# Opto-Electronics and Photonics

## Lecture 19 : Photons

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# Lecture 19: Photons

Light: EM wave

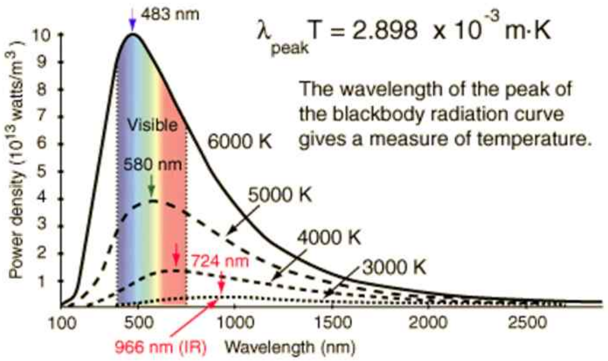
Phenomena that cannot be explained by wave nature of light

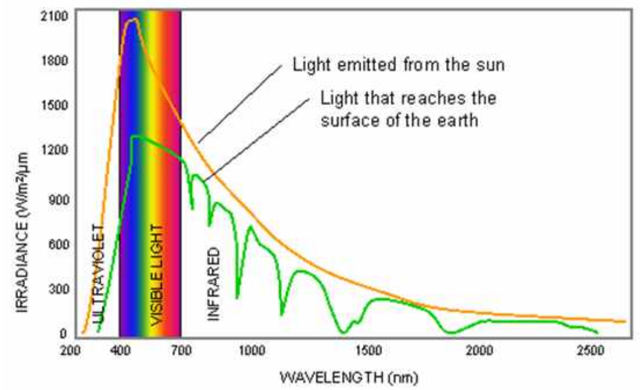
Blackbody Radiation: EM radiation from an object at thermal equilibrium

Temperature

➔ oscillation of charges inside

➔ EM radiation




Temperature of sun
at the surface: 5778K

Thermal image camera

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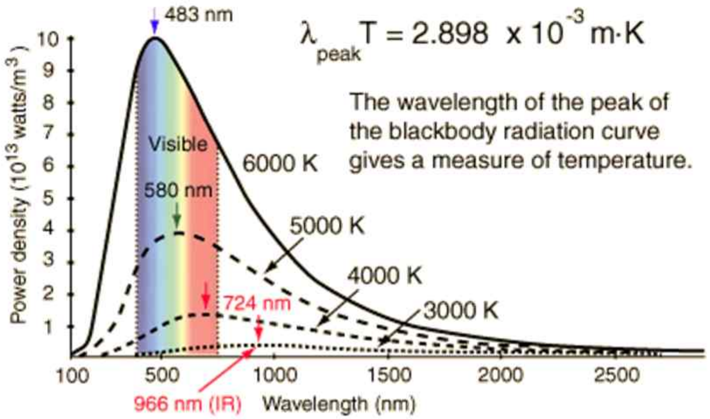
Blackbody Radiation: EM radiation from an object at thermal equilibrium




Temperature
➔ oscillation of charges inside the object
➔ EM radiation

Scientists in 19th century knew much about EM waves and thermodynamics
➔ Strong interests in blackbody radiation

For example,

Gustav Kirchoff
(1824 ~ 1887)

Coined the term "Blackbody Radiation"

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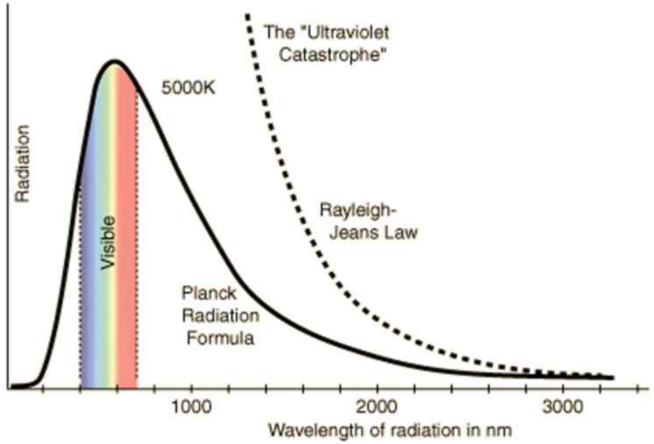


