Semester-4 : Physics Honours

CC-9:
Elements of Modern Physics

Syllabus of Unit-1

Planck"s quantum, Planck"s constant and light as a collection of photons; Blackbody Radiation: Quantum theory of Light; Photo-electric effect and Compton scattering. De Broglie wavelength and matter waves; Davisson-Germer experiment. Wave description of particles by wave packets. Group and Phase velocities and relation between them. Two-Slit experiment with electrons. Probability. Wave amplitude and wave functions. (14 Lectures)

Planck's Constant

Planck's Quantum

Energy of Photon (E) is quantized.

$$E = h\nu = \frac{hc}{\lambda}$$
$$p = \frac{h}{\lambda}$$

here, h is the Planck's constant is given as

$$h = 6.626 \times 10^{-34} \quad \text{Joule-Sec}$$

ν is frequency of light
λ is wave length of the light
c is velocity of light
p is Photon momentum

- **Rest mass of Photon is zero.**
- **Photon always Moves with velocity c**

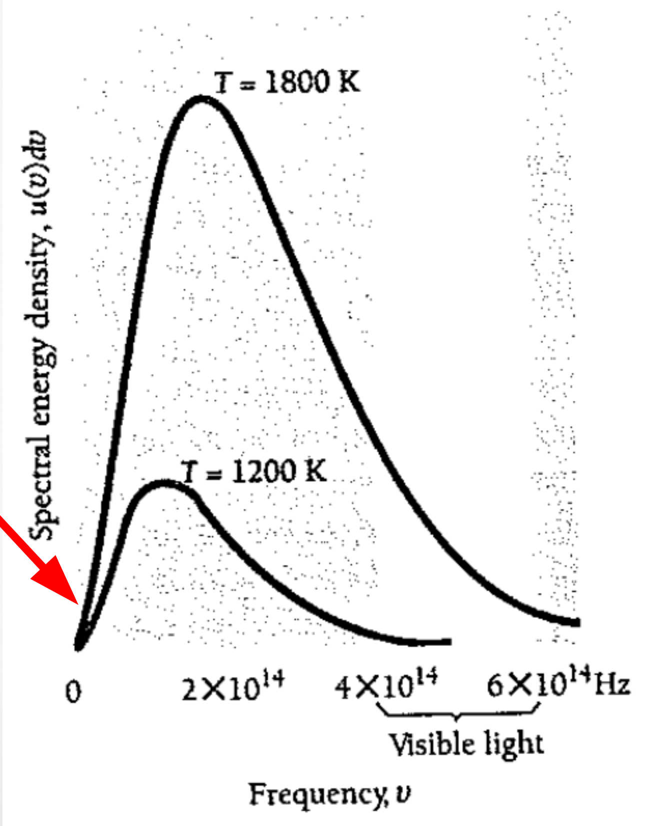
Q. Light is wave or particle?

Blackbody Radiation

Only the quantum theory of light can explain its origin

Density of standing waves in cavity

$$G(\nu)d\nu = \frac{8\pi\nu^2 d\nu}{c^3}$$



Blackbody Radiation

Only the quantum theory of light can explain its origin

Planck Radiation Formula

In 1900 the German physicist Max Planck used "lucky guesswork" (as he later called it) to come up with a formula for the spectral energy density of blackbody radiation:

