



Physics A

PHYA5D

Unit 5D Turning Points in Physics

Data and Formulae Booklet

DATA

FUNDAMENTAL CONSTANTS AND VALUES

| <i>Quantity</i> | <i>Symbol</i> | <i>Value</i> | <i>Units</i> |
|--|---------------|---------------------------|-----------------------------------|
| speed of light in vacuo | c | 3.00×10^8 | m s^{-1} |
| permeability of free space | μ_0 | $4\pi \times 10^{-7}$ | H m^{-1} |
| permittivity of free space | ϵ_0 | 8.85×10^{-12} | F m^{-1} |
| charge of electron | e | -1.60×10^{-19} | C |
| the Planck constant | h | 6.63×10^{-34} | J s |
| gravitational constant | G | 6.67×10^{-11} | $\text{N m}^2 \text{kg}^{-2}$ |
| the Avogadro constant | N_A | 6.02×10^{23} | mol^{-1} |
| molar gas constant | R | 8.31 | $\text{J K}^{-1} \text{mol}^{-1}$ |
| the Boltzmann constant | k | 1.38×10^{-23} | J K^{-1} |
| the Stefan constant | σ | 5.67×10^{-8} | $\text{W m}^{-2} \text{K}^{-4}$ |
| the Wien constant | α | 2.90×10^{-3} | m K |
| electron rest mass (equivalent to 5.5×10^{-4} u) | m_e | 9.11×10^{-31} | kg |
| electron charge/mass ratio | e/m_e | 1.76×10^{11} | C kg^{-1} |
| proton rest mass (equivalent to 1.00728 u) | m_p | $1.67(3) \times 10^{-27}$ | kg |
| proton charge/mass ratio | e/m_p | 9.58×10^7 | C kg^{-1} |
| neutron rest mass (equivalent to 1.00867 u) | m_n | $1.67(5) \times 10^{-27}$ | kg |
| gravitational field strength | g | 9.81 | N kg^{-1} |
| acceleration due to gravity | g | 9.81 | m s^{-2} |
| atomic mass unit (1u is equivalent to 931.3 MeV) | u | 1.661×10^{-27} | kg |

GEOMETRICAL EQUATIONS

| | |
|---------------------------------|------------------------|
| <i>arc length</i> | $= r\theta$ |
| <i>circumference of circle</i> | $= 2\pi r$ |
| <i>area of circle</i> | $= \pi r^2$ |
| <i>surface area of cylinder</i> | $= 2\pi rh$ |
| <i>volume of cylinder</i> | $= \pi r^2 h$ |
| <i>area of sphere</i> | $= 4\pi r^2$ |
| <i>volume of sphere</i> | $= \frac{4}{3}\pi r^3$ |

ASTRONOMICAL DATA

| <i>Body</i> | <i>Mass/kg</i> | <i>Mean radius/m</i> |
|-------------|-----------------------|----------------------|
| Sun | 1.99×10^{30} | 6.96×10^8 |
| Earth | 5.98×10^{24} | 6.37×10^6 |

AS FORMULAE

PARTICLE PHYSICS

Rest energy values

| class | name | symbol | rest energy /MeV |
|---------|-------------|-----------|------------------|
| photon | photon | γ | 0 |
| lepton | neutrino | ν_e | 0 |
| | | ν_μ | 0 |
| | electron | e^\pm | 0.510999 |
| | muon | μ^\pm | 105.659 |
| mesons | π meson | π^\pm | 139.576 |
| | | π^0 | 134.972 |
| | K meson | K^\pm | 493.821 |
| | | K^0 | 497.762 |
| baryons | proton | p | 938.257 |
| | neutron | n | 939.551 |

Properties of quarks

antiquarks have opposite signs

| type | charge | baryon number | strangeness |
|----------|-----------------|----------------|-------------|
| u | $+\frac{2}{3}e$ | $+\frac{1}{3}$ | 0 |
| d | $-\frac{1}{3}e$ | $+\frac{1}{3}$ | 0 |
| s | $-\frac{1}{3}e$ | $+\frac{1}{3}$ | -1 |

Properties of Leptons

| | lepton number |
|---|---------------|
| particles: $e^-, \nu_e; \mu^-, \nu_\mu$ | +1 |
| antiparticles: $e^+, \bar{\nu}_e; \mu^+, \bar{\nu}_\mu$ | -1 |

