Quantum Physics 1
Class 5

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Wave nature of matter

Review: Light as a particle, $E = h\nu$

$$\lambda\,[m] = \frac{hc}{E\,[J]}$$

$$\lambda\,[m] = \frac{6.62\times10^{-34} \times (3\times10^{8})}{E\,[J]} = \frac{2\times10^{-25}}{E\,[J]}$$

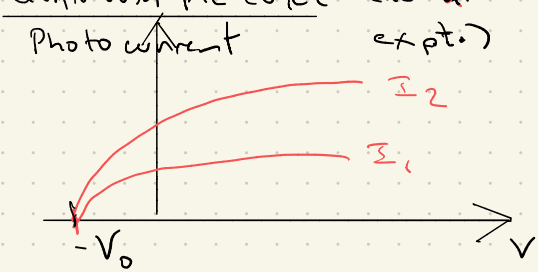
$$\lambda\,[nm]\times10^{-9} = \frac{2\times10^{-25}}{E\,[eV]\times(1.6\times10^{-19})}$$

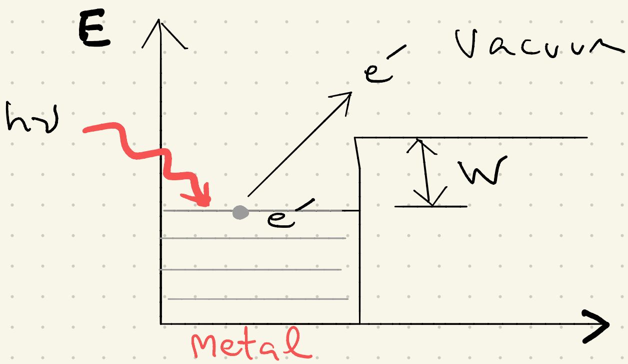
** NB $1\,eV \equiv 1.6\times10^{-19}\,J$

$$\Rightarrow \boxed{\lambda\,[nm] = \frac{1240}{E\,[eV]}}$$

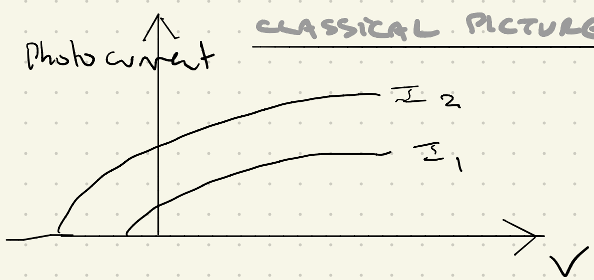
Photoelectric Effect:

QUANTUM PICTURE (actual expt.)