Planck radiation formula

$$u(\nu)\, d\nu = \frac{8\pi h}{c^3} \frac{\nu^3\, d\nu}{e^{h\nu/kT} - 1}$$

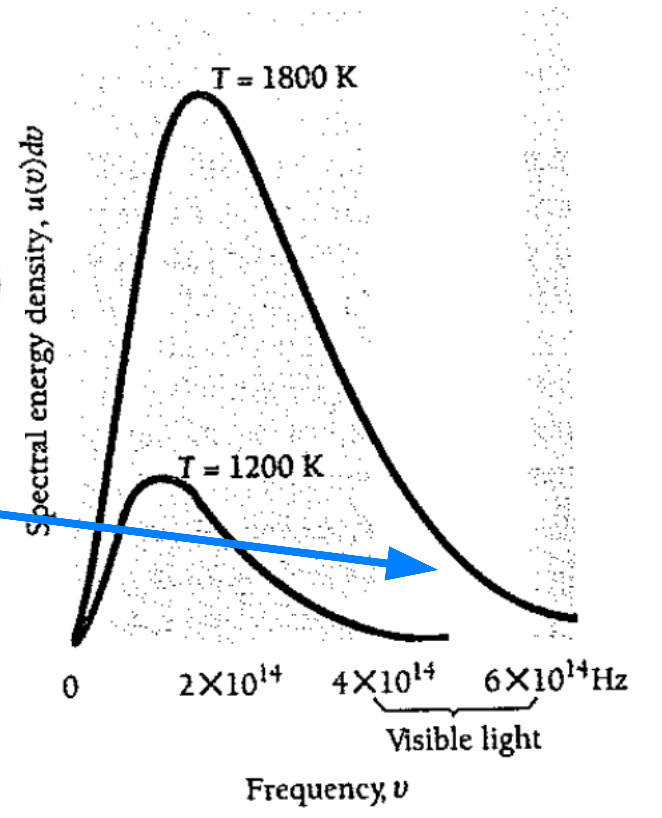
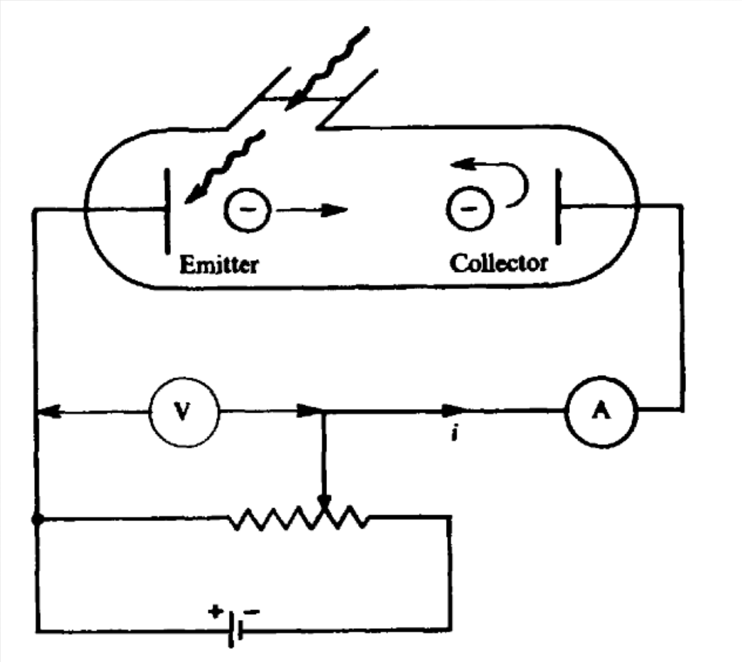
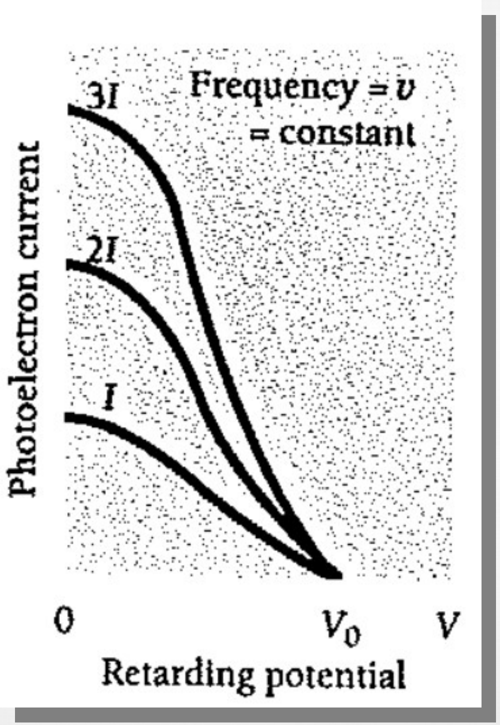


