Cambridge AS & A Level · Physics 9702

Physics 9702 formulas and definitions

All 232 formulas, facts and definitions to learn, by syllabus topic. Formulas the exam gives you are left out.

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AS Level

1 Physical quantities and units

Physical quantity = numerical magnitude × unit

Base units: kg, m, s, A, K

Prefixes: p 10^{-12}, n 10^{-9}, μ 10^{-6}, m 10^{-3}, c 10^{-2}, d 10^{-1}, k 10^{3}, M 10^{6}, G 10^{9}, T 10^{12}

N = kg m s^{-2}, J = kg m^2 s^{-2}, W = kg m^2 s^{-3}, Pa = kg m^{-1} s^{-2}, C = A s, V = kg m^2 s^{-3} A^{-1}, Ω = kg m^2 s^{-3} A^{-2}, Hz = s^{-1}

Percentage uncertainty $= \dfrac{\Delta x}{x} \times 100\%$

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

$y = \dfrac{a^p b^q}{c^r}$: $\dfrac{\Delta y}{y} = p\dfrac{\Delta a}{a} + q\dfrac{\Delta b}{b} + r\dfrac{\Delta c}{c}$

Repeated readings: value = mean, uncertainty = $\frac{1}{2}$ × range

True value = reading – zero error

Components of F at θ to a direction: $F\cos\theta$ along it, $F\sin\theta$ at right angles

Perpendicular vectors: $R = \sqrt{X^2 + Y^2}$, angle $= \tan^{-1}\dfrac{Y}{X}$

Cosine rule $a^2 = b^2 + c^2 - 2bc\cos A$; sine rule $\dfrac{a}{\sin A} = \dfrac{b}{\sin B}$

Circle $A = \pi r^2$; sphere $V = \frac{4}{3}\pi r^3$; cylinder $V = \pi r^2 l$; cuboid $V = lwh$

2 Kinematics

Speed $= \dfrac{\text{distance}}{\text{time}}$; velocity $v = \dfrac{\Delta s}{\Delta t}$ (rate of change of displacement)

Acceleration $a = \dfrac{\Delta v}{\Delta t}$ (rate of change of velocity)

Average speed $= \dfrac{\text{total distance}}{\text{total time}}$; average velocity $= \dfrac{\text{total displacement}}{\text{total time}}$

Gradient of s–t graph = velocity; gradient of v–t graph = acceleration

Area under v–t graph = displacement; area under a–t graph = change in velocity

$v = u + at$

$s = \frac{1}{2}(u + v)t$

Launch at θ to the horizontal: $u_x = u\cos\theta$, $u_y = u\sin\theta$

Speed from components: $v = \sqrt{v_x^2 + v_y^2}$, angle to horizontal $= \tan^{-1}\dfrac{v_y}{v_x}$

Free-fall experiment: $h = \frac{1}{2}gt^2$, so gradient of h against $t^2 = \frac{g}{2}$

Uncertainty in $g = \dfrac{2h}{t^2}$: $\%g = \%h + 2 \times \%t$

3 Dynamics

Momentum $p = mv$ (a vector; units kg m s^{-1} = N s)

Force = rate of change of momentum, $F = \dfrac{\Delta p}{\Delta t}$

$F = ma$ (resultant force, constant mass; a in the direction of F)

Change in momentum $\Delta p = F\Delta t$ = area under a force–time graph

Gradient of a momentum–time graph = resultant force

Force from a steady stream (jet, rocket, hose): $F = \dfrac{\Delta m}{\Delta t}\,v$

Weight $W = mg$

Conservation of momentum: $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ (isolated system)

Kinetic energy $E_k = \frac{1}{2}mv^2$; also $E_k = \dfrac{p^2}{2m}$

Elastic collision: total E_k conserved; relative speed of approach = relative speed of separation

At terminal velocity: resultant force $= 0$ (weight = drag, plus upthrust in a fluid)

