Cambridge AS & A Level · Physics 9702

Physics 9702 formulas and definitions: A2

All 120 formulas, facts and definitions to learn, by syllabus topic. Formulas the exam gives you are left out.

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

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

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

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 $P_0 = I_0V_0 = I_0^2R = \dfrac{V_0^2}{R}$

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

Time constant $\tau = RC$

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

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 $hf = \Phi + \frac{1}{2} m v_{\max}^2$

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: $qV = \frac{1}{2} m v^2$, $p = \sqrt{2qVm}$

Energy levels $hf = E_1 - E_2$

23 Nuclear physics

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

Mass defect $\Delta m = Z m_p + (A - Z) m_n - m_{\text{nucleus}}$; 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 $E = hf = \dfrac{hc}{\lambda}$