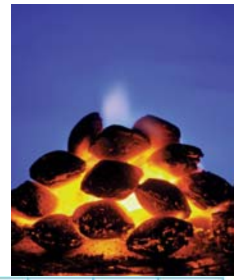
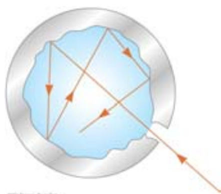
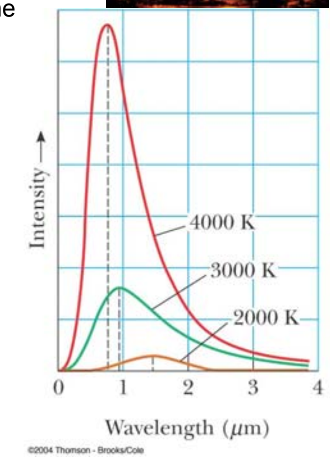
Blackbody Radiation



- A Blackbody is an ideal system that absorbs all radiation incident on it. Emission of radiation by a blackbody is independent of the properties of its wall, but depends only on its temperature

- When the temperature of the blackbody increases, the spectrum of emitted radiation shifts to lower λ.





- Rayleigh-Jeans law was an attempt to explain blackbody radiation based on classical ideas:

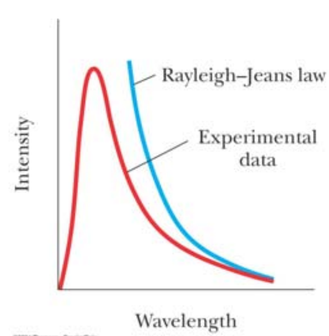
  – Blackbody is modeled in terms of modes of oscillations of the e/m field in the cavity due to the accelerating charges on cavity walls.

  – # of Degrees of Freedom for oscillations go up as λ goes down

  – Equipartition of energy: Each DOF carries an energy $k_B T$: where k_B is the Boltzman constant.
  – Intensity (power per unit area):

$$I(\lambda, T) = \frac{2\pi k_B T}{\lambda^4}$$

Ultraviolet Catastrophe



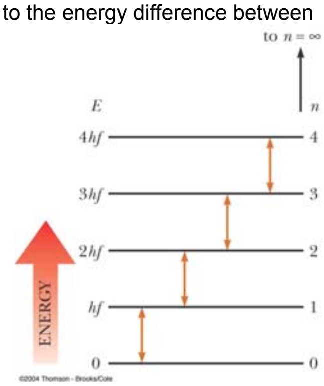
Max Planck's theory of Blackbody radiation

- Planck's assumptions on the nature of the oscillators in the cell walls:
  - The energy of an oscillator can only have a **discrete** set of values E_n:

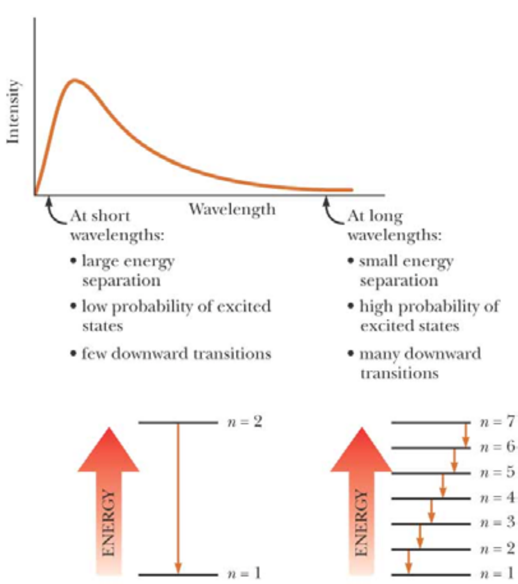
$$E_n = nhf$$

n is the **quantum number**, ***f is*** the frequency of oscillations and ***h*** is a new parameter Planck introduced: it is called **Planck's Constant** now. Energy is said to be **quantized** and each discrete value of energy corresponds to a **quantum state**.

