Blen | Physics Data Booklet

Mathematical equations

Area of a circle	$A = \pi r^2$, where r is the radius
Circumference of a circle	$C = 2\pi r$, where r is the radius
Surface area of a sphere	$A = 4\pi r^2$, where r is the radius
Volume of a sphere	$V = \frac{4}{3}\pi r^3$, where r is the radius

Fundamental constants

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	g	9.81ms^{-2}
Gravitational constant	G	$6.67 \times 10^{-11} \text{ Nm}^2 \text{ kg}^{-2}$
Avogadro's constant	N_A	$6.02 \times 10^{23} \text{ mol}^{-1}$
Gas constant	R	$8.31 \text{JK}^{-1} \text{ mol}^{-1}$
Boltzmann's constant	k_B	$1.38 \times 10^{-23} \text{ JK}^{-1}$
Stefan–Boltzmann constant	σ	$5.67 \times 10^{-8} \text{ Wm}^{-2} \text{ K}^{-4}$
Coulomb constant	k	$8.99 \times 10^{9} \text{ Nm}^2 \text{ C}^{-2}$
Permittivity of free space	ε_0	$8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$
Permeability of free space	μ_0	$4\pi \times 10^{-7} \text{ TmA}^{-1}$
Speed of light in vacuum	c	$3.00 \times 10^{8} \text{ ms}^{-1}$
Planck's constant	h	$6.63 \times 10^{-34} \text{ Js}$
Elementary charge	e	$1.60 \times 10^{-19} \text{ C}$
Electron rest mass	m_e	$9.110 \times 10^{-31} \text{ kg} = 0.000549\text{u} = 0.511 \text{MeVc}^{-2}$
Proton rest mass	m_p	$1.673 \times 10^{-27} \text{ kg} = 1.007276\text{u} = 938 \text{MeVc}^{-2}$
Neutron rest mass	m_n	$1.675 \times 10^{-27} \text{ kg} = 1.008665\text{u} = 940 \text{MeVc}^{-2}$
Unified atomic mass unit	u	$1.661 \times 10^{-27} \text{ kg} = 931.5 \text{MeVc}^{-2}$
Solar constant	S	$1.36 \times 10^{3} \text{ Wm}^{-2}$
Fermi radius	R_0	$1.20 \times 10^{-15} \text{ m}$

Unit conversions

$$1 \text{ radian (rad)} = \frac{180^\circ}{\pi}$$

$$\text{Temperature (K)} = \text{temperature } (^\circ\text{C}) + 273$$

$$1 \text{ light year (ly)} = 9.46 \times 10^{15} \text{ m}$$

$$1 \text{ parsec (pc)} = 3.26 \text{ly}$$

$$1 \text{ astronomical unit (AU)} = 1.50 \times 10^{11} \text{ m}$$

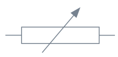
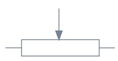
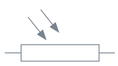
$$1 \text{kilowatt-hour (kWh)} = 3.60 \times 10^{6} \text{ J}$$

$$hc = 1.99 \times 10^{-25} \text{ Jm} = 1.24 \times 10^{-6} \text{ eVm}$$

Metric (SI) multipliers

Prefix	Abbreviation	Value
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Electrical circuit symbols

cell		battery	
ac supply		switch	
voltmeter		ammeter	
resistor		variable resistor	
lamp		potentiometer	
light-dependent resistor (LDR)		thermistor	
transformer		heating element	
diode		capacitor	

Equations—Core

Note: All equations relate to the magnitude of the quantities only. Vector notation has not been used.