4 Forces, density and pressure

Moment $= F \times d$, d = perpendicular distance from the point to the line of action (N m)

Principle of moments: in equilibrium, sum of clockwise moments = sum of anticlockwise moments about the same point

Torque of a couple $= F \times d$, one force × perpendicular distance between the lines of action

Equilibrium: resultant force $= 0$ and resultant torque $= 0$

Three forces in equilibrium form a closed vector triangle

Density $\rho = \dfrac{m}{V}$ (kg m^{-3}; 1 g cm^{-3} $= 1000$ kg m^{-3})

Pressure $p = \dfrac{F}{A}$ (Pa $=$ N m^{-2})

Total pressure at depth h = atmospheric pressure $+\rho gh$

Floating: upthrust = weight; fraction submerged $= \rho_{\text{object}} / \rho_{\text{fluid}}$

Volume of a sphere $\frac{4}{3}\pi r^3$; of a cylinder $\pi r^2 h$

5 Work, energy and power

Work done $W = Fs$, s = displacement in the direction of the force; $W = Fs\cos\theta$ at an angle θ (J)

Work done by a gas at constant pressure $W = p\Delta V$

Change in gravitational potential energy $\Delta E_P = mg\Delta h$ (uniform field)

Kinetic energy $E_K = \frac{1}{2}mv^2$; also $E_K = \dfrac{p^2}{2m}$

Conservation of energy: energy is never created or destroyed; the total energy of a closed system is constant

Efficiency $= \dfrac{\text{useful energy output}}{\text{total energy input}} = \dfrac{\text{useful power output}}{\text{total power input}}$ (no unit)

Power $P = \dfrac{W}{t}$ (W = J s^{-1})

$P = Fv$

Component of weight down a slope $mg\sin\theta$

6 Deformation of solids

Hooke's law $F = kx$ (within the limit of proportionality)

Spring constant $k = \dfrac{F}{x}$ (N m^{-1})

Stress $\sigma = \dfrac{F}{A}$ (Pa = N m^{-2})

Strain $\varepsilon = \dfrac{x}{L}$ (no unit)

Young modulus $E = \dfrac{\sigma}{\varepsilon} = \dfrac{FL}{Ax}$ (Pa)

$k = \dfrac{EA}{L}$ for a wire

Area of a circular cross-section $A = \pi r^2 = \dfrac{\pi d^2}{4}$

Elastic potential energy $E_P = \frac{1}{2}Fx = \frac{1}{2}kx^2$ (within the limit of proportionality)

Work done = area under the force–extension graph

Springs in series $\dfrac{1}{k} = \dfrac{1}{k_1} + \dfrac{1}{k_2}$; in parallel $k = k_1 + k_2$

7 Waves

$v = f\lambda$ (and $c = f\lambda$ for electromagnetic waves)

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

Phase difference $= \dfrac{\Delta x}{\lambda} \times 360^\circ = \dfrac{\Delta t}{T} \times 360^\circ$

Intensity $I = \dfrac{P}{A}$ (W m^{-2})

$I \propto (\text{amplitude})^2$

Malus's law $I = I_0 \cos^2\theta$ (amplitude $A = A_0 \cos\theta$)

CRO: period $=$ divisions $\times$ time-base; amplitude $=$ divisions $\times$ y-gain

Visible light: 400 nm to 700 nm; the order and ranges of the spectrum

8 Superposition

Superposition: resultant displacement $=$ sum of the individual displacements

In phase: amplitude $A_1 + A_2$; antiphase: amplitude $|A_1 - A_2|$

$v = f\lambda$ (and $c = f\lambda$)

Stationary wave: node to node $= \frac{\lambda}{2}$, node to antinode $= \frac{\lambda}{4}$

String fixed at both ends or tube open at both ends: $L = \frac{n\lambda}{2}$

Tube closed at one end: $L = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}, \ldots$

Maximum: path difference $n\lambda$; minimum: $(n + \frac{1}{2})\lambda$ (sources in phase)