- The oscillators emit or absorb energy when making a transition from one quantum state to another. The amount of energy emitted or absorbed is equal to the energy difference between initial and final quantum states:



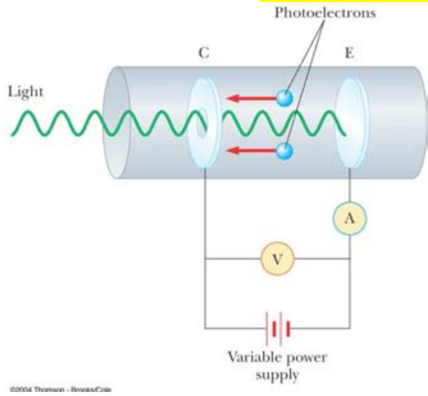
- As l increases the gap between energy levels goes down
- Boltzman's distribution law:
  - the probability of a state of being occupied is proportional to: e^{-E/k_BT}

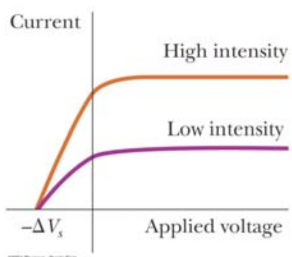


$$I(\lambda, T) = \frac{2\pi hc^2}{\lambda^5 (e^{hc/\lambda k_B T} - 1)}$$

h = 6.626 x 10^{-34} **J.s**

The Photoelectric Effect





•When light (or some other e/m wave) is incident on certain metallic surfaces, electrons are emitted from those surfaces.

• This setup will register a current only when light of appropriate frequency is incident on plate E.

•A negative potential applied against the movement of the photo-electrons will reduce the current and will eventually stop the flow altogether at a stopping potential ΔV_s :

$$K_{max} = e\,\Delta Vs$$

•A classical explanation of the photoelectric effect would predict:

•Kinetic energy of the photoelectrons should increase with light intensity

•Emission of photoelectrons and their kinetic energy should be independent of the light frequency

•When the light intensity is very low there should be a time delay before the photoelectron emission

•Experimental observation:

•Kinetic energy of the photoelectrons is independent of the light intensity but increases with the frequency

•No photoelectrons are emitted below some **cutoff frequency** f_c

•Photoelectrons are emitted instantaneously independent of the intensity.

In 1905 Einstein extended Planck's quantization to e/m waves to explain the photoelectric effect:

- Light and other e/m waves consist of particles (quanta) called photons.
- Each photon has energy ***E = hf,*** where ***f*** is the frequency of the wave.
- An incident light photon gives all its energy to a single electron in the metal

Absorption of light is not continuous: it is delivered in discrete packets

$$K_{max} = hf - \phi$$

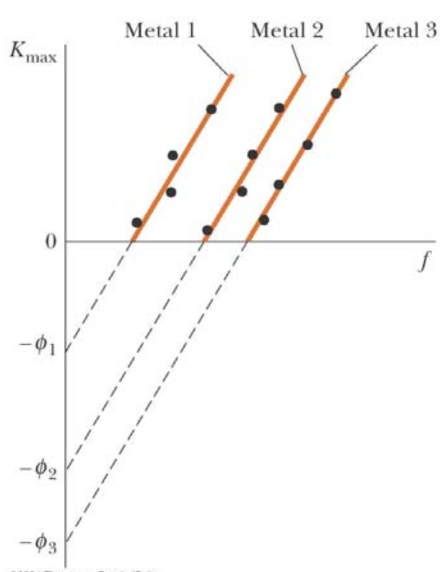
ϕ : **work function** of the metal; the minimum energy required to remove an electron from the metal

Table 40.1

Work Functions of Selected Metals[a]

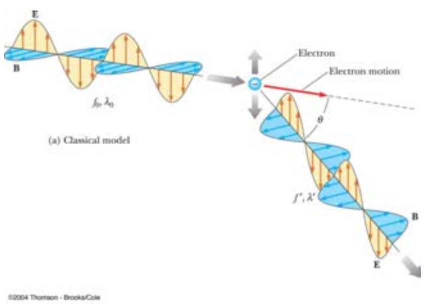
Metal	ϕ (eV)
Na	2.46
Al	4.08
Cu	4.70
Zn	4.31
Ag	4.73
Pt	6.35
Pb	4.14
Fe	4.50

