THERMAL & STATISTICAL PHYSICS
SSP3133

BLACKBODY RADIATION

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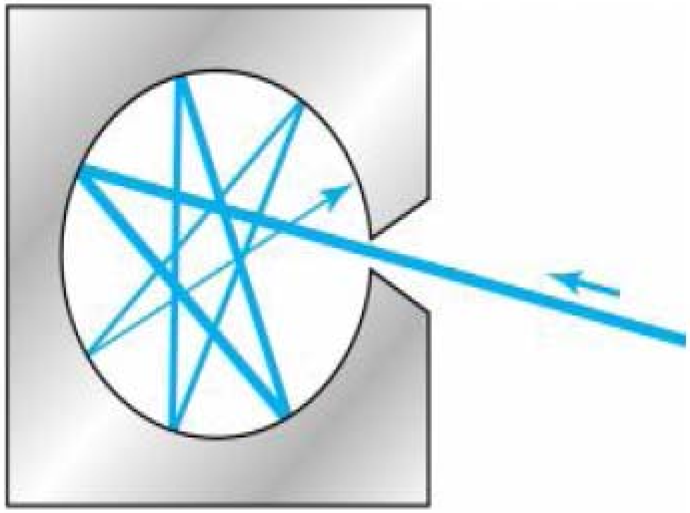
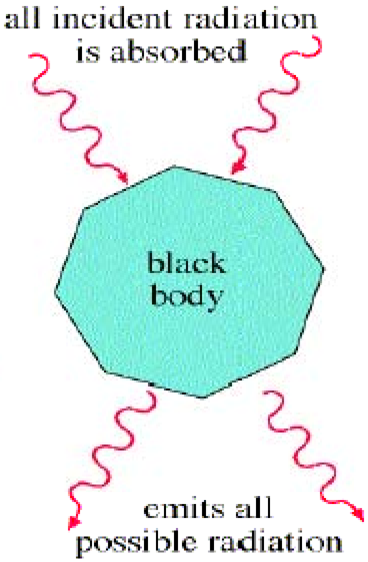
- Acknowledgement : PROFESSOR DR RAMLI ABU HASSAN

Late 1800's the wave picture of light could explain most of the experiments done on light,…..except few,

-One of them is the **blackbody radiation**,

-the characteristic radiation that a body emits when heated.





Blackbody = a cavity, such as a metal box with a small hole drilled into it.

Incoming radiations entering the hole keep bouncing around inside the box with a negligible change of escaping through the hole. ***All incident radiation is absorbed.***

A black body -Also a perfect emitter of radiation –***black body radiation***

What happens to this radiation?

- The radiation is absorbed in the walls of the cavity
- This causes a heating of the cavity walls
- Atoms in the walls of the cavity will vibrate at frequencies characteristic of the temperature of the walls

- These atoms then re-radiate the energy at this new characteristic frequency

  The emitted "thermal" radiation characterizes the equilibrium temperature of the black-body

Basic Laws of Radiation

1) All objects emit radiant energy.
2) Hotter objects emit more energy than colder objects. The amount of energy radiated is proportional to the temperature of the object raised to the fourth power.