CLASSICAL PICTURE

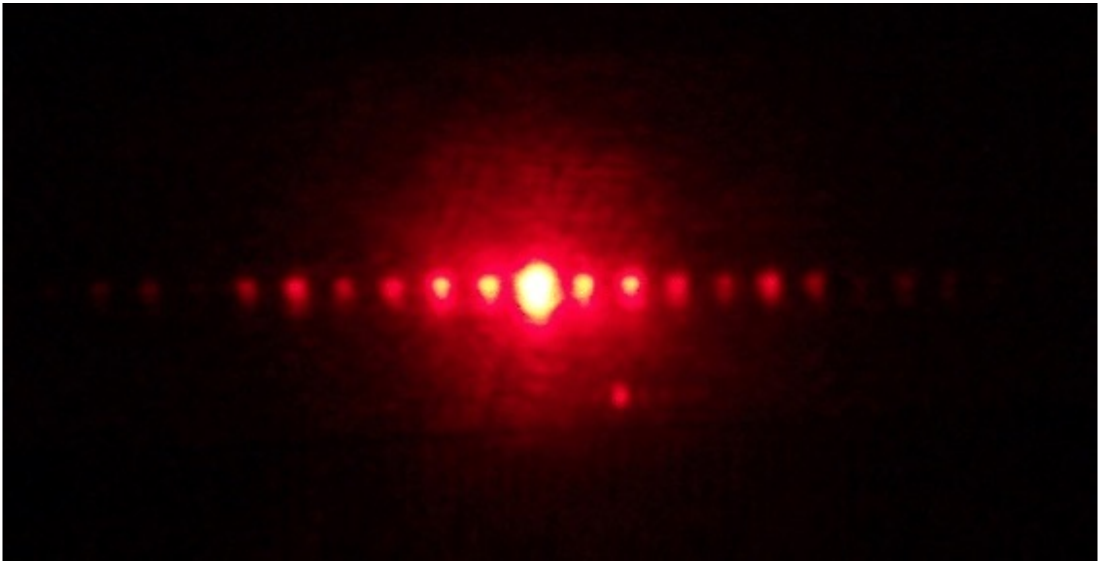


$$\boxed{h\nu = E_k + W}$$

$$\boxed{I \sim n h\nu}$$

Double slit interference for single photon.

Beam of light:



Moiré patterns in red, 2012, DOI: 10.1109/ICEEE.2012.6421153
Conference: Electrical Engineering, Computing Science and Automatic Control (CCE)

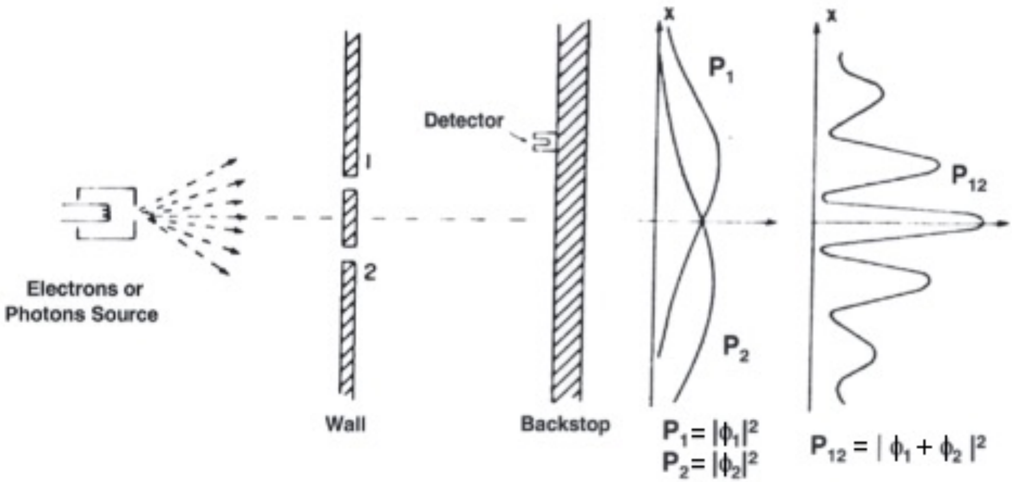


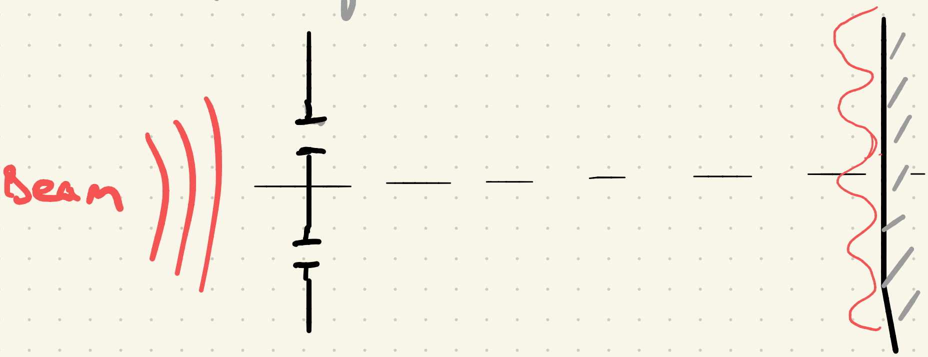
Figure 2. The double-slit experiment.

journal of the Brazilian Chemical Society, J. Braz. Chem. Soc. vol.19 no.2 São Paulo 2008
https://doi.org/10.1590/S0103-50532008000200007

