CHAPTER 14: FLUIDS

1) What is a "fluid" — liquid OR gas (incompressible vs compressible)
→ continually deforms (flows) under shearing stress

2) Pressure $$p = \frac{F}{A}$$

Units pascal = Pa = N/m^2 = kg/(m·s^2)

3) Density $$\rho = \frac{m}{V}$$

Note: density solid > liquid > gas ["rho"]

4) Fluids at rest

$$p_{at\ \ h} = p_{atm} + \rho g h \qquad \Delta p_{gauge} = \rho g h$$

5) Pascal's Principle: Pressure applied to a confined fluid **increases** the pressure throughout by same amount

6) Archimedes Principle: buoyant force on partially or fully submerged object is **directed upward** and has **magnitude equal to weight of fluid displaced**

$$F_B = m_{Fluid\ diplaced}\, g$$

7) Equation of continuity:

$$R_V = Av = \text{constant} \qquad R_m = \rho R_V = \rho A v = \text{constant}$$

8) Bernoulli's Equation:

$$p_a + \frac{1}{2}\rho v_a^2 + \rho g y_a = p_b + \frac{1}{2}\rho v_b^2 + \rho g y_b = \text{constant}$$

Photoelectric Effect

Einstein's Theory:

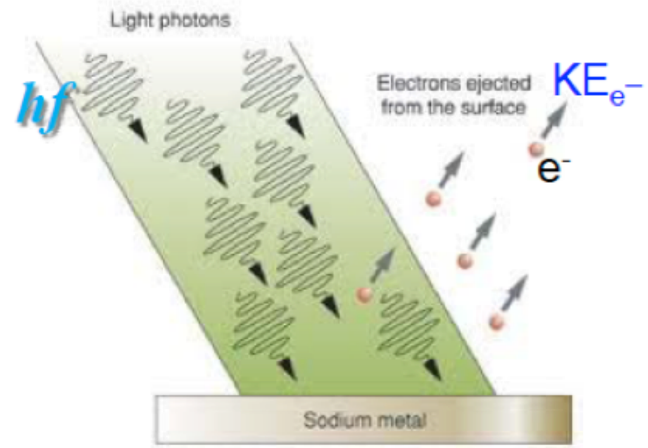
- Light consists of photons with energy $E = hf$
- One electron can discretely absorb one photon
- An electron uses the photon's energy to overcome the potential energy barrier

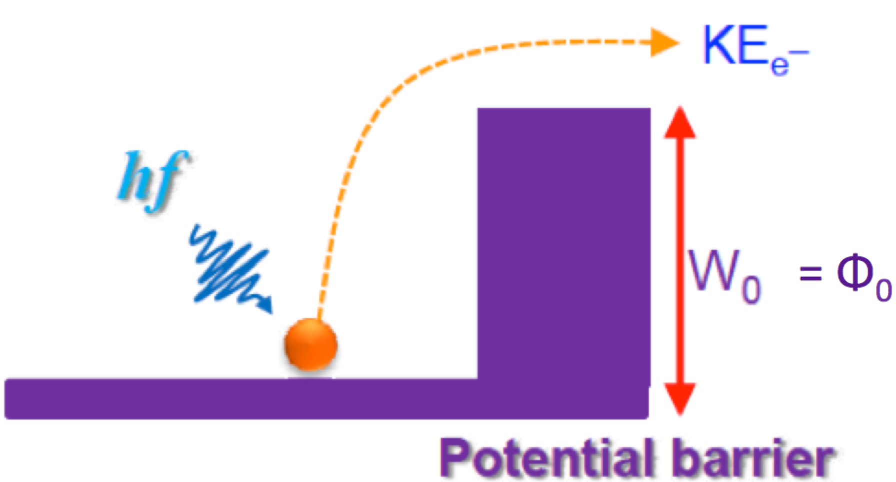
Energy Conservation:

$$hf - \Phi = KE_{max}$$

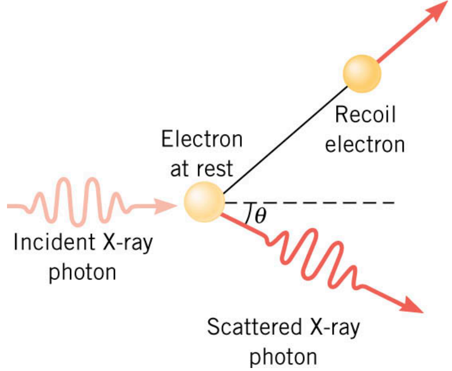
Whether electrons get out depends on frequency NOT intensity of light!!!

