Every formula

Cambridge International AS & A Level Physics

Unlike IGCSE, 9702 gives you a data sheet: it is page 2 of Papers 1, 2 and 4, with more formulae on page 3 of Paper 4. Everything marked GIVEN is printed for you; everything else you must recall. Compiled by GioPhysics from the published syllabus. This is an independent study aid, not a Cambridge document; the official syllabus is the authority.

1 Physical quantities and units

1.4 Scalars and vectors

AS

Components of a vector

$$F_x = F\cos\theta \cdot F_y = F\sin\theta$$

- F — magnitude of the vector
- θ — angle to the chosen axis (° or rad)

The syllabus requires a vector to be represented as two perpendicular components, and coplanar vectors to be added and subtracted.

2 Kinematics

2.1 Equations of motion

AS

Uniformly accelerated motion

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

- s — displacement (m)
- u — initial velocity (m s^{-1})
- a — acceleration (m s^{-2})
- t — time (s)

AS

Uniformly accelerated motion, without time

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

- v — final velocity (m s^{-1})
- u — initial velocity (m s^{-1})
- a — acceleration (m s^{-2})
- s — displacement (m)

AS

Velocity after uniform acceleration

$$v = u + at$$

- v — final velocity (m s^{-1})
- u — initial velocity (m s^{-1})
- a — acceleration (m s^{-2})
- t — time (s)

Not on the data sheet. Two of the four equations of motion are printed for you and two are not — this is one of the two to memorise.

AS

Displacement from average velocity

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

- s — displacement (m)
- u, v — initial and final velocity (m s^{-1})
- t — time (s)

Not on the data sheet.

AS **From the graphs**

velocity = gradient of s–t · acceleration = gradient of v–t · displacement = area under v–t

gradient — of a tangent for non-uniform motion

3 Dynamics

3.1 Momentum and Newton's laws of motion

AS **Newton's second law**

$$F = ma$$

F — resultant force (N)
m — mass (kg)
a — acceleration ($m\ s^{-2}$)

Force and acceleration are in the same direction. A special case of $F = \Delta p/\Delta t$ for constant mass.

AS **Linear momentum**

$$p = mv$$

p — momentum ($kg\ m\ s^{-1}$, N s)
m — mass (kg)
v — velocity ($m\ s^{-1}$)

3.2 Non-uniform motion

AS **Force as rate of change of momentum**

$$F = \Delta p / \Delta t$$

F — resultant force (N)
Δp — change in momentum ($kg\ m\ s^{-1}$)
Δt — time taken (s)

3.3 Linear momentum and its conservation

AS **Conservation of momentum**

total momentum before = total momentum after

p — summed over the system, with direction

For a closed system. Applies in one and two dimensions.

AS **Perfectly elastic collision**

relative speed of approach = relative speed of separation

v — relative speed along the line of collision ($m\ s^{-1}$)

The test for a perfectly elastic collision; total kinetic energy is also conserved.

4 Forces, density and pressure

4.1 Turning effects of forces

AS **Moment of a force**

$$\text{moment} = F \times d$$

F — force (N)
d — perpendicular distance from the pivot (m)

AS

Torque of a couple

$$\text{torque} = F \times d$$

- F — one of the two equal and opposite forces (N)
- d — perpendicular separation of the forces (m)

4.2 Equilibrium of forces

AS

Conditions for equilibrium

$$\text{resultant force} = 0 \cdot \text{resultant moment} = 0$$

- about — any point, for the moment condition

The principle of moments, plus a closed vector triangle for three coplanar forces.

4.3 Density and pressure

AS

Density

$$\rho = m / V$$

- ρ — density (kg m^{-3})
- m — mass (kg)
- V — volume (m^3)

AS

Pressure

$$p = F / A$$

- p — pressure (Pa)
- F — force normal to the surface (N)
- A — area (m^2)

AS

Hydrostatic pressure

$$p = \rho g h$$

- p — pressure due to the column (Pa)
- ρ — density of the fluid (kg m^{-3})
- g — acceleration of free fall (m s^{-2})
- h — depth (m)

The syllabus also asks you to derive it from the definitions of pressure and density.

