

Class 12 Physics: Complete Formula Sheet

All 14 NCERT chapters (Part I and Part II) · CBSE syllabus 2026-27 · NCERT textbook (Reprint 2026-27)

How to use this sheet. Plain boxes cover the CBSE 2026-27 board-exam syllabus. Amber boxes marked ★ **Qualitative only** are topics the 2026-27 syllabus lists for qualitative treatment, so expect conceptual questions on them rather than derivations or numericals. Grey boxes marked ◇ **Not in 2026-27 syllabus** are in the NCERT book but not in the current syllabus. They are kept for reference and JEE/NEET. Constants: $e = 1.6 \times 10^{-19} \text{ C}$, $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$, $\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$, $\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$, $h = 6.63 \times 10^{-34} \text{ J s}$, $c = 3 \times 10^8 \text{ m s}^{-1}$, $m_e = 9.1 \times 10^{-31} \text{ kg}$.

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1 Electric Charges and Fields

CHARGE AND COULOMB'S LAW

- Quantisation: $q = ne$, $n = 0, \pm 1, \pm 2, \dots$
- Charge is additive and conserved.
- Coulomb's law:

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

- Vector form: $\vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{21}^2} \hat{r}_{21}$ (force on q_2 due to q_1)
- Superposition: $\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \dots + \vec{F}_{1n}$

ELECTRIC FIELD

- $\vec{E} = \vec{F}/q$, SI unit N C^{-1} ($= \text{V m}^{-1}$)
- Point charge:

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$$

- System of charges: $\vec{E} = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_{iP}^2} \hat{r}_{iP}$
- Charge densities: $\lambda = \frac{\Delta Q}{\Delta l}$, $\sigma = \frac{\Delta Q}{\Delta S}$, $\rho = \frac{\Delta Q}{\Delta V}$

ELECTRIC DIPOLE

- Dipole moment $\vec{p} = q \times 2a \hat{p}$, from $-q$ to $+q$
- Axial point ($r \gg a$): $\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{2\vec{p}}{r^3}$
- Equatorial point ($r \gg a$): $\vec{E} = -\frac{1}{4\pi\epsilon_0} \frac{\vec{p}}{r^3}$
- Dipole field falls as $1/r^3$; point-charge field as $1/r^2$.

DIPOLE IN A UNIFORM FIELD

- Torque: $\vec{\tau} = \vec{p} \times \vec{E}$, $|\tau| = pE \sin \theta$
- Net force = 0 in a uniform field
- Non-uniform field: net force is non-zero

FLUX AND GAUSS'S LAW

- Flux: $\Delta\phi = \vec{E} \cdot \Delta\vec{S} = E \Delta S \cos \theta$
 - Gauss's law:
- $$\oint \vec{E} \cdot d\vec{S} = \frac{q_{\text{enclosed}}}{\epsilon_0}$$
- Charges outside the surface contribute zero net flux.

APPLICATIONS OF GAUSS'S LAW

- Infinite straight wire: $\vec{E} = \frac{\lambda}{2\pi\epsilon_0 r} \hat{n}$
- Infinite plane sheet: $\vec{E} = \frac{\sigma}{2\epsilon_0} \hat{n}$ (independent of distance)
- Thin spherical shell, outside ($r \geq R$): $\vec{E} = \frac{q}{4\pi\epsilon_0 r^2} \hat{r}$
- Thin spherical shell, inside ($r < R$): $E = 0$



2 Electrostatic Potential and Capacitance

POTENTIAL

- $V = W/q$: work done by an external force to bring a unit positive charge from infinity
- Point charge: $V = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$
- Dipole: $V = \frac{1}{4\pi\epsilon_0} \frac{p \cos \theta}{r^2}$ (zero on the equatorial plane)
- System of charges: $V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_{iP}}$
- Shell: $V = \frac{q}{4\pi\epsilon_0 r}$ outside, $V = \frac{q}{4\pi\epsilon_0 R}$ inside (constant)

POTENTIAL ENERGY

- Two charges: $U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}}$
- Three charges: $U = \frac{1}{4\pi\epsilon_0} \left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right)$
- Single charge in external field: $qV(\vec{r})$
- Two charges in external field: $q_1 V(\vec{r}_1) + q_2 V(\vec{r}_2) + \frac{q_1 q_2}{4\pi\epsilon_0 r_{12}}$
- Dipole in uniform field: $U(\theta) = -pE \cos \theta = -\vec{p} \cdot \vec{E}$

