Planck's Hypothesis

Max Planck
(German) 1900

An oscillator whose natural frequency is f can have only the discrete values of energy

$$E_{oscillator} = nhf \quad (n = 1, 2, 3, \ldots)$$

↑ Planck's constant
$h = 6.63 \times 10^{-34}\ J \cdot s$

<u>photon</u> – a quantum of electromagnetic energy in phenomena in which electromagnetic radiation behaves as if it had a "particle nature."

$$E = nhf \longrightarrow E = \frac{hc}{\lambda}$$

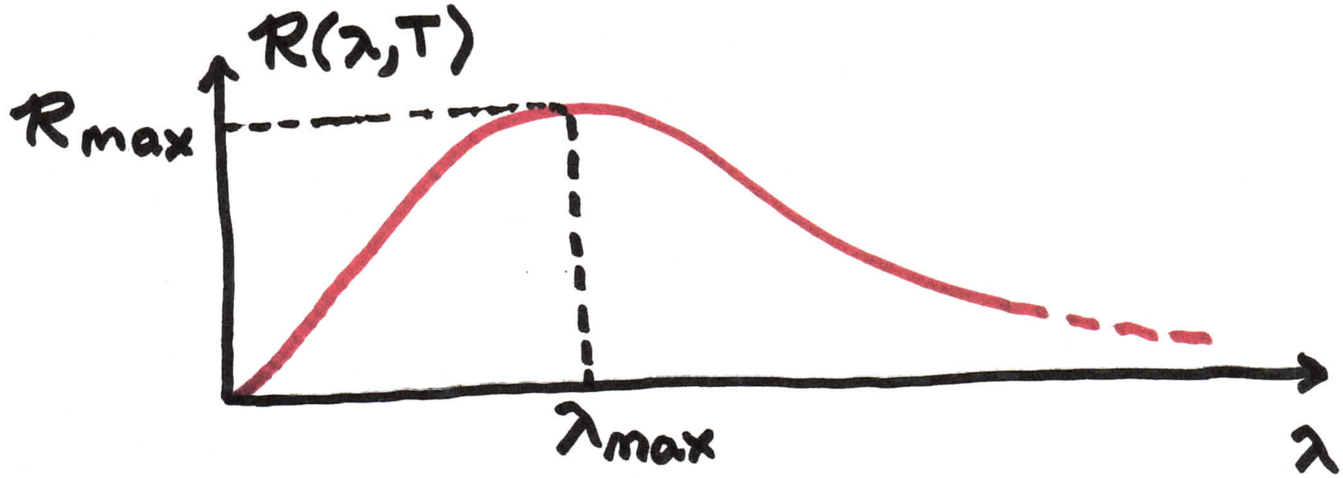
- E ← energy of photon
- n ← 1
- f ← $f = \frac{c}{\lambda}$

$hc = (6.63 \times 10^{-34}\ J \cdot s) \times (3 \times 10^{8}\ m/s) = 1240\ eV \cdot nm$

Problem 1: **Photon Problem**

What is the energy of a single 600-nm photon**?** What is the wavelength of a photon whose energy is 2.50 eV**?**

Wien's Displacement Law



Planck Radiation Law

$$R(\lambda,T) = \frac{2\pi hc^2}{\lambda^5}\frac{1}{\left[e^{hc/k_B\lambda T}-1\right]}$$

To find λ_{max}, set $\frac{\partial R}{\partial \lambda} = 0$ and solve for λ

get $\lambda_{max} T = 2.898 \times 10^6$ nm·K

Wilhelm Wien 1893 (German)