This is the Stefan Boltzmann Law

$$\mathbf{F = \sigma T^4}$$

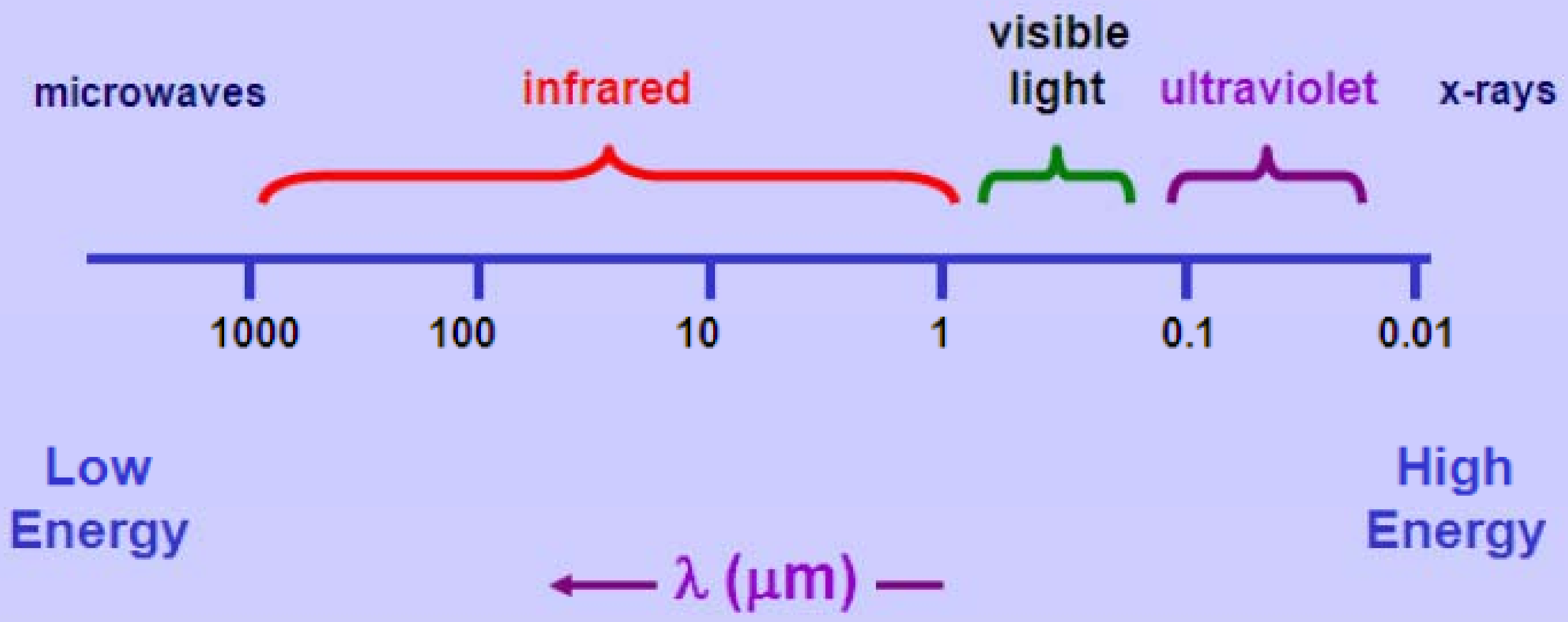
F = flux of energy (W/m^2)
T = temperature (K)
$\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$ (a constant)