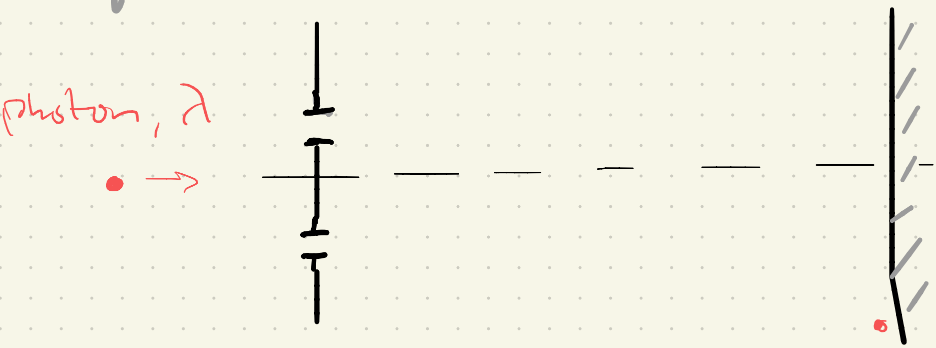
Double slit interference for single photon.

* recall in-class from last time.

Beam of light:



Single Photon:



<u>NB</u>: If light is a particle and has wave like properties, does matter (atoms, e's, etc.) behave like waves???

Found the atoms can interfere!!!

To describe its wave nature de Broglie defined a λ for matter particles

$\lambda = \frac{h}{p}$ (1924 PhD thesis!)

** confirmed in 1927 e's from Ni crystal.

if light: $E = h\nu$ ... ① $E = pc$ ... ②

$p = \frac{h}{\lambda}$ ... ③

Aside:

$c = \lambda\nu$, $\lambda = c/\nu$

$E = pc$

$pc = h\nu$

$p = h\nu/c$

$p = h/\lambda$

then for matter:

$$\lambda = \frac{h}{p} \quad \ldots ①$$

$$E = \frac{1}{2}mv^2 = \frac{p^2}{2m} \quad \ldots ②$$

① + ② ⇓

$$\boxed{\lambda = \frac{h}{\sqrt{2mE}} \quad \ldots ③}$$

** At relativistic speeds

$E^2 = p^2c^2 + m^2c^4$

∴ for photons, $m = 0$

$\Rightarrow E = pc = \frac{hc}{\lambda}$

What is λ for macroscopic particles? ("large masses???)

Inclass 5.1

Consider Helium, He interference:

