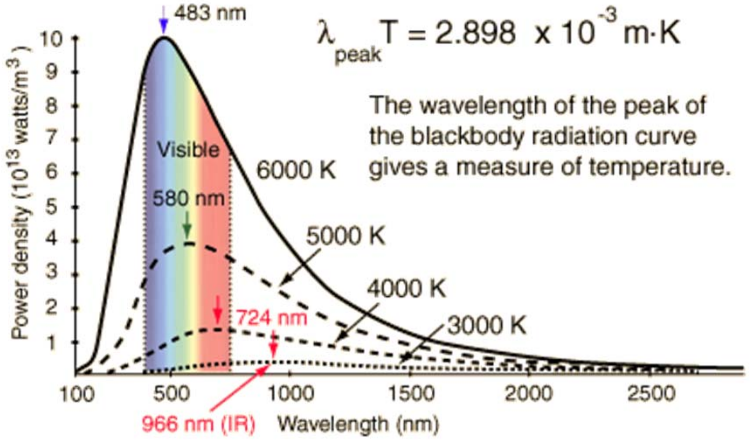
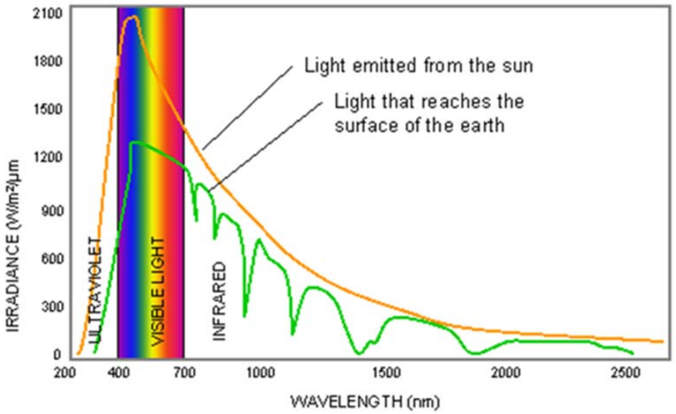
Lect. 19: Light as a Particle (Photon)

Phenomena that cannot be explained by wave nature of light

Blackbody Radiation: EM radiation from an heated object at equilibrium

Temperature
➔ oscillation of charges inside the object
➔ EM radiation

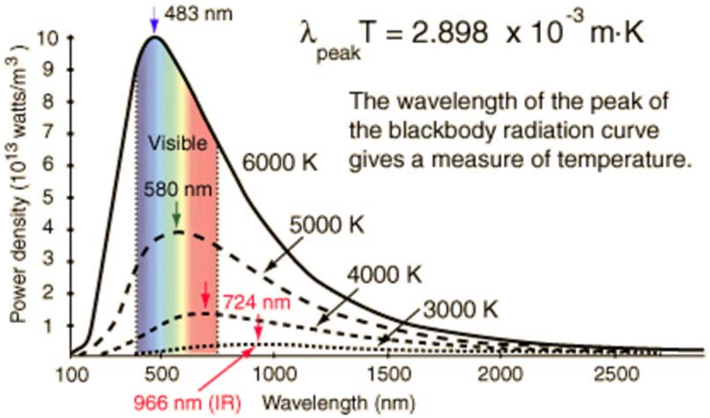




Temperature of sun
at the surface: 5778K

Lect. 19: Light as a Particle (Photon)

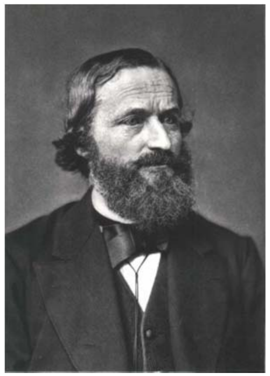
Blackbody Radiation: EM radiation from an heated object at equilibrium



Temperature
➔ oscillation of charges inside the object
➔ EM radiation

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

For example,



Gustav Kirchoff
(1824 ~ 1887)

Coined the term "Blackbody Radiation"

