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Physics Equations

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Classical Physics

Gravitational acceleration, g = 9.81 $m \cdot s^{-2}$ (or $N \cdot kg^{-1}$).

Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}.

Universal gas constant, R = 8.31 $J \cdot K^{-1} \cdot mol^{-1}$.

Boltzmann's constant, $k = 1.38 \times 10^{-23}$ $J \cdot K^{-1}$.

Value	Equation	Equation Explained	Units
Decibel	$10\log_{10}\left(\frac{I_2}{I_1}\right)$	I = intensity (power per area) *Power may be more appropriate in some situations.*	dB = log (W / W)
Density	$\rho = \frac{m}{V}$	density = mass / volume	$kg \cdot m^{-3}$
Energy	$E_p + E_k = E_{total}$	potential energy + kinetic energy = total energy	J = J + J
Gravitational potential energy	$E_p = mgh$	gravitational potential energy = mass * gravitational acceleration * change in height *Used for small changes in height, only (≤ 100 m).*	$J = kg \cdot m \cdot s^{-2} \cdot m$
Kinetic energy	$E_k = \frac{1}{2}mv^2$	kinetic energy = half mass * velocity squared	$J = kg \cdot (m \cdot s^{-1})^2$
Work	$W = Fd$	work (energy) = force * distance (in the direction opposite the force)	J = N · m
Work done by a gas	$\Delta W = P\Delta V$ $W = \left(\frac{F}{A}\right) \cdot (Ad)$	work = pressure * change in volume *This can be derived from the above work equation by multiplying it by area/area.*	$J = Pa \cdot m^3$
Force	$F = ma$ $F = \frac{dp}{dt}$	force = mass * acceleration force = change in momentum / change in time	$N = kg \cdot m \cdot s^{-2}$ $N = N \cdot s \cdot s^{-1}$
Impulse	$\Delta p = F\Delta t = mv - mu$	impulse (change in momentum) = force * change in time = final momentum – initial momentum	N·s = N · s $= kg \cdot m \cdot s^{-1}$
Momentum	$p = mv$	momentum = mass * velocity	$kg \cdot m \cdot s^{-1} = kg \cdot m \cdot s^{-1}$
Conservation of momentum	$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$	initial momentum (u is initial velocities) = final momentum (v is final velocities)	$kg \cdot m \cdot s^{-1} = kg \cdot m \cdot s^{-1}$
Power	$P = \frac{W}{t} = \frac{\Delta E}{t}$ $P = \frac{Fd}{t} = Fv$	power = work / time = change in energy / time power = force * distance / time = force * velocity	$W = J \cdot s^{-1}$ $W = N \cdot m \cdot s^{-1}$ $W = N \cdot m \cdot s^{-1}$
Pressure	$p = \frac{F}{A}$	pressure = force / area	$Pa = N \cdot m^{-2}$
Pressure at depth (hydrostatic pressure)	$p = \rho gh$	pressure = density * gravitational acceleration * depth	$Pa = kg \cdot m^{-3} \cdot m \cdot s^{-2} \cdot m$
Young's modulus	$E = \frac{\sigma}{\epsilon}$ $E = \frac{F/A}{x/L}$ $E = \frac{FL}{Ax}$	Young's modulus = stress / strain = force per area *[stress]* / extension per length *[strain]* = (force * length) / (area * extension) *Memory trick: Flax is a common plant in New Zealand.*	Pa = Pa · [none] $= N \cdot m^{-2} \cdot m^{-1} \cdot m$ $= N \cdot m \cdot m^{-2} \cdot m^{-1}$

Ideal gas equation	$PV = nRT = NkT$ $N = nN_A$ $R = kN_A$	P = pressure V = volume PV = constant n = number of moles R = ideal gas constant T = temperature in kelvins N = number of particles k = Boltzmann's constant N_A = Avogadro constant *Memory trick: N is a much bigger number than n, and N is a bigger letter than n.*	Pa · m^3 = mol · J·K^{-1}·mol^{-1} · K Pa · m^3 = [none] · J·K^{-1} · K [none] = mol · mol^{-1} J·K^{-1}·mol^{-1} = J·K^{-1}·mol^{-1}
Kinetic theory	$PV = \frac{1}{3}Nm < c^2 >$		
Molecular kinetic energy	$E_k = \frac{3RT}{2N_A} = \frac{3}{2}kT$		
Equations of motion	$s = \frac{1}{2}(u+v)t$ $s = ut + \frac{1}{2}at^2$ $s = vt - \frac{1}{2}at^2$ $v = u + at$ $v^2 = u^2 + 2as$	• displacement = average velocity * time • displacement = initial velocity * time + half acceleration * time squared • displacement = final velocity * time – half acceleration * time squared • final velocity = initial velocity + acceleration * time • final velocity squared = initial velocity squared + twice acceleration * displacement	m = m·s^{-1} · s m = m·s^{-1} · s + m·s^{-2} · s^2 m = m·s^{-1} · s – m·s^{-2} · s^2 m·s^{-1} = m·s^{-1} + m·s^{-2} · s m^2·s^{-2} = (m·s^{-1})^2 + m·s^{-2} · m
Equations of motion – differentials and integrals	$v = \frac{ds}{dt}$ $a = \frac{dv}{dt}$ $s = \int v\,dt$ $v = \int a\,dt$	• velocity = change in displ. / change in time • acceleration = change in vel. / change in time • displacement = integral of velocity with respect to time • velocity = integral of accel. wrt to time *There are also higher order quantities: change in acceleration per time is jerk; then jounce or snap; crackle; and pop.*	

