Physics

First examinations 2009

Diploma Programme

Data booklet

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International Baccalaureate Organization

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Contents

Fundamental constants

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	g	$9.81\,\mathrm{m\,s^{-2}}$
Gravitational constant	G	$6.67\times10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$
Avogadro's constant	N_A	$6.02\times10^{23}\,\mathrm{mol^{-1}}$
Gas constant	R	$8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
Boltzmann's constant	k	$1.38\times10^{-23}\,\mathrm{J\,K^{-1}}$
Stefan–Boltzmann constant	σ	$5.67\times10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$
Coulomb constant	k	$8.99\times10^{9}\,\mathrm{N\,m^2\,C^{-2}}$
Permittivity of free space	ε_0	$8.85\times10^{-12}\,\mathrm{C^2\,N^{-1}\,m^{-2}}$
Permeability of free space	μ_0	$4\pi\times10^{-7}\,\mathrm{T\,m\,A^{-1}}$
Speed of light in vacuum	c	$3.00\times10^{8}\,\mathrm{m\,s^{-1}}$
Planck's constant	h	$6.63\times10^{-34}\,\mathrm{J\,s}$
Elementary charge	e	$1.60\times10^{-19}\,\mathrm{C}$
Electron rest mass	m_e	$9.110\times10^{-31}\,\mathrm{kg} = 0.000549\,\mathrm{u} = 0.511\,\mathrm{MeV\,c^{-2}}$
Proton rest mass	m_p	$1.673\times10^{-27}\,\mathrm{kg} = 1.007276\,\mathrm{u} = 938\,\mathrm{MeV\,c^{-2}}$
Neutron rest mass	m_n	$1.675\times10^{-27}\,\mathrm{kg} = 1.008665\,\mathrm{u} = 940\,\mathrm{MeV\,c^{-2}}$
Unified atomic mass unit	u	$1.661\times10^{-27}\,\mathrm{kg} = 931.5\,\mathrm{MeV\,c^{-2}}$

Metric (SI) multipliers

Prefix	Abbreviation	Value
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Unit conversions

1 light year (ly) $= 9.46 \times 10^{15}$ m

1 parsec (pc) $= 3.26$ ly

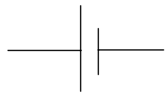
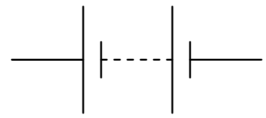
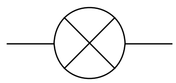
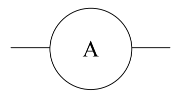
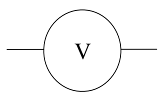
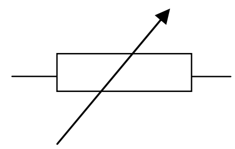
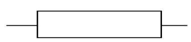
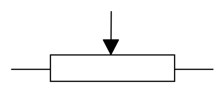
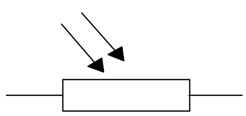
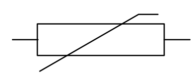
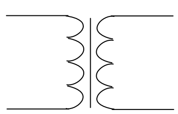
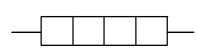
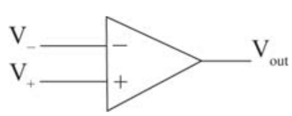
1 astronomical unit (AU) $= 1.50 \times 10^{11}$ m

1 radian (rad) $= \dfrac{180°}{\pi}$

1 kilowatt-hour (kW h) $= 3.60 \times 10^{6}$ J

1 atm $= 1.01 \times 10^{5}\ \text{N m}^{-2} = 101\ \text{kPa} = 760\ \text{mm Hg}$

Electrical circuit symbols

cell		battery	
lamp		ac supply	
switch		ammeter	
voltmeter		variable resistor	
resistor		potentiometer	
light-dependent resistor (LDR)		thermistor	
transformer		heating element	
operational amplifier (op-amp)			

Equations—Core and AHL

Note: All equations relate to the magnitude of the quantities only. Vector notation has not been used.

