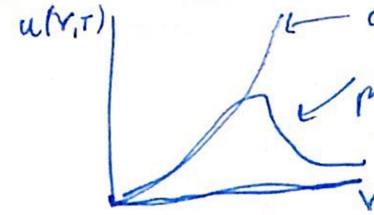
Lecture 2: Photo-effect, two slit exp't, de Broglie relations, electron diffraction

From last time

Black body spectrum



$$u(\nu,T) = \frac{8\pi\nu^2}{c^3} \langle\langle w(\nu) \rangle\rangle$$

$\frac{8\pi\nu^2}{c^3}$ ← # of modes / freq. volume

$\langle\langle w(\nu) \rangle\rangle$ ← thermal energy / mode

Classical:
$$\langle\langle w(\nu) \rangle\rangle = \frac{\int_0^\infty E\, e^{-E/k_BT}\, dE}{\int_0^\infty e^{-E/k_BT}\, dE} = k_BT$$

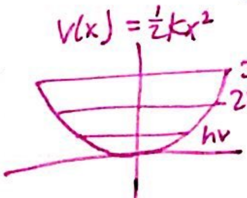
(1907)

Einstein: Issue with the oscillators

particle in well

$$E = \frac{p^2}{2m} + \frac{1}{2}kx^2$$

$V(x) = \frac{1}{2}kx^2$



$$\langle\langle w(\nu) \rangle\rangle = \frac{\sum_{n=0}^{\infty} E_n e^{-E_n/k_BT}}{\sum_{n=0} e^{-E_n/k_BT}} \Bigg|_{E_n = nh\nu} = \frac{h\nu}{e^{\frac{h\nu}{k_BT}} - 1}$$

$$\omega = \sqrt{\frac{k}{m}} = 2\pi\nu$$

$$E_n = nh\nu$$

model for Lattice Variables

$$\frac{1}{L^3}\langle\langle E \rangle\rangle = \frac{1}{L^3}\sum_j (k_BT) \quad \text{Classical}$$

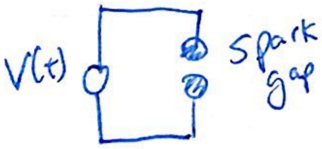
$$\frac{1}{L^3}\langle\langle E \rangle\rangle = \frac{1}{L^3}\sum_i \frac{h\nu_i}{e^{h\nu_i/k_BT} - 1}$$

Planck

$$E_n = (n + \tfrac{1}{2})h\nu$$

Einstein Oscillator

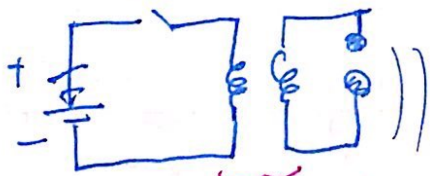
Hertz experiment (1887)



$$\nabla \times \vec{H} = \vec{J} + \frac{\partial}{\partial t}\epsilon_0 \vec{E}$$

$$\nabla \times \vec{E} = -\frac{\partial}{\partial t}\mu_0 \vec{H}$$

$$\oint \vec{E}\cdot d\vec{l} = -\frac{d}{dt}\int \mu_0 \vec{H}\cdot d\vec{a}$$



Current created magnetic field in inductor

that induces a current in second inductor

⇒ voltage → current

put ring here, can see a spark when there is field.

$d\vec{a} = \hat{n}\, da$

See light was discharging

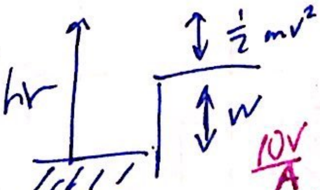
more light → more current

→ Hertz found that uv light was causing the discharge

⇒ light discharging caused by wavelength ... ?