Gravity

Universal gravitational constant, G = 6.67 × 10^{-11} m^3·kg^{-1}·s^{-2} (or N·m^2·kg^{-2}). Earth's mass = 5.97 × 10^{24} kg.

Gravitational acceleration, g = 9.81 m·s^{-2} (or N·kg^{-1}). Moon's mass = 7.35 × 10^{22} kg. (About $^1/_{81}$ Earth's mass.)

Value	Equation	Equation Explained	Units
Newton's law of gravitation	$F = \frac{GMm}{r^2}$	force = gravitational constant * product of masses / square of the distance between the masses	N = N·m^2·kg^{-2} · kg^2 / m^2
Gravitational potential	$\phi = \frac{GM}{r}$	*By equating centripetal force with gravitational force we get v^2 = GM/r.*	m^2·s^{-2} = m^3·kg^{-1}·s^{-2} · kg / m
Gravitational acceleration	$g = \frac{GM}{r^2}$	*Average ~9.81 m·s^{-2} at Earth's surface.* *NZ is a bit less, ~9.799 m·s^{-2} half way along Dominion Rd, Auckland.*	m·s^{-2} = m^3·kg^{-1}·s^{-2} · kg / m^2
Escape velocity	$v_e = \sqrt{\frac{2GM}{r}}$	escape velocity = square root of (gravitational constant * planet's mass / the distance between the planet and the object escaping)	m·s^{-1} = √(m^3·kg^{-1}·s^{-2} · kg / m)
Kepler's third law	$r^3 \propto T^2$	the cube of the orbit radius is proportional to the square of the period	m^3 ∝ s^2

Rotation, Circular Motion & Simple Harmonic Motion

Value	Equation	Notes	Units
Angle	$\theta = \frac{2\pi t}{T} = \omega t = \frac{s}{r}$	swept angle = 2π * time / period = angular frequency * time = displacement / radius	radians = s · s^{-1} = radians·s^{-1} · s = m · m^{-1}
Angular frequency Angular velocity	$\omega = \frac{d\theta}{dt} = \frac{2\pi}{T} = 2\pi f = \frac{v}{r}$	angular velocity = change in angle over change in time = 2π / period = 2π * frequency = linear velocity / radius *This is the differential of angle w.r.t. time. Whether it's angular frequency or angular velocity depends on the situation (although angular velocity is a little different, being a pseudovector).*	radians·s^{-1} = radians per turn · s^{-1} = radians per turn · Hz = m·s^{-1} · m^{-1}
Angular velocity of a spring in SHM	$\omega = \sqrt{\frac{k}{m}}$	angular velocity = square root of (spring constant / mass)	radians·s^{-1} = (N·m^{-1} · kg^{-1})½
Angular acceleration	$\alpha = \frac{d\omega}{dt}$	angular acceleration = change in angular velocity over change in time *This is the differential of angular velocity w.r.t. time.*	radians·s^{-2}
Angular momentum	$L = I\omega$	angular momentum = rotational inertia * angular frequency	kg·m^2·s^{-1} = kg·m^2 · radians·s^{-1}
Angular momentum of thin shell cylinder	$L = mr^2\omega$	angular momentum = mass * radius squared * angular frequency	kg·m^2·s^{-1} = kg · m^2 · radians·s^{-1}
Centripetal force	$F = \frac{mv^2}{r}$	centripetal force (centrifugal force) = mass * velocity squared / radius *This is simply F = ma with the formula for linear acceleration from below substituted in.*	N = kg · (m·s^{-1})^2 · m^{-1}
Energy	$E = \tau\theta$	energy = torque * angle *Hence torque can be given in joules per radian. Dividing both sides by time gives power (see below).*	J = N·m * radians
Elastic potential energy	$E_p = \frac{1}{2}kx^2 = \frac{1}{2}Fx$	elastic potential energy = half * spring constant * displacement squared = half * restoring force * displacement	J = N·m^{-1} · m^2 = N · m
Rotational kinetic energy	$E_k = \frac{1}{2}I\omega^2$	kinetic energy = half * angular momentum * angular frequency squared	J = kg · (m·s^{-1})^2
Frequency	$f = \frac{1}{T}$ $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$	frequency = 1 / period	Hz = s^{-1}
Hooke's Law (force on a spring)	$F = -kX$	restoring force (hence the negative sign) is proportional to the displacement from equilibrium *Can also be stated without the negative sign, as the force required to produce the displacement. Each spring has its own value of k, the spring constant.*	N = N·m^{-1} · m
Linear velocity	$v = \frac{2\pi r}{T} = r\omega$	linear velocity = 2π * radius / period = radius * angular velocity *Also called tangential velocity.*	m·s^{-1} = m · radians·s^{-1}
Linear acceleration	$a = \frac{v^2}{r}$	linear acceleration = velocity squared / radius	m·s^{-2} = (m·s^{-1})^2 · m^{-1}
Moments in equilibrium	$F_1d_1 + F_2d_2 = F_3d_3 + F_4d_4$	sum of anticlockwise moments = sum of clockwise moments	N · m = N · m