1.2 Uncertainties and errors

If: $y = a \pm b$

then: $\Delta y = \Delta a + \Delta b$

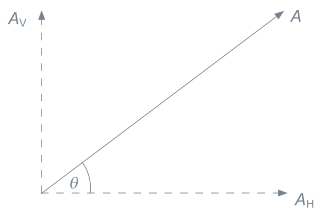
If: $y = \frac{ab}{c}$

then: $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$

If: $y = a^n$

then: $\frac{\Delta y}{y} = \left| n \frac{\Delta a}{a} \right|$

1.3 Vectors and scalars



$A_H = A \cos \theta$

$A_V = A \sin \theta$

2.1 Motion

$v = u + at$

$s = ut + \frac{1}{2} at^2$

$v^2 = u^2 + 2as$

$s = \frac{(v + u)\,t}{2}$

2.2 Forces

$F = ma$

$F_f \le \mu_s R$

$F_f = \mu_d R$

2.3 Work, energy and power

$W = Fs \cos \theta$

$E_K = \frac{1}{2} mv^2$

$E_p = \frac{1}{2} k \Delta x^2$

$\Delta E_p = mg\Delta h$

power $= Fv$

efficiency $= \frac{\text{useful work out}}{\text{total work in}}$

$= \frac{\text{useful power out}}{\text{total power in}}$

2.4 Momentum and impulse

$p = mv$

$F = \frac{\Delta p}{\Delta t}$

$E_K = \frac{p^2}{2m}$

impulse $= F\Delta t = \Delta p$

3.1 Thermal concepts

$Q = mc\Delta T$

$Q = mL$

3.2 Modelling a gas

$p = \frac{F}{A}$

$n = \frac{N}{N_A}$

$pV = nRT$

$\bar{E}_K = \frac{3}{2} k_B T = \frac{3}{2} \frac{R}{N_A} T$

4.1 Oscillations

$T = \frac{1}{f}$

4.2 Travelling waves

$c = f\lambda$

4.3 Wave characteristics

$I \propto A^2$

$I \propto x^2$

$I = I_0 \cos^2 \theta$

4.4 Wave behaviour

$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$

$s = \frac{\lambda D}{d}$

Constructive interference:
path difference $= n\lambda$

Destructive interference:
path difference $= \left(n + \frac{1}{2}\right)\lambda$

5.1 Electric fields

$I = \frac{\Delta q}{\Delta t}$

$F = k \frac{q_1 q_2}{r^2}$

$k = \frac{1}{4\pi\varepsilon_0}$

$V = \frac{W}{q}$

$E = \frac{F}{q}$

$I = nAvq$

5.2 Heating effect of electric currents

Kirchhoff's circuit laws:
$\Sigma V = 0$ (loop)
$\Sigma I = 0$ (junction)

$R = \frac{V}{I}$

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

$R_{total} = R_1 + R_2 + \ldots$

$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

$\rho = \frac{RA}{L}$

5.3 Electric cells

$\varepsilon = I(R + r)$

5.4 Magnetic effects of electric currents

$F = qvB \sin \theta$

$F = BIL \sin \theta$

6.1 Circular motion

$v = \omega r$

$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$

$F = \frac{mv^2}{r} = m\omega^2 r$

6.2 Newton's law of gravitation

$F = G \frac{Mm}{r^2}$

$g = \frac{F}{m}$

$g = G \frac{M}{r^2}$

7.1 Discrete energy and radioactivity

$E = hf$

$\lambda = \frac{hc}{E}$

7.2 Nuclear reactions

$\Delta E = \Delta mc^2$

7.3 The structure of matter

Charge	Quarks			Baryon number
$\frac{2}{3}$ e	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}$ e	d	s	b	$\frac{1}{3}$

All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1

Charge	Leptons		
-1	e	μ	τ
0	ν_e	ν_μ	ν_τ

All leptons have a lepton number of 1 and antileptons have a lepton number of –1

	Gravitational	Weak	Electromagnetic	Strong
Particles experiencing	All	Quarks, leptons	Charged	Quarks, gluons
Particles mediating	Graviton	W^+, W^-, Z^0	γ	Gluons

