



FORMULA SHEET · CLASS 11 AND 12

Physics Formula Sheet for JEE and NEET

The formulas that carry most of the marks in JEE Main, JEE Advanced and NEET physics, grouped the way the NCERT books teach them. Print it, stick it above your desk, and test yourself on one section a day.

JEE

NEET

CBSE 12

01 Units and errors

Force – $[M L T^{-2}]$

Work, energy – $[M L^2 T^{-2}]$

Power – $[M L^2 T^{-3}]$

Pressure, stress – $[M L^{-1} T^{-2}]$

Gravitational constant G – $[M^{-1} L^3 T^{-2}]$

Planck's constant h – $[M L^2 T^{-1}]$

Error in $x = a^p b^q / c^r$ – $\Delta x/x = p(\Delta a/a) + q(\Delta b/b) + r(\Delta c/c)$

02 Kinematics

Equations of motion – $v = u + at$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$

Distance in the n th second – $s_n = u + a(n - \frac{1}{2})$

Projectile – $T = 2u \sin\theta/g$, $H = u^2 \sin^2\theta/2g$, $R = u^2 \sin 2\theta/g$ (maximum at 45°)

Relative velocity – $v_{AB} = v_A - v_B$

Uniform circular motion – $a_c = v^2/r = \omega^2 r$, $v = \omega r$

03 Laws of motion and friction

Newton's second law – $F = dp/dt = ma$

Impulse – $J = F\Delta t = \Delta p$

Friction – $f_s \leq \mu_s N$, $f_k = \mu_k N$, angle of repose: $\tan\theta = \mu_s$

Banked road (no friction) – $\tan\theta = v^2/rg$

Level curve, maximum speed – $v = \sqrt{\mu rg}$

04 Work, energy and power

Work – $W = F \cdot s = Fs \cos\theta$

Kinetic energy – $K = \frac{1}{2}mv^2 = p^2/2m$

Potential energy – mgh (near Earth), $\frac{1}{2}kx^2$ (spring)

Work-energy theorem – $W_{net} = \Delta K$

Power – $P = dW/dt = F \cdot v$

Elastic collision (1D) – $v_1 = [(m_1 - m_2)u_1 + 2m_2u_2]/(m_1 + m_2)$

Coefficient of restitution – $e = (v_2 - v_1)/(u_1 - u_2)$

05 Rotational motion

Torque – $\tau = r \times F = I\alpha$

Angular momentum – $L = I\omega = r \times p$

Rotational kinetic energy – $\frac{1}{2}I\omega^2$

Parallel axis – $I = I_{cm} + Md^2$

Perpendicular axis (lamina) – $I_z = I_x + I_y$

Moments of inertia – ring MR^2 ; disc $\frac{1}{2}MR^2$; solid sphere $(2/5)MR^2$; hollow sphere $(2/3)MR^2$; rod about centre $ML^2/12$, about end $ML^2/3$

Rolling without slipping – $v = \omega R$, $K = \frac{1}{2}mv^2(1 + k^2/R^2)$

Rolling down an incline – $a = g \sin\theta/(1 + k^2/R^2)$

06 Gravitation

Newton's law – $F = Gm_1m_2/r^2$

Surface gravity – $g = GM/R^2$

At height h ($h \ll R$) – $g' \approx g(1 - 2h/R)$

At depth d – $g' = g(1 - d/R)$

Orbital speed – $v_o = \sqrt{GM/r}$

Escape speed – $v_e = \sqrt{2GM/R} = \sqrt{2gR} \approx 11.2$ km/s for Earth

Kepler's third law – $T^2 = 4\pi^2 r^3/GM$

Potential energy – $U = -GMm/r$

07 Solids and fluids

Young's modulus – $Y = (F/A)/(\Delta L/L)$

Pressure at depth – $P = P_0 + \rho gh$

Buoyant force – $F_B = \rho_{fluid} Vg$

Continuity – $A_1 v_1 = A_2 v_2$

Bernoulli – $P + \frac{1}{2} \rho v^2 + \rho gh = \text{constant}$

Stokes' law – $F = 6\pi\eta r v$

Terminal velocity – $v_t = 2r^2(\rho - \sigma)g/9\eta$

Excess pressure – drop $2T/r$, soap bubble $4T/r$

Capillary rise – $h = 2T \cos\theta/\rho g r$

08 Heat and thermodynamics

Thermal expansion – $\Delta L = \alpha L \Delta T$, $\beta = 2\alpha$, $\gamma = 3\alpha$