Pendulum	$T = 2\pi\sqrt{\frac{L}{g}}$	period = 2π * square root of (pendulum length / gravitational acceleration) *For very small swing angles.*	s = √(m / m·s^{-2})
Period	$T = \frac{1}{f}$ $T = 2\pi\sqrt{\frac{m}{k}}$	period = 1 / frequency	s = Hz^{-1}
Power	$P = \tau\omega = \frac{E}{t} = \tau\frac{\theta}{t}$	power = torque * angular frequency *This is the scalar product of two vectors. Throw in 2π / 60 if using rpm, such as for a car engine.*	W = N·m · radians·s^{-1}
Rotational inertia	$I = \frac{L}{\omega}$	rotational inertia = angular momentum / angular frequency *Rotational inertia is also called moment of inertia.*	kg · m^2 = kg·m^2·s^{-1} / radians·s^{-1}
Rotational inertia of thin shell cylinder or pendulum	$I = mr^2$	rotational inertia = mass * radius (from pivot for pendulum) squared	kg·m^2 = kg · m^2
... of solid cylinder	$I = \frac{1}{2}mr^2$	rotational inertia = half * mass * radius squared	kg·m^2 = kg · m^2
... of thin shell sphere	$I = \frac{2}{3}mr^2$	rotational inertia = two thirds * mass * radius squared	kg·m^2 = kg · m^2
... of solid sphere	$I = \frac{2}{5}mr^2$	rotational inertia = two thirds * mass * radius squared	kg·m^2 = kg · m^2
... of long rod pivoted at centre	$I = \frac{1}{12}mL^2$	rotational inertia = one twelfth * mass * length squared	kg·m^2 = kg · m^2
... of long rod pivoted at one end	$I = \frac{1}{3}mL^2$	rotational inertia = one third * mass * length squared	kg·m^2 = kg · m^2
SHM displacement	$x = x_0 \sin(\omega t)$	displacement = amplitude * sine(angular frequency * time) *Sine can be replaced with cosine (depending on start position of SHM).*	m = m · [ratio]
SHM velocity	$v = \omega x_0 \cos(\omega t) = \pm\omega\sqrt{x_0^2 - x^2}$	velocity = angular frequency * amplitude * cosine(angular frequency * time) *Cosine can be replaced with sine (depending on start position of SHM).*	m·s^{-1} = radian·s^{-1} · m · [ratio]
SHM acceleration	$a = -\omega^2 x = -\omega^2 x_0 \sin(\omega t) = -4\pi^2 f^2 x$	acceleration = negative angular velocity squared * dispacement *The negative is because the acceleration is always in a direction opposite to the displacement from equilibrium. Sine can be replaced with cosine depending on start position of SHM.* *This is closely related to Hooke's Law.*	m·s^{-2} = (radians·s^{-1})^2 · m
Torque	$\tau = Fd = \frac{E}{\theta} = I\alpha$	torque = force * pependicular distance = energy per radian = rotational inertia * angular acceleration *τ = Iα assumes the body is not changing size, which would change the rotational inertia (see above).*	N·m = N · m = J · radians^{-1} = kg·m^2 · radians·s^{-2}

Electricity

In a circuit, electromotive force (emf, symbol V or E or ε) is the voltage from sources (eg, a battery), while potential difference (pd, symbol V) is the voltage dropped across resistances.