Phase difference $= \frac{\text{path difference}}{\lambda} \times 360^\circ$

Double slit: $\lambda = \dfrac{ax}{D}$

Diffraction grating: $d\sin\theta = n\lambda$, with $d = \frac{1}{\text{lines per metre}}$

Highest order: largest whole number $n \leq \frac{d}{\lambda}$; total maxima $2n_{\max} + 1$

Intensity $\propto$ (amplitude)^2

9 Electricity

$Q = It$

Number of carriers $N = \dfrac{Q}{e}$

Number density $n = \dfrac{\text{number of carriers}}{\text{volume}}$

$V = \dfrac{W}{Q}$, so $W = QV = VIt$

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

$P = \dfrac{W}{t}$

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

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

Area of a round wire $A = \frac{\pi d^2}{4} = \pi r^2$

Units: $1\ \mathrm{C} = 1\ \mathrm{A\ s}, 1\ \mathrm{V} = 1\ \mathrm{J\ C^{-1}}, 1\ \Omega = 1\ \mathrm{V\ A^{-1}}$, ρ in Ω m

10 D.C. circuits

E.m.f. $E = \frac{W}{Q}$ (energy to electrical, per unit charge)

P.d. $V = \frac{W}{Q}$ (electrical energy to other forms, per unit charge)

$E = V + Ir = I(R + r)$

Terminal p.d. $V = E - Ir$; V–I graph: intercept E, gradient $-r$

Power: total EI, external VI, wasted in the cell I^2r

Kirchhoff's first law: $\sum I_{\text{in}} = \sum I_{\text{out}}$ (conservation of charge)

Kirchhoff's second law: round a closed loop, $\sum E = \sum IR$ (conservation of energy)

Potential divider $V_{\text{out}} = \frac{R_2}{R_1 + R_2} V_{\text{in}}$, $\frac{V_1}{V_2} = \frac{R_1}{R_2}$

Potentiometer (uniform wire, same current) $\frac{V_1}{V_2} = \frac{L_1}{L_2}$

Balanced dividers $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

11 Particle physics

$A = Z + N$ (nucleons = protons + neutrons)

α: $A \to A - 4$, $Z \to Z - 2$; β^-: $Z \to Z + 1$; β^+: $Z \to Z - 1$; γ: no change

α: mass 4 u, charge $+2e$; β^-: charge $-e$; β^+: charge $+e$; β mass 5.5×10^{-4} u

Quark charges: u, c, t $= +\frac{2}{3}e$; d, s, b $= -\frac{1}{3}e$; antiquarks opposite

Proton uud, neutron udd; baryon = 3 quarks, meson = quark + antiquark

β^-: $\mathrm{d} \to \mathrm{u} + \mathrm{e}^- + \bar{\nu}$; β^+: $\mathrm{u} \to \mathrm{d} + \mathrm{e}^+ + \nu$

Charge-to-mass ratio $= \frac{q}{m}$ (C kg^{-1})

$E_{\mathrm{k}} = \frac{1}{2}mv^2$, momentum $p = mv$ (from Dynamics)

A Level

12 Motion in a circle

Angle in radians $\theta = \dfrac{s}{r}$; arc length $s = r\theta$

2π rad $= 360^\circ$; 1 rad $= 57.3^\circ$

Angular speed $\omega = \dfrac{\Delta\theta}{\Delta t}$

$\omega = \dfrac{2\pi}{T} = 2\pi f$

$v = r\omega$; also $v = \dfrac{2\pi r}{T}$

Centripetal acceleration $a = r\omega^2 = \dfrac{v^2}{r}$ (also $a = v\omega$)

Centripetal (resultant) force $F = mr\omega^2 = \dfrac{mv^2}{r}$

Conical pendulum or cone: $T\cos\theta = mg$, $T\sin\theta = \dfrac{mv^2}{r}$, so $\tan\theta = \dfrac{v^2}{rg}$

