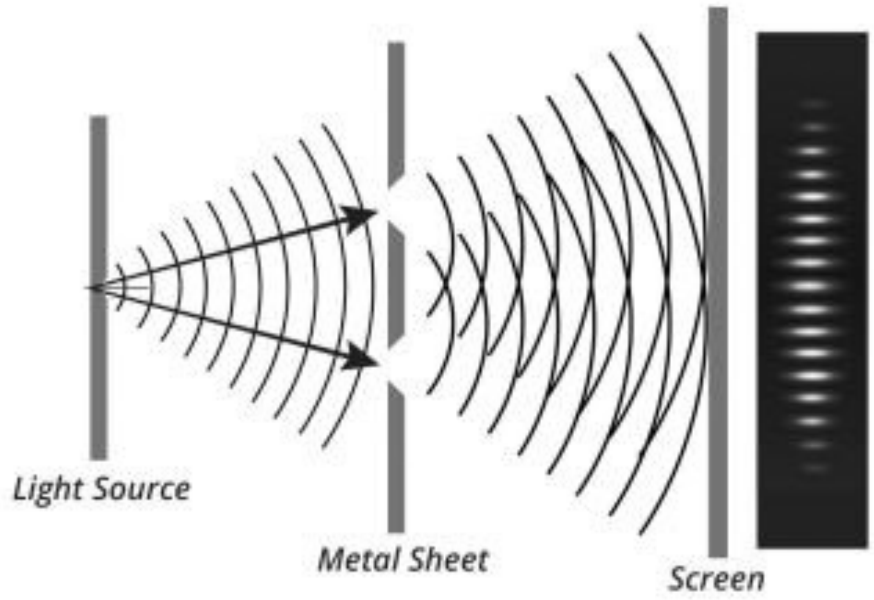
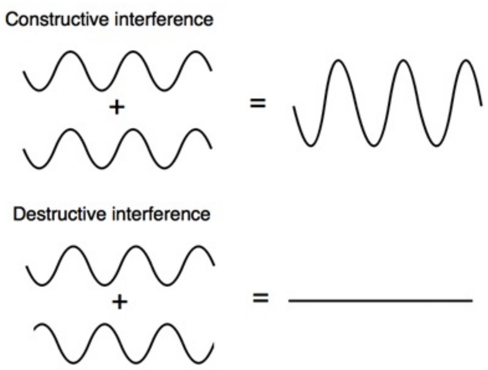
Light as Wave:



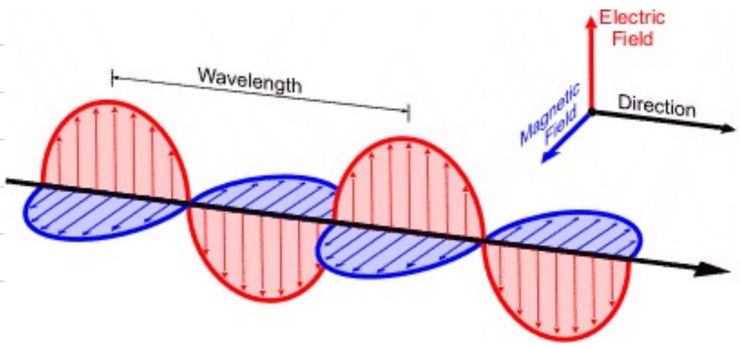
The double slit experiment – can be explained by the wave nature of light





* Maxwell's theory tells that light is electromagnetic (EM) wave: accelerating charge particles produce time varying electric & magnetic fields. Changing electric field produce magnetic field & changing magnetic field produce electric field – this interplay propagates through space without any medium – this is known as EM waves. Maxwell's theory also tells that the electric & magnetic fields are perpendicular to each other & both perpendicular to the direction of propagation