Resistivity, ρ:

Silver 1.59 × 10^{-8} Ω·m
Copper 1.68 × 10^{-8} Ω·m
Gold 2.44 × 10^{-8} Ω·m
Aluminum 2.65 × 10^{-8} Ω·m
Iron 9.71 × 10^{-8} Ω·m
Steel 20 × 10^{-8} Ω·m
Lead 22 × 10^{-8} Ω·m
Mercury 98 × 10^{-8} Ω·m

Carbon 3.5 × 10^{-5} Ω·m
Germanium 0.60 Ω·m
Silicon 2300 Ω·m

Wood 10^{8} to 10^{11} Ω·m
Glass 10^{9} to 10^{14} Ω·m
Mica 10^{11} to 10^{15} Ω·m
Fused quartz 7.5 × 10^{17} Ω·m

Charge carrier density, n:

Copper 8.47 × 10^{28} m^{-3}
Gold 5.90 × 10^{28} m^{-3}
Silver 5.86 × 10^{28} m^{-3}

Aluminium 1.81 × 10^{29} m^{-3}
Iron 1.70 × 10^{29} m^{-3}
Lead 1.32 × 10^{29} m^{-3}

Diamond 1.6 × 10^{-21} m^{-3}
Germanium 2.33 × 10^{19} m^{-3}
Silicon 9.65 × 10^{15} m^{-3}

Value	Equation	Notes	Units
Current	$I = \frac{Q}{t}$	current = charge / time	A = C · s^{-1}
Current in a conductor	$I = nAve$ or $I = nevA$	• n is the number of available charge carriers (normally electrons) per cubic metre. This is a constant for a particular material (eg, copper). • A is the cross-sectional area of the conductor (wire). • v is the charge carrier (electron) drift velocity. • e (also written as q) is the charge of each charge carrier (typically electrons).	A = m^{-3} · m^{2} · m·s^{-1} · C A = m^{-3} · C · m·s^{-1} · m^{2}
Kirchhoff's First Law	$I_T = I_1 + I_2$	*In a circuit, the total current flowing into a junction is equal to the total current flowing out of the junction.*	A = A + A
Kirchhoff's Second Law	$\sum emf = \sum pd$	*In a circuit, around any loop the emf sum equals the pd sum. Alternatively, around any loop the sum of all emfs and pds equals zero.*	V = V
Ohm's Law	$V = IR$	voltage = current times resistance	V = A · Ω
Power	$P = IV$	power = current * voltage	W = A · V
Power	$P = I^2R$ $P = \frac{V^2}{R}$	power = current squared * resistance power = voltage squared / resistance *These come from substituting Ohm's Law into P = IV.*	W = A^{2} · Ω W = V^{2} · Ω^{-1}
Resistivity	$\rho = \frac{RA}{L}$ $R = \frac{\rho L}{A}$	resistivity = resistance * area / length resistance = resistivity * length / area	Ω·m = Ω · m^{2} · m^{-1} Ω = Ω·m · m · m^{-2}
Resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ $R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$	reciprocal of total resistance = sum of reciprocals of individual parallel resistances	$\Omega^{-1} = \Omega^{-1} + \Omega^{-1}$ $\Omega = (\Omega^{-1} + \Omega^{-1})^{-1}$
Resistors in series	$R_T = R_1 + R_2$	total resistance = sum of individual series resistances	Ω = Ω + Ω
Voltage	$V = \frac{E_p}{Q}$	voltage (potential difference) = potential energy per charge *This is a nice simple definition of voltage.*	V = J · C^{-1}