CAPACITANCE

- $C = Q/V$, SI unit farad (F)
- Parallel plate (vacuum):

$$C_0 = \frac{\epsilon_0 A}{d}$$
- Filled with dielectric: $C = \frac{K\epsilon_0 A}{d} = KC_0$
- Series: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$ (same Q on each)
- Parallel: $C = C_1 + C_2 + \dots$ (same V across each)

FIELD AND POTENTIAL

- $E = -\frac{dV}{dr}$, i.e. $|\vec{E}| = \frac{|\delta V|}{\delta l}$ along the normal to the equipotential
- $\vec{E}$ points in the direction of steepest decrease of V
- $\vec{E}$ is perpendicular to every equipotential surface
- No work is done moving a charge along an equipotential surface

CONDUCTORS AND DIELECTRICS

- Inside a conductor: $E = 0$; V is constant throughout
- Just outside the surface: $\vec{E} = \frac{\sigma}{\epsilon_0} \hat{n}$
- Excess charge resides only on the surface
- Polarisation: $\vec{P} = \chi_e \vec{E}$ (χ_e = electric susceptibility)
- Dielectric constant: $K = \epsilon_r = \epsilon/\epsilon_0$

ENERGY STORED (FORMULAE ONLY)

- $U = \frac{Q^2}{2C} = \frac{1}{2} CV^2 = \frac{1}{2} QV$
- Energy density of the field: $u = \frac{1}{2} \epsilon_0 E^2$

3 Current Electricity

CURRENT, OHM'S LAW, RESISTIVITY

- $I = \frac{q}{t}$; instantaneous $I = \frac{dq}{dt}$
- Ohm's law: $V = IR$
- $R = \rho \frac{l}{A}$; conductivity $\sigma = 1/\rho$
- Current density $j = I/A$; $\vec{j} = \sigma \vec{E}$

DRIFT VELOCITY AND MOBILITY

- $\vec{v}_d = -\frac{e\vec{E}}{m} \tau$ (τ = relaxation time)
- $I = neA v_d$
- $\rho = \frac{m}{ne^2 \tau}$
- Mobility: $\mu = \frac{|v_d|}{E} = \frac{e\tau}{m}$



TEMPERATURE, ENERGY, POWER

- $\rho_T = \rho_0 [1 + \alpha(T - T_0)]$ (α = temperature coefficient of resistivity)
- $R_2 = R_1 [1 + \alpha(T_2 - T_1)]$
- Power: $P = VI = I^2 R = \frac{V^2}{R}$
- Energy: $W = VIt$

RESISTORS IN COMBINATION

- Series: $R = R_1 + R_2 + \dots$
- Parallel: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

CELL: EMF AND INTERNAL RESISTANCE

- Terminal voltage: $V = \varepsilon - Ir$
- Current through external R : $I = \frac{\varepsilon}{R + r}$
- Series: $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$, $r_{eq} = r_1 + r_2$
- Parallel: $\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$, $r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$

KIRCHHOFF'S RULES AND WHEATSTONE BRIDGE

- Junction rule: $\sum I_{in} = \sum I_{out}$ (charge conservation)
- Loop rule: $\sum \Delta V = 0$ round any closed loop (energy conservation)
- Balanced bridge ($I_g = 0$):

$$\frac{R_2}{R_1} = \frac{R_4}{R_3}$$

4 Moving Charges and Magnetism**LORENTZ FORCE**

- $\vec{F} = q [\vec{E} + \vec{v} \times \vec{B}]$
- Magnetic part: $F = qvB \sin \theta$; zero when $\vec{v} \parallel \vec{B}$
- Magnetic force does no work (it is always $\perp$ to $\vec{v}$)
- Current-carrying conductor: $\vec{F} = I \vec{l} \times \vec{B}$

CHARGE MOVING IN A UNIFORM $\vec{B}$

- Radius: $r = \frac{mv}{qB}$ (for $\vec{v} \perp \vec{B}$)
- Angular frequency $\omega = \frac{qB}{m}$; frequency $\nu = \frac{qB}{2\pi m}$
- Period $T = \frac{2\pi m}{qB}$ (independent of speed)
- Helix pitch: $p = v_{\parallel} T = \frac{2\pi m v_{\parallel}}{qB}$