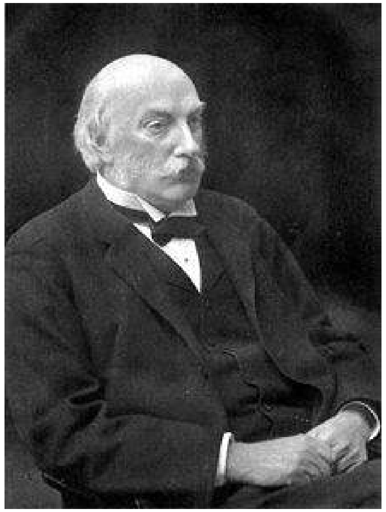

Rayleigh-Jeans Law

(Spectral energy density)

$$\frac{8\pi\nu^2}{c^3}kT$$

John Strutt (Lord Rayleigh)
(1842~1919)
Nobel Prize in Physics in 1904

(Sir) James Jean
(1877~1946)

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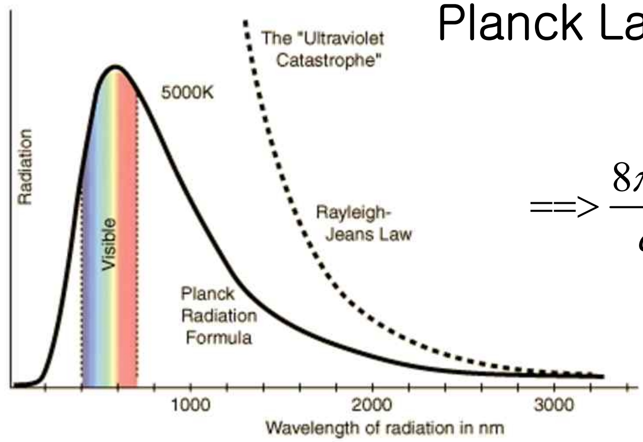
Rayleigh-Jeans Law: $\frac{8\pi\nu^2}{c^3}kT$




Planck Law: $\frac{8\pi\nu^2}{c^3}\frac{h\nu}{e^{\frac{h\nu}{kT}}-1}$

$$==> \frac{8\pi\nu^2}{c^3}\frac{h\nu}{1+\frac{h\nu}{kT}-1} = \frac{8\pi\nu^2}{c^3}kT$$

Max Planck (1858~1947)
Nobel Prize in Physics in 1918

In 1900, Planck proposed EM energies are quantized

"Packets of energy" ➔ photon

$E_{photon} = h\nu$

(h: Planck constant, $6.626 \times 10^{-34}$ J-s or $4.136 \times 10^{-15}$ eV-s)

➔ Beginning of Quantum Mechanics

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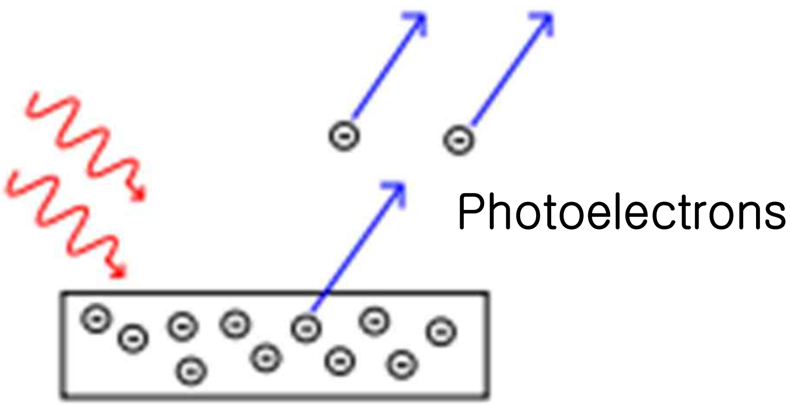
Photoelectric effect: Electron emission when light shines on a material




Discovered in 1887 by

Heinrich Hertz
(1857 - 1894)