Simple picture view:





Compton Effect



$$p = \frac{E}{c} = \frac{hf}{c} = \frac{h\not{c}}{\not{c}\lambda} \quad \boxed{\Rightarrow \; p_{photon} = \frac{h}{\lambda}}$$

Momentum of a photon in terms of its wavelength.

$$\boxed{\lambda' - \lambda = \frac{h}{m_{scatterer}c}(1 - \cos\phi_{photon})}$$

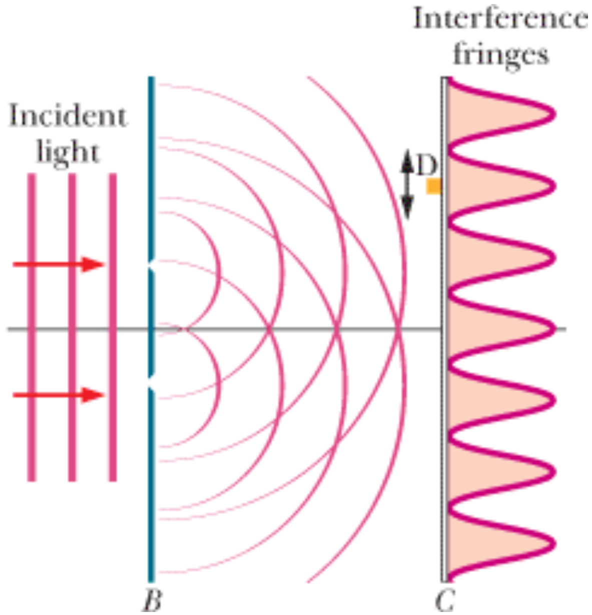
- In words, this equation states that the difference in the wavelengths between the scattered photon and the incident photon is related to the scattering angle by the above relationship.

- Notice: cos ϕ can vary between -1 and +1, so the shift in the photon's wavelength will vary between 0 and 2h/mc.

Probability Waves

Light as a Probability Wave

Double Slit Experiment for Light

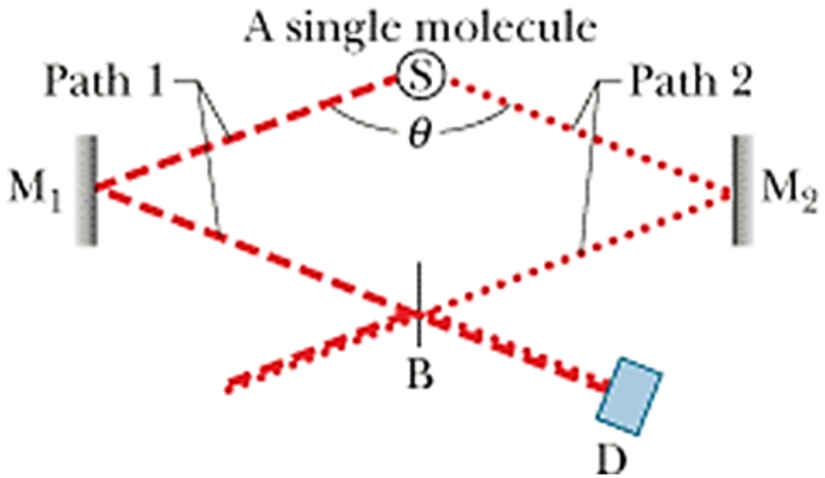


Single Photon Diffraction

The same diffraction pattern emerges even if photons are sent through one at a time!!!

Which path does the photon follow?

Wide-angle "DSE" for Light



A single photon interferes with itself?!

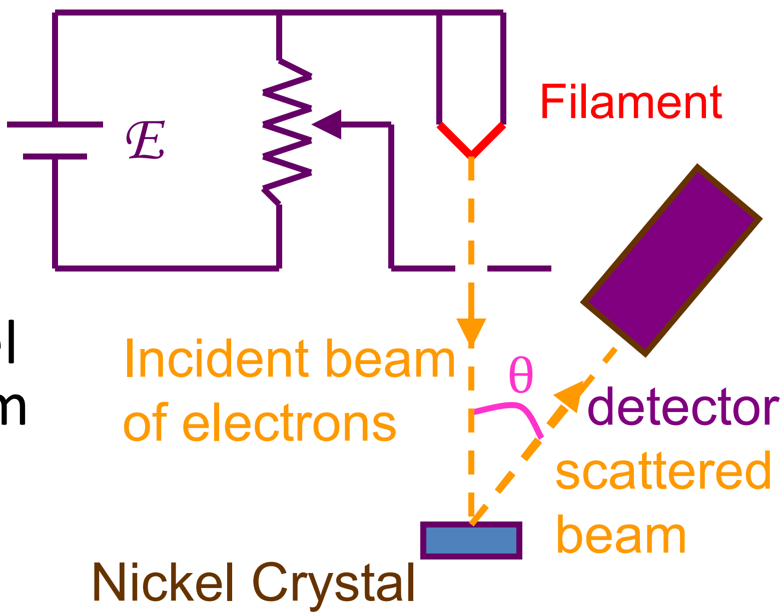
Consistent Interpretation
(*Probabilistic*)