AS

Upthrust (Archimedes' principle)

$$F = \rho g V$$

- F — upthrust (N)
- ρ — density of the fluid (kg m^{-3})
- V — volume of fluid displaced (m^3)

5 Work, energy and power

5.1 Energy conservation

AS

Work done by a force

$$W = Fs \cos \theta$$

- W — work done (J)
- F — force (N)
- s — displacement (m)
- θ — angle between force and displacement (°)

Work is force × displacement in the direction of the force.

AS

Power

$$P = W / t$$

- P — power (W)
- W — work done (J)
- t — time (s)

AS

Power of a force moving at constant velocity

$$P = Fv$$

- P — power (W)
- F — force (N)
- v — velocity ($m\ s^{-1}$)

The syllabus asks you to derive this one.

AS

Efficiency

$$\text{efficiency} = \text{useful energy output} / \text{total energy input}$$

- energy — or power, in the same unit top and bottom

5.2 Gravitational potential energy and kinetic energy

AS

Change in gravitational potential energy

$$EP = mgh$$

- EP — change in g.p.e. (J)
- m — mass (kg)
- g — gravitational field strength ($N\ kg^{-1}$)
- h — change in height (m)

For a uniform field. Derived from $W = Fs$.

AS

Kinetic energy

$$EK = \tfrac{1}{2}mv^2$$

- EK — kinetic energy (J)
- m — mass (kg)
- v — speed ($m\ s^{-1}$)

The syllabus asks you to derive this from the equations of motion.

6 Deformation of solids

6.1 Stress and strain

AS

Hooke's law

$$F = kx$$

$k = F / x$ · $x = F / k$

- F — load (N)
- k — spring constant ($N\ m^{-1}$)
- x — extension (m)

AS

Tensile stress

$$\sigma = F / A$$

- σ — stress (Pa)
- F — force (N)
- A — cross-sectional area (m^2)

AS **Tensile strain**

$$\varepsilon = x / L$$

- ε — strain (a ratio, no unit)
- x — extension (m)
- L — original length (m)

AS **The Young modulus**

$$E = \sigma / \varepsilon$$

- E — Young modulus (Pa)
- σ — stress (Pa)
- ε — strain

6.2 Elastic and plastic behaviour

AS **Elastic potential energy**

$$EP = \tfrac{1}{2}Fx = \tfrac{1}{2}kx^2$$

- EP — strain energy (J)
- F — load (N)
- x — extension (m)
- k — spring constant ($N\ m^{-1}$)

Within the limit of proportionality. It is the area under a force–extension graph.

7 Waves

7.1 Progressive waves

AS **The wave equation**

$$v = f\lambda$$

$f = v / \lambda$ · $\lambda = v / f$

- v — wave speed ($m\ s^{-1}$)
- f — frequency (Hz)
- λ — wavelength (m)

The syllabus asks you to derive it from the definitions of speed, frequency and wavelength.

AS **Intensity**

$$\text{intensity} = \text{power} / \text{area}$$

- I — intensity ($W\ m^{-2}$)
- P — power (W)
- A — area (m^2)

AS **Intensity and amplitude**

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

- $I \propto A^2$ — for a progressive wave

7.3 Doppler effect for sound waves

AS **Observed frequency from a moving source**

$$f_o = f_s v / (v \pm v_s)$$

- f_o — observed frequency (Hz)
- f_s — source frequency (Hz)
- v — speed of sound ($m\ s^{-1}$)
- v_s — speed of the source ($m\ s^{-1}$)

Minus when the source approaches, plus when it recedes.