Heat – $Q = mc\Delta T$, $Q = mL$ (change of state)

First law – $\Delta U = Q - W$ (W = work done by the gas)

Isothermal work – $W = nRT \ln(V_2/V_1)$

Adiabatic – $PV^\gamma = \text{constant}$, $W = (P_1 V_1 - P_2 V_2)/(\gamma - 1)$

Specific heats – $C_p - C_v = R$, $\gamma = C_p/C_v$ (monatomic 5/3, diatomic 7/5)

Efficiency – $\eta = W/Q_1$; Carnot $\eta = 1 - T_2/T_1$

Refrigerator – $\text{COP} = T_2/(T_1 - T_2)$

Kinetic theory – $P = \frac{1}{3} \rho v_{\text{rms}}^2$, $v_{\text{rms}} = \sqrt{3RT/M}$, average KE per molecule = $(3/2)kT$

Radiation – Stefan $E = \sigma e T^4$; Wien $\lambda_m T = b \approx 2.9 \times 10^{-3} \text{ m K}$

Newton's law of cooling – $dT/dt = -k(T - T_0)$

09 Oscillations and waves

SHM – $x = A \sin(\omega t + \phi)$, $v = \omega \sqrt{A^2 - x^2}$, $a = -\omega^2 x$

Time period – spring $T = 2\pi\sqrt{m/k}$; simple pendulum $T = 2\pi\sqrt{L/g}$

Energy in SHM – $E = \frac{1}{2} k A^2$

Wave speed – $v = f\lambda$; on a string $v = \sqrt{T/\mu}$; sound in a gas $v = \sqrt{\gamma RT/M}$

Open pipe or string – $f_n = nv/2L$

Closed pipe – $f_n = (2n - 1)v/4L$ (odd harmonics only)

Beats – $f_{\text{beat}} = |f_1 - f_2|$

Doppler effect – $f' = f(v \pm v_o)/(v \mp v_s)$ (upper signs: moving towards each other)

10 Electrostatics

Coulomb's law – $F = kq_1 q_2 / r^2$, $k = 1/4\pi\epsilon_0 \approx 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$

Point charge – $E = kq/r^2$, $V = kq/r$

Dipole – axial $E = 2kp/r^3$, equatorial $E = kp/r^3$, torque $\tau = p \times E$

Gauss's law – $\Phi = q_{\text{enc}}/\epsilon_0$

Line charge – $E = \lambda/2\pi\epsilon_0 r$

Infinite sheet – $E = \sigma/2\epsilon_0$

Capacitance – $C = Q/V$; parallel plates $C = \epsilon_0 A/d$

Energy stored – $U = \frac{1}{2} CV^2 = Q^2/2C$

Combinations – series $1/C = \sum 1/C_i$; parallel $C = \sum C_i$

11 Current electricity

Current – $I = dq/dt = nAev_d$

Ohm's law – $V = IR$, $R = \rho L/A$

Temperature – $R_T = R_0(1 + \alpha\Delta T)$

Combinations – series $R = \sum R_i$; parallel $1/R = \sum 1/R_i$

Power – $P = VI = I^2 R = V^2/R$

Cell – $V = E - Ir$; maximum power to the load when $R = r$

Kirchhoff – $\sum I = 0$ at a junction; $\sum V = 0$ round a loop

Wheatstone bridge (balanced) – $P/Q = R/S$

12 Magnetism and induction

Force on a charge – $F = q(v \times B)$; radius $r = mv/qB$; period $T = 2\pi m/qB$

Force on a wire – $F = IL \times B$

Biot-Savart – $dB = (\mu_0/4\pi) I dl \times \hat{r}/r^2$

Long straight wire – $B = \mu_0 I/2\pi r$

Centre of a loop – $B = \mu_0 I/2R$

Solenoid – $B = \mu_0 nI$

Parallel wires, force per length – $\mu_0 I_1 I_2/2\pi d$

Faraday's law – $\epsilon = -d\Phi/dt$; motional emf $\epsilon = Blv$

Inductance – $U = \frac{1}{2} LI^2$; solenoid $L = \mu_0 n^2 A l$

Growth in an LR circuit – $I = I_0(1 - e^{-t/\tau})$, $\tau = L/R$; RC circuit $\tau = RC$