Basic Laws of Radiation

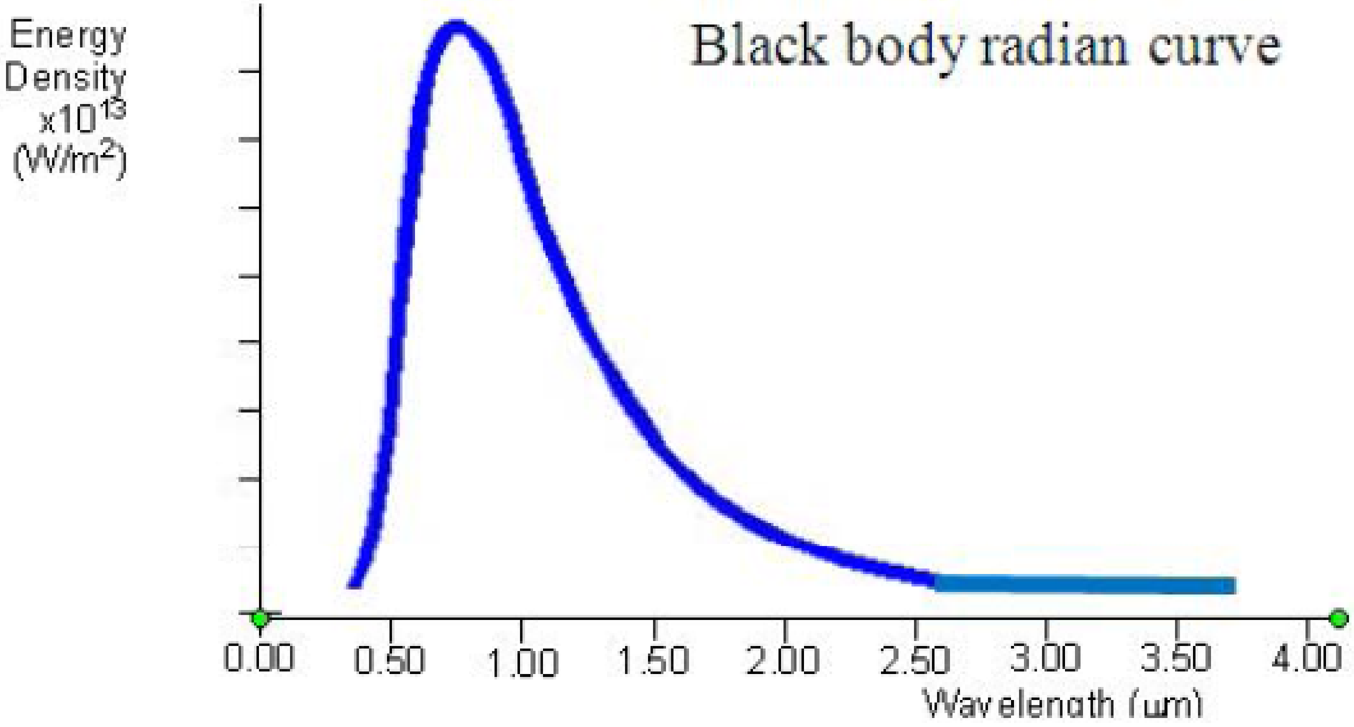
1) All objects emit radiant energy.
2) Hotter objects emit more energy than colder objects (per unit area). The amount of energy radiated is proportional to the temperature of the object.
3) The hotter the object, the shorter the wavelength (λ) of emitted energy.
4) This is Wien's Law

$$\lambda_{max} \cong \frac{3000 \ \mu m}{T(K)}$$

Electromagnetic Spectrum



Black body radiation is defined as thermal radiation of a black body, and can be given by Plank's law as a function of temperature T and wavelength.