AC Current

Value	Equation	Notes	Units
AC current in inductor	$I_L = \frac{V}{\omega L} = \frac{V}{2\pi f L}$	V is the RMS voltage	A = V / Hz · H
AC Ohm's Law	$V = IZ$	RMS voltage = RMS current * impedance	V = A · Ω
Reactance (AC circuits)	$X = X_L + X_C = \omega L - \frac{1}{\omega C}$		Ω = Ω + Ω
Capacitive reactance	$X_C = -\frac{1}{\omega C} = -\frac{1}{2\pi f C}$ $X_C = \frac{1}{j\omega C} = \frac{1}{j2\pi f C}$	*Capacitive reactance is the negative imaginary component of impedance.* *In electrical engineering j is used instead of i for the imaginary unit (and the negative sign is accounted for by the j being on the bottom).*	Ω
Inductive reactance	$X_L = \omega L = 2\pi f L$ $X_L = j\omega L = j2\pi f L$	*Inductive reactance is the positive imaginary component of impedance.*	Ω
Impedance	$Z = R + jX$ $\lvert Z \rvert = \sqrt{R^2 + X^2}$	complex impedance = real resistance + imaginary reactance *j is the imaginary unit (i is used in mathematics).*	Ω = Ω + Ω $\Omega = (\Omega^2 + \Omega^2)^{½}$
Angular frequency	$\omega = 2\pi f_c$	angular frequency = 2π * cutoff frequency	$\text{radians}\cdot s^{-1} = (H\cdot F)^{-½}$
Resonant angular frequency	$\omega_0 = \frac{1}{\sqrt{LC}}$	resonant angular frequency = reciprocal of square root of product of inductance and capacitance *Used for tuned (resonant) circuits.*	$\text{radians}\cdot s^{-1} = (H\cdot F)^{-½}$
Resonant frequency	$f_0 = \frac{1}{2\pi\sqrt{LC}}$	resonant frequency = reciprocal of (2π * square root of product of inductance and capacitance) *Used for tuned (resonant) circuits.*	$Hz = [\text{const.}] \cdot (H\cdot F)^{-½}$
Time constant	$\tau = RC = \frac{1}{2\pi f_c}$ $\tau = \frac{L}{R}$	time constant = resistance * capacitance = reciprocal of (2π * cutoff frequency) *The time constant is the reciprocal of angular frequency.* time constant = inductance / resistance	s = Ω · F $s = H \cdot \Omega^{-1}$

Capacitors & Electric Fields

The electron volt is a unit of energy:
electron volt = elementary charge * volts. 1 eV = 1 *e* * V.

Elementary charge, $e = 1.6 \times 10^{-19}$ C.

Charge on an electron = $-e = -1.6 \times 10^{-19}$ C.

Mass of electron = 9.11×10^{-31} kg.

Permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12}$ F·m^{-1}.

Coulomb constant $k_e = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}$ N·m^{2}·C^{-2}.

Relative permittivity, ε_r:

Vaccuum 1.
Air 1.00.
Paper 2.3 (waxed paper 2.5).
Body tissue 8.
PTFE (Teflon) 2.1.
BoPET (Mylar) 3.1.
Glass 3.7 – 10.
Silicon 11.68.

Value	Equation	Notes	Units
Capacitance	$C = \frac{Q}{V} = \varepsilon\frac{A}{d}$ $Q = CV$ $V = \frac{Q}{C}$	capacitance = charge / voltage = permittivity * plate area / distance between plates *Where d is much smaller than dimensions of the area of plates. See permittivity below.* charge = capacitance * voltage voltage = charge / capacitance	F = C·V^{-1} = F·m^{-1} · [none] · m^{2} · m^{-1} C = F·V V = C·F^{-1}
Current in a capacitor	$\frac{Q}{t} = C\frac{V}{t}$ $I = C\frac{dV}{dt}$	*Divide both sides of Q = CV by t.* charge / time = capacitance * voltage / time current = charge * change in voltage / change in time	C·s^{-1} = F · V · s^{-1} A = F · V·s^{-1}
Current in a conductor	$I = ne\frac{E}{B}A$	*This is a version of the formula in the electricity section replacing charge carrier drift velocity, v, with E / B.*	A = m^{-3} · C · V·m^{-1} · T^{-1} · m^{2}
Capacitors in parallel	$C_T = C_1 + C_2$	total capacitance = sum of individual parallel capacitances (because the plate area is added)	F = F + F
Capacitors in series	$\frac{1}{C_T} = \frac{1}{C_2} + \frac{1}{C_2}$	reciprocal of total capacitance = sum of reciprocals of individual series capacitance	F^{-1} = F^{-1} + F^{-1}
Electric field between parallel plates	$E = \frac{V}{d} = \frac{F}{Q}$	electric field strength = voltage per distance = force per charge *Remember the electron has a negative charge if determining the direction of the force.*	V·m^{-1} = N·C^{-1}
Permittivity	$\varepsilon = \varepsilon_0\varepsilon_r$	permittivity = permittivity of free space * relative permittivity *The relative permittivity is also called the dielectric constant, and is a dimensionless ratio, different for each dielectric material.*	F·m^{-1}= F·m^{-1} · [none]
Electric field for a charge	$E = \frac{q}{4\pi\varepsilon_0 r^2}$ or $E = k_e\frac{q}{r^2}$	electric field = charge / (constant * permittivity of free space * square of the distance to the charge) electric field = Coulomb constant * charge / square of the distance to the charge	V·m^{-1} = C · F^{-1}·m · m^{-2} V·m^{-1} = N·m^{2}·C^{-2} · C · m^{-2}
Coulomb's law (force between two charges)	$F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$ or $F = k_e\frac{q_1 q_2}{r^2}$	*Multiply by q each side of the equation for the electric field for a charge, then use E = F/Q to replace the left side with F.* force = charge 1 * charge 2 / (constant * permittivity of free space * square of the distance between the charges) force = Coulomb constant * charge 1 * charge 2 / square of the distance between the charges	N = C · C · [none] · F·m^{-1} · m^{-2} N = N·m^{2}·C^{-2} · C · C · m^{-2}