8.1 Energy sources

power $= \frac{\text{energy}}{\text{time}}$

power $= \frac{1}{2} A\rho v^3$

8.2 Thermal energy transfer

$P = e\sigma AT^4$

$\lambda_{max}(\text{metres}) = \frac{2.90 \times 10^{-3}}{T(\text{kelvin})}$

$I = \frac{\text{power}}{A}$

albedo $= \frac{\text{total scattered power}}{\text{total incident power}}$

Equations—AHL

9.1 Simple harmonic motion

$$\omega = \frac{2\pi}{T}$$

$$a = -\omega^2 x$$

$$x = x_0 \sin \omega t; \; x = x_0 \cos \omega t$$

$$v = \omega x_0 \cos \omega t; \; v = \omega x_0 \sin \omega t$$

$$v = \pm\omega \sqrt{(x_0^{\,2} - x^2)}$$

$$E_K = \frac{1}{2} m\omega^2 (x_0^{\,2} - x^2)$$

$$E_T = \frac{1}{2} m\omega^2 x_0^{\,2}$$

pendulum: $T = 2\pi \sqrt{\frac{l}{g}}$

mass-spring: $T = 2\pi \sqrt{\frac{m}{k}}$

9.2 Single-slit diffraction

$$\theta = \frac{\lambda}{b}$$

9.3 Interference

$$n\lambda = d\sin\theta$$

Constructive interference: $2dn$

$$= \left(m + \frac{1}{2}\right)\lambda$$

Destructive interference: $2dn = m\lambda$

9.4 Resolution

$$\theta = 1.22 \frac{\lambda}{b}$$

$$R = \frac{\lambda}{\Delta\lambda} = mN$$

9.5 Doppler effect

Moving source: $f' = f \left(\frac{v}{v \pm u_s}\right)$

Moving observer: $f' = f \left(\frac{v \pm u_o}{v}\right)$

$$\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$$

10.1 Describing fields

$$W = q\Delta V_e$$

$$W = m\Delta V_g$$

10.2 Fields at work

$V_g = -\frac{GM}{r}$	$V_e = -\frac{kQ}{r}$
$g = -\frac{\Delta V_g}{\Delta r}$	$E = -\frac{\Delta V_e}{\Delta r}$
$E_p = mV_g = -\frac{GMm}{r}$	$E_p = qV_e = \frac{kQq}{r}$
$F_g = \frac{GMm}{r^2}$	$F_e = \frac{kQq}{r^2}$

$$V_{esc} \sqrt{\frac{2GM}{r}}$$

$$V_{orbit} \sqrt{\frac{GM}{r}}$$

11.1 Electromagnetic induction

$$\Phi = BA \cos \theta$$

$$\varepsilon = -N \frac{\Delta\Phi}{\Delta t}$$

$$\varepsilon = Bvl$$

$$\varepsilon = BvlN$$

11.2 Power generation and transmission

$$I_{rms} = \frac{I_o}{\sqrt{2}}$$

$$V_{rms} = \frac{V_o}{\sqrt{2}}$$

$$R = \frac{V_o}{I_o} = \frac{V_{rms}}{I_{rms}}$$

$$P_{max} = I_0 V_0$$

$$\bar{P} = \frac{1}{2} I_0 V_0$$

$$\frac{\varepsilon_p}{\varepsilon_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

11.3 Capacitance

$$C = \frac{q}{V}$$

$$C_{parallel} = C_1 + C_2 + \ldots$$

$$\frac{1}{C_{series}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$$

$$C = \varepsilon \frac{A}{d}$$

$$E = \frac{1}{2} CV^2$$

$$\tau = RC$$

$$q = q_0 e^{-\frac{t}{\tau}}$$

$$I = I_0 e^{-\frac{t}{\tau}}$$

$$V = V_0 e^{-\frac{t}{\tau}}$$

12.1 The interaction of matter with radiation

$$E = hf$$

$$E_{max} = hf - \Phi$$

$$E = \frac{13.6}{n^2}\, eV$$

$$mvr = \frac{nh}{2\pi}$$

$$Pr(r) = |\psi|^2 \Delta V$$

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

$$\Delta E \Delta t \geq \frac{h}{4\pi}$$

12.2 Nuclear physics

$$R = R_0 A^{\frac{1}{3}}$$

$$N = N_0 e^{-\lambda t}$$

$$A = \lambda N_0 e^{-\lambda t}$$

$$\sin\theta \approx \frac{\lambda}{D}$$

Equations—Options

A.1 The beginnings of relativity

$x' = x - vt$

$u' = u - v$

A.2 Lorentz transformations

$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$

$x' = \gamma (x - vt)$; $\Delta x' = \gamma (\Delta x - v\Delta t)$

$t' = \gamma \left(t - \frac{vx}{c^2}\right)$; $\Delta t' = \gamma \left(\Delta t - \frac{v\Delta x}{c^2}\right)$

