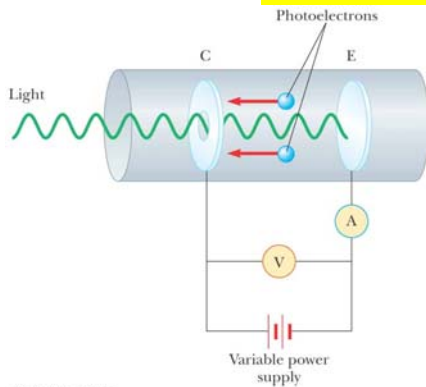# The Photoelectric Effect

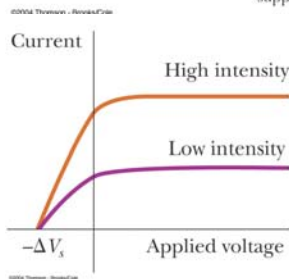Photoelectrons

C   E

Light

•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 :

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

Variable power supply

Current

High intensity

Low intensity

$-\Delta V_s$ Applied voltage

•**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

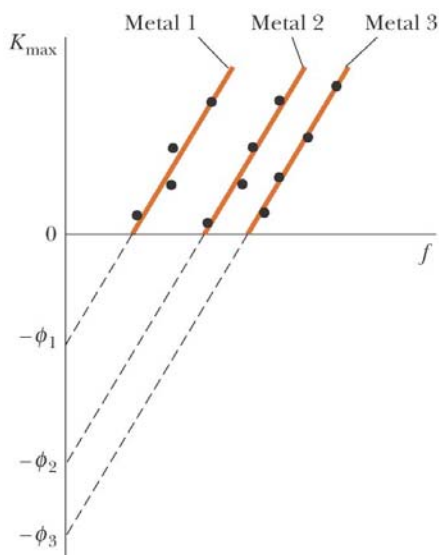**Absorption of light is not continuous: it is delivered in discrete packets**

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

ϕ : **work function** of the metal; the minimum energy required to remove an electron from the metal
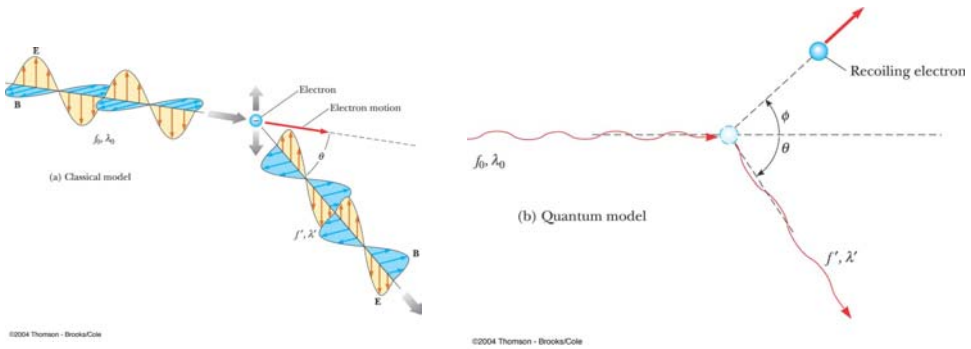
Table 40.1

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**
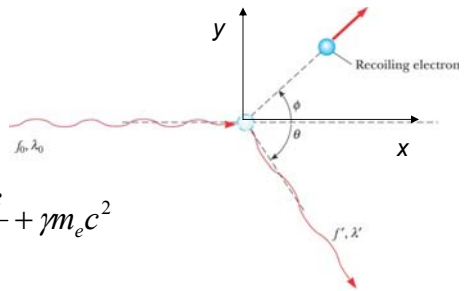

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The Compton Effect: Scattering of X-rays from electrons

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

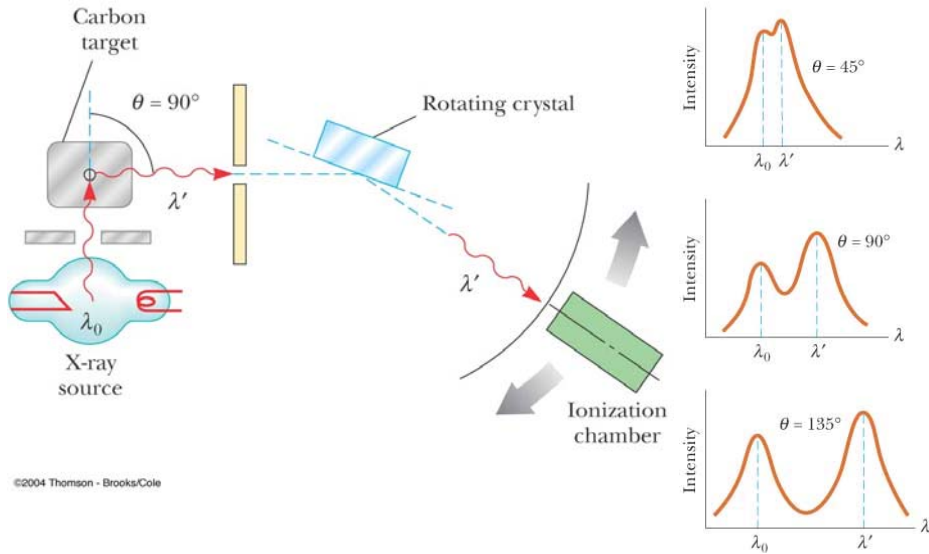## The Compton Effect: Scattering of X-rays from electrons

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

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

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

Carbon target

$\theta = 90°$

λ'

λ_0

X-ray source

Rotating crystal

λ'

Ionization chamber

Intensity

$\theta = 0°$
Primary beam

λ_0

λ

Intensity

$\theta = 45°$

λ_0 λ'

λ

Intensity

$\theta = 90°$

λ_0 λ'

λ

Intensity

$\theta = 135°$

λ_0 λ'

λ

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.