

# **A Guide to Equations & Formulae for Physics**

**Physical Sciences Centre**

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## Work and Energy

$$\text{Work Done, } W = \int_{s_1}^{s_2} \mathbf{F} \cdot d\mathbf{s}$$

$$\text{Kinetic Energy, } K = \frac{1}{2}mv^2$$

Work-Kinetic Energy,

$$W_T = \Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$\text{Average Power, } P_{av} = \frac{\Delta W}{\Delta t}$$

Instantaneous Power,

$$P = \frac{dW}{dt} = \mathbf{F} \cdot \mathbf{v}$$

Potential energy function,  $\Delta U = -W$

Gravitational Potential Energy,

$$U = U_0 + mgh$$

Conservative Force,

$$F_x = -\frac{dU}{dx} \text{ and } \mathbf{F} = -\nabla U$$

## Motion in one dimension

$$\text{Average velocity, } v_{av} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$

Instantaneous velocity,

$$v = \lim_{\Delta t \rightarrow 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

Constant Acceleration Equations,

$$v = v_0 + at$$

$$x - x_0 = \frac{1}{2}(v_0 + v)t$$

$$x = x_0 + v_0t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

Instantaneous acceleration,

$$a = \lim_{\Delta t \rightarrow 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

$$\text{Newton's Law, } \mathbf{F} = ma = \frac{mdv}{dt}$$

## Gravitation

Newton's Law of Gravitation,

$$F_g = G \frac{m_1 m_2}{r^2}$$

Acceleration due to gravity on Earth,

$$\mathbf{g} = \frac{GM_E}{R_E^2}$$

## Thermal Properties of Matter

Ideal-gas Equation,  $pV = nRT$

Total mass,  $m = nM$

Molecular mass,  $M = N_A m$

Kinetic energy (ideal gas),

$$K = \frac{3}{2}nRT = \frac{3}{2}N_A kT$$

Root-mean-square speed,

$$v_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$$

Molar heat capacities for ideal gases,

(monatomic)  $C_V = \frac{3}{2}R$

(diatomic)  $C_V = \frac{5}{2}R$

Maxwell-Boltzmann Distribution,

$$f(v) = 4\pi \left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-mv^2/2kT}$$

## Temperature and Heat

Temperature Scales,  $T_F = \frac{9}{5}T_C + 32^\circ$

$$T_K = T_C + 273.15$$

For Gas-thermometer Scale,  $\frac{T_2}{T_1} = \frac{p_2}{p_1}$

Linear change,  $\Delta L = \alpha L_0 \Delta T$

Change in Volume,

$$\Delta V = \beta V_0 \Delta T \quad \beta = 3\alpha$$

Heat energy transferred,  $Q = mc\Delta T$

Heat current (conduction),

$$H = \frac{dQ}{dt} = kA \frac{T_H - T_L}{L}$$

Heat current (radiation),  $H = Ae\sigma T^4$

### Simple Harmonic Motion (SHM)

Angular Frequency,  $\omega = 2\pi f = \frac{2\pi}{T}$

Acceleration,  $a = \frac{F}{m} = -\frac{k}{m}x$

Conservation of energy,

$$E = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 = \text{constant}$$

Period,  $T = 2\pi\sqrt{\frac{m}{k}}$

Period,  $T = 2\pi\sqrt{\frac{L}{g}}$

(a simple pendulum)

Period,  $T = 2\pi\sqrt{\frac{I}{mgd}}$

(a physical pendulum)

### Waves

Speed,  $v = f\lambda$   $k = \frac{2\pi}{\lambda}$   $\omega = 2\pi f$

Wave function for a sinusoidal wave,

$$y(x,t) = A \sin(\omega t - kx)$$

Wave Equation,  $\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 y}{\partial t^2}$

Energy of one photon,  $E = hf = \frac{hc}{\lambda}$

Photoelectric Effect,  $eV_0 = hf - \phi$

Emission of X-rays,  $eV = hf_{\max} = \frac{hc}{\lambda_{\min}}$

Doppler Effect,

$$f_L = \frac{v \pm v_L}{v \pm v_S} f_S$$

Electromagnetic wave speed,

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

Index of Refraction,  $n = \frac{c}{v}$

Law of Refraction,  $n_a \sin \theta_a = n_b \sin \theta_b$

Total Internal Reflection,  $\sin \theta_{\text{crit}} = \frac{n_b}{n_a}$

Constructive Interference,  $d \sin \theta = m\lambda$

Destructive Interference,

$$d \sin \theta = (m + \frac{1}{2})\lambda$$

Transverse wave in a string,  $v = \sqrt{\frac{F}{\mu}}$

Longitudinal Wave in a fluid,  $v = \sqrt{\frac{B}{\rho}}$

Longitudinal Wave in a rod,  $v = \sqrt{\frac{Y}{\rho}}$

Intensity of a wave,  $I = \frac{1}{2} \omega B k A^2$

Intensity level,  $\beta = (10 \text{dB}) \log \frac{I}{I_0}$

### Momentum and Impulse

Momentum (particle),

$$\mathbf{p} = m\mathbf{v} \quad \text{and} \quad \sum \mathbf{F} = \frac{d\mathbf{p}}{dt}$$

Impulse-momentum Theorem,

$$\mathbf{J} = \int_{t_1}^{t_2} \mathbf{F} dt = \mathbf{p}_2 - \mathbf{p}_1$$

## Rotational Motion

$$\text{Angular Velocity, } \omega = \lim_{\Delta t \rightarrow 0} \frac{\Delta \theta}{\Delta t} = \frac{d\theta}{dt}$$