13 Alternating current

RMS value – $V_{\text{rms}} = V_0/\sqrt{2}$

Reactance – $X_L = \omega L$, $X_C = 1/\omega C$

Impedance – $Z = \sqrt{R^2 + (X_L - X_C)^2}$

Resonance – $f_0 = 1/(2\pi\sqrt{LC})$, $Q = \omega_0 L/R$

Power – $P = V_{\text{rms}} I_{\text{rms}} \cos\phi$

Ideal transformer – $V_s/V_p = N_s/N_p = I_p/I_s$

14 Optics

Mirror – $1/v + 1/u = 1/f$, $f = R/2$, $m = -v/u$

Lens – $1/v - 1/u = 1/f$, $m = v/u$, $P = 1/f$ (dioptries, f in metres)

Lens maker's formula – $1/f = (\mu - 1)(1/R_1 - 1/R_2)$

Lenses in contact – $1/F = 1/f_1 + 1/f_2$

Snell's law – $n_1 \sin i = n_2 \sin r$; critical angle $\sin C = 1/\mu$

Prism – $\mu = \sin[(A + \delta_m)/2]/\sin(A/2)$; thin prism $\delta = (\mu - 1)A$

Young's double slit – fringe width $\beta = \lambda D/d$

Single slit, first minimum – $a \sin \theta = \lambda$

Polarisation – Malus $I = I_0 \cos^2 \theta$; Brewster $\tan i_p = \mu$

Instruments – telescope $m = f_o/f_e$; compound microscope $m \approx (L/f_o)(D/f_e)$

15 Modern physics

Photon – $E = hf = hc/\lambda$, $hc \approx 1240 \text{ eV nm}$

Photoelectric effect – $K_{\max} = hf - \phi = eV_0$

de Broglie – $\lambda = h/p = h/\sqrt{2mK}$; electron through V volts: $\lambda \approx 1.227/\sqrt{V} \text{ nm}$

Bohr model – $r_n = 0.529 n^2/Z \text{ \AA}$, $E_n = -13.6 Z^2/n^2 \text{ eV}$

Spectral lines – $1/\lambda = RZ^2(1/n_1^2 - 1/n_2^2)$, $R \approx 1.097 \times 10^7 \text{ m}^{-1}$

How to use this sheet

- 1 Cover the right-hand side of each line and say the formula out loud before you look.
- 2 Write the units next to every answer: it catches half of all slips.
- 3 Pair each formula with one solved question from your NCERT book or a previous paper.

Radioactive decay – $N = N_0 e^{-\lambda t}$, $T_{1/2} = 0.693/\lambda$, mean life $\tau = 1/\lambda$

Mass-energy – $E = mc^2$; $1 \text{ u} = 931.5 \text{ MeV}$

Nuclear radius – $R = R_0 A^{1/3}$

Diodes – a p-n junction conducts in forward bias above its barrier (about 0.7 V for silicon); a Zener diode in reverse breakdown regulates voltage

Logic and rectifiers – NAND and NOR are universal gates; full-wave output frequency = $2 \times$ input

16 Constants worth knowing

$g = 9.8 \text{ m s}^{-2}$	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
$c = 3 \times 10^8 \text{ m s}^{-1}$	$h = 6.63 \times 10^{-34} \text{ J s}$
$e = 1.6 \times 10^{-19} \text{ C}$	$m_e = 9.1 \times 10^{-31} \text{ kg}$
$N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$	$R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$
$k_B = 1.38 \times 10^{-23} \text{ J K}^{-1}$	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$	

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FORMULA SHEET · CLASS 11 AND 12

JEE Maths Formula Sheet

The results you are expected to know without deriving them in the exam hall, from quadratic roots to shortest distances between skew lines. Every line here comes up in JEE Main papers year after year.

JEE

CBSE 12

01 Algebra

Quadratic roots – $x = [-b \pm \sqrt{(b^2 - 4ac)}]/2a$; $\alpha + \beta = -b/a$, $\alpha\beta = c/a$

Nature of roots – $D > 0$ real and distinct; $D = 0$ equal; $D < 0$ complex

Arithmetic progression – $a_n = a + (n - 1)d$, $S_n = (n/2)[2a + (n - 1)d]$

Geometric progression – $a_n = ar^{n-1}$, $S_n = a(r^n - 1)/(r - 1)$, $S_\infty = a/(1 - r)$ for $|r| < 1$