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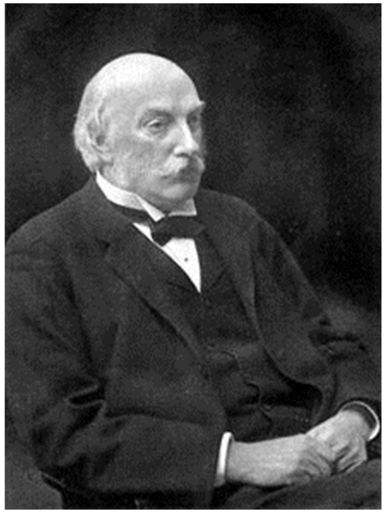
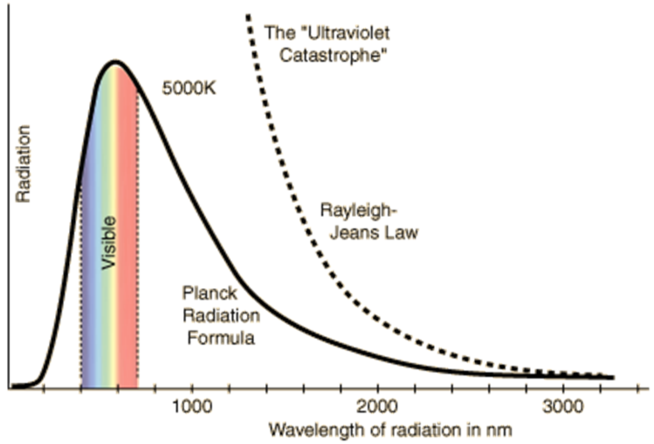
Rayleigh-Jeans Law : $$\frac{8\pi\nu^2}{c^3}kT$$



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

(Sir) James Jean
(1877~1946)



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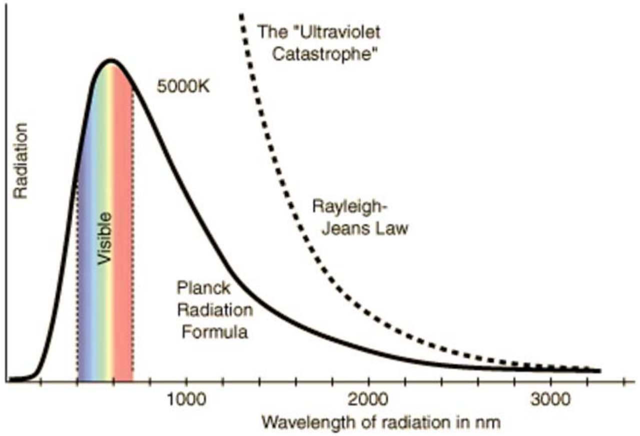
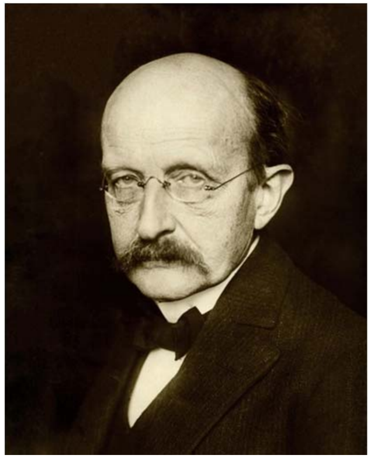
Rayleigh-Jeans Law: $\dfrac{8\pi\nu^2}{c^3}kT$





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, 6.626×10^{-34} J-s, 4.136×10^{-15} eV-s)

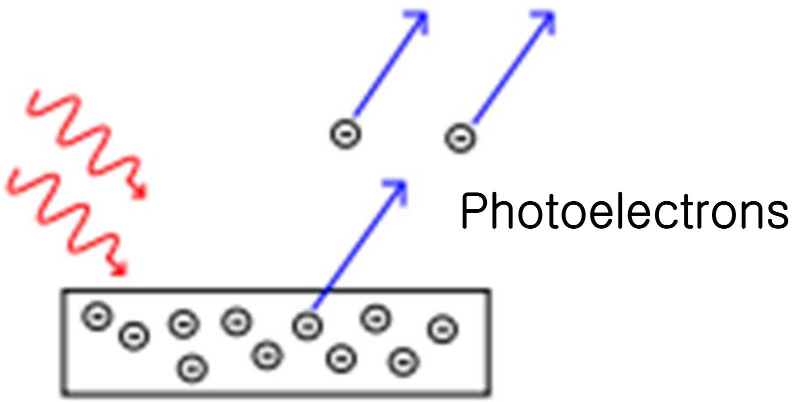
Classical	Rayleigh-Jeans Law	Planck Law	Quantum
	$\dfrac{8\pi\nu^2}{c^3}kT$	$\dfrac{8\pi\nu^2}{c^3}\dfrac{h\nu}{e^{\frac{h\nu}{kT}}-1}$	