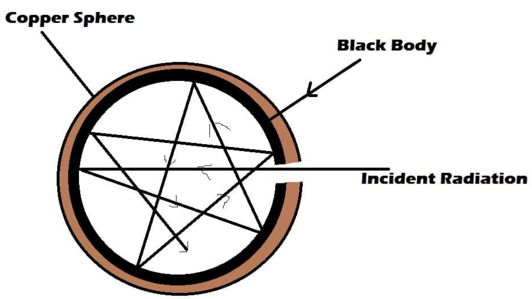
Maxwell's Equations	Maxwell's Equations
Differential form	Integral form
$\nabla \cdot \vec{E} = \dfrac{\rho}{\varepsilon_0}$	$\oint \vec{E} \cdot d\vec{a} = \dfrac{Q_{enc}}{\varepsilon_0}$
$\nabla \times \vec{E} = \boxed{-\dfrac{\partial \vec{B}}{\partial t}}$	$\oint \vec{E} \cdot d\vec{l} = \boxed{-\int \dfrac{\partial \vec{B}}{\partial t} \cdot d\vec{a}}$
$\nabla \cdot \vec{B} = 0$	$\oint \vec{B} \cdot d\vec{a} = 0$
$\nabla \times \vec{B} = \mu_0 \vec{J} + \boxed{\mu_0 \varepsilon_0 \dfrac{\partial \vec{E}}{\partial t}}$	$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc} + \boxed{\mu_0 \varepsilon_0 \int \dfrac{\partial \vec{E}}{\partial t}}$

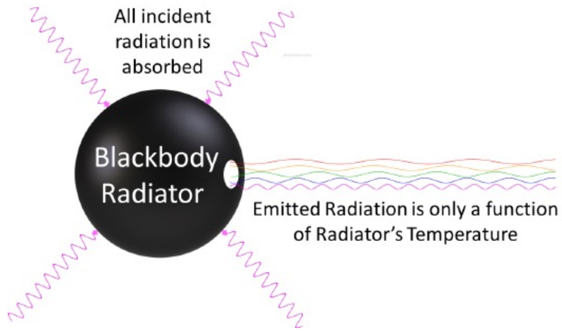


Hertz's experiment proved that Maxwell's theory is correct.

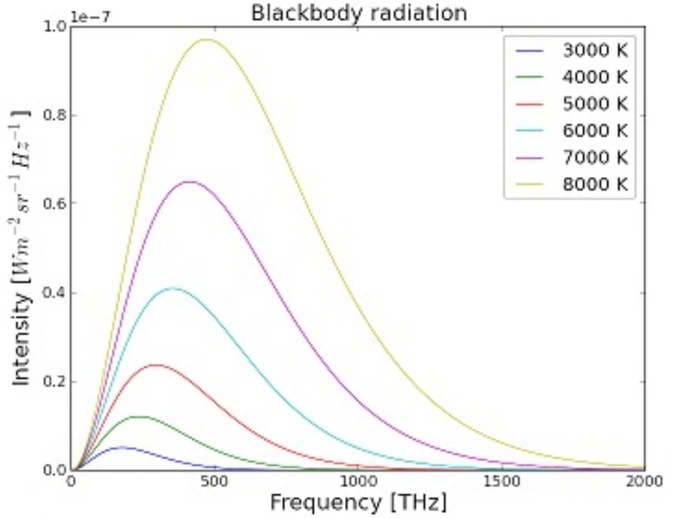
Blackbody Radiation: Though the fundamental nature of light was understood from Maxwell's theory, there was very little understanding of how light interacted with matter: i.e., how light is emitted or absorbed by an object.

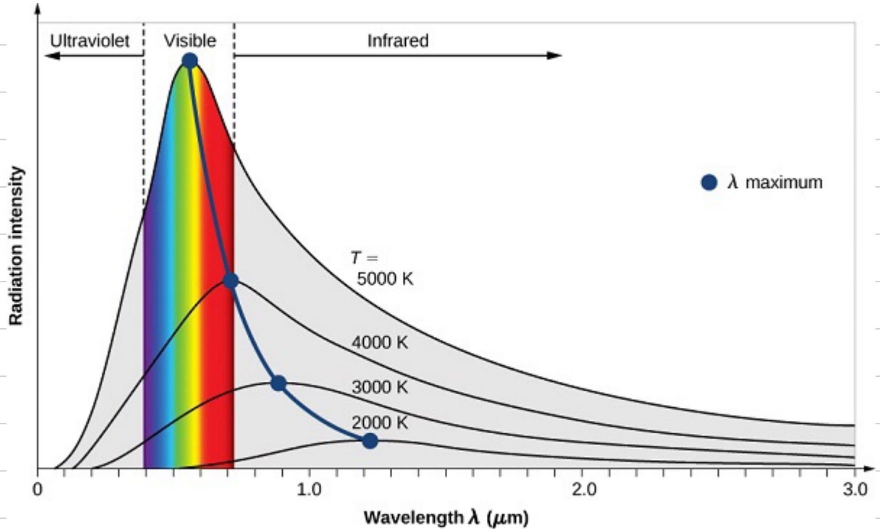
* All objects radiate energy in the form of EM waves with all frequencies; but depending on the temperature only one frequency dominates.
* An object's ability to absorb & radiate energy are related: a good absorber is also a good radiator
* Blackbody is an ideal object that absorbs all radiation incident upon it regradless of frequency. When heated a blackbody emitts radiation of all frequencies. Radiation increases with temperature.