Photo-electric effect





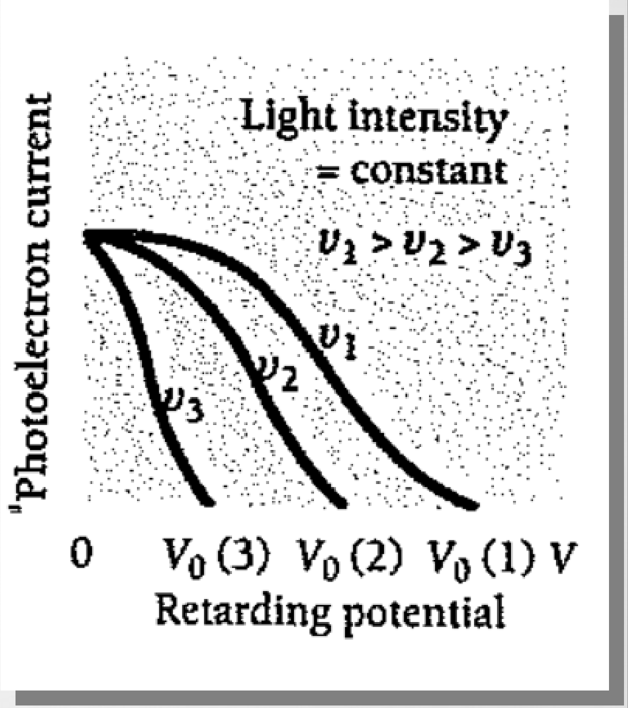
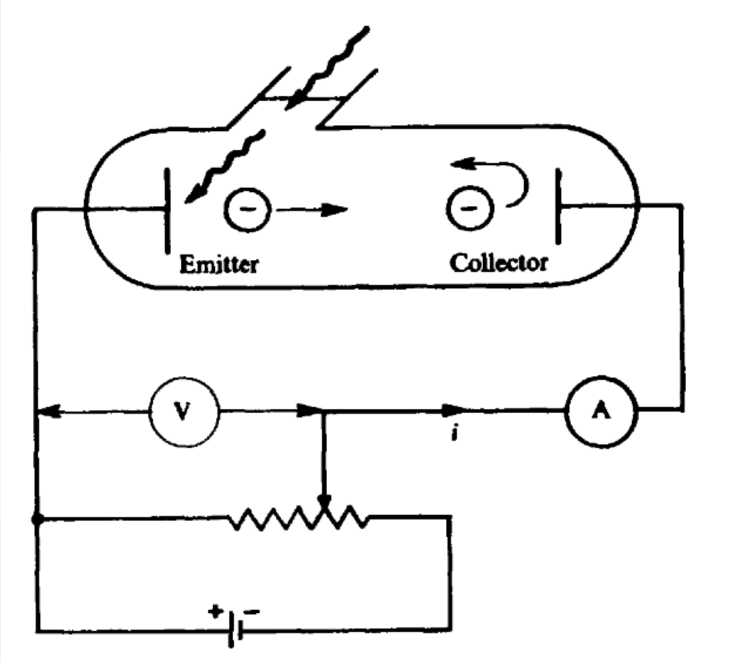


Photo-electric effect



Einstein’s Photoelectric effect equation:

$$eV_s = h\nu - \phi$$

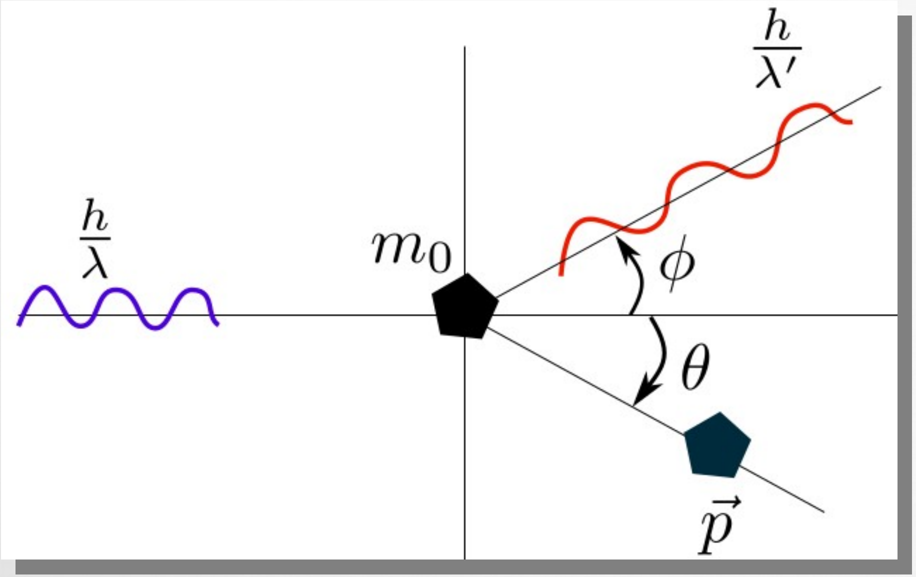
Maximum kinetic enegy of
Some of the emitted electrons:

$$K_{max} = eV_s,$$

Maximum kinetic energy of emitted electron

= (energy carried by photon) – (binding energy of the least tightly bound electron)

