Ch. 40 Quantum Physics

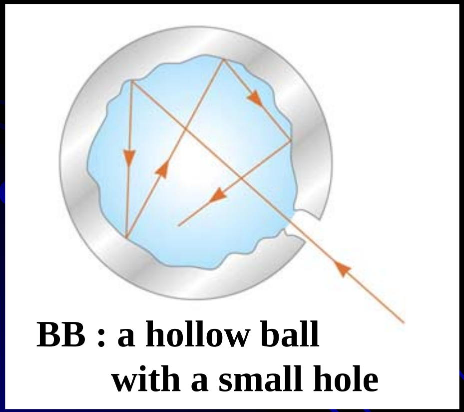
$\Rightarrow$ Understanding of matter on the atomic scale.

40.1 Blackbody radiation and Planck's hypothesis

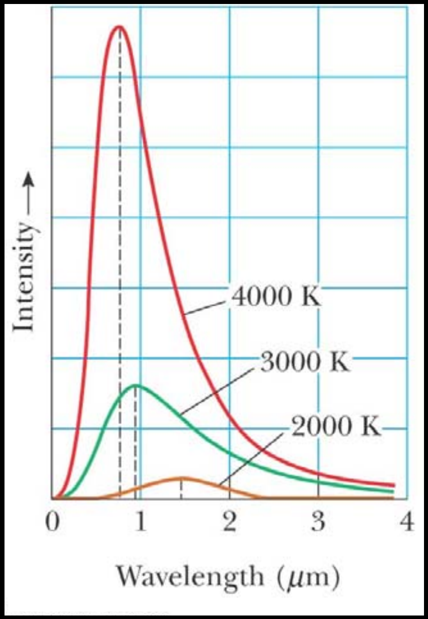
- Thermal radiation : An object at any T emits radiation.
  The characteristic of the radiation depends on T.

- **Blackbody radiation** (W. Herschel, 1800):

Distribution of I for $T_1 < T_2 < T_3$.



Intensity of blackbody radiation versus wavelength at three different temperatures. →

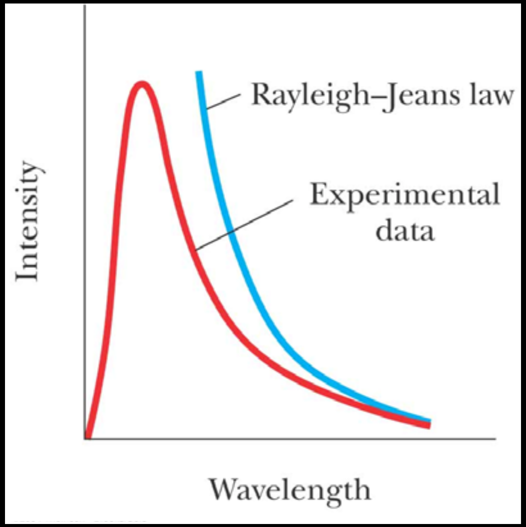


- **Planck's formula** for blackbody radiation (1900)

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

At long wavelength

$$I(\lambda, T) = 2\pi c k_B T / \lambda^4 \qquad \text{(R–J's law)}$$



- Two assumptions for Planck's theory :

1) The molecules can have only discrete values of energy E_n.

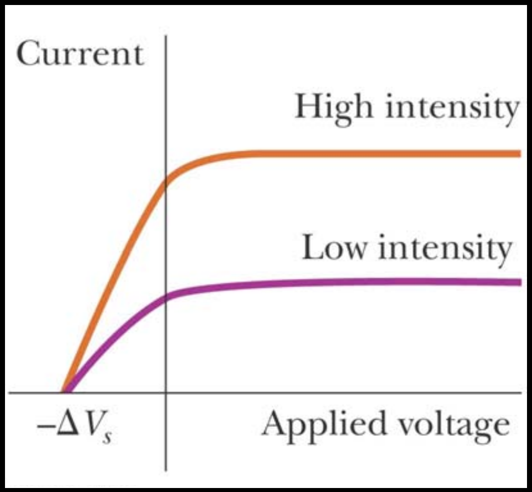
Quantized energy : $\boxed{E_n = nhf}$

with
- n Quantum number,
- h (= 6.626×10^{-34} J·s) Planck's constant (*fundamental constant of nature*),
- f Natural frequency of oscillations of molecules,
- hf Quantum of energy.