Means – $AM \geq GM \geq HM$ for positive numbers

Sums – $\Sigma n = n(n + 1)/2$, $\Sigma n^2 = n(n + 1)(2n + 1)/6$, $\Sigma n^3 = [n(n + 1)/2]^2$

Binomial theorem – $(x + y)^n = \Sigma {}^nC_r x^{n-r}y^r$; general term $T_{r+1} = {}^nC_r x^{n-r}y^r$

Logarithms – $\log(xy) = \log x + \log y$; $\log_a x = \log_b x / \log_b a$

02 Counting and probability

Permutations – ${}^nP_r = n!/(n - r)!$

Combinations – ${}^nC_r = n!/[r!(n - r)!]$; ${}^nC_r + {}^nC_{r-1} = {}^{n+1}C_r$

Circular arrangements – $(n - 1)!$

Addition rule – $P(A \cup B) = P(A) + P(B) - P(A \cap B)$

Conditional probability – $P(A|B) = P(A \cap B)/P(B)$

Bayes' theorem – $P(A_i|B) = P(B|A_i)P(A_i) / \Sigma P(B|A_j)P(A_j)$

Random variable – mean $\mu = \Sigma x_i p_i$, variance $\sigma^2 = \Sigma x_i^2 p_i - \mu^2$; binomial: mean np , variance npq

03 Complex numbers

Forms – $z = x + iy = r(\cos\theta + i \sin\theta) = re^{i\theta}$, $|z| = \sqrt{(x^2 + y^2)}$

Conjugate – $z \bar{z} = |z|^2$

De Moivre – $(\cos\theta + i \sin\theta)^n = \cos n\theta + i \sin n\theta$

Cube roots of unity – $1, \omega, \omega^2$; $1 + \omega + \omega^2 = 0$, $\omega^3 = 1$

Triangle inequality – $|z_1 + z_2| \leq |z_1| + |z_2|$

04 Trigonometry

Identities – $\sin^2\theta + \cos^2\theta = 1$; $1 + \tan^2\theta = \sec^2\theta$; $1 + \cot^2\theta = \operatorname{cosec}^2\theta$

Compound angles – $\sin(A \pm B) = \sin A \cos B \pm \cos A \sin B$; $\cos(A \pm B) = \cos A \cos B \mp \sin A \sin B$

$\tan(A \pm B)$ – $(\tan A \pm \tan B)/(1 \mp \tan A \tan B)$

Double angle – $\sin 2A = 2\sin A \cos A$; $\cos 2A = 1 - 2\sin^2 A = 2\cos^2 A - 1$; $\tan 2A = 2\tan A/(1 - \tan^2 A)$

Triple angle – $\sin 3A = 3\sin A - 4\sin^3 A$; $\cos 3A = 4\cos^3 A - 3\cos A$

Sum to product – $\sin C + \sin D = 2\sin[(C + D)/2]\cos[(C - D)/2]$; $\cos C + \cos D = 2\cos[(C + D)/2]\cos[(C - D)/2]$

Sine and cosine rules – $a/\sin A = b/\sin B = c/\sin C = 2R$; $c^2 = a^2 + b^2 - 2ab \cos C$

General solutions – $\sin\theta = \sin\alpha \Rightarrow \theta = n\pi + (-1)^n\alpha$; $\cos\theta = \cos\alpha \Rightarrow \theta = 2n\pi \pm \alpha$; $\tan\theta = \tan\alpha \Rightarrow \theta = n\pi + \alpha$

05 Coordinate geometry

Distance – $\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$

Section formula – $[(mx_2 + nx_1)/(m + n), (my_2 + ny_1)/(m + n)]$

Lines – $y = mx + c$; $y - y_1 = m(x - x_1)$; $\tan\theta = |(m_1 - m_2)/(1 + m_1 m_2)|$

Point to line distance – $|ax_1 + by_1 + c|/\sqrt{(a^2 + b^2)}$

Area of a triangle – $\frac{1}{2}|x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2)|$

Circle – $x^2 + y^2 + 2gx + 2fy + c = 0$, centre $(-g, -f)$, $r = \sqrt{(g^2 + f^2 - c)}$

Parabola $y^2 = 4ax$ – focus $(a, 0)$, directrix $x = -a$, latus rectum $4a$, tangent $y = mx + a/m$

Ellipse $x^2/a^2 + y^2/b^2 = 1$ ($a > b$) – $e = \sqrt{(1 - b^2/a^2)}$, foci $(\pm ae, 0)$, latus rectum $2b^2/a$