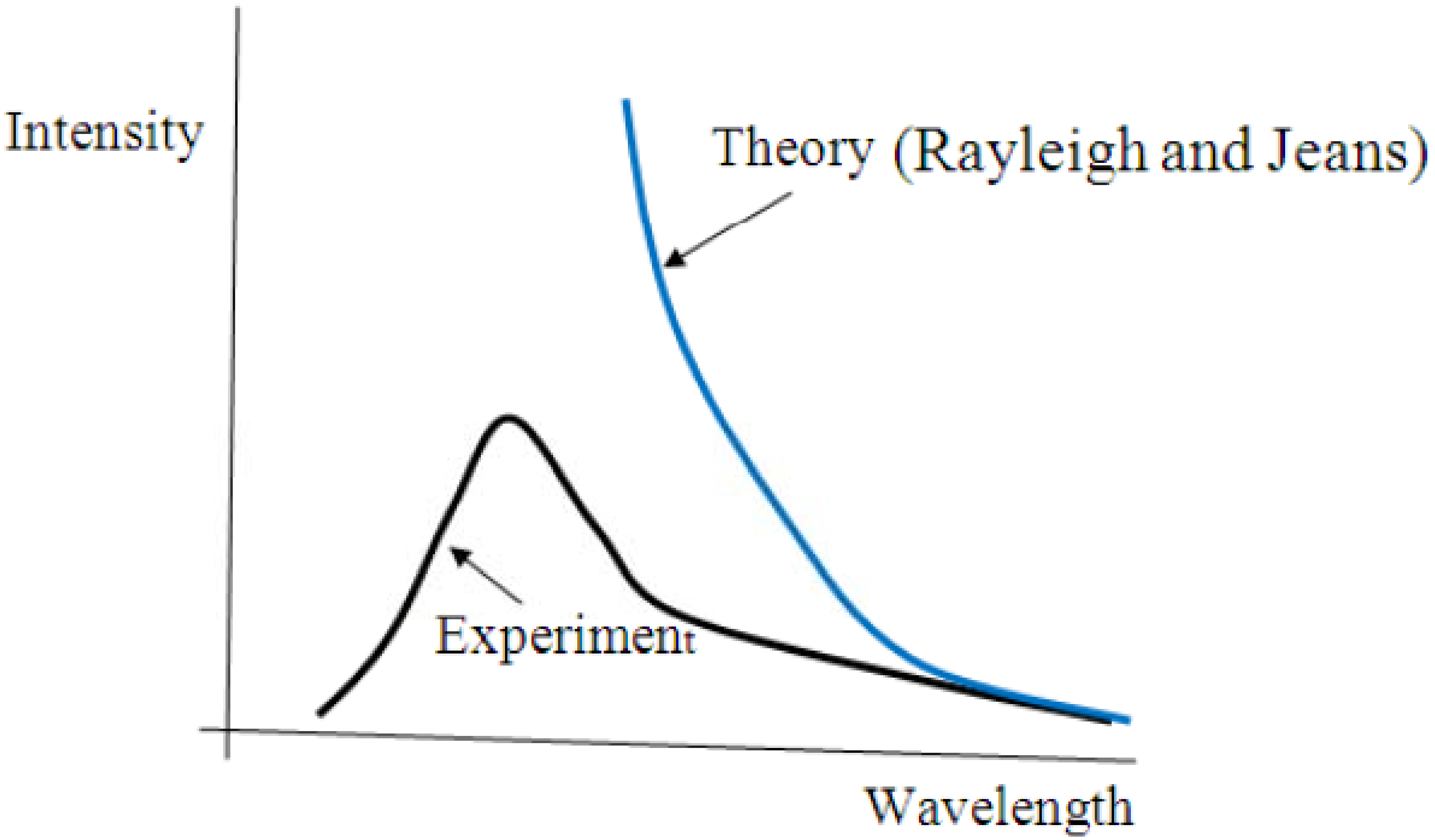


Rayleigh and Jeans -- formula by considering the radiation within the black body cavity to be made up of a series of standing waves

$$I = \frac{2\pi ckT}{\lambda^4}$$

$\lambda \rightarrow \propto$ $\quad I \rightarrow 0$ -agrees with the experiment

$\lambda \rightarrow 0$ $\quad I \rightarrow \propto$ -not agrees with the experiment



The ultraviolet catastrophe

-The failure of the wave theory (Rayleigh-Jeans formula) to account for the decrease in energy emitted at short wavelengths

Max Planck,

-formula that agreed with experimental data

-idea: the oscillating electrons of the surface atoms of the black body emitted radiation according to Maxwell's laws of electromagnetism.

Planck theory on blackbody radiation

-the molecules of a mass cannot have arbitrary energies but instead are **quantized**