this constant is determined numerically

Problem 2: Blackbody Radiation Problem

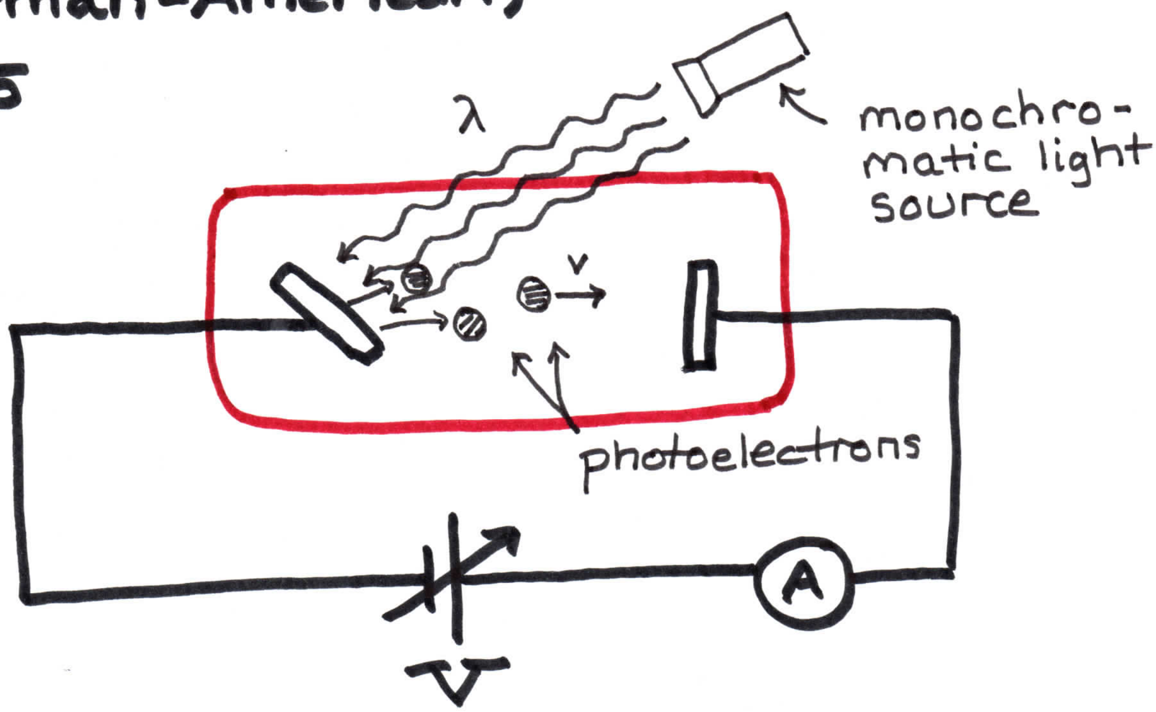
Assuming that a typical skin temperature of a student sitting in a lecture hall is 30 °C, at what wavelength does the student radiate more electromagnetic energy than any other?

Problem 3: Blackbody Radiation Problem

The sun radiates more energy (per wavelength) at 509 nm than any other wavelength. The radius of the sun is 7.0×10^8 m. Calculate the power emitted by the surface of the sun over the entire electromagnetic spectrum. Remember the Stephan-Boltzmann Law: $P = \sigma A e T^4$. Take the emissivity of the surface of the sun to be 1.00.

Photoelectric Effect

Albert Einstein
(German-American)
1905

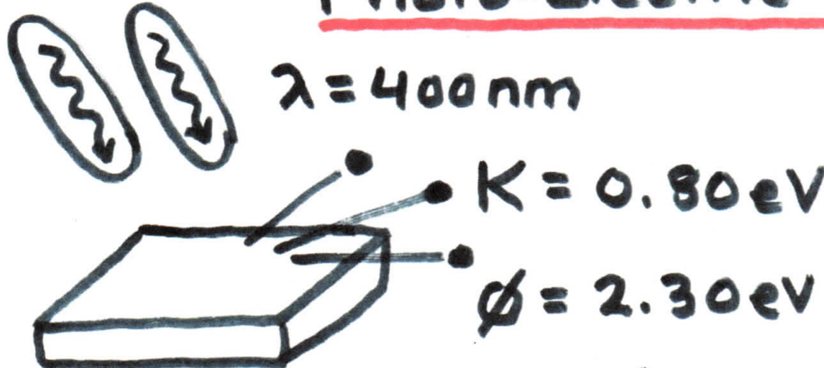


One photoelectron is liberated by one photon according to the conservation of energy equation

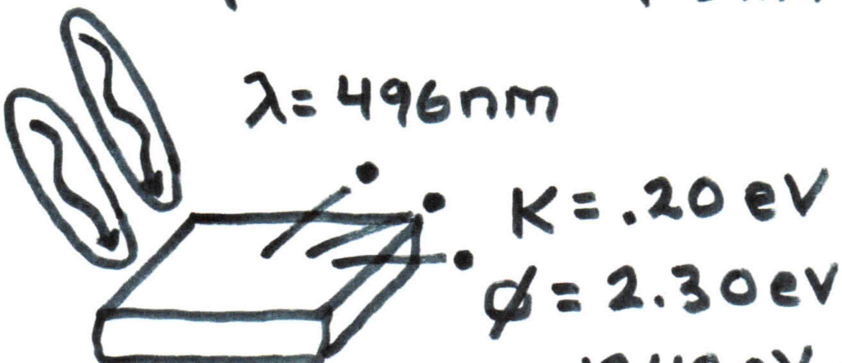
$$E = \phi + K$$

- E: energy of the incident photons, $E = \frac{hc}{\lambda}$
- ϕ: work function of the photo-sensitive material
- K: kinetic energy of the liberated photo-electron, $K = \frac{1}{2} m_e v^2$