Angular Acceleration,

$$\alpha = \lim_{\Delta t \rightarrow 0} \frac{\Delta \omega}{\Delta t} = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2}$$

Constant angular acceleration

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$$

$$\omega = \omega_0 + \alpha t$$

$$\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$$

Tangential Speed,  $v = r\omega$

Tangential Acceleration,  $a = r\alpha$

Centripetal Acceleration,  $a = \frac{v^2}{r} = r\omega^2$

Moment of Inertia (body),  $I = \int r^2 dm$

Moment of Inertia (particles),

$$I = \sum_i m_i r_i^2$$

Rotational Kinetic Energy,  $K = \frac{1}{2} I \omega^2$

## Torque

Torque,  $\tau = Fl$

Vector Torque,  $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$

Total Torque,  $\sum \tau = I\alpha$

Work Done by Torque,

$$W = \tau(\theta_2 - \theta_1) = \tau \Delta \theta$$

Power,  $P = \tau\omega$

Angular Momentum (particle),

$$\mathbf{L} = \mathbf{r} \times \mathbf{p} = \mathbf{r} \times m\mathbf{v}$$

Angular Momentum (rigid body),

$$L = I\omega$$

and Total Torque,  $\sum \boldsymbol{\tau} = \frac{d\mathbf{L}}{dt}$

## Electricity and Magnetism

Coulomb's Law,  $F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$

Electric Field,  $\mathbf{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{\mathbf{r}}$

Dipole moment,  $p = ql$

Vector torque,  $\boldsymbol{\tau} = \mathbf{p} \times \mathbf{E}$

Potential Energy,  $u = -\mathbf{p} \cdot \mathbf{E}$

Gauss's Law,  $\int \mathbf{E} \cdot d\mathbf{A} = \frac{\sum q_i}{\epsilon_0} = \frac{Q_{encl}}{\epsilon_0}$

Potential Difference,  $V_a - V_b = \int_a^b \mathbf{E} \cdot d\mathbf{l}$

Potential,  $V = \frac{U}{q'} = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$

Electric Field,  $\mathbf{E} = -\nabla V$

Capacitance,  $C = \frac{Q}{V}$

Parallel plate capacitor,  $C = \epsilon_0 \frac{A}{d}$

Capacitors in series,

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$$

Capacitors in parallel,

$$C = C_1 + C_2 + \dots$$

Energy stored in a capacitor,

$$U = \frac{Q^2}{2C} = \frac{1}{2} CV^2 = \frac{1}{2} QV$$

Energy density,  $u = \frac{1}{2} \epsilon_0 E^2$

Energy density (in a dielectric),

$$u = \frac{1}{2} \epsilon E^2$$

Current,

$$I = \frac{\Delta Q}{\Delta t} = nqAv_d$$

Current Density,

$$\mathbf{J} = n_1 q_1 v_{d1} + n_2 q_2 v_{d2} \dots$$

$$\text{Resistivity, } \rho = \frac{E}{J}$$

$$\text{Resistance, } R = \frac{\rho L}{A}$$

Ohm's Law,  $V = IR$

Terminal potential difference,  
(source with internal resistance)

$$V = \mathcal{E} - Ir$$

Power dissipated,

$$P = VI = I^2 R = \frac{V^2}{R}$$

Resistors in series,  $R = R_1 + R_2 \dots$

Resistors in parallel,  $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \dots$

Force on a charge in a magnetic field,

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$$

Force on a conductor in a magnetic

$$\text{field, } \mathbf{F} = I\ell \times \mathbf{B}$$

$$\text{Energy Density, } u = \frac{B^2}{2\mu_0}$$

$$\text{Bohr Magnetron, } \mu = \frac{e\hbar}{2m} = \frac{eh}{4\pi m}$$

Faraday's Law: induced emf,

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

## Elasticity

$$\text{Stress} = \frac{F}{A} \quad \text{Strain} = \frac{\Delta l}{l_0} \quad \text{Pressure} = \frac{F}{A}$$

$$\text{Elastic Modulus} = \frac{\text{Stress}}{\text{Strain}}$$

Young's modulus,

$$Y = \frac{\text{Tensile Stress}}{\text{Tensile Strain}} = \frac{l_0 F}{A \Delta l}$$

$$\text{Poisson's ratio } (\sigma), \frac{\Delta w}{w_0} = -\sigma \frac{\Delta l}{l_0}$$

$$\text{Bulk Modulus, } B = -\frac{\Delta p}{\Delta V / V_0}$$

$$\text{Compressibility, } k = \frac{1}{B} = -\frac{1}{V_0} \frac{\Delta V}{\Delta p}$$

Shear Modulus,

$$S = \frac{\text{Shear Stress}}{\text{Shear Strain}} = \frac{F/A}{\phi}$$

## Quantum Mechanics

The Schrödinger Equation,

$$-\frac{\hbar^2}{2m} \left( \frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} \right) + U\psi = E\psi$$

Uncertainty Principle,

$$\Delta x \Delta p_x \geq \frac{\hbar}{4\pi}$$

Fermi-Dirac Distribution,

$$f(E) = \frac{1}{e^{(E-E_F)/kT} + 1}$$

$$\text{de Broglie wavelength, } \lambda = \frac{h}{p}$$

Energy of a photon,

$$E = hf = \hbar\omega$$