-good agreement for all wavelengths

Planck Formula

$$E = nhf$$

$n = 0,1,2,...$ is an integer

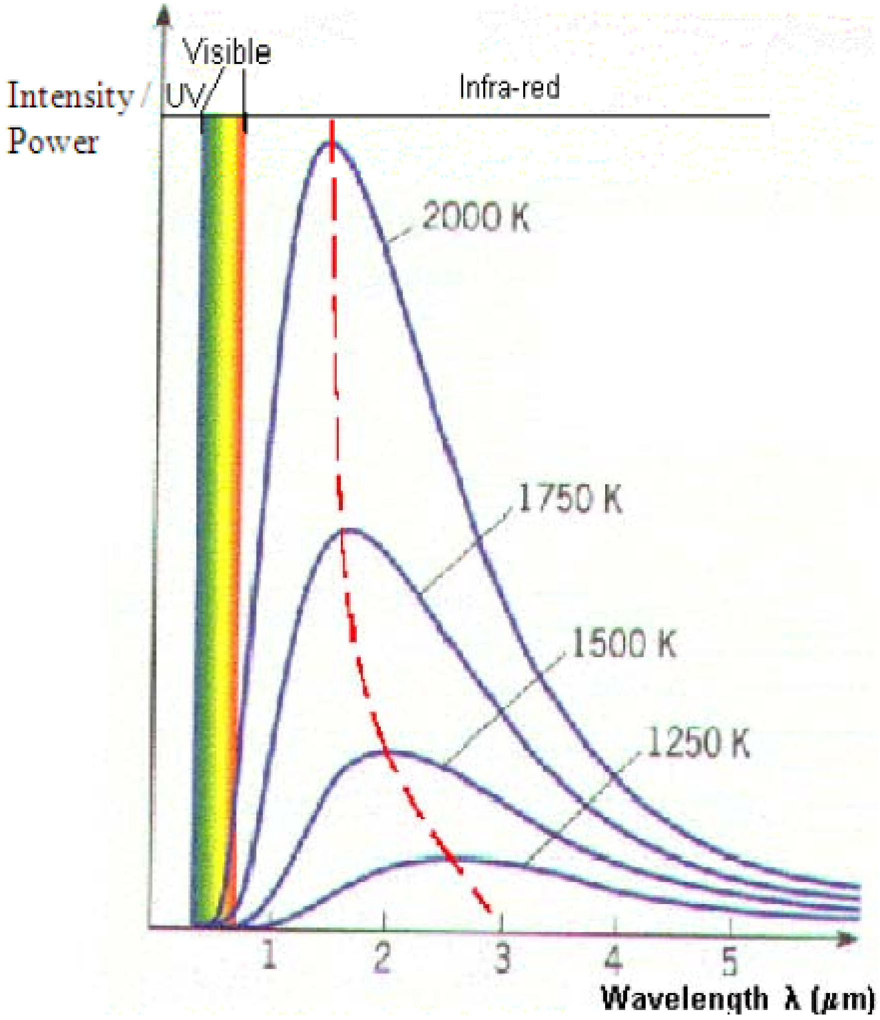
f - the frequency of vibration of the molecule

h - *Planck's constant:*

-when a molecule went from a higher energy state to a lower one it emitted quanta (packet) of radiation, or ***photon****, which carried away the excess energy*

-successfully explain the blackbody radiation curves

The black body radiation curve



The black body radiation curve

-radiate energy at every wavelength
-at higher λ close to but never touches the x-axis

-peak wavelength, at which most of the radiant energy is emitted
-area under the curve –energy emitted at certain T