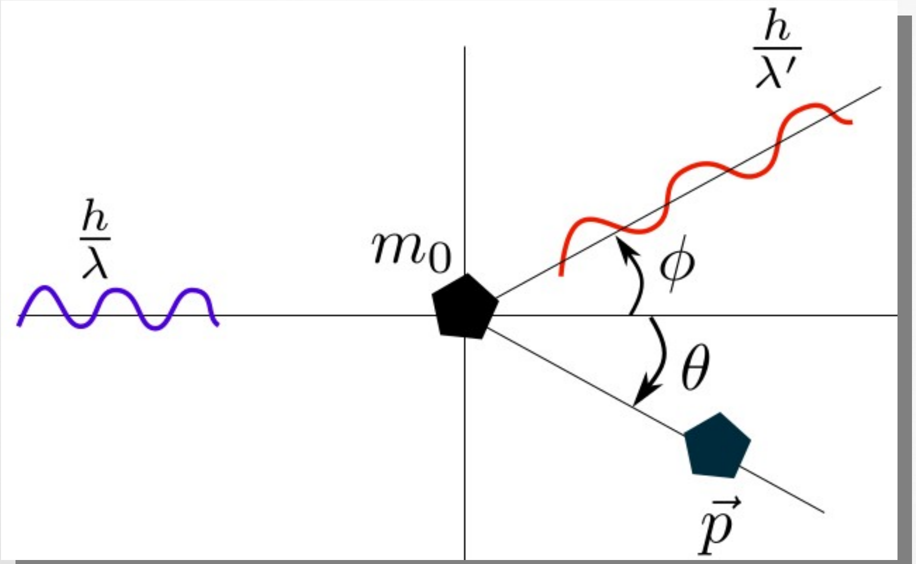
Compton scattering



Calculate change in wavelength for the scattered photon:

Using energy and momentum conservation rules, we derive the above formula..

Compton scattering



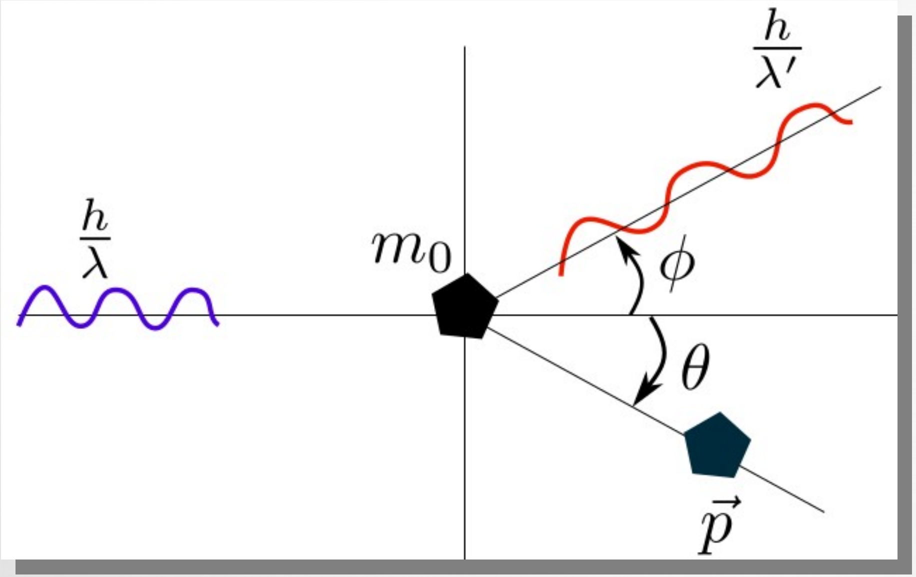
$$\frac{h}{\lambda} = \frac{h}{\lambda'} \cos\phi + p\cos\theta,$$

$$0 = \frac{h}{\lambda'} \sin\phi - p\sin\theta$$

$$h\nu - h\nu' = KE,$$

$$E = \sqrt{p^2c^2 + m_0^2c^4} = KE + m_0c^2$$

Compton scattering



Change in wavelength

$$\lambda' - \lambda = \frac{h}{m_0 c}(1 - \cos\phi)$$

Using energy and momentum conservation rules, derive the above formula..

