A Guide to Equations & Formulae for Physics

Physical Sciences Centre

www.physsci.heacademy.ac.uk
psc@hull.ac.uk

Version 1 compiled by Simone Richardson and Della Grice.
The Physical Sciences Centre is grateful to the
colleagues who gave their time and comments.

Work and Energy

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

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

Work-Kinetic Energy,
$W_T = \Delta K = \frac{1}{2} mv_f^2 - \frac{1}{2} mv_i^2$

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

Instantaneous Power,
$P = \dfrac{dW}{dt} = \mathbf{F} \cdot \mathbf{v}$

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

Gravitational Potential Energy,
$U = U_0 + mgh$

Conservative Force,
$F_x = -\dfrac{dU}{dx}$ and $\mathbf{F} = -\nabla U$

Motion in one dimension

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

Instantaneous velocity,
$v = \lim_{\Delta t \to 0} \dfrac{\Delta x}{\Delta t} = \dfrac{dx}{dt}$

Constant Acceleration Equations,
$v = v_0 + at$
$x - x_0 = \frac{1}{2}(v_0 + v)\, t$
$x = x_0 + v_0 t + \frac{1}{2} at^2$
$v^2 = v_0{}^2 + 2a(x - x_0)$

Instantaneous acceleration,
$a = \lim_{\Delta t \to 0} \dfrac{\Delta v}{\Delta t} = \dfrac{dv}{dt}$

Newton's Law, $\mathbf{F} = ma = \dfrac{m dv}{dt}$

Gravitation

Newton's Law of Gravitation,
$F_g = G \dfrac{m_1 m_2}{r^2}$

Acceleration due to gravity on Earth,
$\mathbf{g} = \dfrac{GM_E}{R_E^2}$

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

Molar heat capacities for ideal gases,
(monatomic) $C_V = \frac{3}{2} R$
(diatomic) $C_V = \frac{5}{2} R$

Maxwell-Boltzmann Distribution,
$f(v) = 4\pi (\dfrac{m}{2\pi kT})^{3/2} v^2 e^{-mv^2/2kT}$

Temperature and Heat

Temperature Scales, $T_F = \frac{9}{5} T_C + 32°$
$T_K = T_C + 273.15$

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

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

Change in Volume,
$\Delta V = \beta V_0 \Delta T$ $\beta = 3\alpha$

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

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,
$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

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

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

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

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

Destructive Interference,
$d\sin\theta = \left(m + \frac{1}{2}\right)\lambda$

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, $I = \frac{1}{2}\omega BkA^2$

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

Momentum and Impulse

Momentum (particle),
$\mathbf{p} = m\mathbf{v}$ and $\sum \mathbf{F} = \frac{d\mathbf{p}}{dt}$

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

Rotational Motion

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

Angular Acceleration,
$\alpha = \lim_{\Delta t \to 0} \frac{\Delta\omega}{\Delta t} = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2}$

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, $\tau = \mathbf{r} \times \mathbf{F}$

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

Angular Momentum (rigid body),
$L = I\omega$

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

Electricity and Magnetism

Coulomb's Law, $F = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2}$

Electric Field, $\mathbf{E} = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \hat{\mathbf{r}}$

Dipole moment, $p = ql$

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

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

Gauss's Law, $\int \mathbf{E} \cdot d\mathbf{A} = \frac{\sum q_i}{\varepsilon_0} = \frac{Q_{encl}}{\varepsilon_0}$

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

Potential, $V = \frac{U}{q'} = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$

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

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

Parallel plate capacitor, $C = \varepsilon_0 \frac{A}{d}$

Capacitors in series,
$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots\cdot\cdot$

Capacitors in parallel,
$C = C_1 + C_2 + \cdots\cdot$

Energy stored in a capacitor,
$U = \frac{Q^2}{2C} = \frac{1}{2} CV^2 = \frac{1}{2} QV$

Energy density, $u = \frac{1}{2}\varepsilon_0 E^2$

Energy density (in a dielectric),
$u = \frac{1}{2}\varepsilon E^2$

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

Current Density,
$\mathbf{J} = n_1 q_1 v_{d_1} + n_2 q_2 v_{d_2}$ ....

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

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

Ohm's Law, $V = IR$

Terminal potential difference,
(source with internal resistance)
$V = \varepsilon - Ir$

Power dissipated,
$P = V\,I = I^2 R = \frac{V^2}{R}$

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

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

Force on a charge in a magnetic field,
$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$

Force on a conductor in a magnetic field, $\mathbf{F} = \mathrm{I}\ell \times \mathbf{B}$

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

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

Faraday's Law: induced emf,
$\varepsilon = -\frac{\mathrm{d}\Phi_B}{\mathrm{d}t}$

Elasticity

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

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

Young's modulus,
$\mathrm{Y} = \frac{\text{Tensile Stress}}{\text{Tensile Strain}} = \frac{l_0 F}{A\Delta l}$

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

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

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

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

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,
$\Delta x \Delta p_x \geq \frac{h}{4\pi}$

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

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

Energy of a photon,
$E = hf = \hbar\omega$