Potential energy change in uniform electric field (ie, between parallel plates)	$\Delta E_p = Fd$ $= EQd = QV$	potential energy of a charge = voltage * charge *This comes from multiplying out the previous equation, or by rearranging the definition of the volt.*	J = N·m = (N·C^{-1})·C·m = (V·m^{-1})·C·m = C·V
Electric potential energy stored in a capacitor	$E_p = \frac{1}{2}CV^2$ $= \frac{1}{2}QV = \frac{1}{2}\frac{Q^2}{C}$	potential energy = half * capacitance * voltage squared = half * charge * voltage = half * charge squared / capacitance	J = F·V^2 J = C·V J = C^2·F^{-1}
Time constant	$\tau = RC$	time constant = resistance * capacitance = reciprocal of (2π * cutoff frequency)	s = Ω * F
Capacitor charging voltage	$V_c = V_s\left(1 - e^{-\frac{t}{\tau}}\right)$	capacitor voltage = supply voltage * (1 - reciprocal of *e* [Euler's number] to the power of (time / time constant) *99.3% of max. voltage after 5τ, so ~ fully charged.*	V = V · ([const.] - [const.] ^ (s ·s^{-1})
Capacitor discharging voltage	$V_c = V_s e^{-\frac{t}{\tau}}$	capacitor voltage = supply voltage * reciprocal of *e* [Euler's number] to the power of (time / time constant) *0.7% of max. voltage after 5τ, so ~ fully discharged.*	V = V · ([const.] ^ (s ·s^{-1})

Magnetism

Permeability of free space (aka magnetic constant), $\mu_0 = 4\pi \times 10^{-7}$ H·m^{-1} = 1.26×10^{-6} H·m^{-1} (or T·m·A^{-1} or N·A^{-2}).

A related constant sometimes used by schools, k = $\frac{\mu_0}{2\pi}$ = 2.0×10^{-7} T·m·A^{-1}.

Value	Equation	Notes	Units
Magnetic flux density	$B = \frac{\phi}{A}$ $\phi = BA$ $\phi = BA\sin\theta$	magnetic flux density = magnetic flux per area magnetic flux = magnetic flux density * area magnetic flux = magnetic flux density * area * angle of loop *Lowercase phi. Other symbols used include Φ (beware! also used for magnetic flux **linkage**) and Φ_B . Magnetic flux density is often just called "magnetic field".*	T = Wb · m^{-2} Wb = T · m^2
Flux linkage in solenoid	$\Phi = BAN$	magnetic flux **linkage** = magnetic flux density * area * number of turns in solenoid *That's an uppercase phi. Other symbols used include Ψ and Λ .*	Wb = T · m^2 · [none]
Flux linkage in rotating coil (armature)	$\Phi = BAN\sin(2\pi ft)$	magnetic flux **linkage** = magnetic flux density * area * number of turns in solenoid * sine of angle.	Wb = T · m^2 · [none] · [none]
Induced emf in a loop	$\varepsilon = -\frac{d\phi}{dt}$	emf = change in magnetic flux / change in time	V = Wb · s^{-1}
Induced emf in a rotating coil (armature)	$\varepsilon = BAN\omega\cos(\omega t)$ $\varepsilon = BAN2\pi f\cos(2\pi ft)$	These equations are the differential of the equation above for flux linkage in a rotating coil.	V = Wb · s^{-1}
Induced emf in an inductor	$\varepsilon = -L\frac{dI}{dt}$	emf = inductance * charge in current / change in time	V = H · A · s^{-1}
Energy in an inductor	$E = \frac{1}{2}LI^2$	energy = ½ * inductance * current squared	J = [none] · H · A^2
Force on a conductor	$F = BIL\sin\theta$	force = magnetic flux density * current * length of conductor (in field) * sine of angle of current to magnetic flux density	N = T · A · m · [none]
Force on parallel conductors per unit length	$F = \frac{\mu_0 I_1 I_2}{2\pi r}$	force per metre = permeability of free space * product of two currents / (2π * distance between wires)	N·m^{-1} = N·A^{-2} · A^2 · m^{-1}
Force on a moving charge	$F = Bqv\sin\theta$ $F = Bev\sin\theta$ (for electron)	force = magnetic field * charge * velocity of particle sine of angle of current to magnetic flux density	N = T · C · m·s^{-1} · [none]
Magnetic flux density around a conductor	$B = \frac{\mu_0 I}{2\pi r}$ $B = \frac{kI}{d}$	magnetic flux density = permeability of free space * current / (2π * distance from conductor) magnetic flux density = k * current / distance from conductor	T = T·m·A^{-1} · A · [const.] · m^{-1} T = T·m·A^{-1} · A · m^{-1}
Hall Voltage	$V_H = \frac{BI}{ntq}$	Hall voltage = magnetic flux density * current / (number of electrons per m^3 * thickness of conductor * charge of electron)	V = T · A · m^3 · m^{-1} · C^{-1}
Induced voltage (EMF) in a conductor	$V = BvL$	induced voltage (EMF) = magnetic flux density * velocity of conductor * length of conductor in magnetic field	V = T · m·s^{-1} · m
Transformer	$\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$	N = number of turns, V = voltage, I = current; p = primary coil, s = secondary coil *The number of turns ratio is the same as the voltage ratio and the reciprocal of the current ratio.*	[ratio] = [ratio] = [ratio]