Photons and Energy Levels

photon energy $E = hf = hc/\lambda$

photoelectricity $hf = \phi + E_{K(\max)}$

energy levels $hf = E_1 - E_2$

de Broglie Wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

ELECTRICITY

current and pd $I = \frac{\Delta Q}{\Delta t}$ $V = \frac{W}{Q}$ $R = \frac{V}{I}$

emf $\varepsilon = \frac{E}{Q}$ $\varepsilon = I(R + r)$

resistors in series $R = R_1 + R_2 + R_3 + \dots$

resistors in parallel $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$

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

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

alternating current $I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$ $V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$

MECHANICS

moments moment = Fd

velocity and acceleration $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$

equations of motion $v = u + at$ $s = \frac{(u+v)t}{2}$

$v^2 = u^2 + 2as$ $s = ut + \frac{at^2}{2}$

force $F = ma$

work, energy and power $W = Fs \cos \theta$ $E_K = \frac{1}{2}mv^2$ $\Delta E_p = mg\Delta h$

$P = \frac{\Delta W}{\Delta t}$, $P = Fv$

efficiency = $\frac{\text{useful output power}}{\text{input power}}$

MATERIALS

density $\rho = \frac{m}{V}$ Hooke's law $F = k \Delta L$

Young modulus = $\frac{\text{tensile stress}}{\text{tensile strain}}$ tensile stress = $\frac{F}{A}$
tensile strain = $\frac{\Delta L}{L}$

energy stored $E = \frac{1}{2}F\Delta L$

WAVES

wave speed $c = f\lambda$ period $T = \frac{1}{f}$

fringe spacing $w = \frac{\lambda D}{s}$ diffraction grating $d \sin \theta = n\lambda$

refractive index of a substance s , $n = \frac{c}{c_s}$

for two different substances of refractive indices n_1 and n_2 ,

law of refraction $n_1 \sin \theta_1 = n_2 \sin \theta_2$

critical angle $\sin \theta_c = \frac{n_2}{n_1}$ for $n_1 > n_2$

A2 FORMULAE**MOMENTUM**

force $F = \frac{\Delta(mv)}{\Delta t}$

impulse $F \Delta t = \Delta(mv)$

CIRCULAR MOTION

angular velocity $\omega = \frac{v}{r}$

$$\omega = 2\pi f$$

centripetal acceleration $a = \frac{v^2}{r} = \omega^2 r$

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

OSCILLATIONS

acceleration $a = -(2\pi f)^2 x$

displacement $x = A \cos(2\pi f t)$

speed $v = \pm 2\pi f \sqrt{A^2 - x^2}$

maximum speed $v_{\max} = 2\pi f A$

maximum acceleration $a_{\max} = (2\pi f)^2 A$

for a mass-spring system $T = 2\pi \sqrt{\frac{m}{k}}$

for a simple pendulum $T = 2\pi \sqrt{\frac{l}{g}}$

GRAVITATIONAL FIELDS

force between two masses $F = \frac{G m_1 m_2}{r^2}$

gravitational field strength $g = \frac{F}{m}$

magnitude of gravitational field strength in a radial field $g = \frac{GM}{r^2}$

gravitational potential $\Delta W = m\Delta V$

$$V = -\frac{GM}{r}$$

$$g = -\frac{\Delta V}{\Delta r}$$

ELECTRIC FIELDS AND CAPACITORS

force between two point charges $F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$

force on a charge $F = EQ$

field strength for a uniform field $E = \frac{V}{d}$

field strength for a radial field $E = \frac{Q}{4\pi\epsilon_0 r^2}$

electric potential $\Delta W = Q\Delta V$

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

capacitance $C = \frac{Q}{V}$

decay of charge $Q = Q_0 e^{-t/RC}$

time constant RC

capacitor energy stored $E = \frac{1}{2} QV = \frac{1}{2} CV^2 = \frac{1}{2} \frac{Q^2}{C}$