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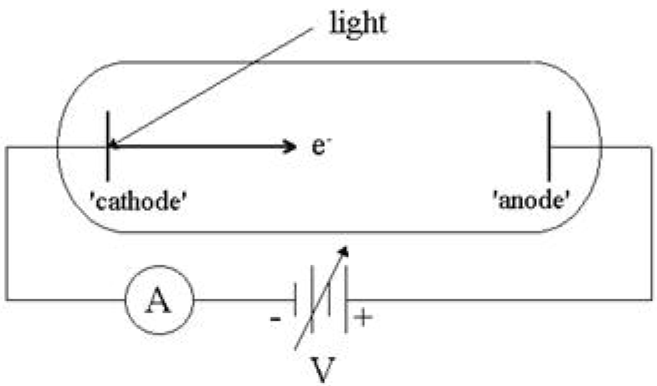
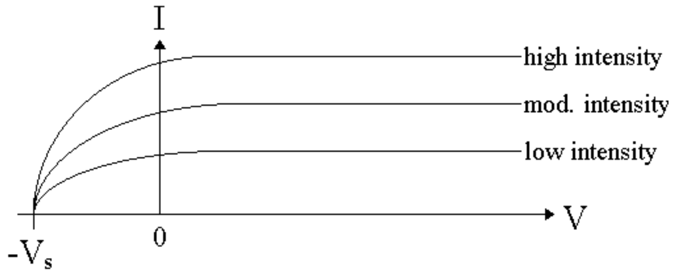
Photoelectric effect




– Amount of photoelectrons depends on light intensity

– Same minimum voltage for current flow regardless of light intensity

$$qV_s = \frac{1}{2}mv_{\max}^2 (= K_{\max})$$

➔ Same max. kinetic energy for emitted electrons regardless of light intensity?

– What determines the max. kinetic energy of photoelectrons?

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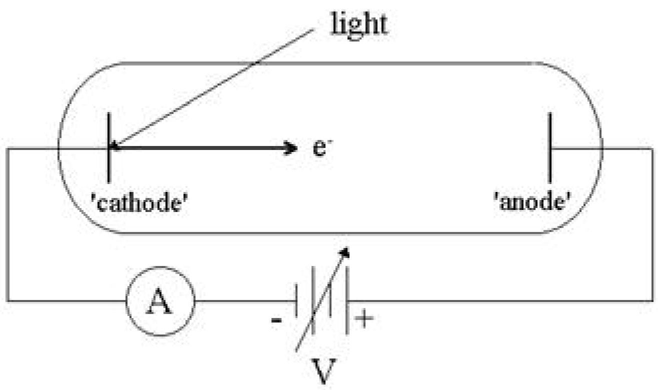


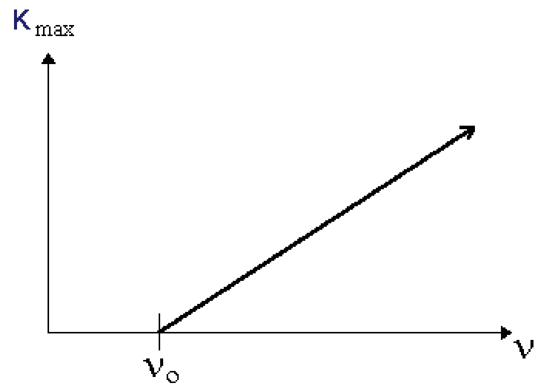


– $K_{max}$ increases with photon frequency $\nu$

– No photoelectrons if $\nu$ is smaller than a certain value ($\nu_0$)

➔ These cannot be explained by EM waves

Larger intensity ➔ Larger E-field ➔ Larger force (F=qE)

➔ Photoelectronics should have larger kinetic energy

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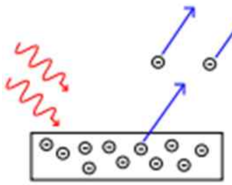