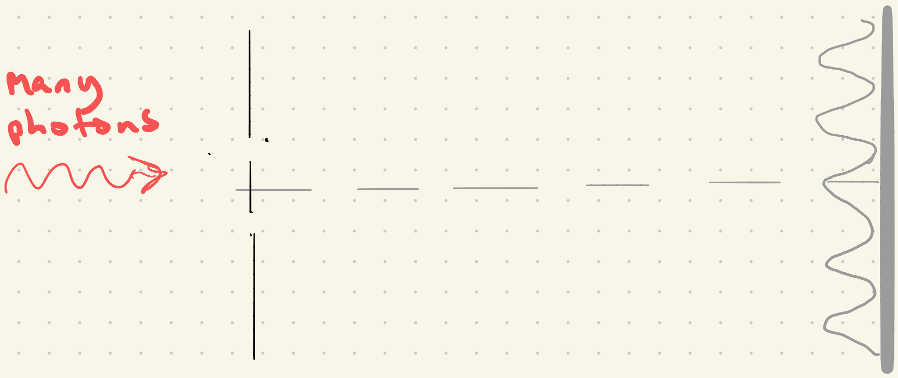
$m = 6.6 \times 10^{-27}$ kg   Find: λ

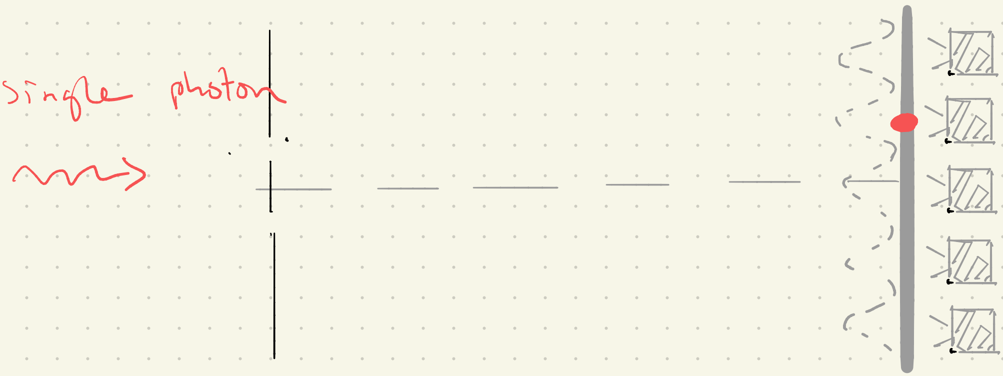
$v = 2.2 \times 10^{3}$ m/s   (Solu: 0.045 nm)

assume very tiny slits

In-class 5.2, 5.3, 5.4

double slit   single slit   small diffraction envelope.





For light:

$$E = hc/\lambda$$

$$\lambda = hc/E$$

$$= \frac{hc}{pc}$$

$$\lambda = \frac{h}{p}$$

recall:

$E^2 = p^2c^2 + m^2c^4$

$m = 0$ for photon

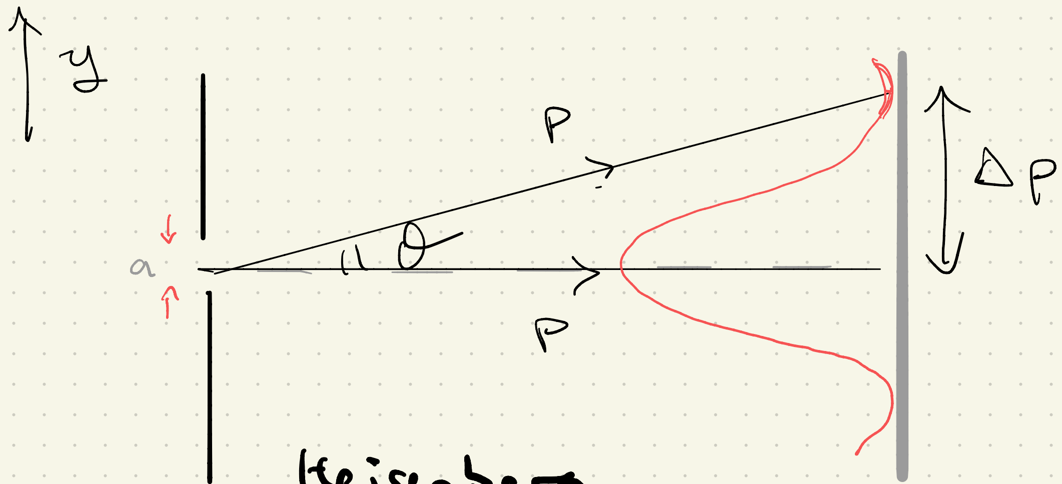
$\Rightarrow E = pc$

For matter:

de Broglie: $\boxed{\lambda = \frac{h}{p}}$; $E = \frac{p^2}{2m}$

$$\boxed{\lambda = \frac{h}{\sqrt{2mE}}}$$

Consider again matter diffraction:



Heisenberg Uncertainty principle!

Heisenberg Uncertainty Principle

- Measurement of position (y) and momentum (p) at the same time

$$\Delta y \, \Delta p = a \cdot \left(p \frac{\lambda}{a}\right)$$

$$= p\lambda$$

$$= \left(\frac{h}{\lambda}\right) \cdot \lambda$$

$$= h$$

$$\boxed{\Delta y \, \Delta p \sim h}$$

Aside:

$$\frac{\Delta p}{p} = \sin\theta = \frac{m\lambda}{a}\bigg|_{m=1}$$

$$\frac{\Delta p}{p} = \tan\theta$$

$$\Delta p = p \sin\theta = p \frac{\lambda}{a}$$