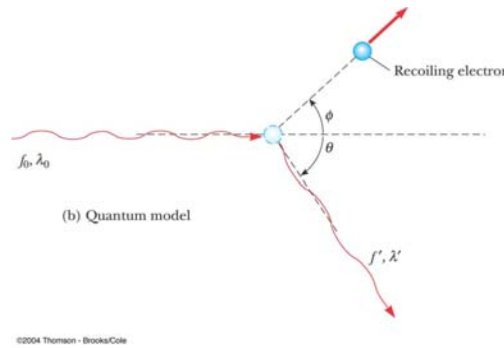
$$K_{max} = hf - \phi$$ **Equation of a line**



The Compton Effect: Scattering of X-rays from electrons

Einstein: Photons of light: Energy = *hf*; momentum = *E/c=hf/c*





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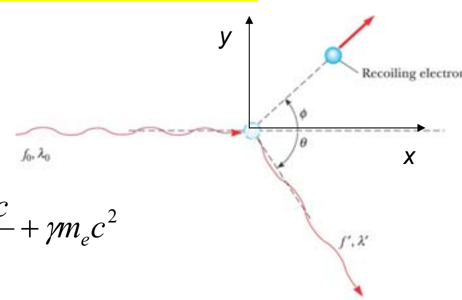

Energy conservation:

$$\frac{hc}{\lambda_0} + m_e c^2 = \frac{hc}{\lambda'} + \gamma m_e c^2$$

Momentum conservation: x direction:

$$\frac{h}{\lambda_0} = \frac{h}{\lambda'}\cos\theta + \gamma m_e v \cos\phi$$

Momentum conservation: y direction:

$$0 = \frac{h}{\lambda'}\sin\theta - \gamma m_e v \sin\phi$$

$$\lambda' - \lambda_0 = \frac{h}{m_e c}(1 - \cos\theta)$$

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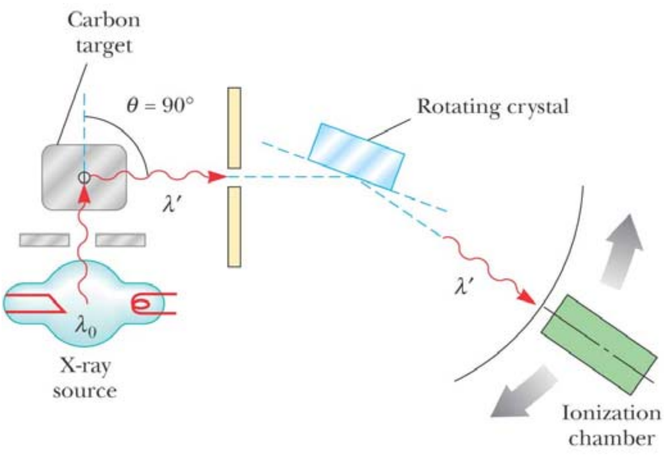

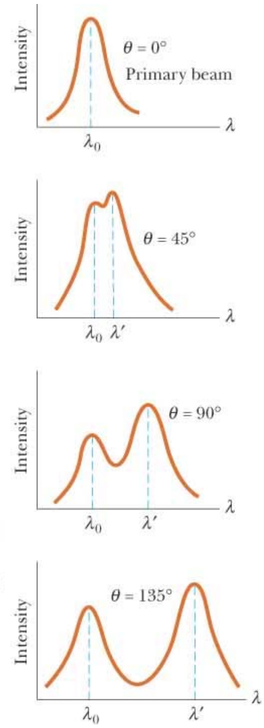

Light: particles or waves ?

Are not gross bodies and Light convertible into one another, and may not bodies receive much of their activity from the particles of light which enter their composition ?

Newton, ***Opticks*** (4th ed. 1730)

The particle (photon) model of light and the wave model of light complement each other; some experiments can only be described by the wave model while some others can only be described by the particle model.