Hyperbola $x^2/a^2 - y^2/b^2 = 1$ – $e = \sqrt{(1 + b^2/a^2)}$, asymptotes $y = \pm(b/a)x$

06 Limits and derivatives

Standard limits – $\sin x/x \rightarrow 1$; $(e^x - 1)/x \rightarrow 1$; $\ln(1+x)/x \rightarrow 1$ as $x \rightarrow 0$; $(1 + 1/x)^x \rightarrow e$ as $x \rightarrow \infty$

Power limit – $\lim_{x \rightarrow a} (x^n - a^n)/(x - a) = na^{n-1}$

Derivatives – $x^n \rightarrow nx^{n-1}$; $e^x \rightarrow e^x$; $\ln x \rightarrow 1/x$; $\sin x \rightarrow \cos x$; $\cos x \rightarrow -\sin x$; $\tan x \rightarrow \sec^2 x$

Inverse trig – $\sin^{-1}x \rightarrow 1/\sqrt{1-x^2}$; $\tan^{-1}x \rightarrow 1/(1+x^2)$

Rules – $(uv)' = u'v + uv'$; $(u/v)' = (u'v - uv')/v^2$; $dy/dx = (dy/du)(du/dx)$

Maxima and minima – $f'(x) = 0$ with $f''(x) < 0$ gives a maximum, $f''(x) > 0$ a minimum

Mean value theorem – $f'(c) = [f(b) - f(a)]/(b - a)$ for some c in (a, b)

07 Integrals

Standard forms – $\int x^n dx = x^{n+1}/(n+1) + C$ ($n \neq -1$); $\int dx/x = \ln|x| + C$; $\int a^x dx = a^x/\ln a + C$

Trigonometric – $\int \sin x dx = -\cos x + C$; $\int \cos x dx = \sin x + C$; $\int \sec^2 x dx = \tan x + C$; $\int \tan x dx = \ln|\sec x| + C$

Special forms – $\int dx/(x^2 + a^2) = (1/a)\tan^{-1}(x/a) + C$; $\int dx/\sqrt{a^2 - x^2} = \sin^{-1}(x/a) + C$

More special forms – $\int dx/(x^2 - a^2) = (1/2a)\ln|(x-a)/(x+a)| + C$; $\int dx/\sqrt{x^2 \pm a^2} = \ln|x + \sqrt{x^2 \pm a^2}| + C$

By parts – $\int u dv = uv - \int v du$ (choose u by ILATE)

Useful result – $\int e^x[f(x) + f'(x)]dx = e^x f(x) + C$

Definite integrals – $\int_a^b f(x)dx = \int_a^b f(a+b-x)dx$

Odd and even – $\int_{-a}^a f(x)dx = 0$ if f is odd, $2\int_0^a f(x)dx$ if f is even

How to use this sheet

- 1 Derive two results from each section once by hand, so you can rebuild them if memory fails.
- 2 Keep this sheet beside you while doing previous papers; mark every formula you had to look up.
- 3 Before the exam, rewrite the marked lines from memory on a blank page.

08 Differential equations

Linear – $dy/dx + Py = Q$; integrating factor $e^{\int P dx}$; $y \cdot IF = \int Q \cdot IF dx + C$

Homogeneous – substitute $y = vx$

Variables separable – collect x and y terms on opposite sides, then integrate

09 Vectors and 3D

Dot product – $a \cdot b = |a||b|\cos\theta = a_1b_1 + a_2b_2 + a_3b_3$

Cross product – $|a \times b| = |a||b|\sin\theta$

Projection of a on b – $(a \cdot b)/|b|$

Scalar triple product – $[a \ b \ c] = a \cdot (b \times c)$; zero if coplanar

Line – $r = a + \lambda b$; angle between lines $\cos\theta = |b_1 \cdot b_2|/(|b_1||b_2|)$

Plane (JEE Advanced) – $ax + by + cz = d$; point to plane $|ax_1 + by_1 + cz_1 - d|/\sqrt{a^2 + b^2 + c^2}$

Skew lines, shortest distance – $|(a_2 - a_1) \cdot (b_1 \times b_2)|/|b_1 \times b_2|$

Direction cosines – $l^2 + m^2 + n^2 = 1$

10 Matrices, determinants, statistics

Transpose and inverse – $(AB)^T = B^T A^T$; $A^{-1} = \text{adj}(A)/|A|$ when $|A| \neq 0$