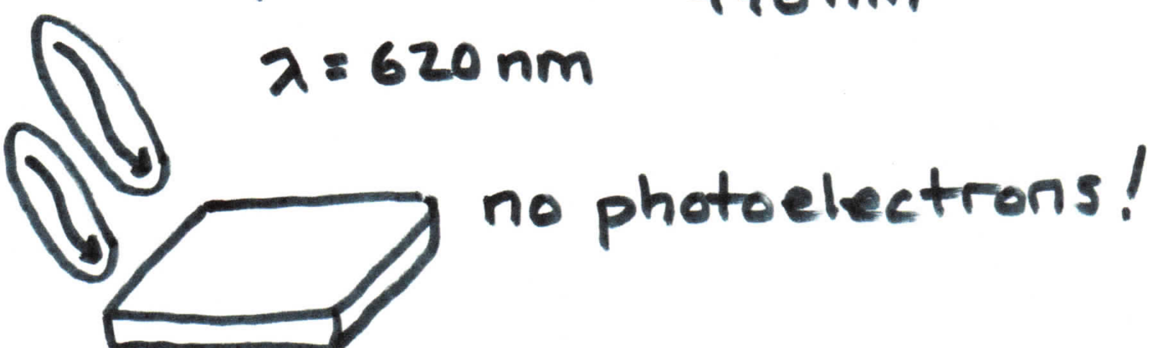
Photo-Electric Effect



$$E_{photons} = \frac{1240\,eV\cdot nm}{400\,nm} = 3.10\,eV$$



$$E_{photons} = \frac{1240\,eV\cdot nm}{496\,nm} = 2.50\,eV$$



$$E_{photons} = \frac{1240\,eV\cdot nm}{620\,nm} = 2.00\,eV$$

* paper by A. Einstein (1905)

Table 40.1 Work Functions of Selected Metals

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

Note: Values are typical for metals listed. Actual values may vary depending on whether the metal is a single crystal or polycrystalline. Values may also depend on the face from which electrons are ejected from crystalline metals. Furthermore, different experimental procedures may produce differing values.

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Problem 4: Photoelectric Effect Problem

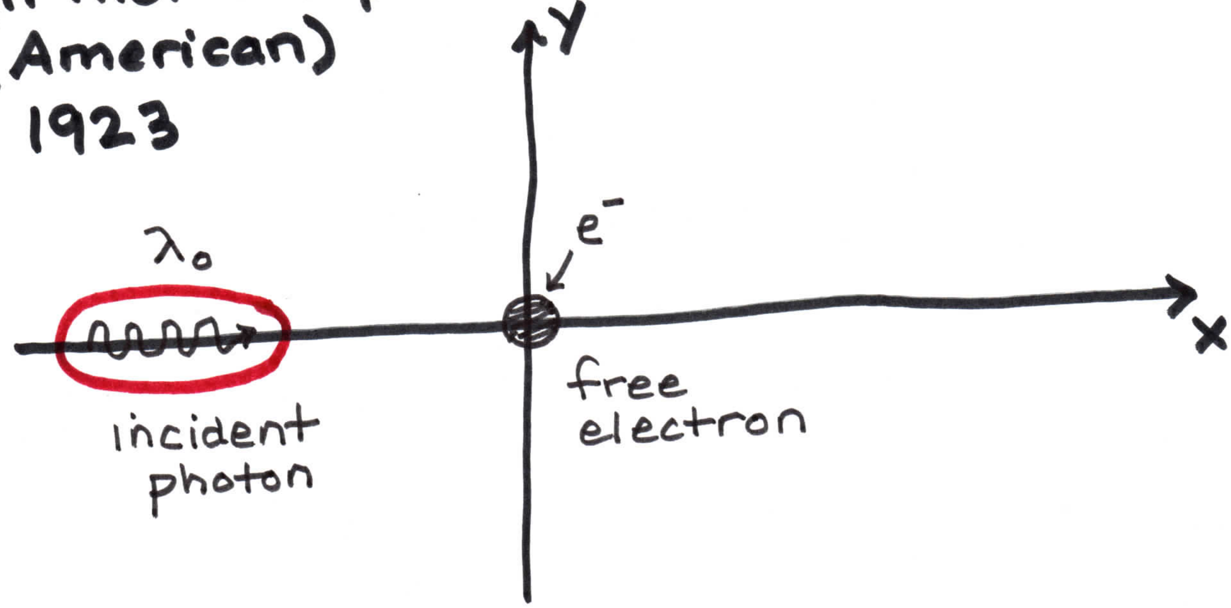
Suppose that a photosensitive material has a work function of 2.46 eV. If the surface is illuminated with monochromatic radiation with wavelength 400 nm, what would be the maximum speed of photo-electrons liberated from the surface?