Optics & Waves

Speed of light in air or vacuum, $c = 3.00 \times 10^8$ m·s^{-1}. (This is the two-way speed of light because it is impossible to measure the one-way speed of light.)

Permittivity of free space (aka electric constant), $\varepsilon_0 = 8.85 \times 10^{-12}$ F·m^{-1} (or C^2·N^{-1}·m^{-2} or C·V^{-1}·m^{-1}).

Permeability of free space (aka magnetic constant), $\mu_0 = 4\pi \times 10^{-7}$ H·m^{-1} = 1.26×10^{-6} H·m^{-1} (or N·A^{-2}).

Value	Equation	Notes	Units
Doppler change	$f = \frac{f_0(v \pm v_r)}{v \mp v_s}$ $\lambda = \frac{\lambda_0(v \pm v_s)}{v \mp v_r}$	f; λ = observed frequency; observed wavelength f_0; λ_0 = original frequency; original wavelength v = velocity of waves; v_r = receiver velocity; v_s = source velocity *The observed frequency is increased if the source and receiver are moving toward each other, reduced if they are moving apart.* *Note the reversal of the sign in the denominators.* *Note the reversal of v_r and v_s in the wavelength equation.*	Hz = Hz · (m·s^{-1}) m = m · (m·s^{-1})
Magnification	$m = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$	magnification = distance to the image / distance to the object = height of image / height of object *The negative sign indicates real images are inverted relative to the object.*	[none] = m / m
Magnification, "Newtonian" version	$m = \frac{f}{s_o} = \frac{s_i}{f}$ $m = \frac{f}{f - d_o}$	magnification = focal length / distance from object to focal point = distance from image to (near) focal point / focal length *$s_i = d_i - f$; $s_o = d_o - f$*	[none] = m / m
Period, frequency	$T = \frac{1}{f}$ $\quad f = \frac{1}{T}$	period (the time for one full wave) is the reciprocal of the frequency	s = 1 / Hz Hz = 1 / s
Speed of light	$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$	*The speed of light is equal to the reciprocal of the geometric mean of the permittivity of free space and the permeability of free space (aka the electric constant and the magnetic constant respectively).*	m·s^{-1} = 1 / √ (F·m^{-1} · H·m^{-1})
Speed, frequency, wavelength	$c = f\lambda$ $v = f\lambda$	speed of light = frequency * wavelength *(e.m. radiation in air)* speed = frequency * wavelength *(other situations such as sound)*	m·s^{-1} = Hz · m
Refractive index	$n = \frac{c}{v}$ $\frac{n_1}{n_2} = \frac{v_2}{v_1} = \frac{\lambda_2}{\lambda_1}$	refractive index of medium = speed of light / speed of light in medium *Hence minimum refractive index is 1.*	[none] = m·s^{-1} / m·s^{-1}
Snell's Law	$n_1 \sin\theta_1 = n_2 \sin\theta_2$	refractive index 1 * sine of angle 1 = refractive index 2 * sine of angle 2	[none]
Thin lens formula	$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$	the reciprocal of the focal length = the reciprocal of the object distance + the reciprocal of the image distance	m^{-1} = m^{-1} + m^{-1}
Thin lens formula, "Newtonian" version	$s_i s_o = f^2$	the distance from the object to the focal point * the distance from the image to the (near) focal point = the square of the focal length *$s_i = d_i - f$; $s_o = d_o - f$*	m · m = m^2
Diffraction grating equation	$n\lambda = d\sin\theta = \frac{\sin\theta}{N}$	d = line separation in diffraction grating N = number of lines per metre in diffraction grating	m = m · [ratio] m = [ratio] / m^{-1}
Twin slit equation	$n\lambda = \frac{dx}{L}$	d = slit separation; x = fringe separation; L = distance to screen *This is a version of the above equation. For very small angles sinθ ≈ tanθ, and tanθ = x / L.*	m = m · m / m
Polarised light, Malus' Law	$I = I_0 \cos^2\theta$	intensity = input intensity * the square of the angle between the polarisers	W = W
Intensity vs Amplitude	$I \propto A^2$	intensity is proportional to the square of the amplitude	