2) The molecules emit or absorb energy in discrete packets (***photons***).

40.2 The photoelectric effect (Heinrich Hertz, 1887)

- Light → metal surface → photoelectrons.

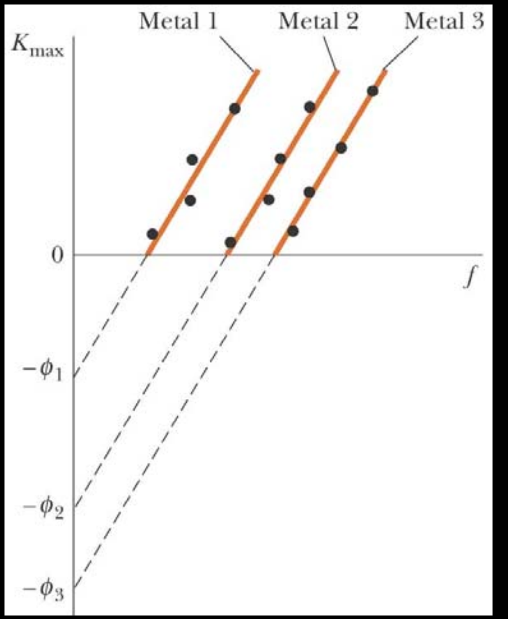


Maximum *KE* of photoelectrons :

$$\boxed{K_{max} = e\,\Delta V_s}$$

- Several features of the photoelectric effect :

1) For $f < f_c$ (cutoff frequency), no photoelectrons are emitted.
2) Maximum *KE* of the photoelectrons is independent of light intensity.
3) Maximum *KE* of the photoelectrons increasing with increasing light frequency.



The photoelectric effect

1) $f_c = \phi / h$. If $hf < \phi$, the electrons are never ejected from the metal surface, regardless of light intensity.

2) $K_{max}(f, \phi)$, not on the light intensity.

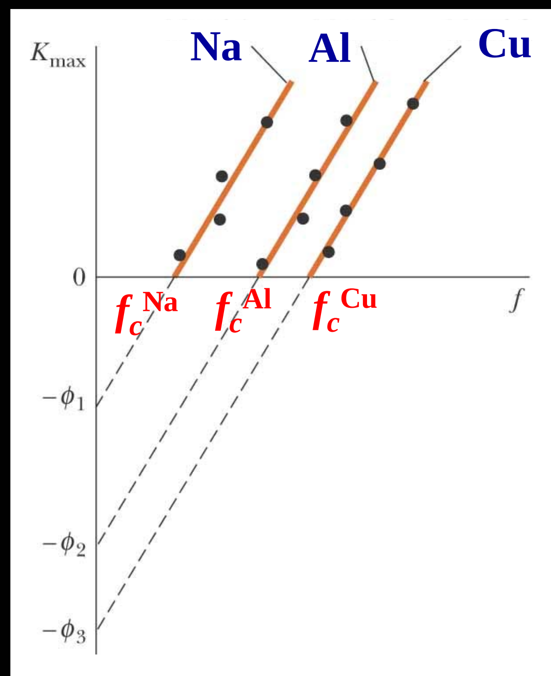
→ Nobel prize (1921)