7.5 Polarisation

AS

Malus's law

$$I = I_0 \cos^2\theta$$

- I — transmitted intensity (W m⁻²)
- I_0 — intensity of the plane-polarised wave (W m⁻²)
- θ — angle between the polariser axes (°)

8 Superposition

8.3 Interference

AS

Double-slit interference

$$\lambda = ax / D$$

- λ — wavelength (m)
- a — slit separation (m)
- x — fringe separation (m)
- D — slit-to-screen distance (m)

For light, with D much greater than a.

8.4 The diffraction grating

AS

Grating equation

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

- d — grating spacing (m)
- θ — angle of the maximum (°)
- n — order of the maximum
- λ — wavelength (m)

9 Electricity

9.1 Electric current

AS

Charge and current

$$Q = It$$

- Q — charge (C)
- I — current (A)
- t — time (s)

AS

Current and drift velocity

$$I = Anvq$$

- I — current (A)
- A — cross-sectional area (m^2)
- n — number density of charge carriers (m^{-3})
- v — drift speed ($m\ s^{-1}$)
- q — charge on each carrier (C)

9.2 Potential difference and power

AS

Potential difference

$$V = W / Q$$

- V — potential difference (V)
- W — work done (J)
- Q — charge (C)

AS **Electrical power**

$$P = VI = I^2R = V^2/R$$

- P — power (W)
- V — potential difference (V)
- I — current (A)
- R — resistance (Ω)

9.3 Resistance and resistivity

AS **Resistance**

$$V = IR$$

$R = V / I$ · $I = V / R$

- V — potential difference (V)
- I — current (A)
- R — resistance (Ω)

AS **Resistivity**

$$R = \rho L / A$$

- R — resistance (Ω)
- ρ — resistivity (Ω m)
- L — length (m)
- A — cross-sectional area (m^2)

10 D.C. circuits

10.2 Kirchhoff's laws

AS **Kirchhoff's first law**

$$\Sigma I(in) = \Sigma I(out)$$

- I — current at a junction (A)

A consequence of conservation of charge.

AS **Kirchhoff's second law**

$$\Sigma E = \Sigma IR$$

- E — e.m.f. round a loop (V)
- IR — potential difference across each component (V)

A consequence of conservation of energy.

AS **Resistors in series**

$$R = R_1 + R_2 + \dots$$

- R — combined resistance (Ω)

AS **Resistors in parallel**

$$1/R = 1/R_1 + 1/R_2 + \dots$$

- R — combined resistance (Ω)

10.3 Potential dividers

AS DERIVED

Potential divider

$$V_{out} = V_{in} \times R_2 / (R_1 + R_2)$$

- V_{out} — p.d. across R_2 (V)
- V_{in} — supply p.d. (V)
- R_1, R_2 — the two resistances (Ω)

Not printed in the syllabus: it follows from V = IR with the same current through both. The syllabus requires the potential divider and the potentiometer to be used.

11 Particle physics

11.1 Atoms, nuclei and radiation

AS

Nuclide notation

$$^{A}ZX \cdot A = Z + N$$

- A — nucleon number
- Z — proton number
- N — number of neutrons

11.2 Fundamental particles

AS

Quark charges

$$\text{up, charm, top} = +\tfrac{2}{3}e \cdot \text{down, strange, bottom} = -\tfrac{1}{3}e$$

- e — elementary charge (C)
- antiquark — carries the opposite charge

A proton is uud and a neutron is udd.

12 Motion in a circle

12.1 Kinematics of uniform circular motion

A LEVEL

Angular speed

$$\omega = 2\pi / T$$

- ω — angular speed (rad s^{-1})
- T — period (s)

A LEVEL

Linear and angular speed

$$v = r\omega$$

- v — linear speed (m s^{-1})
- r — radius (m)
- ω — angular speed (rad s^{-1})

12.2 Centripetal acceleration and force

A LEVEL

Centripetal acceleration

$$a = r\omega^2 = v^2/r$$

- a — centripetal acceleration (m s^{-2})
- r — radius (m)
- v — linear speed (m s^{-1})

A LEVEL

Centripetal force

$$F = mr\omega^2 = mv^2/r$$

- F — centripetal force (N)
- m — mass (kg)

Directed towards the centre. Note that IGCSE explicitly excludes this equation; A Level requires it.