1. Light is emitted as a **particle**.
2. Light is absorbed as a **particle**.
3. Light travels as a **probability wave**.

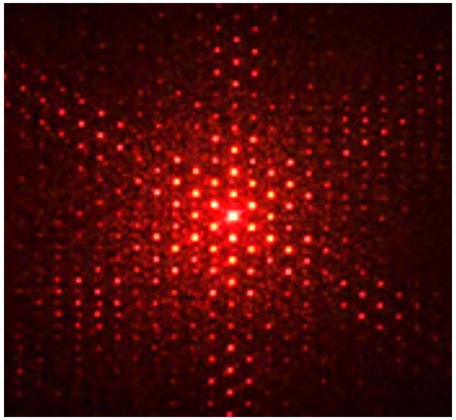
Matter Waves – de Broglie Wavelength

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

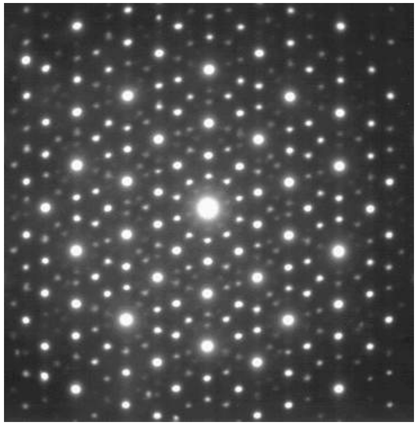
- 1927 – Davisson and Germer at Bell Laboratories performed an experiment which confirmed de Broglie's idea.
  - Thomson in Scotland independently did a similar experiment also verifying this claim.
- Davison and Germer found that the electrons were diffracted from the nickel crystal just as X-rays were diffracted from a crystal (serendipity….)



Photon Diffraction



Electron Diffraction



Davisson & Germer

Schrodinger Equation

$$\frac{\partial^2\psi(x)}{\partial x^2}+\frac{8\pi^2 m}{h^2}[E-U(x,t)]\psi(x)=0$$

$$\Rightarrow \quad \boxed{\frac{\partial^2\psi(x)}{\partial x^2}+k^2\psi(x)=0}$$

By comparing the two equations we have:

$$k=\sqrt{\frac{8\pi^2 m}{h^2}\left[E-U\left(x,t\right)\right]}=\frac{2\pi}{h}\sqrt{2m\left[E-U\left(x,t\right)\right]}$$

The solution to this Diff. Eq. is the probability wave:

$$\psi(x)=Ae^{ikx}+Be^{-ikx}$$

$$\mathrm{Prob}(x,t)=\left|\Psi\right|^2=\Psi\Psi^*=\psi(x)\psi^*(x)e^{-i\omega t}e^{i\omega t}=\psi(x)\psi^*(x)$$

Reflection

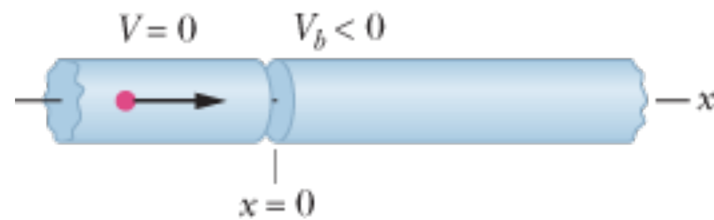
In region 1, the electron is free, so we have:

$$\psi_1(x) = Ae^{ikx} + Be^{-ikx} \qquad k = \frac{2\pi\sqrt{2mE}}{h}$$

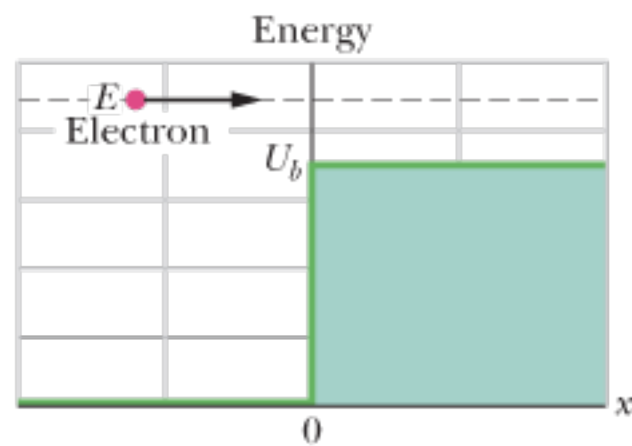
Particle moving to the right

Particle moving to the right

Can the electron be reflected by the region of negative potential?