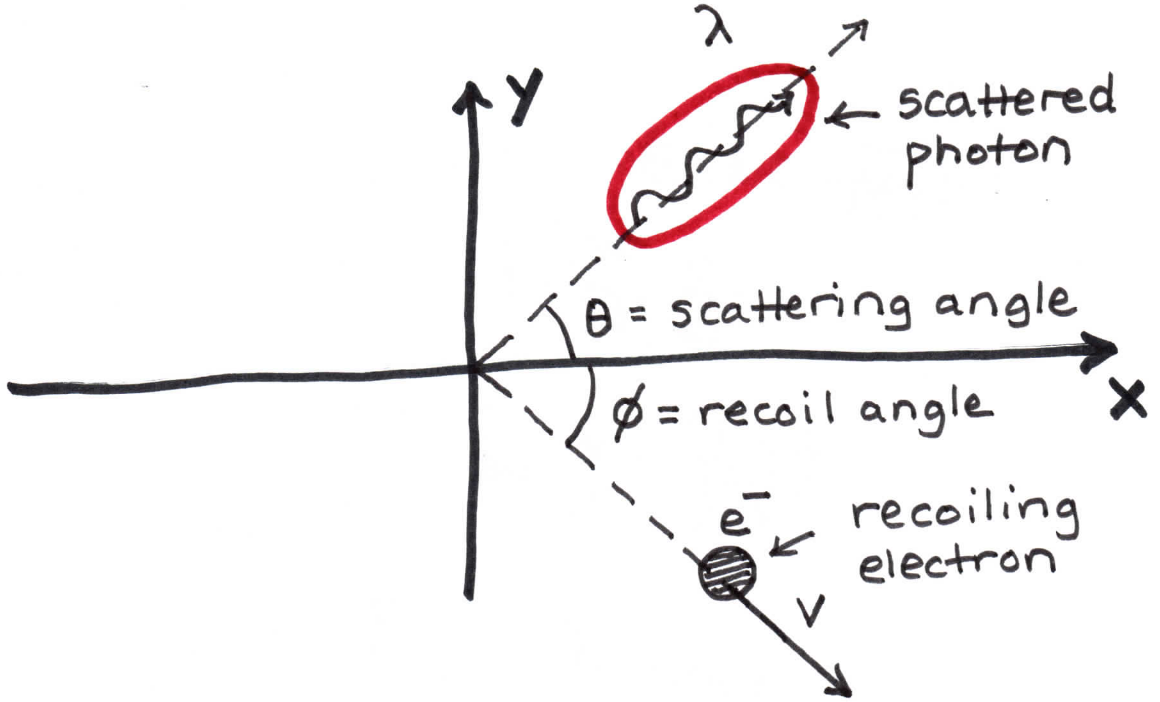
Problem 5: Photoelectric Effect Problem

A certain photo-sensitive material is illuminated by 496-nm monochromatic light, and photoelectrons are liberated. If this same material is illuminated by 620-nm light and it is found that those photoelectrons have only 60% of the kinetic energy of ones illuminated by the 496-nm source, what must the work function of the photo-sensitive material be?

Compton Scattering

Arthur Compton
(American)
1923





① conserve E : $E_0 = E$

$$\frac{hc}{\lambda_0} + m_e c^2 = m_e c^2 \cdot \frac{1}{\sqrt{1-v^2/c^2}} + \frac{hc}{\lambda}$$

② conserve P_x : $P_{x0} = P_x$

$$\frac{h}{\lambda_0} = \frac{h}{\lambda}\cos\theta + m_e v \frac{1}{\sqrt{1-v^2/c^2}} \cos\phi$$

③ conserve P_y : $P_{y0} = P_y$

$$\frac{h}{\lambda}\sin\theta = m_e v \frac{1}{\sqrt{1-v^2/c^2}} \sin\phi$$

Solution for λ :

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

$$\frac{h}{m_e c} = \frac{6.63\times10^{-34}\,J\cdot s}{(9.11\times10^{-31}\,kg)(3\times10^{8}\,m/s)} = .00243\,nm$$

called the Compton wavelength of the electron (λ_c)

Problem 6: **Compton Scattering Problem**

Suppose that it is found that a certain photon, when Compton scattered through an angle of 60 degrees, suffers a 40 percent decrease in energy. What must the wavelength (in nm) of the original photon have been? The Compton wavelength of an electron is .00243 nm.

Problem 7: Compton Scattering Problem

Compare the wavelengths and energy losses of Compton-scattered 600-nm photons and .002-nm photons from free electrons. Take the scattering angles of both to be 90°.