BIOT-SAVART LAW

- $d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{l} \times \vec{r}}{r^3}$
- $|dB| = \frac{\mu_0}{4\pi} \frac{I dl \sin \theta}{r^2}$
- Circular loop, on axis: $B = \frac{\mu_0 I R^2}{2(x^2 + R^2)^{3/2}}$
- At the centre: $B = \frac{\mu_0 I}{2R}$; for N turns multiply by N

AMPERE'S CIRCITAL LAW

- $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_e$
- Infinitely long straight wire: $B = \frac{\mu_0 I}{2\pi r}$
- Field lines are circles round the wire (right-hand rule).

★ SOLENOID (QUALITATIVE ONLY)

- Inside a long solenoid: $B = \mu_0 n I$ (n = turns per unit length)
- Field inside is uniform; outside it is nearly zero

PARALLEL CURRENTS AND THE AMPERE

- Force per unit length: $f = \frac{\mu_0 I_a I_b}{2\pi d}$
- Like currents attract; opposite currents repel
- 1 A: the current that gives $2 \times 10^{-7} \text{ N m}^{-1}$ between two wires 1 m apart



CURRENT LOOP AS A MAGNETIC DIPOLE

- Magnetic moment: $\vec{m} = NI\vec{A}$
- Torque: $\vec{\tau} = \vec{m} \times \vec{B}$, $\tau = NIAB \sin \theta$
- Field on the axis far away: $B = \frac{\mu_0}{4\pi} \frac{2m}{x^3}$

MOVING COIL GALVANOMETER

- Equilibrium: $NIAB = k\phi$ (k = torsional constant)
- Current sensitivity: $\frac{\phi}{I} = \frac{NAB}{k}$
- Voltage sensitivity: $\frac{\phi}{V} = \frac{NAB}{kR}$
- Ammeter: small shunt r_s in parallel, $r_s = \frac{I_g R_G}{I - I_g}$
- Voltmeter: large R in series, $R = \frac{V}{I_g} - R_G$

5 Magnetism and Matter**★ BAR MAGNET (QUALITATIVE ONLY)**

- Behaves like a solenoid; dipole moment $\vec{m}$ points S to N
- Axial field: $B = \frac{\mu_0}{4\pi} \frac{2m}{r^3}$; equatorial: $B = \frac{\mu_0}{4\pi} \frac{m}{r^3}$ (opposite to $\vec{m}$)
- Torque: $\vec{\tau} = \vec{m} \times \vec{B}$; energy $U = -\vec{m} \cdot \vec{B}$
- Field lines are closed loops; they never intersect

MAGNETISATION

- $\vec{M} = \frac{\vec{m}_{net}}{V}$ ($A m^{-1}$)
- $\vec{B} = \mu_0(\vec{H} + \vec{M})$
- $\vec{M} = \chi \vec{H}$ (χ = magnetic susceptibility)
- $\vec{B} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$, $\mu_r = 1 + \chi$

MAGNETIC MATERIALS

Property	Diamagnetic	Paramagnetic	Ferromagnetic
χ	$-1 \leq \chi < 0$	$0 < \chi < \epsilon$ (small)	$\chi \gg 1$
μ_r	$0 \leq \mu_r < 1$	$1 < \mu_r < 1 + \epsilon$	$\mu_r \gg 1$
In a field	moves to weaker region	moves to stronger region	strongly attracted
Examples	Bi, Cu, Pb, Si, water, NaCl	Al, Na, Ca, O ₂ , CuCl ₂	Fe, Ni, Co, Gd

Superconductors are perfect diamagnets ($\chi = -1$, Meissner effect). Above the Curie temperature a ferromagnet becomes paramagnetic.

◇ GAUSS'S LAW FOR MAGNETISM

- $\oint \vec{B} \cdot d\vec{S} = 0$: net magnetic flux through any closed surface is zero (no isolated poles)

6 Electromagnetic Induction**FLUX, FARADAY AND LENZ**

- $\Phi_B = \vec{B} \cdot \vec{A} = BA \cos \theta$ (weber, Wb)
- Faraday's law:

$$\epsilon = -N \frac{d\Phi_B}{dt}$$
- Lenz's law: the induced current opposes the change in flux that produces it (the minus sign)

MOTIONAL EMF

- Rod of length l moving with speed $v \perp$ to B : $\epsilon = Blv$
- The work done to move the rod is dissipated as Joule heat in the circuit (Lenz's law and energy conservation).