13 Gravitational fields

13.2 Gravitational force between point masses

A LEVEL

Newton's law of gravitation

$$F = Gm_1m_2 / r^2$$

- F — gravitational force (N)
- G — gravitational constant (N m^2 kg^{-2})
- m_1, m_2 — the two point masses (kg)
- r — separation (m)

13.3 Gravitational field of a point mass

A LEVEL

Gravitational field strength

$$g = GM / r^2$$

- g — field strength (N kg^{-1})
- M — mass of the point mass (kg)
- r — distance from it (m)

The syllabus asks you to derive it from Newton's law of gravitation.

13.4 Gravitational potential

A LEVEL

Gravitational potential

$$\varphi = -GM / r$$

- φ — gravitational potential (J kg^{-1})
- M — mass (kg)
- r — distance (m)

Negative because the zero of potential is at infinity.

A LEVEL

Gravitational potential energy

$$E_P = -GMm / r$$

- E_P — potential energy of the pair (J)
- M, m — the two point masses (kg)

14 Temperature

14.2 Temperature scales

A LEVEL

Kelvin and Celsius

$$T / \text{K} = \theta / {}^\circ\text{C} + 273.15$$

- T — thermodynamic temperature (K)
- θ — temperature (°C)

273.15 here, where IGCSE uses 273.

14.3 Specific heat capacity and specific latent heat

A LEVEL

Specific heat capacity

$$E = mc\Delta\theta$$

- E — energy supplied (J)
- m — mass (kg)
- c — specific heat capacity (J kg^{-1} K^{-1})
- $\Delta\theta$ — temperature change (K or °C)

A LEVEL

Specific latent heat

$$E = mL$$

- E — energy supplied (J)
- m — mass changing state (kg)
- L — specific latent heat ($J\ kg^{-1}$)

Not examined at IGCSE; it appears here.

15 Ideal gases

15.2 Equation of state

A LEVEL

Ideal gas equation, by moles

$$pV = nRT$$

- p — pressure (Pa)
- V — volume (m^3)
- n — amount of substance (mol)
- R — molar gas constant ($J\ K^{-1}\ mol^{-1}$)
- T — thermodynamic temperature (K)

A LEVEL

Ideal gas equation, by molecules

$$pV = NkT$$

- N — number of molecules
- k — Boltzmann constant ($J\ K^{-1}$)

A LEVEL

Boltzmann constant

$$k = R / NA$$

- k — Boltzmann constant ($J\ K^{-1}$)
- R — molar gas constant ($J\ K^{-1}\ mol^{-1}$)
- NA — Avogadro constant (mol^{-1})

15.3 Kinetic theory of gases

A LEVEL

Pressure of an ideal gas

$$p = \tfrac{1}{3}\ (Nm/V)\ \langle c^2 \rangle$$

- N — number of molecules
- m — mass of one molecule (kg)
- V — volume (m^3)
- $\langle c^2 \rangle$ — mean-square speed ($m^2\ s^{-2}$)

A LEVEL

Average translational kinetic energy of a molecule

$$\tfrac{1}{2}m\langle c^2 \rangle = (3/2)kT$$

- k — Boltzmann constant ($J\ K^{-1}$)
- T — thermodynamic temperature (K)

Deduced by comparing $pV = \tfrac{1}{3}Nm\langle c^2 \rangle$ with $pV = NkT$.

16 Thermodynamics

16.1 Internal energy

A LEVEL

Work done by an expanding gas

$$W = p\Delta V$$

- W — work done (J)
- p — pressure (Pa)
- ΔV — change in volume (m^3)

At constant pressure.