(Spectral energy density: energy per bandwidth per volume)

Beginning of Quantum Mechanics

Lect. 19: Light as a Particle (Photon)

Photoelectric effects: Electron emission when light shines on a material



Discovered in 1887 by

Heinrich Hertz
(1857 - 1894)

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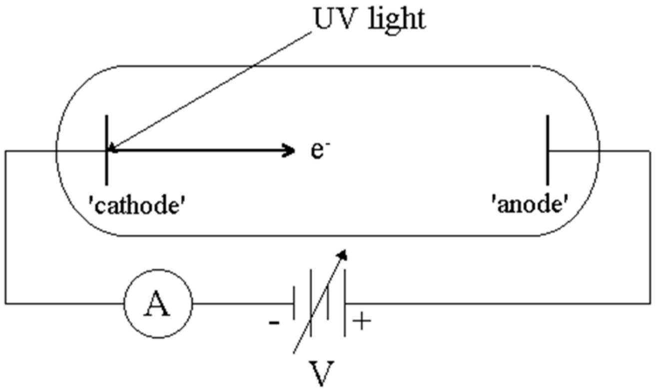
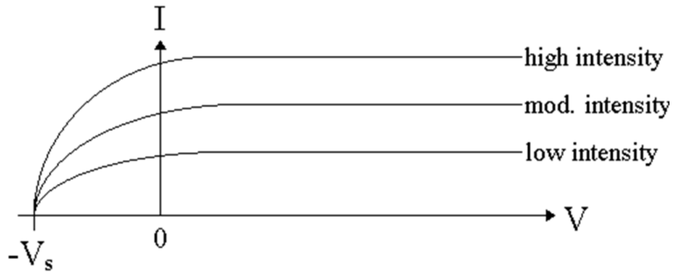
Photoelectric effect





- Amount of photoelectrons depends on light intensity
- Same minimum voltage for current flow regardless of light intensity

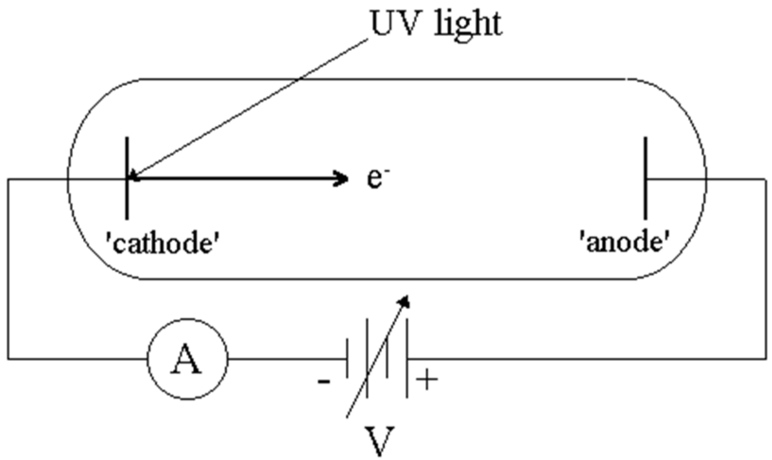
$$qV_s = \frac{1}{2}mv_{max}^2 (= K_{max})$$

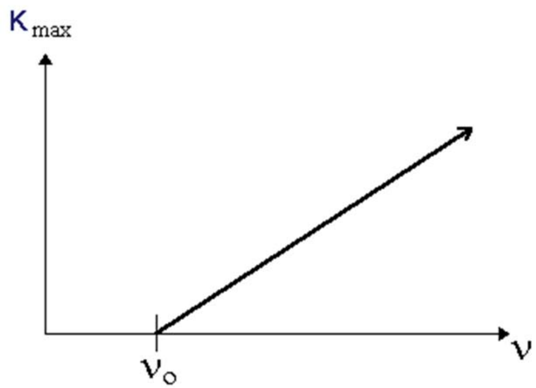
➔ Same max. kinetic energy for emitted electrons regardless of light intensity?