Blackbody Spectrum:





Why the blackbody spectrum has this shape was not understood for a long time.

* Failed Attempts:

Wien's distribution law: energy density per unit frequency of blackbody radiation is given by

$$u(f,T) = A f^3 e^{-f\beta/T}$$

{ A, β are constant &
{ T is the temperature

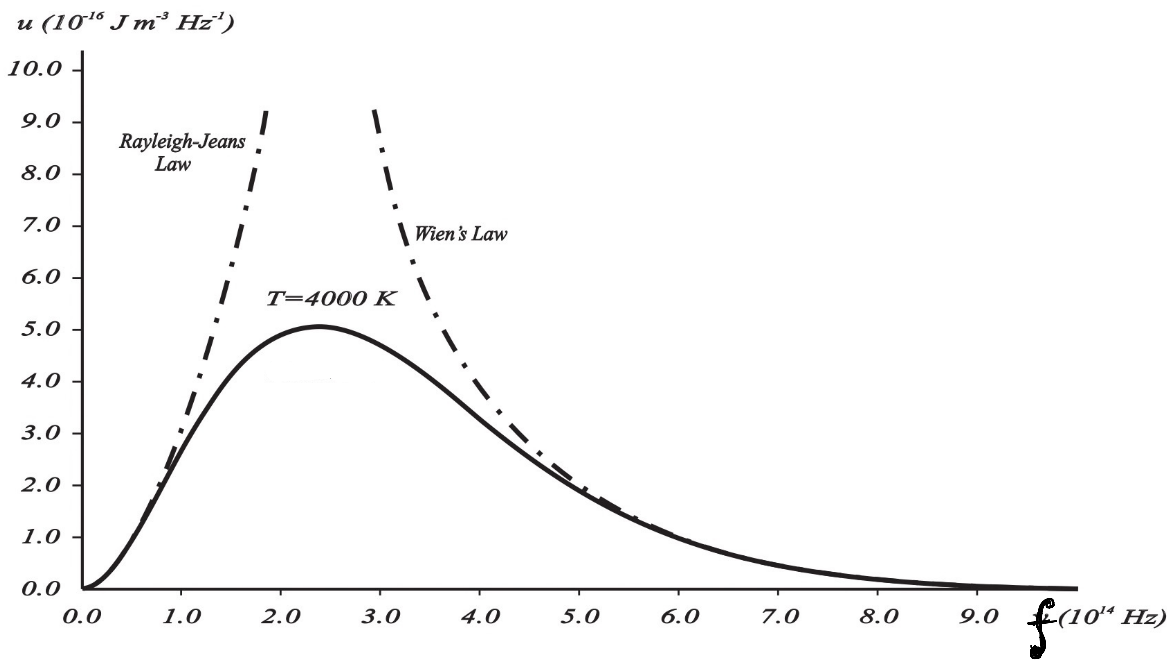
Rayleigh's distribution;

$$u(f,T) = \frac{8\pi}{c^3} f^2 k_B T$$

$k_B = 1.3807 \times 10^{-23}\ J K^{-1}$ is the Boltzmann's constant

$c = 3 \times 10^8$ m/s is the speed of light.