16.2 The first law of thermodynamics

A LEVEL

First law of thermodynamics

$$\Delta U = q + W$$

- ΔU — increase in internal energy (J)
- q — energy supplied by heating (J)
- W — work done on the system (J)

17 Oscillations

17.1 Simple harmonic oscillations

A LEVEL

Defining equation of s.h.m.

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

- a — acceleration ($m\ s^{-2}$)
- ω — angular frequency ($rad\ s^{-1}$)
- x — displacement from equilibrium (m)

A LEVEL

Displacement in s.h.m.

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

- x_0 — amplitude (m)
- t — time (s)

A solution of $a = -\omega^2 x$.

A LEVEL

Velocity in s.h.m.

$$v = v_0 \cos \omega t \cdot v = \pm\omega\sqrt{(x_0^2 - x^2)}$$

- v_0 — maximum speed, $= \omega x_0$ ($m\ s^{-1}$)
- x_0 — amplitude (m)

17.2 Energy in simple harmonic motion

A LEVEL

Total energy of an oscillator

$$E = \tfrac{1}{2}m\omega^2 x_0^2$$

- E — total energy (J)
- m — mass (kg)
- ω — angular frequency ($rad\ s^{-1}$)
- x_0 — amplitude (m)

18 Electric fields

18.1 Electric fields and field lines

A LEVEL

Force on a charge in a field

$$F = qE$$

- F — force (N)
- q — charge (C)
- E — electric field strength ($N\ C^{-1}$, $V\ m^{-1}$)

18.2 Uniform electric fields

A LEVEL

Field between parallel plates

$$E = V / d$$

- E — field strength (V m^{-1})
- V — potential difference (V)
- d — plate separation (m)

18.3 Electric force between point charges

A LEVEL

Coulomb's law

$$F = Q_1Q_2 / (4\pi\varepsilon_0 r^2)$$

- F — force (N)
- Q_1, Q_2 — the two point charges (C)
- ε_0 — permittivity of free space (F m^{-1})
- r — separation (m)

In free space.

18.4 Electric field of a point charge

A LEVEL

Field due to a point charge

$$E = Q / (4\pi\varepsilon_0 r^2)$$

- E — field strength (V m^{-1})
- Q — point charge (C)

18.5 Electric potential

A LEVEL

Potential due to a point charge

$$V = Q / (4\pi\varepsilon_0 r)$$

- V — electric potential (V)
- Q — point charge (C)

A LEVEL

Electrical potential energy

$$EP = Qq / (4\pi\varepsilon_0 r)$$

- EP — potential energy of the pair (J)
- Q, q — the two point charges (C)

A LEVEL

Field as potential gradient

$$E = - dV / dx$$

- E — field strength (V m^{-1})
- dV/dx — potential gradient (V m^{-1})

19 Capacitance

19.1 Capacitors and capacitance

A LEVEL

Capacitance

$$C = Q / V$$

- C — capacitance (F)
- Q — charge (C)
- V — potential difference (V)

A LEVEL

Capacitors in series

$$1/C = 1/C_1 + 1/C_2 + \dots$$

C — combined capacitance (F)

The opposite way round from resistors — the syllabus asks you to derive both from C = Q/V.

A LEVEL

Capacitors in parallel

$$C = C_1 + C_2 + \dots$$

C — combined capacitance (F)

19.2 Energy stored in a capacitor

A LEVEL

Energy stored

$$W = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2$$

W — energy stored (J)
Q — charge (C)
V — potential difference (V)
C — capacitance (F)

The area under a charge–p.d. graph.