Einstein (1905)

$$h\nu = W + \frac{1}{2}mv^2$$



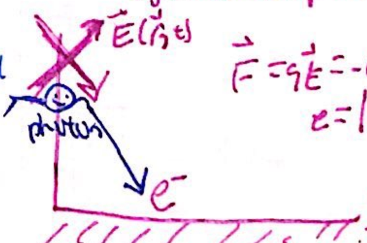
photoelectric effect

Easier to pull some electrons off of metal than others.

$\frac{10V}{A} = 10^9 V$

$I(\text{sunlight}) = \frac{1500W}{m^2}$

$$I = \frac{E^2}{Z_0} = \frac{(10^9)^2}{377\Omega} = \frac{10^{18}}{377}\frac{W}{cm^2}$$



$$\vec{F} = q\vec{E} = -e\vec{E}$$
$$e = |q|$$

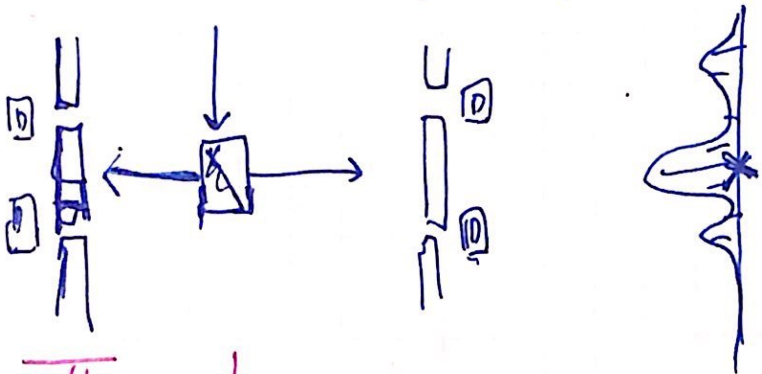
$$\frac{d}{dt}\vec{r} = \frac{\vec{p}}{m}$$
$$\frac{d}{dt}\vec{p} = q\vec{E}$$

Young 2 slit Experiment

1 slit

2 slits

Is light a particle or a wave?



office hours ~4pm aim for this room

Theory 1st try

1. Start with Maxwell equations
2. Predict Diffraction pattern
3. Intensity $\vec{S} = \vec{E} \times \vec{H}$, $I = |\vec{S}|$
4. Probability $\propto$ Intensity

predicts both pos. & neg. energy photons.

Energy, momentum

$E = h\nu = \hbar\omega$ $\quad \omega = 2\pi\nu$ $\quad \hbar = \frac{h}{2\pi}$

$\omega = ck$ $\quad k = \frac{2\pi}{\lambda}$

$E = \hbar\omega = \hbar ck = c(\hbar k) = cp$

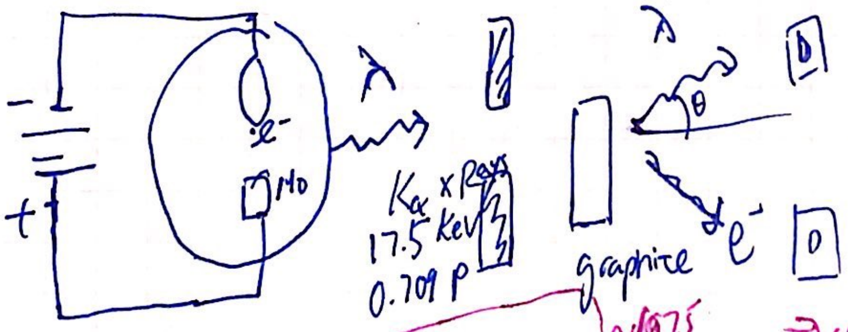
$p = \hbar k$

Relativistic particles

$E = \sqrt{(mc^2)^2 + c^2p^2} \rightarrow mc^2 + \frac{p^2}{2m} + \dots$

if $E \rightarrow \infty$

$E \rightarrow c|p|$



Compton worked out Kinematics of photon

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

~1925

$\Rightarrow$ certain that photons have momentum.

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

photon : $E = \hbar\omega$
$p = \hbar k$

particles: $\hbar\omega = E$
$\hbar k = p$