Collegedunia NCERT Formula Sheet

The Ultimate Formula Reference for Class 12 Physics

Chapter 11: Dual Nature of Radiation and Matter

Constant / Unit	Value
Planck constant, h	6.626×10^{-34} J·s
h in eV·s	4.136×10^{-15} eV·s
hc	1240 eV·nm
Electron mass, m_e	9.11×10^{-31} kg
Elementary charge, e	1.6×10^{-19} C
Electron volt (eV)	1.6×10^{-19} J
Typical work function ϕ	2–5 eV (most metals)

1 Photoelectric Effect

When light shines on a metal, electrons are ejected. The details of this emission — threshold frequency, instantaneous response, KE depending on frequency not intensity — contradict the wave picture and demand the photon hypothesis (NCERT 11.2–11.4).

Why classical wave theory fails

Classical waves predict: (i) any frequency should work given enough intensity, (ii) emission should take time to build up at low intensity, (iii) KE should rise with intensity. **Experiment shows the opposite**: (i) below threshold ν_0, no emission ever; (ii) emission is instantaneous; (iii) KE depends on **frequency only**, not intensity.

Photon energy & momentum

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

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

Each photon is a discrete packet — a quantum of light. Photons have momentum even though they have zero rest mass.

Einstein's photoelectric equation

$$KE_{\text{max}} = h\nu - \phi_0$$

$$\frac{1}{2}m_e v_{\text{max}}^2 = h\nu - h\nu_0$$

where ϕ_0 = work function (J or eV); ν_0 = threshold frequency.

One photon ejects one electron. KE depends only on ν, never on intensity. Light's particle nature, written as one equation.

Threshold & work function

$$\phi_0 = h\nu_0 = \frac{hc}{\lambda_0}$$

Below ν_0, no emission — a single photon cannot pay the energy cost of liberating an electron. Different metals have different ϕ_0: caesium ~ 2 eV, platinum ~ 6 eV.

Stopping potential

$$eV_0 = KE_{\text{max}} = h\nu - \phi_0$$

$$V_0 = \frac{h}{e}\nu - \frac{\phi_0}{e}$$

V_0 is the reverse voltage that stops even the fastest photoelectrons. Plot V_0 vs ν: **straight line** with slope h/e (used to measure h) and x-intercept ν_0.

Photocurrent dependence

Photocurrent (number of electrons / second) is proportional to **intensity** (number of photons / second), provided $\nu > \nu_0$. But **KE per electron** depends only on ν. Saturation current rises with intensity; stopping potential rises with frequency.

2 Wave–Particle Duality of Matter

If light has particle properties, perhaps matter has wave properties. de Broglie's hypothesis predicted matter waves; Davisson and Germer confirmed them with electron diffraction (NCERT 11.5–11.6).

de Broglie wavelength

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

Every moving particle has a wavelength. For an electron at 100 V, $\lambda \sim 0.12$ nm — comparable to atomic spacing, so electrons can be diffracted by crystals. For a 1 kg cricket ball, $\lambda \sim 10^{-34}$ m: completely undetectable.

Electron accelerated through potential V

$$\lambda = \frac{h}{\sqrt{2m_e eV}}$$

$$\lambda = \frac{1.227}{\sqrt{V}}\ \text{nm} \quad \text{(for } V \text{ in volts)}$$

At 150 V: $\lambda \approx 0.1$ nm. The basis of the **electron microscope**, which resolves features far smaller than light microscopes can.

Particle from kinetic energy

$$\lambda = \frac{h}{\sqrt{2mK}}$$

where K = kinetic energy (J).

Same equation as above with $K = eV$. Use directly when the particle's KE (not accelerating voltage) is given.

Davisson–Germer experiment

Electrons accelerated through 54 V hitting a Ni crystal showed a strong reflection peak at $50°$ — exactly matching Bragg-diffraction predictions for $\lambda \approx 0.165$ nm, the de Broglie wavelength at 54 V. **First direct experimental proof** that electrons behave as waves.

Wavelength from temperature (thermal particles)

$$\lambda = \frac{h}{\sqrt{2mk_BT \cdot \frac{3}{2}}} = \frac{h}{\sqrt{3mk_BT}}$$

Average thermal energy is $\frac{3}{2}k_BT$. Used for thermal neutrons in reactors and ultra-cold atoms. Lower $T \Rightarrow$ larger $\lambda \Rightarrow$ more wave-like.

3 Photons & Photon Numbers

Many problems involve counting photons — the link between continuous wave intensity and discrete photon flux (NCERT 11.4 cont.).

Photon flux from a source

Photons per second: $N = \dfrac{P}{h\nu} = \dfrac{P\lambda}{hc}$

where P = power of source (W).

A 100 W bulb emits $\sim$ $\mathbf{10^{20}}$ visible photons/sec. Macroscopic intensity hides the granularity of light — which is why classical wave theory works so well at high photon counts.

Number of electrons emitted

$$\boldsymbol{n_e = \frac{I}{e}}$$

where $\boldsymbol{I}$ = photocurrent (A); $\boldsymbol{n_e}$ = electrons / second.

Combined with photon flux, this gives quantum efficiency: $\boldsymbol{\eta = n_e/N}$. Typical photocathodes: $\boldsymbol{\eta \sim 1\%}$ to $\mathbf{30\%}$.

JEE/NEET Extension: Compton effect

When a photon scatters off a free electron, its wavelength **increases**:

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

where $\lambda_C = h/(m_e c) = 2.43 \times 10^{-12}$ m is the Compton wavelength. Confirms photon momentum and energy conservation in scattering.

Photoelectric instant truths

Below threshold: **no** emission, no matter how bright the light.
Above threshold: emission is **instantaneous**, no time delay.
KE depends on ν alone; **count of electrons** depends on intensity alone.
These four facts together kill the wave theory of light.

Photons vs electrons

Photons: rest mass = 0, always travel at c, energy $= h\nu$, momentum $= h/\lambda$. Electrons: rest mass $\neq 0$, travel below c, energy $= p^2/(2m)$ for slow speeds. **Both** have wave properties — but the formula for $\lambda = h/p$ is universal, applicable to either.

Quick Reference — Dual Nature

Quantity / Concept	Expression	Notes
Photon energy	$h\nu = hc/\lambda$	Discrete packets
Photon momentum	h/λ	Even with zero rest mass
Einstein PE equation	$h\nu - \phi_0$	$= KE_{\text{max}}$
Work function	$h\nu_0 = hc/\lambda_0$	Material constant
Threshold frequency	ϕ_0/h	Below: no emission
Stopping potential	$V_0 = (h/e)\nu - \phi_0/e$	Linear in ν
de Broglie wavelength	$h/p = h/(mv)$	For all particles
λ from accelerating V	$h/\sqrt{2m_eeV}$	$= 1.227/\sqrt{V}$ nm
λ from KE	$h/\sqrt{2mK}$	General
λ from temp	$h/\sqrt{3mk_BT}$	Thermal particles
Photon flux	$P/(h\nu)$	Photons per second
Photocurrent	$eN \cdot \eta$	η = quantum efficiency
Compton shift (ext.)	$\lambda_C(1 - \cos\theta)$	$\lambda_C = 2.43$ pm