Determinants – $|AB| = |A||B|$; $|kA| = k^n|A|$; $|\text{adj } A| = |A|^{n-1}$ ($n \times n$)

Cramer's rule – $x = D_x/D$; a unique solution when $D \neq 0$

Variance – $\sigma^2 = \Sigma(x - \bar{x})^2/n = \Sigma x^2/n - \bar{x}^2$; coefficient of variation = $(\sigma/\bar{x}) \times 100$

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REVISION NOTES · CLASS 11 AND 12

Chemistry Quick Revision for JEE and NEET

Physical chemistry formulas, inorganic trends and the organic reactions examiners return to most often, condensed onto a few pages for the last weeks before JEE or NEET.

JEE

NEET

CBSE 12

01 Mole concept and solutions

Moles – $n = \text{mass/molar mass} = \text{number of particles}/N_A$

Molarity – $M = \text{moles of solute/litres of solution}$; **molality** $m = \text{moles of solute/kg of solvent}$

Mole fraction – $x_A = n_A/(n_A + n_B)$

Normality – $N = M \times n\text{-factor}$; **dilution** $M_1V_1 = M_2V_2$

Raoult's law – $p_A = x_A p_A^\circ$; **relative lowering** $(p^\circ - p)/p^\circ = x_{\text{solute}}$

Colligative properties – $\Delta T_b = iK_b m$; $\Delta T_f = iK_f m$; **osmotic pressure** $\pi = iCRT$

Henry's law – $p = K_H x$

02 Atomic structure

Bohr energy – $E_n = -13.6 Z^2/n^2 \text{ eV}$; **radius** $r_n = 0.529 n^2/Z \text{ \AA}$

de Broglie – $\lambda = h/mv$; **Heisenberg** $\Delta x \cdot \Delta p \geq h/4\pi$

Quantum numbers – n ; l from 0 to $n - 1$; m_l from $-l$ to $+l$; $m_s = \pm 1/2$

Capacity – $2n^2$ electrons per shell; $2l + 1$ orbitals per subshell

Nodes – radial $n - l - 1$; angular l

Filling order – $(n + l)$ rule, then Pauli exclusion and Hund's rule

03 Gases

Ideal gas – $PV = nRT$, $R = 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1} = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$

Dalton – $p_i = x_i p_{\text{total}}$

Graham – rate $\propto 1/\sqrt{M}$

van der Waals – $(P + a n^2/V^2)(V - nb) = nRT$

Compressibility – $Z = PV/nRT$

Molecular speeds – $u_{\text{rms}} = \sqrt{3RT/M}$, $u_{\text{avg}} = \sqrt{8RT/\pi M}$, $u_{\text{mp}} = \sqrt{2RT/M}$

04 Thermodynamics

First law – $\Delta U = q + w$ ($w = \text{work done on the system}$); $w = -P_{\text{ext}}\Delta V$

Enthalpy – $\Delta H = \Delta U + \Delta n_g RT$; **Hess's law** adds reaction enthalpies

Gibbs energy – $\Delta G = \Delta H - T\Delta S$; spontaneous when $\Delta G < 0$

Link to equilibrium – $\Delta G^\circ = -RT \ln K = -2.303RT \log K$

Link to cells – $\Delta G^\circ = -nFE^\circ_{\text{cell}}$

05 Equilibrium

K_p and K_c – $K_p = K_c(RT)^{\Delta n}$

pH – $\text{pH} = -\log[H^+]$; $\text{pH} + \text{pOH} = 14$ and $K_w = 10^{-14}$ at 25°C

Weak acid – $[H^+] = \sqrt{K_a C}$, **degree of dissociation** $\alpha = \sqrt{K_a/C}$

Buffer (Henderson) – $\text{pH} = \text{p}K_a + \log([\text{salt}]/[\text{acid}])$

Salt of weak acid and strong base – $\text{pH} = 7 + \frac{1}{2}(\text{p}K_a + \log C)$

Solubility product – $K_{\text{sp}} = s^2$ for AB ; $4s^3$ for AB_2

06 Electrochemistry and kinetics

Cell emf – $E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$

Nernst equation (298 K) – $E = E^\circ - (0.0591/n) \log Q$

Faraday's law – $m = (M/nF)It$, $F = 96,500 \text{ C mol}^{-1}$

Conductivity – $\Lambda_m = \kappa \times 1000/M$ (κ in S cm^{-1}); **Kohlrausch** $\Lambda_m^\circ = v_+ \lambda_+^\circ + v_- \lambda_-^\circ$