Quantum Physics, Relativity

Speed of light in air or vacuum, c = 3.00 × 10^8 m/s. (This is the two-way speed of light because it is impossible to measure the one-way speed of light.)

Planck constant, h = 6.63 × 10^{-34} J·Hz^{-1}.

Rydberg constant, R_∞ = 1.10 × 10^7 m^{-1}. (To 3 sig fig this is the same as the Rydberg constant for each element.)

Rydberg unit of energy, 1 R_y = 2.18 × 10^{-18} J = 13.6 eV.

Value	Equation	Notes	Units
de Broglie wavelength	$\lambda = \frac{h}{p} = \frac{h}{mv}$	wavelength = Planck's constant over momentum	m = J·Hz^{-1} / N·s
Photon energy, work function, electron kinetic energy	$hf = \Phi + \frac{1}{2}mv^2_{\text{max}}$	energy of photon = work function + kinetic energy *The work function is the minimum amount of energy required to remove an electron from a metal in a vacuum. It is different for each metal; more reactive metals have lower work functions. Φ = hf_0 .*	J = J + kg · (m·$s^{-1})^2$
Kinetic energy of electron	$E_k = Ve$	kinetic energy of electron = applied voltage * electron charge *The kinetic energy of the electron is found by measuring the voltage required to stop the flow of electrons produced by the photoelectric effect.*	J = J·C^{-1} · C
Energy-mass equivalence	$E = mc^2$	energy = mass x speed of light squared *For more information about this equation see the E = mc^2 page.*	J = kg · (m·$s^{-1})^2$
Lorentz factor	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$	Lorentz factor = the reciprocal of the square root of one minus the square of the velocity over the speed of light	[none]
Photon energy	$E = hf = \frac{hc}{\lambda} = pc$	energy of photon = Planck constant * photon frequency = Planck constant * speed of light / wavelength = momentum * the speed of light	J = J·Hz^{-1} · Hz
Energy of atomic orbitals of H atom	$E_n = -\frac{R_y Z^2}{n^2}$ $E_n = -\frac{hcR_\infty Z^2}{n^2}$	electron shell energy = Rydberg unit of energy * atomic number squared over the energy level squared electron shell energy = Planck contant * speed of light * Rydberg constant * atomic number squared over the energy level squared	J = J · [const.] / [const.]
Rydberg formula	$\frac{1}{\lambda} = \frac{R_\infty Z^2}{n^2}$	reciprocal of the wavelength = Rydberg constant * atomic number squared over the energy level squared	m^{-1} = m^{-1} · [const.]

Nuclear Physics

Elementary charge, e = 1.60 × 10^{-19} C.

Electron-volt: 1 eV = 1.60 × 10^{-19} J.

Avogadro constant, N_A = 6.02 × 10^{23} mol^{-1}.

Natural log of 2, ln(2) = 0.693.

Value	Equation	Notes	Units
Activity of a radioactive substance	$A = \lambda N$ $A_0 = \lambda N_0$	activity = decay constant * number of radioactive particles original activity = decay constant * original number of radioactive particles	Bq = s^{-1}
Decay constant	$\lambda = \frac{\ln(2)}{t_{\frac{1}{2}}}$	Decay constant = ln(2) / half life	s^{-1} = 1 / s
Half life	$t_{\frac{1}{2}} = \frac{\ln(2)}{\lambda}$	Half life = ln(2) / decay constant	s = [const.] / s^{-1}
Radioactive decay	$x = x_0 e^{-\lambda t}$ $A = A_0 e^{-\lambda t}$ $N = N_0 e^{-\lambda t}$	value = original value * e to the power of negative decay constant * time in seconds *x could represent activity (A), number of undecayed nuclei (N), or received count rate.*	Bq = Bq · [none] [quantity] = [quantity] · [none]