

Chapter 11 · Dual Nature of Radiation and Matter

CBSE Class 12 Physics (042) · Unit VII · Unit VII + VIII = 12 marks · Ultimate Revision Sheet

60-SECOND RECALL

Einstein's equation	$h\nu = \phi_0 + K_{\max}$
Max KE	$K_{\max} = h\nu - \phi_0 = eV_0$
Threshold	$\phi_0 = h\nu_0 = hc/\lambda_0$
Stopping potential	Depends on frequency , NOT on intensity
Photocurrent	Depends on intensity , NOT on frequency
de Broglie	$\lambda = h/p = h/mv \cdot \lambda = h/\sqrt{2mK}$
Accelerated electron	$\lambda = 12.27/\sqrt{V} \text{ \AA}$
h	$6.63 \times 10^{-34} \text{ J s}$

1. The Photoelectric Effect

DEFINITIONS Photoelectric effect: the emission of electrons from a metal surface when light of suitable frequency falls on it.

Work function ϕ_0 : the minimum energy required to free an electron from the metal surface.

Threshold frequency ν_0 : the minimum frequency below which no emission occurs, however intense the light.

Stopping potential V_0 : the negative potential at which the photocurrent becomes zero.

- THE FOUR EXPERIMENTAL LAWS**
1. Emission is **instantaneous** — no time lag (less than 10^{-9} s).
 2. For a given metal, emission occurs only above the **threshold frequency**.
 3. The **photocurrent** $\propto$ **intensity** (more photons $\rightarrow$ more electrons).
 4. The **maximum kinetic energy** $\propto$ **frequency**, and is **independent of intensity**.

EINSTEIN'S EQUATION

$$h\nu = \phi_0 + K_{\max} \rightarrow K_{\max} = h\nu - h\nu_0 = eV_0$$

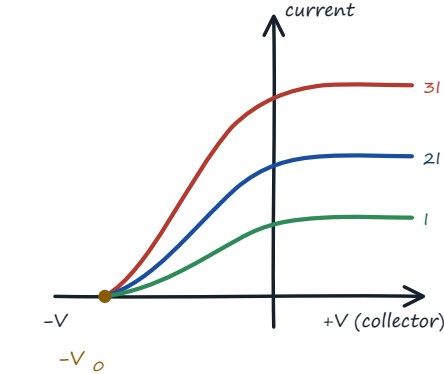
$$eV_0 = h\nu - \phi_0 \rightarrow V_0 = (h/e)\nu - \phi_0/e$$

The graph of V_0 against ν is a straight line of slope h/e — the same slope for every metal — with intercept $-\phi_0/e$. This graph is asked repeatedly.

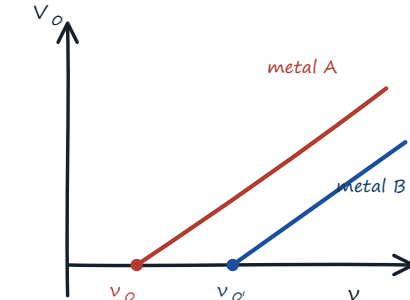
THE TRAP THAT SEPARATES GRADES Intensity controls the **NUMBER** of electrons; frequency controls their **ENERGY**.

Doubling the intensity **doubles the photocurrent** but leaves the **stopping potential unchanged**. Raising the frequency **raises the stopping potential** but leaves the **saturation current unchanged**. Wave theory failed on exactly three points: it could not explain the **threshold frequency**, the **instantaneous emission**, or why $K_{\max}$ is independent of intensity.

(a) Photocurrent vs collector plate potential



(b) Stopping potential vs frequency



Both lines have the **SAME** slope = h/e . Only the threshold v_0 shifts, because the work function differs.
 $eV_0 = h\nu - \phi$

The whole chapter is in these two graphs: **intensity** → more electrons, **frequency** → more energy per electron. Below v_0 nothing happens however bright the light.

2. Photons

PROPERTIES

Energy $E = h\nu = hc/\lambda$ · **Momentum** $p = h\nu/c = h/\lambda$

Photons have **zero rest mass**, travel at c , are **electrically neutral** (so undeflected by electric or magnetic fields), and in a collision with an electron both **energy and momentum are conserved**. The number of photons emitted per second by a source of power P is $n = P/h\nu$.

3. Matter Waves — de Broglie

FORMULAS

$\lambda = h/p = h/mv$

$\lambda = h/\sqrt{2mK}$ (K = kinetic energy)

$\lambda = h/\sqrt{2mqV}$ → for an electron, $\lambda = 12.27/\sqrt{V}$ Å (V in volts)

TRAP $\lambda \propto 1/\sqrt{m}$ at the same kinetic energy — so at equal energy a **proton** has a **shorter wavelength** than an electron, and a cricket ball's wavelength is far too small to observe. That is precisely why matter waves are invisible in daily life.

The **Davisson–Germer experiment** confirmed matter waves by observing electron **diffraction** from a nickel crystal.

WORKED EXAMPLE Light of wavelength **400 nm** falls on a metal of work function **2.0 eV**. Find $K_{\max}$ and the stopping potential.

$$E = hc/\lambda = (1240 \text{ eV nm})/(400 \text{ nm}) = \mathbf{3.1 \text{ eV}}$$
 (using $hc = 1240 \text{ eV nm}$ saves time)

$$K_{\max} = E - \phi_0 = 3.1 - 2.0 = \mathbf{1.1 \text{ eV}}$$

$$\text{Stopping potential } V_0 = K_{\max}/e = \mathbf{1.1 \text{ V}}$$

$$\text{Threshold wavelength } \lambda_0 = 1240/2.0 = \mathbf{620 \text{ nm}}$$

4. Question Triggers what the wording is really asking

If the question says...	The answer is...
"intensity is doubled"	Photocurrent doubles; V_0 unchanged
"frequency is increased"	V_0 and $K_{\max}$ rise ; saturation current unchanged
"no emission however bright the light"	Frequency is below threshold
"slope of the V_0 vs ν graph"	h/e — same for all metals
"wavelength of an accelerated electron"	$\lambda = 12.27/\sqrt{V} \text{ \AA}$
"which has shorter λ at the same KE"	The heavier particle
"experiment confirming the wave nature of electrons"	Davisson–Germer

MOST-ASKED BOARD QUESTIONS

- [3M]** State Einstein's photoelectric equation and explain the laws of photoelectric emission with it.
- [3M]** Sketch and explain the graphs of photocurrent vs intensity, photocurrent vs potential, and V_0 vs ν .
- [2M]** Define work function, threshold frequency and stopping potential.
- [2M]** Derive the de Broglie wavelength of an electron accelerated through V volts.
- [2M]** Numerical on $K_{\max}$, V_0 and λ_0 .
- [1M]** Name the experiment that verified the wave nature of electrons. → Davisson–Germer

THE HABIT THAT SCORES — Memorise $hc = 1240 \text{ eV nm}$. Every photoelectric numerical in the paper collapses to one line with it, and you avoid converting joules to electron-volts under time pressure.