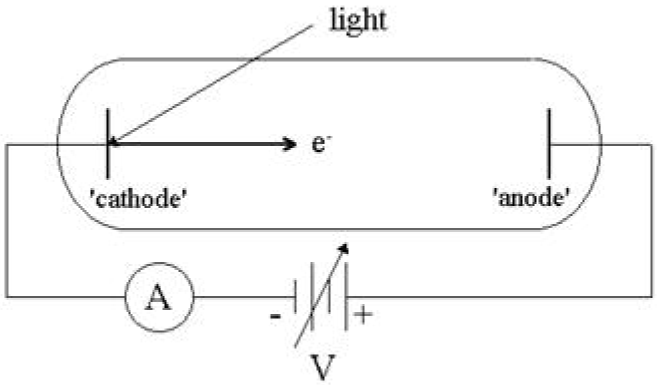


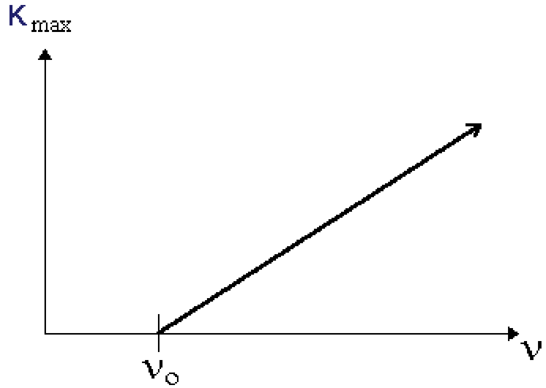


Einstein's explanation: Light delivers energy in chunks (1905)

Light quantum ➔ photon

$$E_{photon} = h\nu$$

$$E_{photon} = h\nu \;= h\frac{c}{\lambda} \;\simeq 4.136\times10^{-15}(eV\cdot\sec)\frac{3\times10^{8}\,\text{m/sec}}{\lambda} \;\simeq \frac{1.24}{\lambda[\mu m]}eV$$

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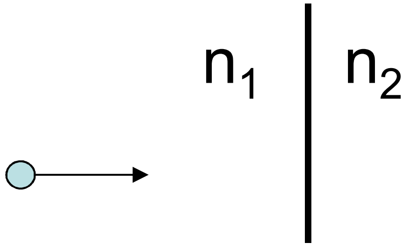
How can photons explain what we have learned about EM waves

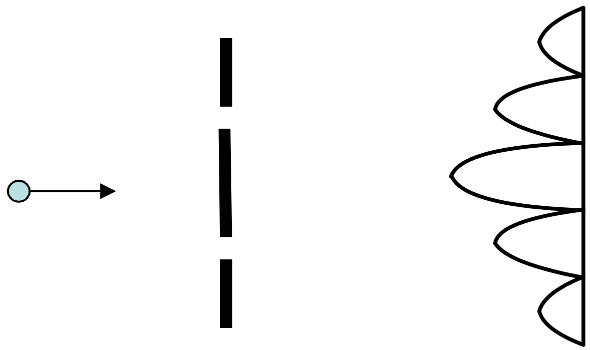
➔ reflection, interference, waveguide …

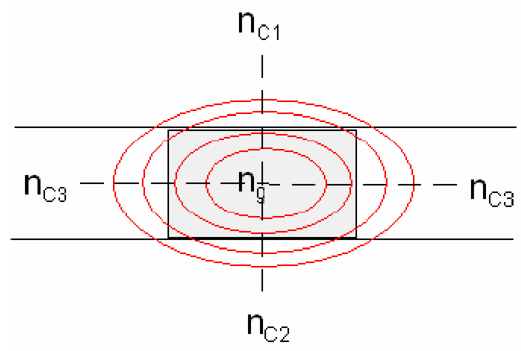



$$R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$$

Probabilistic Interpretation from QM

➔ R represents the probability for detecting the reflected photon






- Use whichever (wave or photon) is more convenient for the given problem

- Wave/particle duality applies to everything in nature (Quantum Physics)

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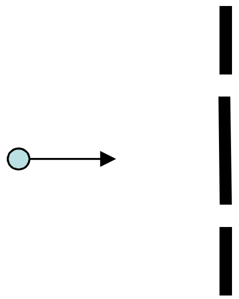
What if a single photon is incident on a double slit?



Which slit does it pass slit?

➔ Both slits simultaneously

Superposition of two probabilistic states

$$\psi = a\psi_a + b\psi_b$$

The state is determined after measurement

Possible to 'entangle' two photons

$$\psi_1 = a\psi_{1a} + b\psi_{1b}$$

$$\psi_2 = a\psi_{2a} + b\psi_{2b}$$

We do not know which state each photon is in

But when one photon is measured to be in one state

Then the other photon must be in the same state

➔ Basis of quantum computers

# Lecture 19: Photons

Homework (Due on 11/22)

Around the turn of the 20th century, there were two experimental observations concerning EM waves that could not be explained by the wave nature of light.

**(a)** Briefly describe these experimental observations why they could not be explained by then existing theories.

**(b)** Identify two scientists who came up with new theoretical interpretations for the nature of light in order to explain those observations. Briefly explain their interpretations.