- What determines the max. kinetic energy of photoelectrons?

W.-Y. Choi

Lect. 19: Light as a Particle (Photon)





- K_{max} increases with photon frequency, ν
- No photoelectrons if ν is smaller than a certain value

➔ 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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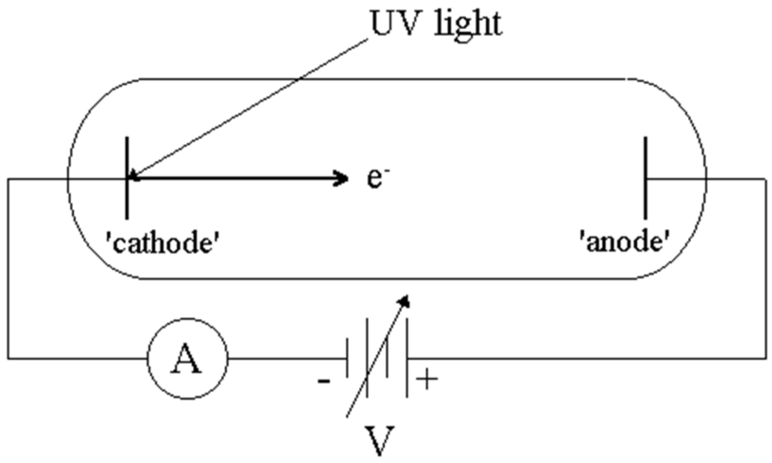
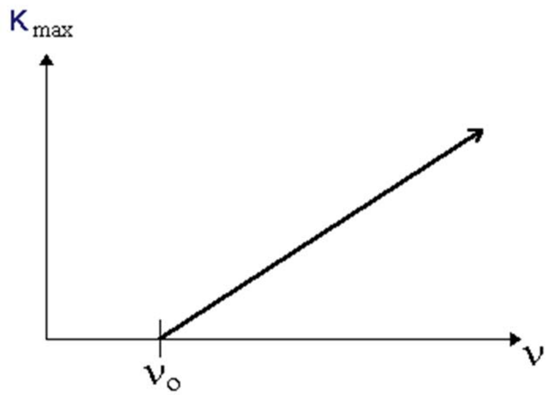




Einstein's explanation: Light delivers energy in chunks (1905)

Light quantum ➔ photon

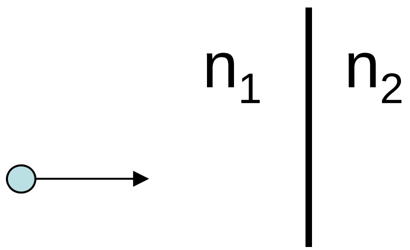
$$E_{photon} = h\nu$$

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

Lect. 19: Light as a Particle (Photon)

How can photons explain what we have learned about EM waves

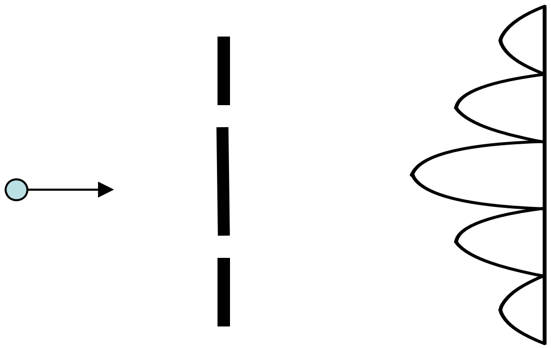
➔ reflection, interference, waveguide …

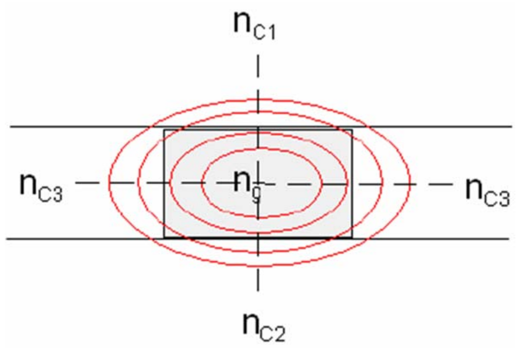


$$R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$$

Probabilistic Interpretation from QM

➔ R represents probability for detecting the reflected photon





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

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

Lect. 19: Light as a Particle (Photon)

Homework

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.