MUTUAL INDUCTANCE

- $N_1 \Phi_1 = M_{12} I_2$; $\varepsilon_1 = -M \frac{dI_2}{dt}$
- Coaxial solenoids: $M_{12} = M_{21} = \mu_0 n_1 n_2 \pi r_1^2 l$
- Unit: henry (H)

SELF-INDUCTANCE

- $N \Phi_B = LI$; $\varepsilon = -L \frac{dI}{dt}$
- Long solenoid: $L = \mu_0 n^2 Al$; with core: $L = \mu_r \mu_0 n^2 Al$
- Energy stored: $W = \frac{1}{2} LI^2$

AC GENERATOR

- Flux $\Phi_B = BA \cos \omega t$; induced emf $\varepsilon = NBA \omega \sin \omega t = \varepsilon_0 \sin \omega t$
- Peak emf: $\varepsilon_0 = NBA \omega$, where $\omega = 2\pi \nu$

7 Alternating Current**AC BASICS AND RMS VALUES**

- $v = v_m \sin \omega t$, $i = i_m \sin \omega t$
- $I = \frac{i_m}{\sqrt{2}} = 0.707 i_m$, $V = \frac{v_m}{\sqrt{2}}$
- Average power in R : $\bar{P} = \frac{1}{2} i_m^2 R = I^2 R$
- Mean of i over a full cycle = 0

PURE R, L, C

Element	Reactance	Phase of i	Avg power
R	R	in phase	$I^2 R$
L	$X_L = \omega L$	lags v by $\pi/2$	0
C	$X_C = \frac{1}{\omega C}$	leads v by $\pi/2$	0

SERIES LCR CIRCUIT

- Impedance:
$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$
- $i_m = \frac{v_m}{Z}$; phase $\tan \phi = \frac{X_C - X_L}{R}$
- Resonance: $X_L = X_C$, $\omega_0 = \frac{1}{\sqrt{LC}}$, $Z = R$ (current is maximum)

POWER AND POWER FACTOR

- $P = VI \cos \phi$; power factor $\cos \phi = \frac{R}{Z}$
- Pure L or C : $\phi = \pi/2$, $P = 0$ (wattless current)
- Resonance or pure R : $\cos \phi = 1$

TRANSFORMER (IDEAL)

- $$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$
- Step-up: $N_s > N_p$; step-down: $N_s < N_p$. Losses: flux leakage, winding resistance, eddy currents, hysteresis.

8 Electromagnetic Waves**DISPLACEMENT CURRENT**

- $i_d = \varepsilon_0 \frac{d\Phi_E}{dt}$
- Ampere-Maxwell law: $\oint \vec{B} \cdot d\vec{l} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$

EM WAVE PROPERTIES

- $E_x = E_0 \sin(kz - \omega t)$, $B_y = B_0 \sin(kz - \omega t)$
- $k = 2\pi/\lambda$, $\omega = 2\pi\nu$, $c = \nu\lambda$
- $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$; in a medium $v = \frac{1}{\sqrt{\mu \varepsilon}}$
- $\frac{E_0}{B_0} = c$; $\vec{E}$, $\vec{B}$ and the direction of travel are mutually $\perp$ (transverse)



ELECTROMAGNETIC SPECTRUM

Type	Wavelength range	Production / use
Radio	> 0.1 m	Oscillating charges in antennas; radio, TV, cellphones
Microwave	0.1 m to 1 mm	Klystron, magnetron; radar, microwave ovens
Infrared	1 mm to 700 nm	Hot bodies; remote controls, physical therapy, greenhouse effect
Visible	700 nm to 400 nm	Electron transitions in atoms; vision
Ultraviolet	400 nm to 1 nm	Sun, special lamps; LASIK, water purification
X-rays	1 nm to 10^{-3} nm	X-ray tubes; medical diagnosis
Gamma rays	< 10^{-3} nm	Radioactive decay of nuclei; cancer treatment

9 Ray Optics and Optical Instruments**SPHERICAL MIRRORS**

- Focal length $f = R/2$
- Mirror equation:
$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$
- Magnification $m = \frac{h'}{h} = -\frac{v}{u}$
- Cartesian sign convention: distances measured from the pole; along incident light positive.