19.3 Discharging a capacitor

A LEVEL

Time constant

$$\tau = RC$$

τ — time constant (s)
R — resistance (Ω)
C — capacitance (F)

A LEVEL

Capacitor discharge

$$x = x_0\, e^{(-t/RC)}$$

x — current, charge or potential difference
x_0 — its initial value
t — time (s)

20 Magnetic fields

20.2 Force on a current-carrying conductor

A LEVEL

Force on a current-carrying conductor

$$F = BIL \sin \theta$$

F — force (N)
B — magnetic flux density (T)
I — current (A)
L — length in the field (m)
θ — angle between the conductor and the field (°)

Direction from Fleming's left-hand rule.

20.3 Force on a moving charge

A LEVEL

Force on a moving charge

$$F = BQv \sin \theta$$

F — force (N)
B — magnetic flux density (T)
Q — charge (C)
v — speed (m s^{-1})

A LEVEL

Hall voltage

$$V_H = BI / (ntq)$$

V_H — Hall voltage (V)
n — number density of charge carriers (m^{-3})
t — thickness (m)
q — charge on each carrier (C)

The syllabus asks you to derive it as well as use it.

20.5 Electromagnetic induction

A LEVEL

Magnetic flux

$$\Phi = BA$$

Φ — magnetic flux (Wb)
B — flux density normal to the area (T)
A — area (m^2)

A LEVEL

Faraday's and Lenz's laws

$$E = - d(N\Phi) / dt$$

E — induced e.m.f. (V)
$N\Phi$ — flux linkage (Wb)

The magnitude is the rate of change of flux linkage; the minus sign is Lenz's law.

21 Alternating currents

21.1 Characteristics of alternating currents

A LEVEL

Sinusoidal alternating current or voltage

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

x — current or voltage at time t
x_0 — peak value
ω — angular frequency (rad s^{-1})

A LEVEL

Root-mean-square values

$$I_{r.m.s.} = I_0/\sqrt{2} \cdot V_{r.m.s.} = V_0/\sqrt{2}$$

I_0, V_0 — peak current and voltage (A, V)

For a sinusoidal alternating current only.

A LEVEL

Mean power in a resistive load

$$\text{mean power} = \tfrac{1}{2} \times \text{maximum power}$$

P — power (W)

For a sinusoidally alternating current.

22 Quantum physics

22.1 Energy and momentum of a photon

A LEVEL

Photon energy

$$E = hf$$

$E = hc / \lambda$

E — photon energy (J)
h — Planck constant (J s)
f — frequency (Hz)

A LEVEL

Photon momentum

$$p = E / c$$

p — momentum (kg m s^{-1})
E — photon energy (J)
c — speed of light (m s^{-1})

22.2

Photoelectric effect

A LEVEL

Photoelectric equation

$$hf = \Phi + \tfrac{1}{2}mv^2_{max}$$

hf — photon energy (J)
Φ — work function (J)
$\tfrac{1}{2}mv^2_{max}$ — maximum kinetic energy of the electron (J)

22.3

Wave–particle duality

A LEVEL

de Broglie wavelength

$$\lambda = h / p$$

λ — de Broglie wavelength (m)
h — Planck constant (J s)
p — momentum (kg m s^{-1})

22.4

Energy levels in atoms and line spectra

A LEVEL

Transition between energy levels

$$hf = E_1 - E_2$$

E_1, E_2 — the two energy levels (J)
f — frequency of the emitted photon (Hz)

23

Nuclear physics

23.1

Mass defect and nuclear binding energy

A LEVEL

Mass-energy equivalence

$$E = mc^2$$

E — energy (J)
m — mass (kg)
c — speed of light in free space (m s^{-1})

A LEVEL

Energy released in a nuclear reaction

$$E = c^2\Delta m$$

Δm — mass defect (kg)
E — energy released (J)

23.2

Radioactive decay

A LEVEL

Activity and decay constant

$$A = \lambda N$$

A — activity (Bq)
λ — decay constant (s^{-1})
N — number of undecayed nuclei

A LEVEL

Decay constant and half-life

$$\lambda = 0.693 / t_{\frac{1}{2}}$$

λ — decay constant (s^{-1})
$t_{½}$ — half-life (s)