$u' = \frac{u - v}{1 - \frac{uv}{c^2}}$

$\Delta t = \gamma \Delta t_0$

$L = \frac{L_0}{\gamma}$

$(ct')^2 - (x')^2 = (ct)^2 - (x)^2$

A.3 Spacetime diagrams

$\theta = tan^{-1}\left(\frac{v}{c}\right)$

A.4 Relativistic mechanics (HL only)

$E = \gamma m_0 c^2$

$E_0 = m_0 c^2$

$E_K = (\gamma - 1) m_0 c^2$

$p = \gamma m_0 v$

$E^2 = p^2c^2 + m_0^2 c^4$

$qV = \Delta E_K$

A.5 General relativity (HL only)

$\frac{\Delta f}{f} = \frac{g\Delta h}{c^2}$

$R_s = \frac{2GM}{c^2}$

$\Delta t = \frac{\Delta t_0}{\sqrt{1 - \frac{R_s}{r}}}$

B.1 Rigid bodies and rotational dynamics

$\Gamma = Fr \sin \theta$

$I = \sum mr^2$

$\Gamma = I\alpha$

$\omega = 2\pi f$

$\omega_f = \omega_i + \alpha t$

$\omega_f^2 = \omega_i^2 + 2\alpha\theta$

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

$L = I\omega$

$E_{Krot} = \frac{1}{2} I\omega^2$

B.2 Thermodynamics

$Q = \Delta U + W$

$U = \frac{3}{2} nRT$

$\Delta S = \frac{\Delta Q}{T}$

$pV^{\frac{5}{3}}$ = constant

(for monatomic gases)

$W = p\Delta V$

$\eta = \frac{\text{useful work done}}{\text{energy input}}$

$\eta_{Carnot} = 1 - \frac{T_{cold}}{T_{hot}}$

B.3 Fluids and fluid dynamics (HL only)

$B = \rho_f V_f g$

$P = P_0 + \rho g d$

$Av = constant$

$\frac{1}{2}\rho v^2 + \rho g z + p = constant$

$F_D = 6\pi\eta r v$

$R = \frac{vr\rho}{\eta}$

B.4 Forced vibrations and resonance (HL only)

$Q = 2\pi \frac{\text{energy stored}}{\text{energy dissipated per cycle}}$

$Q = 2\pi \times$ resonant frequency

$\times \frac{\text{energy stored}}{\text{power loss}}$

C.1 Introduction to imaging

$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

$P = \frac{1}{f}$

$m = \frac{h_i}{h_o} = -\frac{v}{u}$

$M = \frac{\theta_i}{\theta_o}$

$M_{near\ point} = \frac{D}{f} + 1$; $M_{infinity} = \frac{D}{f}$

C.2 Imaging instrumentation

$M = \frac{f_o}{f_e}$

C.3 Fibre optics

$n = \frac{1}{\sin c}$

attenuation $= 10 log \frac{I}{I_0}$

C.4 Medical imaging (HL only)

$L_I = 10 log \frac{I_1}{I_0}$

$I = I_0 e^{-\mu x}$

$\mu x_{\frac{1}{2}} = ln 2$

$Z = \rho c$

D.1 Stellar quantities

$d\ (parsec) = \frac{1}{p\ (arc\text{-}second)}$

$L = \sigma A T^4$

$b = \frac{L}{4\pi d^2}$

D.2 Stellar characteristics and stellar evolution

$\lambda_{max} T = 2.9 \times 10^{-3} mK$

$L \propto M^{3.5}$

D.3 Cosmology

$z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c}$

$z = \frac{R}{R_0} - 1$

$v = H_0 d$

$T \approx \frac{1}{H_0}$

D.5 Further cosmology (HL only)

$v = \sqrt{\frac{4\pi G\rho}{3}}\, r$

$\rho_c = \frac{3H^2}{8\pi G}$