Davisson-Germer Experiment

Existance of matter wave

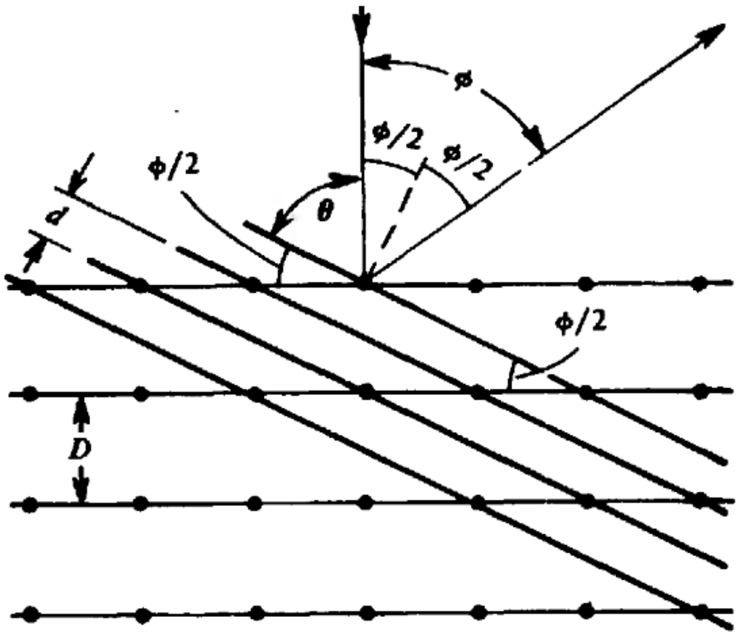
In one of their experiments, Davisson and Germer used electrons incident normally on a nickel crystal surface cut parallel to the principal Bragg planes. They observed constructive interference at an angle of 50° to the normal to the surface.
(The interatomic spacing of nickel is 2.15 A.)

$$\lambda = \frac{h}{m_0 v} = \frac{hc}{\sqrt{2(m_0 c^2)K}}$$

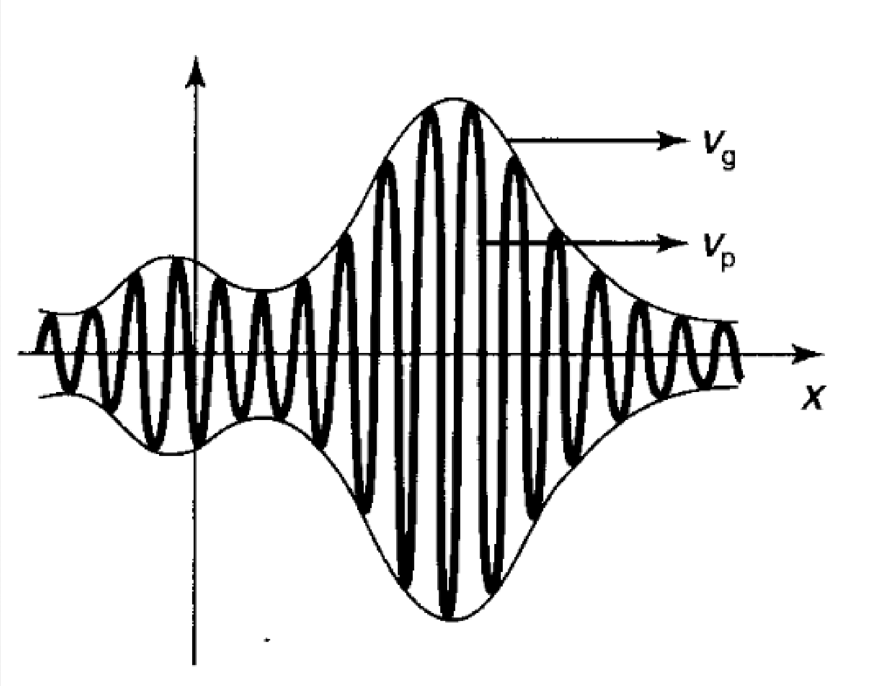
$$D \sin \phi = n\lambda$$

$$\sin \theta = \cos \frac{\phi}{2}$$

$$d = D \sin \frac{\phi}{2}$$



Group velocity & Phase velocity



"envelope" travels at the group velocity;
the "ripples" travel at the phase velocity.