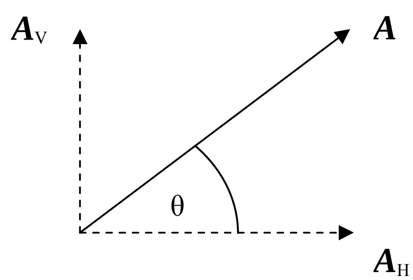
Core	AHL
Topic 1: Physics and physical measurement	

If $y = a \pm b$

then $\Delta y = \Delta a + \Delta b$

If $y = \dfrac{ab}{c}$

then $\dfrac{\Delta y}{y} = \dfrac{\Delta a}{a} + \dfrac{\Delta b}{b} + \dfrac{\Delta c}{c}$



$A_{\mathrm{H}} = A\cos\theta$

$A_{\mathrm{V}} = A\sin\theta$

Core	AHL
Topic 2: Mechanics $s = \frac{u+v}{2}t$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $F = ma$ $p = mv$ $F = \frac{\Delta p}{\Delta t}$ $\text{Impulse} = F\Delta t = m\Delta v$ $W = Fs\cos\theta$ $E_K = \frac{1}{2}mv^2$ $E_K = \frac{p^2}{2m}$ $\Delta E_P = mg\Delta h$ $\text{power} = Fv$ $a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$	
Topic 3: Thermal physics $P = \frac{F}{A}$ $Q = mc\Delta T$ $Q = mL$	**Topic 10: Thermal physics** $PV = nRT$ $W = P\Delta V$ $Q = \Delta U + W$

Core	AHL
Topic 4: Oscillations and waves	**Topic 11: Wave phenomena**
$\omega = \frac{2\pi}{T}$	$f' = f\left(\frac{v}{v \pm u_s}\right)$ moving source
$x = x_0 \sin \omega t$; $x = x_0 \cos \omega t$	$f' = f\left(\frac{v \pm u_o}{v}\right)$ moving observer
$v = v_0 \cos \omega t$; $v = -v_0 \sin \omega t$	$\Delta f = \frac{v}{c} f$
$v = \pm\omega\sqrt{(x_0^{\;2} - x^2)}$	$\theta = \frac{\lambda}{b}$
$E_K = \frac{1}{2} m\omega^2 (x_0^{\;2} - x^2)$	$\theta = 1.22 \frac{\lambda}{b}$
$E_{K(max)} = \frac{1}{2} m\omega^2 x_0^{\;2}$	$I = I_0 \cos^2 \theta$
$E_T = \frac{1}{2} m\omega^2 x_0^{\;2}$	$n = \tan\phi$
$v = f\lambda$	
$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$	
path difference $= n\lambda$	
path difference $= \left(n + \frac{1}{2}\right)\lambda$	

Core	AHL
Topic 5: Electric currents	**Topic 12: Electromagnetic induction**
$Ve = \frac{1}{2}mv^2$	$\Phi = BA\cos\theta$
$I = \frac{\Delta q}{\Delta t}$	$\varepsilon = Bvl$
$R = \frac{V}{I}$	$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$
$R = \frac{\rho L}{A}$	$\frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s}$
$P = VI = I^2R = \frac{V^2}{R}$	$I_{rms} = \frac{I_0}{\sqrt{2}}$
$\varepsilon = I(R+r)$	$V_{rms} = \frac{V_0}{\sqrt{2}}$
$R = R_1 + R_2 + \cdots$	$R = \frac{V_0}{I_0} = \frac{V_{rms}}{I_{rms}}$
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$	$P_{max} = I_0V_0$
	$P_{av} = \frac{1}{2}I_0V_0$

Topic 6: Fields and forces

$F = G\frac{m_1m_2}{r^2}$	$F = k\frac{q_1q_2}{r^2}$
$g = \frac{F}{m}$	$E = \frac{F}{q}$

$F = \frac{q_1q_2}{4\pi\varepsilon_0 r^2}$

$F = qvB\sin\theta$

$F = BIL\sin\theta$

Topic 9: Motion in fields

$\Delta V = \frac{\Delta E_p}{m}$	$\Delta V = \frac{\Delta E_p}{q}$
$V = -\frac{Gm}{r}$	$V = \frac{kq}{r} = \frac{q}{4\pi\varepsilon_0 r}$
$g = -\frac{\Delta V}{\Delta r}$	$E = -\frac{\Delta V}{\Delta x}$

Core	AHL
Topic 7: Atomic and nuclear physics $E = mc^2$	**Topic 13: Quantum physics and nuclear physics** $E = hf$ $hf = \phi + E_{\text{max}}$ $hf = hf_0 + eV$ $p = \frac{h}{\lambda}$ $E_{\text{K}} = \frac{n^2 h^2}{8 m_{\text{e}} L^2}$ $\Delta x \, \Delta p \geq \frac{h}{4\pi}$ $\Delta E \, \Delta t \geq \frac{h}{4\pi}$ $N = N_0 \text{e}^{-\lambda t}$ $A = -\frac{\Delta N}{\Delta t}$ $A = \lambda N = \lambda N_0 \text{e}^{-\lambda t}$ $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