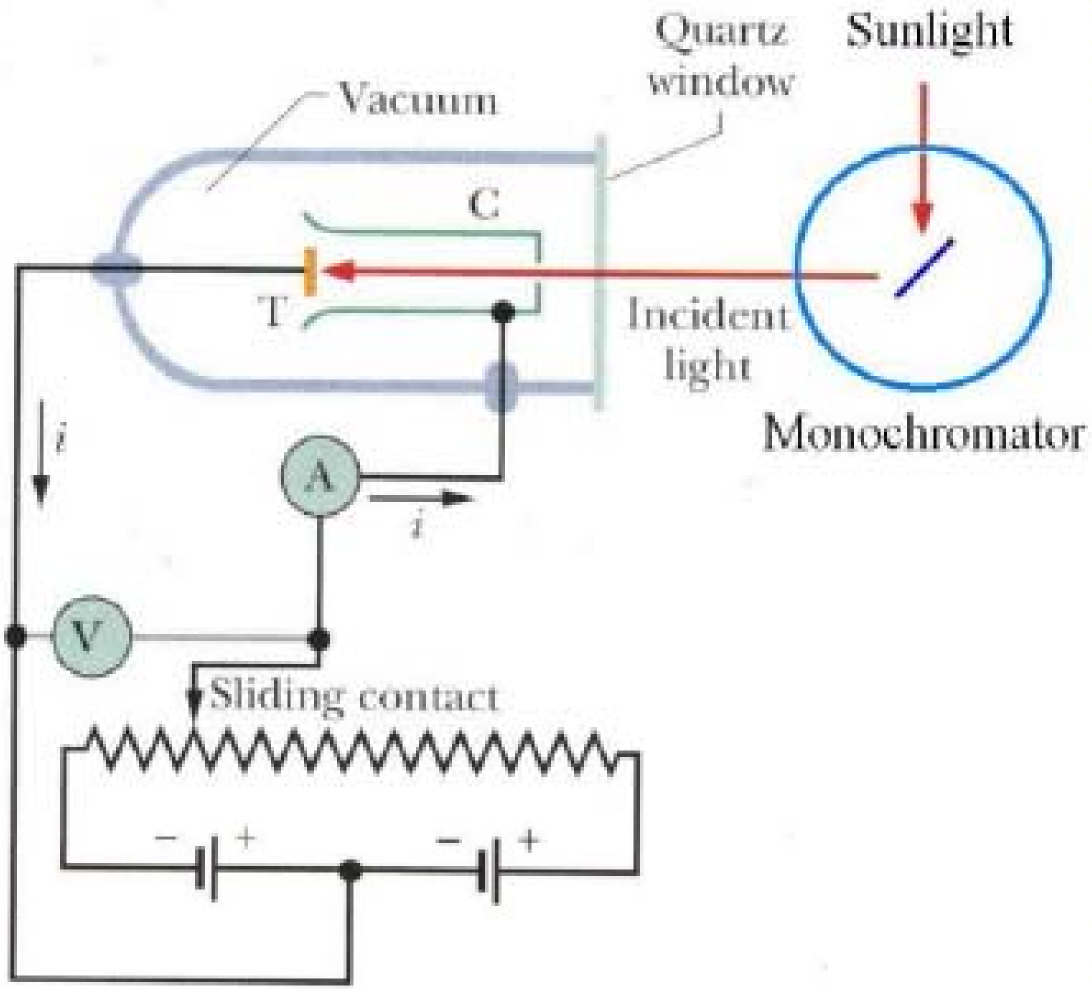
THE PHOTOELECTRIC EFFECT

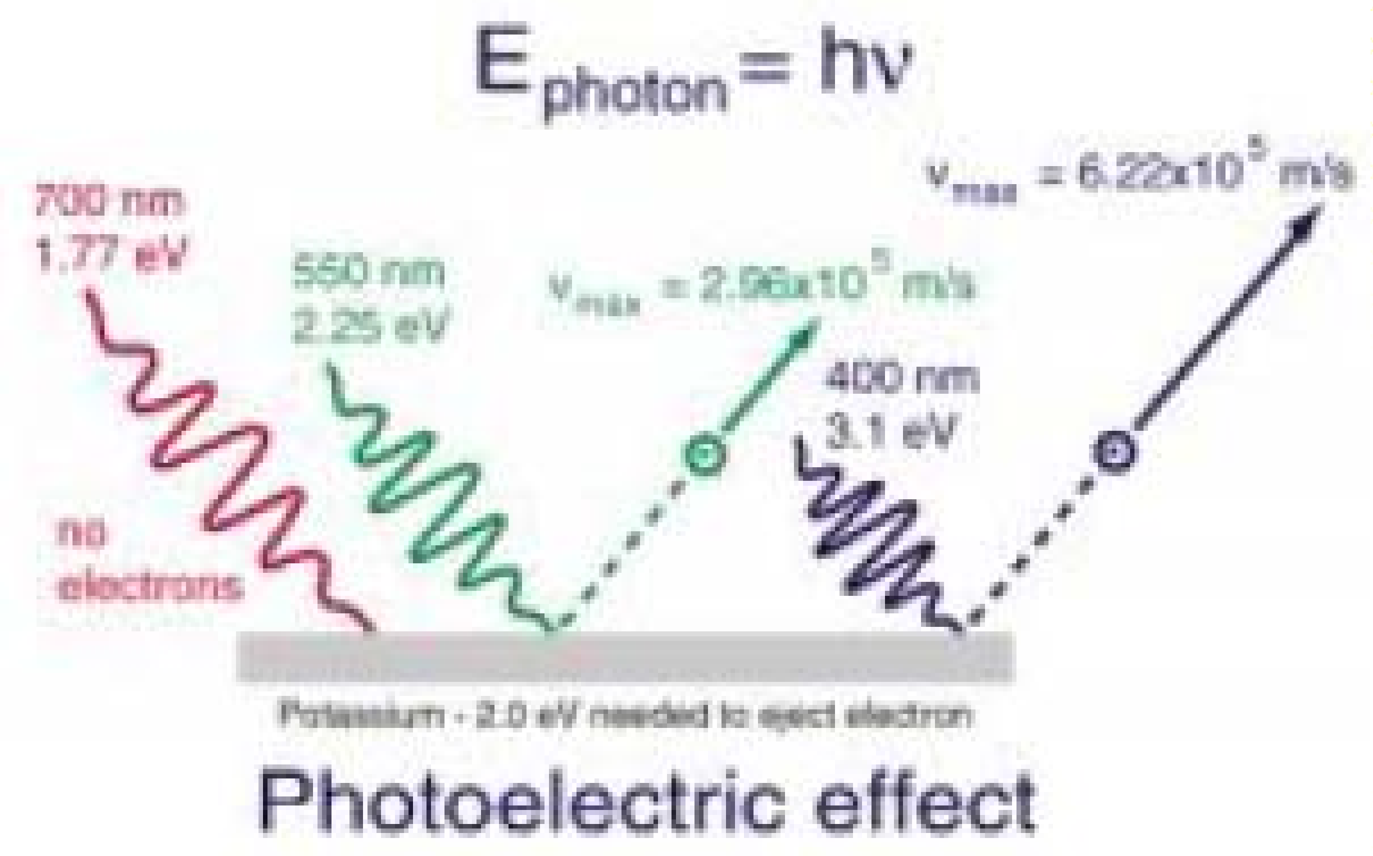
When light is shone on metal

- the surface may become positively charged
- electrons gain energy from the light waves, and leave the metal's surface.

Some effects that could not be explained by wave theory of light

- frequency of the light > threshold frequency
- Weak beams of light can cause electrons to be emitted –not possible if light was a wave
- the kinetic energy of the electron depends on frequency not intensity


Quartz window
Sunlight
Vacuum
C
T
Incident light
Monochromator
i
A
i
V
Sliding contact
−
+
−
+


$E_{photon} = h\nu$
700 nm
1.77 eV
no electrons
550 nm
2.25 eV
$v_{max} = 2.96\times10^5$ m/s
400 nm
3.1 eV
$v_{max} = 6.22\times10^5$ m/s
Potassium - 2.0 eV needed to eject electron
Photoelectric effect

Einstein explained:

- One photon gave all its energy to one electron
- One electron can only accept one photon of energy, so this must have the required frequency to have the necessary escape energy
- The intensity will not make any difference

Classical limit of Quantum Statistical Distributions