REFRACTION AND TIR

- Snell's law: $n_1 \sin i = n_2 \sin r$; $n_{21} = \frac{n_2}{n_1} = \frac{v_1}{v_2}$
- Apparent depth: $\frac{\text{real depth}}{\text{apparent depth}} = n$
- Critical angle (denser to rarer): $\sin i_c = \frac{1}{n_{21}}$, with n_{21} of the denser w.r.t. rarer medium
- TIR needs: light going denser to rarer, and $i > i_c$

SPHERICAL SURFACE AND LENSES

- Single surface: $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$
- Lens maker's formula:
$$\frac{1}{f} = (n_{21} - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$
- Thin lens: $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$; $m = \frac{h'}{h} = \frac{v}{u}$

POWER AND LENS COMBINATIONS

- $P = \frac{1}{f}$ (f in metres), unit dioptre (D)
- Lenses in contact: $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \dots$, $P = P_1 + P_2 + \dots$
- Total magnification: $m = m_1 m_2 m_3 \dots$

PRISM

- $r_1 + r_2 = A$; $A + \delta = i + e$
- Minimum deviation ($i = e$, $r_1 = r_2 = A/2$):
$$n_{21} = \frac{\sin [(A + D_m)/2]}{\sin (A/2)}$$
- Thin prism: $D_m = (n_{21} - 1)A$

OPTICAL INSTRUMENTS ($D = 25$ CM)

- Simple microscope: $m = 1 + \frac{D}{f}$ (image at D);
 $m = \frac{D}{f}$ (image at infinity)
- Compound microscope (final image at infinity):
 $m = m_o m_e = \frac{L}{f_o} \cdot \frac{D}{f_e}$, L = tube length
- Telescope (normal adjustment): $m = \frac{f_o}{f_e}$; tube length $f_o + f_e$
- Reflecting telescopes (Cassegrain) avoid chromatic aberration and need no huge lens.



10 Wave Optics

HUYGENS PRINCIPLE AND REFRACTION

- $n_{21} = \frac{v_1}{v_2} = \frac{\sin i}{\sin r}$
- In a medium of index n : $\lambda' = \lambda/n$, speed c/n ; frequency unchanged
- Reflection: angle of incidence = angle of reflection

INTERFERENCE

- Constructive: path difference = $n\lambda$; destructive: = $(n + \frac{1}{2})\lambda$
- Resultant intensity: $I = 4I_0 \cos^2 \frac{\phi}{2}$
- Sustained interference needs coherent sources (constant phase difference)

YOUNG'S DOUBLE SLIT (FINAL EXPRESSIONS ONLY)

- Bright fringes: $x_n = \frac{n\lambda D}{d}$; dark fringes: $x_n = \left(n + \frac{1}{2}\right) \frac{\lambda D}{d}$
- Fringe width:

$$\beta = \frac{\lambda D}{d}$$
- d = slit separation, D = slit-to-screen distance. Fringes are equally spaced.

★ SINGLE-SLIT DIFFRACTION (QUALITATIVE ONLY)

- Minima: $\theta \approx \frac{n\lambda}{a}$, $n = \pm 1, \pm 2, \dots$
- Central maximum: angular width $\frac{2\lambda}{a}$; it is twice as wide as other maxima

◇ POLARISATION

- Malus' law: $I = I_0 \cos^2 \theta$
- Unpolarised light through a polaroid: intensity halves

11 Dual Nature of Radiation and Matter

PHOTON

- Energy $E = h\nu = \frac{hc}{\lambda}$
- Momentum $p = \frac{h\nu}{c} = \frac{h}{\lambda}$
- $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$

EINSTEIN'S PHOTOELECTRIC EQUATION

- $K_{max} = h\nu - \phi_0 = eV_0$
- Work function $\phi_0 = h\nu_0$; threshold wavelength $\lambda_0 = c/\nu_0$
- $V_0 = \frac{h}{e}\nu - \frac{\phi_0}{e}$: straight-line graph of V_0 vs ν , slope h/e

PHOTOELECTRIC OBSERVATIONS

- Photocurrent $\propto$ intensity (for $\nu > \nu_0$)
- Stopping potential depends on ν , not on intensity
- No emission below ν_0 , however intense the light; emission is instantaneous