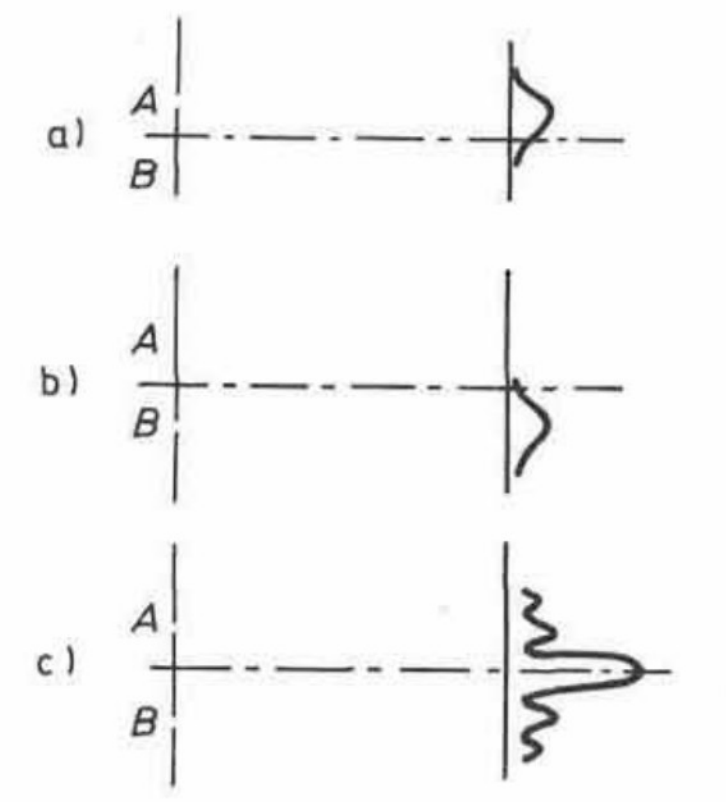
dispersion relation: Relation for $\boldsymbol{\omega}$ as a function of **k**

$$v_{\text{group}} = \frac{d\omega}{dk}$$

$$v_{\text{phase}} = \frac{\omega}{k}.$$

$$v_{\text{classical}} = v_{\text{group}} = 2v_{\text{phase}}.$$

Double slit experiment with electrons



a) Slit A open, slit B closed

b) Slit B open, slit A closed

c) Both slits are open

Probability

- *N(j)* represents no of events with value j
- *P(j)* is the probability for getting value j

$$P(j) = \frac{N(j)}{N}$$

- Average value of j is <*j*>

$$\langle j \rangle = \frac{\sum_j jP(j)}{N}$$

Time for some Mathematics

- **Probability**
- **Wave function**
- **Wave amplitude**

$$\int_{-\infty}^{+\infty} \rho(x)\,dx = 1,$$

$$\langle x \rangle = \int_{-\infty}^{+\infty} x\rho(x)\,dx,$$

$$\langle f(x) \rangle = \int_{-\infty}^{+\infty} f(x)\rho(x)\,dx,$$

$$\sigma^2 \equiv \langle (\Delta x)^2 \rangle = \langle x^2 \rangle - \langle x \rangle^2.$$

Time for some Mathematics

Sample problem from the book Griffiths:

∗**Problem 1.6** Consider the **Gaussian** distribution

$$\rho(x) = Ae^{-\lambda(x-a)^2},$$

where A, a, and λ are constants. (Look up any integrals you need.)

(a) Use Equation 1.16 to determine A.

(b) Find $\langle x \rangle$, $\langle x^2 \rangle$, and σ.

(c) Sketch the graph of $\rho(x)$.

Wave function and Probability:

We return now to the statistical interpretation of the wave function. Which says that $|\Psi(x, t)|^2$ is the probability density for finding the particle at point x, at time t.

Thank you for your attention