A LEVEL

Exponential decay

$$x = x_0 e^{(-\lambda t)}$$

x — activity, number of nuclei or count rate
x_0 — its initial value

24 Medical physics

24.1 Production and use of ultrasound

A LEVEL

Specific acoustic impedance

$$Z = \rho c$$

Z — specific acoustic impedance ($kg\ m^{-2}\ s^{-1}$)
ρ — density of the medium ($kg\ m^{-3}$)
c — speed of sound in the medium ($m\ s^{-1}$)

A LEVEL

Intensity reflection coefficient

$$I_R / I_0 = (Z_1 - Z_2)^2 / (Z_1 + Z_2)^2$$

I_R — reflected intensity ($W\ m^{-2}$)
I_0 — incident intensity ($W\ m^{-2}$)
Z_1, Z_2 — impedances either side of the boundary

A LEVEL

Attenuation of ultrasound

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

μ — linear attenuation coefficient (m^{-1})
x — distance travelled in the medium (m)

24.2 Production and use of X-rays

A LEVEL

Attenuation of X-rays

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

I — transmitted intensity ($W\ m^{-2}$)
I_0 — incident intensity ($W\ m^{-2}$)
μ — linear attenuation coefficient (m^{-1})
x — thickness (m)

25 Astronomy and cosmology

25.1 Standard candles

A LEVEL

Radiant flux intensity (inverse square law)

$$F = L / (4\pi d^2)$$

F — radiant flux intensity ($W\ m^{-2}$)
L — luminosity of the source (W)
d — distance (m)

25.2 Stellar radii

A LEVEL

Wien's displacement law

$$\lambda_{max} \propto 1 / T$$

λ_{max} — peak wavelength (m)
T — surface temperature (K)

A LEVEL

Stefan-Boltzmann law

$$L = 4\pi\sigma r^2 T^4$$

L — luminosity (W)
σ — Stefan–Boltzmann constant ($W\ m^{-2}\ K^{-4}$)
r — stellar radius (m)
T — surface temperature (K)

25.3 Hubble's law and the Big Bang theory

A LEVEL

Doppler redshift

$$\Delta\lambda/\lambda \approx \Delta f/f \approx v/c$$

Δλ — change in wavelength (m)
v — speed of recession ($m\ s^{-1}$)
c — speed of light ($m\ s^{-1}$)

For v much less than c.

A LEVEL

Hubble's law

$$v \approx H_0 d$$

v — speed of recession ($m\ s^{-1}$)
H_0 — Hubble constant (s^{-1})
d — distance to the galaxy (m)

– Values to know

AS	Acceleration of free fall, g	$9.81\ m\ s^{-2}$
AS	Speed of light in free space, c	$3.00 \times 10^{8}\ m\ s^{-1}$
AS	Elementary charge, e	$1.60 \times 10^{-19}\ C$
AS	Unified atomic mass unit, 1 u	$1.66 \times 10^{-27}\ kg$
AS	Rest mass of proton, mp	$1.67 \times 10^{-27}\ kg$
AS	Rest mass of electron, me	$9.11 \times 10^{-31}\ kg$
AS	Avogadro constant, NA	$6.02 \times 10^{23}\ mol^{-1}$
AS	Molar gas constant, R	$8.31\ J\ K^{-1}\ mol^{-1}$
AS	Boltzmann constant, k	$1.38 \times 10^{-23}\ J\ K^{-1}$
AS	Gravitational constant, G	$6.67 \times 10^{-11}\ N\ m^{2}\ kg^{-2}$
AS	Permittivity of free space, ε_0	$8.85 \times 10^{-12}\ F\ m^{-1}$
AS	Planck constant, h	$6.63 \times 10^{-34}\ J\ s$
A LEVEL	Stefan–Boltzmann constant, σ	$5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$