DE BROGLIE RELATION

- $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mK}}$
- Electron accelerated through V : $\lambda = \frac{h}{\sqrt{2meV}} = \frac{1.227}{\sqrt{V}} \text{ nm}$



12 Atoms

RUTHERFORD SCATTERING

- Distance of closest approach (K = kinetic energy of the alpha particle):

$$d = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{K}$$

- Most alpha particles pass undeflected: the atom is mostly empty, with a tiny massive nucleus

BOHR'S POSTULATES

- Stationary orbits: $L = mvr = \frac{nh}{2\pi}$
- Transition: $h\nu = E_i - E_f$

BOHR MODEL OF HYDROGEN

- Radius: $r_n = \frac{n^2 h^2 \epsilon_0}{\pi m e^2} = n^2 a_0$, Bohr radius $a_0 = 5.29 \times 10^{-11} \text{ m}$
- Speed: $v_n = \frac{e^2}{2\epsilon_0 n h} = \frac{1}{n} \frac{e^2}{4\pi\epsilon_0 (h/2\pi)}$
- Energy:

$$E_n = -\frac{me^4}{8n^2\epsilon_0^2 h^2} = -\frac{13.6}{n^2} \text{ eV}$$

- KE = $-E_n$, PE = $2E_n$; ionisation energy of H = 13.6 eV

★ LINE SPECTRA (QUALITATIVE ONLY)

- Photon emitted when the electron drops from n_i to n_f : $h\nu_{if} = E_{n_i} - E_{n_f}$
- Each allowed transition gives one line, so hydrogen emits a discrete line spectrum

13 Nuclei

COMPOSITION AND SIZE

- $A = Z + N$; $1 \text{ u} = 1.660539 \times 10^{-27} \text{ kg}$
- Radius: $R = R_0 A^{1/3}$, $R_0 = 1.2 \times 10^{-15} \text{ m}$
- Nuclear density is the same for all nuclei (about $2.3 \times 10^{17} \text{ kg m}^{-3}$)

MASS-ENERGY AND BINDING ENERGY

- $E = mc^2$; $1 \text{ u} \equiv 931.5 \text{ MeV}$
- Mass defect: $\Delta M = [Zm_p + (A - Z)m_n] - M$
- Binding energy $E_b = \Delta M c^2$; per nucleon $E_{bn} = E_b/A$
- E_{bn} peaks at about 8.75 MeV near $A = 56$; roughly constant (about 8 MeV) for $30 < A < 170$

NUCLEAR FORCE

- Much stronger than Coulomb force; short range (a few fm)
- Nearly independent of charge (n-n, p-p and n-p similar)

FISSION AND FUSION

- ${}_0^1\text{n} + {}_{92}^{235}\text{U} \rightarrow {}_{92}^{236}\text{U} \rightarrow {}_{56}^{144}\text{Ba} + {}_{36}^{89}\text{Kr} + 3{}_0^1\text{n}$ (about 200 MeV)
- ${}_1^1\text{H} + {}_1^1\text{H} \rightarrow {}_2^2\text{H} + e^+ + \nu + 0.42 \text{ MeV}$
- ${}_1^2\text{H} + {}_1^2\text{H} \rightarrow {}_2^3\text{He} + {}_0^1\text{n} + 3.27 \text{ MeV}$



14 Semiconductor Electronics

ENERGY BANDS (QUALITATIVE)

- Conductor: bands overlap, or the conduction band is partly filled
- Insulator: $E_g > 3 \text{ eV}$
- Semiconductor: $E_g < 3 \text{ eV}$ (Si about 1.1 eV, Ge about 0.7 eV)

P-N JUNCTION DIODE

- Diffusion and drift form a depletion layer and barrier potential
- Forward bias: barrier lowered, current rises sharply past the threshold (about 0.7 V for Si, 0.2 V for Ge)
- Reverse bias: barrier raised, very small current until breakdown

CARRIER CONCENTRATION

- Intrinsic: $n_e = n_h = n_i$
- In equilibrium:

$$n_e n_h = n_i^2$$

- n-type (pentavalent dopant, e.g. As, P): $n_e \gg n_h$
- p-type (trivalent dopant, e.g. B, Al, In): $n_h \gg n_e$

DIODE AS A RECTIFIER

- Half-wave: one diode, output frequency = input frequency ν
- Full-wave (centre-tap, two diodes): output frequency = 2ν
- A capacitor filter smooths the pulsating dc

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