Classically, the electron has too much energy to be reflected by the potential step.



Probability is just: $|\psi|^2$

Probability electron is incoming: $|A|^2$

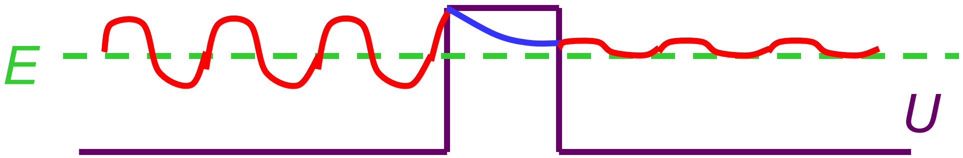
Probability electron is reflected: $|B|^2$

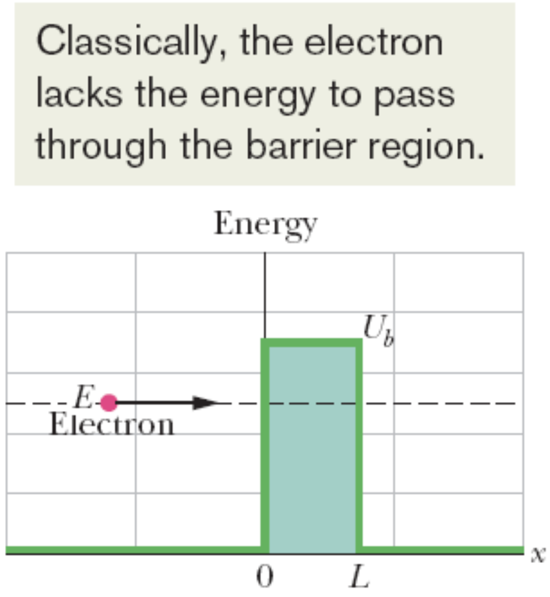
Reflection coefficient: $R = \frac{|B|^2}{|A|^2}$

Tunneling

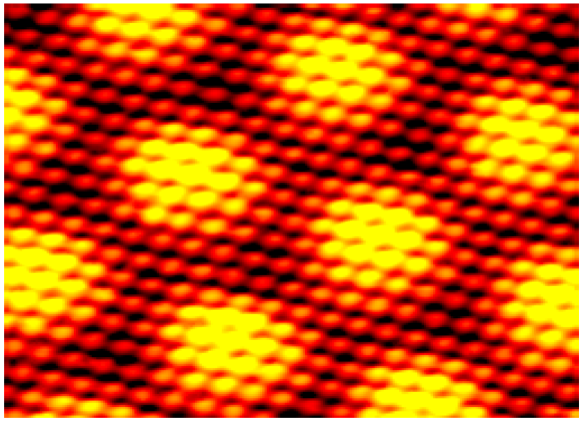
$$\text{Transmission coefficient: } T = 1 - R = 1 - \frac{|B|^2}{|A|^2}$$

This is true even when E < U!!!!





One atomic layer of Ag on Ni(111)



7x5 nm^2

Heisenberg's Uncertainty Principle:

measured values cannot be assigned to the position and the momentum of a particle simultaneously with unlimited precision.

$$\Delta x \cdot \Delta p_x \geq \hbar$$
$$\Delta y \cdot \Delta p_y \geq \hbar \qquad \text{(Heisenberg's uncertainty principle).}$$
$$\Delta z \cdot \Delta p_z \geq \hbar$$

Here Δx and Δp_x represent the intrinsic uncertainties in the measurements of the x components of $\boldsymbol{r}$ and $\boldsymbol{p}$, with parallel meanings for the y and z terms. Even with the best measuring instruments, each product of a position uncertainty and a momentum uncertainty will be greater than $\hbar$, never less.

- This expression includes a wave traveling to the right and one traveling to the left. To simplify take only the rightward solution (B=0) so that

$$\text{Prob}(x) = \psi(x)\psi^*(x) = A^2 e^{ikx} e^{-ikx} = A^2$$