* Ultraviolet Catastrophe: Apart from low frequency Rayleigh's formula diverges at high frequency



Planck's distribution: Max Planck explained the blackbody spectrum in 1900. Planck postulated that oscillating charges emitt radiation of frequency, say f, in integer multiple of hf where h is called the Planck's constant.

$$\boxed{E = nhf \; ; \; n = 0, 1, 2, 3 \ldots}$$

Planck named hf as the "quantum" of radiation. This is called Planck's quantization rule.

* Based on the quantization rule Planck calculated average energy density of radiation between frequency f & $f+df$ at temperature T is given by

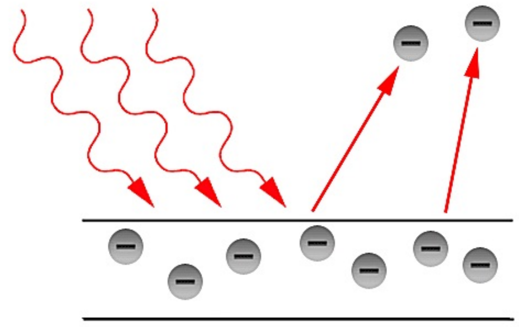
$$\boxed{u(f,T) = \frac{8\pi f^2}{c^3} \frac{hf}{e^{hf/k_B T} - 1}}$$

This is called Planck's distribution - it explains the blackbody spectrum.

* Planck's theory shows that radiation or light is quantized.

Photoelectric Effect : certain metals eject electrons when irradiated by light.
The following properties are also observed

- If the frequency of the incident radiation is smaller than the metal's threshold frequency—a frequency that depends on the properties of the metal—no electron can be emitted regardless of the radiation's intensity (Philip Lenard, 1902).
- No matter how low the intensity of the incident radiation, electrons will be ejected *instantly* the moment the frequency of the radiation exceeds the threshold frequency ν_0.
- At any frequency above ν_0, the number of electrons ejected increases with the intensity of the light but does not depend on the light's frequency.
- The kinetic energy of the ejected electrons depends on the frequency but not on the intensity of the beam; the kinetic energy of the ejected electron increases *linearly* with the incident frequency.



* The photoelectric effect can not be explained by the classical wave nature of light. According to the classical theory light of any frequency with sufficient intensity can eject an electron.

* Einstein's Explanation (1905): Based on Planck's quantization of light Einstein assumed that light is made "photons" each carrying an energy hf. Irrespective of the intensity of the light, an electron in the metal will completely absorb the energy hf.

Part of the absorbed energy hf is spent to eject the electron from the metal's work function W – this is the energy required to free an electron from the surface of the metal. The rest of the energy gives the ejected electron Kinetic energy

$$hf = W + K$$

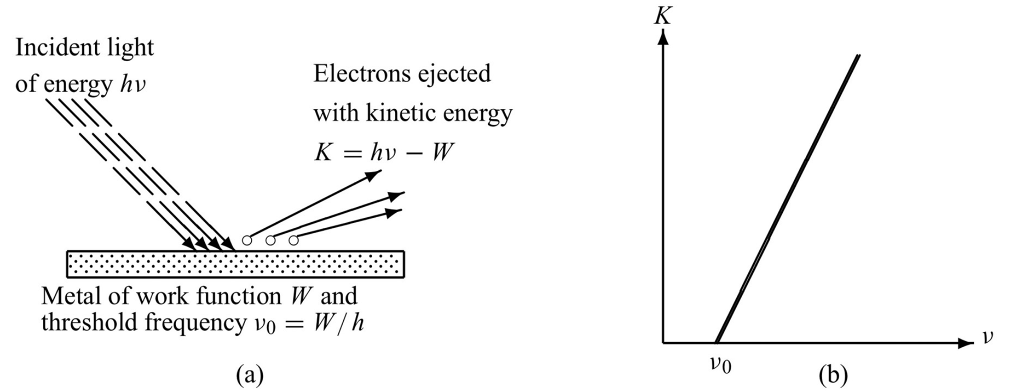
If $hf = W$ then $K=0 \Rightarrow$ electron is just released from the surface.

$f_0 = f = W/h$ is the threshold frequency – ie the minimum frequency to eject an electron. W depends on the property of the metal.

For $f < f_0$ no electron will be released

For $f > f_0$

$$K = hf - W = hf - hf_0 = h(f - f_0)$$



In this picture frequency is denoted by ν & ν_0.