Zero order – $t_{1/2} = [A]_0/2k$

First order – $k = (2.303/t) \log([A]_0/[A])$, $t_{1/2} = 0.693/k$

Arrhenius – $k = Ae^{-E_a/RT}$; $\log(k_2/k_1) = [E_a/2.303R](1/T_1 - 1/T_2)$

07 Periodic trends and bonding

Atomic radius – decreases across a period, increases down a group

Ionisation enthalpy – increases across a period; exceptions $N > O$, $Be > B$, $Mg > Al$

Electronegativity – fluorine is highest (4.0 on the Pauling scale); chlorine has the most negative electron gain enthalpy

Bond order (MOT) – $(N_b - N_a)/2$; O_2 has bond order 2 and is paramagnetic; N_2 has bond order 3

Hybridisation – 2 sp linear; 3 sp² trigonal planar; 4 sp³ tetrahedral; 5 sp³d trigonal bipyramidal; 6 sp³d² octahedral

Shapes – H_2O bent 104.5°; NH_3 pyramidal 107°; SF_4 see-saw; ClF_3 T-shaped; XeF_2 linear; XeF_4 square planar

Formal charge – valence electrons – non-bonding electrons – $\frac{1}{2}$ bonding electrons

08 Coordination compounds

Crystal field (octahedral) – $t_{2g} -0.4\Delta_o$, $e_g +0.6\Delta_o$

Spectrochemical series – $I^- < Br^- < Cl^- < F^- < OH^- < H_2O < NH_3 < en < CN^- < CO$

Magnetic moment (spin only) – $\mu = \sqrt{n(n+2)}$ BM, n = unpaired electrons

09 Named reactions

Aldol – aldehydes or ketones with α -H in dilute alkali give β -hydroxy carbonyl compounds

Cannizzaro – aldehydes without α -H in concentrated alkali give an alcohol and a carboxylate

Wurtz – $2R-X + 2Na$ in dry ether give R-R

Friedel-Crafts – alkylation or acylation of benzene with $AlCl_3$

Reimer-Tiemann – phenol + $CHCl_3$ + NaOH give salicylaldehyde

Kolbe – sodium phenoxide + CO_2 give salicylic acid

Hell-Volhard-Zelinsky – carboxylic acid + X_2 /red P gives the α -halo acid

Hoffmann bromamide – amide + $Br_2/NaOH$ gives an amine with one carbon fewer

Sandmeyer – diazonium salt + CuX gives an aryl halide

Gabriel phthalimide – a route to pure primary amines

Clemmensen and Wolff-Kishner – reduce $C=O$ to CH_2 ($Zn-Hg/HCl$; NH_2NH_2/KOH)

Rosenmund – acid chloride + $H_2/Pd-BaSO_4$ gives an aldehyde

Etard – toluene + CrO_2Cl_2 gives benzaldehyde

Williamson – $RO^-Na^+ + R'X$ gives the ether $R-O-R'$

10 Organic rules of thumb

Markovnikov – H adds to the carbon with more hydrogens; HBr with peroxide adds anti-Markovnikov

Substitution – S_N1 favours $3^\circ > 2^\circ > 1^\circ$ and racemises; S_N2 favours $1^\circ > 2^\circ > 3^\circ$ with inversion

Carbocation stability – $3^\circ > 2^\circ > 1^\circ > \text{methyl}$

Acidity – carboxylic acids > phenols > water > alcohols; electron-withdrawing groups raise acidity

11 Laboratory tests

Tollens' reagent – silver mirror with aldehydes

Fehling's solution – red precipitate with aliphatic aldehydes

Iodoform test – CH_3CO- or $CH_3CH(OH)-$ groups give yellow CHI_3

Lucas test – tertiary alcohols turn cloudy at once

Carbylamine test – primary amines give a foul-smelling isocyanide

Neutral $FeCl_3$ – violet colour with phenols

2,4-DNP – orange precipitate with aldehydes and ketones

Hinsberg's reagent – tells primary, secondary and tertiary amines apart

How to use these notes

- 1 Learn named reactions as reagent $\rightarrow$ product pairs, then test yourself by covering one side.
- 2 For trends, remember the exceptions: they are what the questions ask about.
- 3 NCERT lines are the source for most inorganic questions; read the relevant chapter after this sheet.

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