PHYS 2170

General Physics 3 for Majors

Fall 2021

Lecture 26

Photons

October 25

1 What is a photon?

photon = quantum (particle) of light (EM wave)

- energy of a single photon: $E = hf$ (Hz)
  - Planck's constant $h \approx 6.6 \times 10^{-34}$ J·s
  - $E = \hbar\omega$, $\omega = 2\pi f$
  - "theorist's" Planck's constant $\hbar = \frac{h}{2\pi} \sim 10^{-34}$ J·s

- momentum: $p = \frac{h}{\lambda}$ $\quad p = \hbar k$, $k = \frac{2\pi}{\lambda}$

since photons are quanta of light: $\omega = ck$ $\quad [\lambda \cdot f = c]$

How much energy stored in visible photon:

$\lambda \sim 500$ nm $\quad E = 4 \times 10^{-19}$ J

2 Do all observers agree on the energy of a photon?

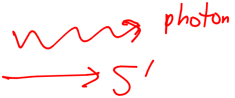
$E = \hbar\omega \; (= hf)$ consistent w/ special relativity:

In frame S, $E = \hbar\omega = \hbar(ck)$, $p = \hbar k = E/c$ massless ✓

In frame S' moving at vel. $v = c\beta$ relative to S:

$$E' = \gamma(E - \beta \cdot cp) \qquad \gamma = (1-\beta^2)^{-1/2}$$

$$cp' = \gamma(cp - \beta E)$$

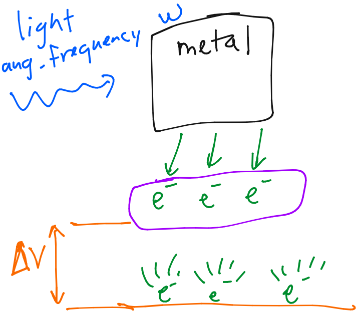


$$E' = \gamma(E - \beta E) = \frac{1-\beta}{\sqrt{1-\beta^2}} E \qquad \left(\text{ditto: } p' = \frac{1-\beta}{\sqrt{1-\beta^2}} p\right)$$

$$= \frac{1-\beta}{\sqrt{(1-\beta)(1+\beta)}} E = \sqrt{\frac{1-\beta}{1+\beta}} E$$

$$\underbrace{(hf')}_{E'} = \sqrt{\frac{1-\beta}{1+\beta}} \underbrace{(hf)}_{E}$$

3 Describe the photoelectric effect.



if $\Delta V > \Delta V_c$, no electrons detected

each electron must have kinetic energy

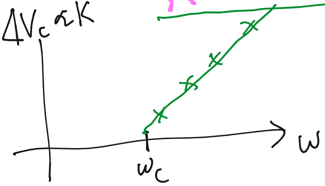
$$K = e|\Delta V_c|$$

- If $\omega < \omega_c$, no e^- emitted.
- Surprising since energy carried by light/photons is (macroscopically) unrelated to ω.

  $[E_{tot} = \hbar\omega \cdot N_{phot}]$ (N_{phot} can be large)

- each electron has same kinetic energy

- Deduce: $K \overset{?}{=} \hbar\omega - \hbar\omega_c$ [or 0 if $\omega < \omega_c$]



$\hbar\omega_c = \phi$ ← "work function"

4 If a photon of wavelength $\lambda = 100$ nm is incident on a metal, you see electrons of kinetic energy 8 eV emitted. Will electrons be emitted if $\lambda = 400$ nm? Recall that 1 eV $\approx 1.6 \times 10^{-19}$ J.

Energy of 100 nm photon is...:

$$E_{100} = \hbar\omega = hf = \frac{hc}{\lambda} = \frac{(6.6\times10^{-34})(3\times10^{8})}{10^{-7}} = 1.98\times10^{-18} \checkmark$$

in eV: $$\frac{1.98\times10^{-18}}{1.6\times10^{-19}} \approx 12.4 \text{ eV}$$

The work function $\phi = E_{100} - K = 12.4\text{ eV} - 8\text{ eV} \approx 4.4\text{ eV}$

Energy of 400 nm photon:

$$E_{100} = \frac{hc}{100\text{nm}} \qquad E_{400} = \frac{hc}{400\text{ nm}} = \frac{1}{4}E_{100} \approx 3.1\text{ eV}$$

$3.1\text{ eV} < \phi = 4.4\text{ eV}$: no photon detected.