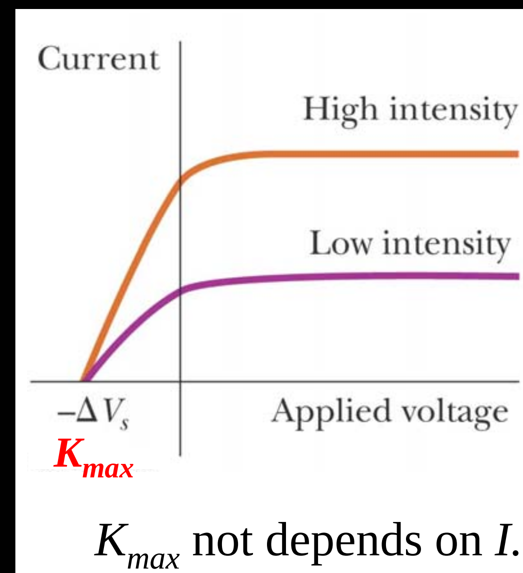
3) $K_{max} \propto f$

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

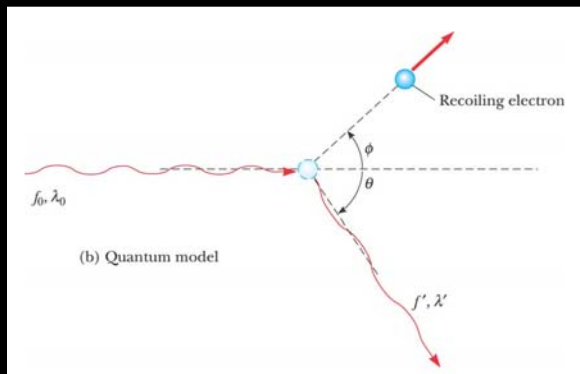


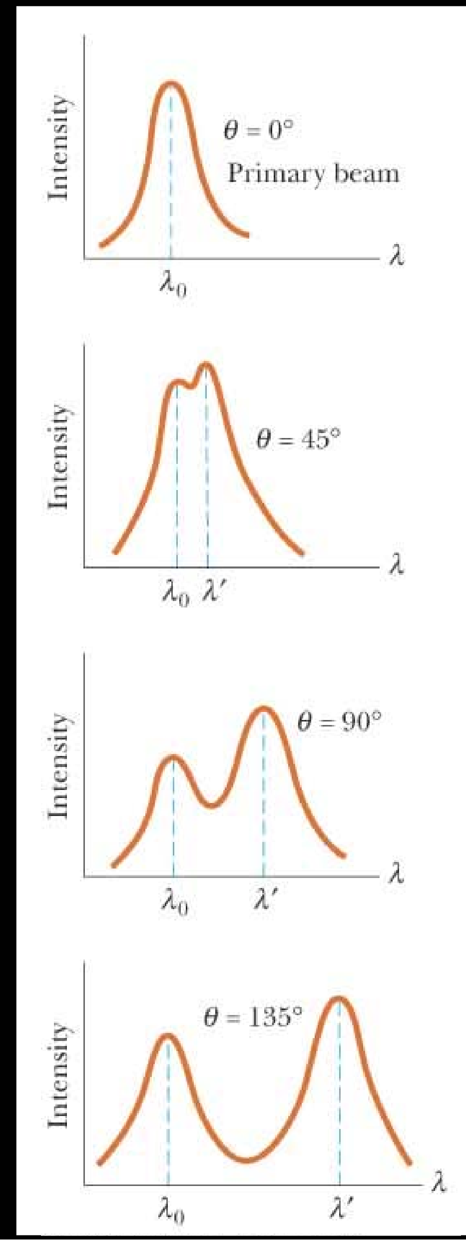


The greater the work function, the higher the minimum frequency needed to emit photoelectrons.

40.3 The Compton effect

→ Scattering of short λ light (X-rays) with electrons of material.





- Momentum of a photon : $p = E / c = hf / c = h / \lambda$

→ Shift of λ to a longer λ´ indicating a loss of energy.

$$\boxed{\lambda' = \lambda_o + (h / m_e c)(1 - \cos\theta)}$$

$$= \lambda_o + \lambda_c (1 - \cos\theta)$$

with Compton wavelength

$$\lambda_c = h / m_e c = 2.426 \text{ pm}$$

Compton shift : $\Delta\lambda = \lambda' - \lambda$

$$= \lambda_c (1 - \cos\theta)$$