Vertical circle: top $mg + N = \dfrac{mv^2}{r}$; bottom $N - mg = \dfrac{mv^2}{r}$

Circle at latitude ϕ on a planet of radius R: radius $R\cos\phi$

13 Gravitational fields

Field strength $g = \dfrac{F}{m}$ (force per unit mass)

Newton's law $F = \dfrac{Gm_1m_2}{r^2}$

$g = \dfrac{GM}{r^2}$ for a point mass (and outside a uniform sphere)

$E_P = m\phi$; $\Delta E_P = GMm\left(\dfrac{1}{r_1} - \dfrac{1}{r_2}\right)$

$g = -\dfrac{d\phi}{dr}$ (field strength = minus potential gradient: it points towards lower potential); size $\dfrac{d\phi}{dr}$, so for a point mass $g = \dfrac{GM}{r^2} = \dfrac{|\phi|}{r}$

Orbit: $\dfrac{GMm}{r^2} = \dfrac{mv^2}{r} = mr\omega^2$, so $v = \sqrt{\dfrac{GM}{r}}$

$T^2 = \dfrac{4\pi^2}{GM}r^3$ (so $T^2 \propto r^3$)

Orbiting mass: $E_K = \dfrac{GMm}{2r}$, total energy $= -\dfrac{GMm}{2r}$

Geostationary: $T = 24$ h, west to east, above the Equator

14 Temperature

$T/\mathrm{K} = \theta/^\circ\mathrm{C} + 273.15$; absolute zero $= 0$ K $= -273.15\,^\circ$C

A temperature change is the same number in K and °C: $\Delta T = \Delta\theta$

Specific heat capacity $Q = mc\,\Delta\theta$

Specific latent heat $Q = mL$

Energy from a heater $Q = Pt = VIt$

Energy balance: energy lost by hotter parts = energy gained by colder parts

Heating curve: gradient $\dfrac{\Delta\theta}{\Delta t} = \dfrac{P}{mc}$; flat section $P\,\Delta t = mL$

Constant-volume gas thermometer: $\dfrac{T}{T_0} = \dfrac{p}{p_0} = \dfrac{\Delta h}{\Delta h_0}$ (T in kelvin)

15 Ideal gases

$N = nN_\mathrm{A}$, with $N_\mathrm{A} = 6.02 \times 10^{23}$ mol^{-1}

Ideal gas: $pV \propto T$, with T in kelvin

Equation of state $pV = nRT$

Equation of state $pV = NkT$

Boltzmann constant $k = \dfrac{R}{N_\mathrm{A}}$

Fixed amount of gas: $\dfrac{p_1V_1}{T_1} = \dfrac{p_2V_2}{T_2}$

R.m.s. speed $c_\mathrm{r.m.s.} = \sqrt{\langle c^2\rangle}$

Mean translational kinetic energy $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$

$c_\mathrm{r.m.s.} = \sqrt{\dfrac{3kT}{m}}$

Total kinetic energy (internal energy) of an ideal gas $U = \frac{3}{2}NkT = \frac{3}{2}nRT$

16 Thermodynamics

Internal energy = sum of the random kinetic and potential energies of the molecules

First law: $\Delta U = q + W$ (ΔU increase in internal energy, q thermal energy supplied to the system, W work done on the system)

Work done by a gas at constant pressure: $p\Delta V$; work done on the gas $W = -p\Delta V$

Work done = area under the p–V graph; net work in a cycle = area enclosed

Ideal gas: $U = \frac{3}{2}NkT = \frac{3}{2}nRT = \frac{3}{2}pV$, so $\Delta U = \frac{3}{2}Nk\,\Delta T$

Equation of state $pV = nRT = NkT$; fixed mass $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$

Heating: $q = mc\Delta\theta$; change of state: $q = mL$

Complete cycle or constant temperature (ideal gas): $\Delta U = 0$

17 Oscillations

$x = x_0 \sin \omega t$ (the same form is on the data sheet, but only as the a.c. formula)