MAGNETIC FIELDS

force on a current $F = BIl$

force on a moving charge $F = BQv$

magnetic flux $\Phi = BA$

magnetic flux linkage $N\Phi = BAN$

magnitude of induced emf $\epsilon = N \frac{\Delta\Phi}{\Delta t}$

emf induced in a rotating coil $N\Phi = BAN \cos \theta$
 $\epsilon = BAN\omega \sin \omega t$

transformer equations $\frac{N_s}{N_p} = \frac{V_s}{V_p}$

$$\text{efficiency} = \frac{I_s V_s}{I_p V_p}$$

RADIOACTIVITY AND NUCLEAR PHYSICS

the inverse square law for γ radiation $I = \frac{k}{x^2}$

radioactive decay $\frac{\Delta N}{\Delta t} = -\lambda N, N = N_0 e^{-\lambda t}$

activity $A = \lambda N$

half-life $T_{1/2} = \frac{\ln 2}{\lambda}$

nuclear radius $R = r_0 A^{1/3}$

energy-mass equation $E = mc^2$

GASES AND THERMAL PHYSICS

gas law $pV = nRT$

$$pV = NkT$$

kinetic theory model $pV = \frac{1}{3} N m (c_{\text{rms}})^2$

kinetic energy of gas molecule $\frac{1}{2} m (c_{\text{rms}})^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$

energy to change temperature $Q = mc\Delta T$

energy to change state $Q = mL$

OPTIONS FORMULAE**ASTROPHYSICS***1 astronomical unit* = 1.50×10^{11} m*1 light year* = 9.46×10^{15} m*1 parsec* = $206265 \text{ AU} = 3.08 \times 10^{16} \text{ m} = 3.261 \text{ yr}$ *Hubble constant, H* = $65 \text{ km s}^{-1} \text{ Mpc}^{-1}$ *lens equation* $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ $M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$ *in normal adjustment* $M = \frac{f_0}{f_e}$ *resolving power* $\theta \approx \frac{\lambda}{D}$ *magnitude equation* $m - M = 5 \log \frac{d}{10}$ *Wien's law* $\lambda_{\text{max}} T = 0.0029 \text{ m K}$ *Hubble law* $v = H d$ *Stefan's law* $P = \sigma A T^4$ *Doppler shift for $v \ll c$* $z = \frac{\Delta f}{f} = -\frac{\Delta \lambda}{\lambda} = \frac{v}{c}$ *Schwarzschild radius* $R_s = \frac{2GM}{c^2}$ **MEDICAL PHYSICS***lens equations* $P = \frac{1}{f}$

$$m = \frac{v}{u}$$

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

intensity level intensity level = $10 \log \frac{I}{I_0}$ *absorption* $I = I_0 e^{-\mu x}$

$$\mu_m = \frac{\mu}{\rho}$$

APPLIED PHYSICS*moment of inertia* $I = \Sigma mr^2$ *angular kinetic energy* $E_k = \frac{1}{2} I \omega^2$ *equations of angular motion*

$$\omega_2 = \omega_1 + \alpha t$$

$$\omega_2^2 = \omega_1^2 + 2\alpha\theta$$

$$\theta = \omega_1 t + \frac{1}{2} \alpha t^2$$

$$\theta = \frac{1}{2} (\omega_1 + \omega_2) t$$

torque

$$T = I \alpha$$

angular momentum

$$\text{angular momentum} = I \omega$$

work done

$$W = T \theta$$

power

$$P = T \omega$$

thermodynamics

$$Q = \Delta U + W$$

$$W = p \Delta V$$

adiabatic change

$$pV^\gamma = \text{constant}$$

isothermal change

$$pV = \text{constant}$$

heat engines

$$\text{efficiency} = \frac{W}{Q_{\text{in}}} = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}}$$

$$\text{maximum efficiency} = \frac{T_H - T_C}{T_H}$$

work done per cycle = area of loop*input power* = calorific value \times fuel flow rate*indicated power* = (area of p-V loop) \times (no of cycles per second) \times number of cylinders*output of brake power* $P = T \omega$ *friction power* = indicated power – brake power*heat pumps and refrigerators*

$$\text{refrigerator: } COP_{\text{ref}} = \frac{Q_{\text{out}}}{W} = \frac{Q_{\text{out}}}{Q_{\text{in}} - Q_{\text{out}}}$$

$$\text{heat pump: } COP_{\text{hp}} = \frac{Q_{\text{in}}}{W} = \frac{Q_{\text{in}}}{Q_{\text{in}} - Q_{\text{out}}}$$

TURNING POINTS IN PHYSICS*electrons in fields* $F = \frac{eV}{d}$

$$F = Bev$$

$$r = \frac{mv}{Be}$$

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

$$\frac{QV}{d} = mg$$

$$F = 6\pi \eta r v$$

wave particle duality $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$$

special relativity

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

$$l = l_0 \left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}} \quad t = t_0 \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$$