The average number of noninteracting quantum particles in state j is

$$\overline{n}_j = \frac{1}{e^{\beta(E_j-\mu)}-1} \quad \text{or} \quad \overline{n}_j = \frac{1}{e^{\beta(E_j-\mu)}+1}$$

-ve : BED
+ve: FDD

Low population (n→0) there are much more energetically accessible states than particles. This limit is achieved for all states of energy ε_j when

$$e^{\beta(E_j-\mu)} >> 1$$

$$\overline{n}_j \approx e^{-\beta(E_j-\mu)}$$

the average number of particles is

$$\overline{N} = \sum_j \overline{n_j} \approx \sum_j e^{-\beta(E_j-\mu)}$$

$$\beta\mu = \ln \overline{N} - \ln \sum_j e^{-\beta\varepsilon_j}$$

Since $$\frac{\overline{n_j}}{N} = \frac{e^{-\beta E_j}}{\sum_j e^{-\beta E_j}}$$

Which is the classical Boltzmann distribution.

Therefore, in the limit $\vec{U}_f \Rightarrow 0$ when both the FD and the BE distributions converge to the classical Boltzmann distribution

AT LAST!

THANK YOU FOR YOUR PATIENCE GUYS…

REFERENCES:

1. REAF, F : “Fundamentals Of Statistical And Thermal Physics”, McGraw-Hill.

2. KITTEL & KROMER: “Thermal Physics”, W.H. Freeman & Company.