$T = \frac{1}{f}, \omega = 2\pi f = \frac{2\pi}{T}$

Maximum speed $v_0 = \omega x_0$; maximum acceleration $a_0 = \omega^2 x_0$

Total energy $E = \frac{1}{2}m\omega^2 x_0^2 = \frac{1}{2}mv_0^2$

Kinetic energy at x: $\frac{1}{2}m\omega^2(x_0^2 - x^2)$; potential energy at x: $\frac{1}{2}m\omega^2 x^2$

Phase difference $\phi = \frac{\Delta t}{T} \times 2\pi$ rad

Definition of s.h.m.: acceleration proportional to displacement from a fixed point and in the opposite direction

Resonance: maximum amplitude when driving frequency = natural frequency

18 Electric fields

Field strength $E = \frac{F}{q}$ (force per unit positive charge), so $F = qE$

Uniform field between plates $E = \frac{\Delta V}{\Delta d} = \frac{V}{d}$

Acceleration in a uniform field $a = \frac{qE}{m}$

Coulomb's law $F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$

Point charge $E = \frac{Q}{4\pi\varepsilon_0 r^2}$

$E_P = qV$; energy gained moving through a p.d. $= qV$

$E = -\frac{dV}{dx}$ (field = minus potential gradient); at a sphere's surface $E = \frac{V}{r}$

$v = u + at$

19 Capacitance

Capacitance $C = \frac{Q}{V}$ (so $Q = CV$)

Isolated sphere $C = 4\pi\varepsilon_0 r$ (from $V = \frac{Q}{4\pi\varepsilon_0 r}$)

Energy stored $W = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{Q^2}{2C}$

Time constant $\tau = RC$

$\ln x = \ln x_0 - \dfrac{t}{RC}$; $t_{1/2} = RC \ln 2$

$I = \dfrac{Q}{t}$, $V = IR$, $I_0 = \dfrac{V_0}{R}$

20 Magnetic fields

Force on a current $F = BIL \sin\theta$; on a coil side of N turns $F = NBIL$

Flux density $B = \dfrac{F}{IL}$ (wire at right angles to the field); $1\ \mathrm{T} = 1\ \mathrm{N\ A^{-1}\ m^{-1}}$

Force on a moving charge $F = BQv \sin\theta$

Radius in a field $r = \dfrac{mv}{BQ}$ (from $BQv = \dfrac{mv^2}{r}$); period $T = \dfrac{2\pi m}{BQ}$

Velocity selector $v = \dfrac{E}{B}$ (from $QE = BQv$)

Magnetic flux $\Phi = BA$ (A at right angles to B); $1\ \mathrm{Wb} = 1\ \mathrm{T\ m^2}$

Flux linkage $N\Phi = NBA$

Faraday and Lenz: $E = -\dfrac{d(N\Phi)}{dt}$; for a steady change $E = \dfrac{\Delta(N\Phi)}{\Delta t}$

Conductor cutting flux $E = Blv$; e.m.f. = flux cut per second

$E = \dfrac{V}{d}$, $F = QE$, $\frac{1}{2}mv^2 = QV$, $F = \dfrac{mv^2}{r}$

21 Alternating currents

$\omega = 2\pi f = \dfrac{2\pi}{T}$, $f = \dfrac{1}{T}$

$I_{\mathrm{r.m.s.}} = \dfrac{I_0}{\sqrt{2}}$, $V_{\mathrm{r.m.s.}} = \dfrac{V_0}{\sqrt{2}}$ (sinusoidal only)

Mean power $\langle P \rangle = \frac{1}{2}P_0$ (sinusoidal); $\langle P \rangle = I_{\mathrm{r.m.s.}}V_{\mathrm{r.m.s.}} = I_{\mathrm{r.m.s.}}^2 R = \dfrac{V_{\mathrm{r.m.s.}}^2}{R}$

Peak power $P_0 = I_0 V_0 = I_0^2 R = \dfrac{V_0^2}{R}$

Half-wave rectified sinusoid: $\langle P \rangle = \frac{1}{4}P_0$, $V_{\mathrm{r.m.s.}} = \dfrac{V_0}{2}$

Time constant $\tau = RC$

Energy in a capacitor $W = \frac{1}{2}CV^2$

22 Quantum physics

Photon energy $E = hf$

$c = f\lambda$, so $E = \dfrac{hc}{\lambda}$

Photons per second $N = \dfrac{P}{hf}$; intensity = power per unit area

Photon momentum $p = \dfrac{E}{c} = \dfrac{h}{\lambda}$

Force from a beam: absorbed $F = \dfrac{P}{c}$, reflected straight back $F = \dfrac{2P}{c}$; pressure $= \dfrac{F}{A}$

$1\ \text{eV} = 1.60 \times 10^{-19}$ J

Photoelectric equation $hf = \Phi + \frac{1}{2}mv_{\max}^2$

Threshold $f_0 = \dfrac{\Phi}{h}$, $\lambda_0 = \dfrac{hc}{\Phi}$

de Broglie wavelength $\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$

Charge accelerated through V: $qV = \frac{1}{2}mv^2$, $p = \sqrt{2qVm}$

Energy levels $hf = E_1 - E_2$

23 Nuclear physics

Mass–energy $E = mc^2$; energy released $E = c^2\Delta m$

Mass defect $\Delta m = Zm_p + (A - Z)m_n - m_{\text{nucleus}}$; binding energy $= \Delta m\, c^2$

Binding energy per nucleon $= \dfrac{\text{binding energy}}{A}$

Energy released = total binding energy after − total binding energy before

Nucleon number and proton number conserved in nuclear equations

Activity $A = \lambda N$

$\ln x = \ln x_0 - \lambda t$; fraction left after n half-lives $= \left(\frac{1}{2}\right)^n$

Number of nuclei $N = \dfrac{\text{mass}}{A_r \times 1\ \text{u}} = \dfrac{\text{mass in g}}{A_r} N_A$

$1\ \text{eV} = 1.60 \times 10^{-19}$ J, so $1\ \text{MeV} = 1.60 \times 10^{-13}$ J

24 Medical physics

Specific acoustic impedance $Z = \rho c$; unit kg m^{-2} s^{-1}

Fraction transmitted at a boundary $= 1 - \dfrac{I_R}{I_0}$

Echo depth $= \dfrac{ct}{2}$ (t = time from pulse to echo)

Attenuation $I = I_0 e^{-\mu x}$; $\ln\left(\dfrac{I}{I_0}\right) = -\mu x$

Two layers: $I = I_0 e^{-(\mu_1 x_1 + \mu_2 x_2)}$

Minimum X-ray wavelength $\lambda_{\min} = \dfrac{hc}{eV}$ (from $eV = \dfrac{hc}{\lambda}$)
Photon energy $E = hf = \dfrac{hc}{\lambda}$; 1 MeV $= 1.60 \times 10^{-13}$ J
Energy of each annihilation photon $E = m_e c^2$ (two photons, total $2m_e c^2$)
β^+ decay: nucleus → daughter $+^{0}_{+1}\mathrm{e} + \nu$

25 Astronomy and cosmology

Radiant flux intensity $F = \dfrac{L}{4\pi d^2}$ (inverse square law)
Distance from a standard candle $d = \sqrt{\dfrac{L}{4\pi F}}$
Wien's displacement law $\lambda_{\max} \propto \dfrac{1}{T}$, so $\lambda_1 T_1 = \lambda_2 T_2$
Hubble's law $v \approx H_0 d$ (H_0 in s^{-1})
Speed at a star's equator $v = \dfrac{2\pi R}{T}$
Mass converted per second $\dfrac{\Delta m}{\Delta t} = \dfrac{L}{c^2}$ (from $E = mc^2$)
$c = \lambda f$; photon energy $E = hf = \dfrac{hc}{\lambda}$