Core	AHL
Topic 8: Energy, power and climate change $\text{power} = \frac{1}{2} A\rho v^3$ $\text{power per unit length} = \frac{1}{2} A^2 \rho g v$ $I = \frac{\text{power}}{A}$ $\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$ $C_s = \frac{Q}{A\Delta T}$ $\text{power} = \sigma A T^4$ $\text{power} = e\sigma A T^4$ $\Delta T = \frac{(I_{in} - I_{out})\Delta t}{C_s}$	

Equations—Options SL

Option A: Sight and wave phenomena

$$f' = f\left(\frac{v}{v \pm u_s}\right) \quad \text{moving source}$$

$$f' = f\left(\frac{v \pm u_o}{v}\right) \quad \text{moving observer}$$

$$\Delta f = \frac{v}{c} f$$

$$\theta = \frac{\lambda}{b}$$

$$\theta = 1.22 \frac{\lambda}{b}$$

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

$$n = \tan \phi$$

Option B: Quantum physics and nuclear physics

$$E = hf$$

$$hf = \phi + E_{\text{max}}$$

$$hf = hf_0 + eV$$

$$p = \frac{h}{\lambda}$$

$$E_K = \frac{n^2 h^2}{8 m_e L^2}$$

$$\Delta x \, \Delta p \geq \frac{h}{4\pi}$$

$$\Delta E \, \Delta t \geq \frac{h}{4\pi}$$

$$N = N_0 e^{-\lambda t}$$

$$A = -\frac{\Delta N}{\Delta t}$$

$$A = \lambda N = \lambda N_0 e^{-\lambda t}$$

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

Option C: Digital technology

$$G = -\frac{R_F}{R}$$

$$G = 1 + \frac{R_F}{R}$$

Option D: Relativity and particle physics

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$\Delta t = \gamma \Delta t_0$$

$$L = \frac{L_0}{\gamma}$$

$$\Delta E \, \Delta t \geq \frac{h}{4\pi}$$

$$R \approx \frac{h}{4\pi mc}$$

$$E = hf$$

Equations—Options SL and HL

Core (SL and HL)	Extension (HL only)
Option E: Astrophysics $L = \sigma A T^4$ $\lambda_{\max}\,(\text{metres}) = \dfrac{2.90 \times 10^{-3}}{T\,(\text{kelvin})}$ $d\left(\text{parsec}\right) = \dfrac{1}{p\left(\text{arc-second}\right)}$ $b = \dfrac{L}{4\pi d^2}$ $m - M = 5\lg\left(\dfrac{d}{10}\right)$	$L \propto m^n$ where $3 < n < 4$ $\dfrac{\Delta\lambda}{\lambda} \cong \dfrac{v}{c}$ $v = H_0 d$
Option F: Communications $n = \dfrac{1}{\sin C}$ $\text{attenuation / dB} = 10\lg\dfrac{I_1}{I_2}$	$G = -\dfrac{R_F}{R}$ $G = 1 + \dfrac{R_F}{R}$

Core (SL and HL)	Extension (HL only)
Option G: Electromagnetic waves	
$\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$	$\lambda_{\text{min}}=\frac{hc}{eV}$
$P=\frac{1}{f}$	$2d\sin\theta=n\lambda$
$m=\frac{h_{\text{i}}}{h_{\text{o}}}=-\frac{v}{u}$ $\quad M=\frac{\theta_{\text{i}}}{\theta_{\text{o}}}$	$2nt=m\lambda$
$M=\frac{f_{\text{o}}}{f_{\text{e}}}$	$2nt=\left(m+\frac{1}{2}\right)\lambda$
$m=\frac{D}{f}+1$ $\quad m=\frac{D}{f}$	$2nt\cos\phi=m\lambda$
$s=\frac{\lambda D}{d}$	$2nt\cos\phi=\left(m+\frac{1}{2}\right)\lambda$
$\sin\theta=\frac{n\lambda}{d}$	
$\frac{x}{D}=\frac{n\lambda}{d}$	
$\frac{x}{D}=(n+\frac{1}{2})\frac{\lambda}{d}$	
$d\sin\theta=n\lambda$	

Equations—Options HL

Option H: Relativity

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$\Delta t = \gamma \Delta t_0$$

$$L = \frac{L_0}{\gamma}$$

$$u_x{}' = \frac{u_x - v}{1-\frac{u_x v}{c^2}}$$

$$E_0 = m_0 c^2$$

$$E = \gamma m_0 c^2$$

$$p = \gamma m_0 u$$

$$E_K = (\gamma - 1) m_0 c^2$$

$$E^2 = p^2 c^2 + m_0^2 c^4$$

$$\frac{\Delta f}{f} = \frac{g \Delta h}{c^2}$$

$$R_s = \frac{2GM}{c^2}$$

$$\Delta t = \frac{\Delta t_0}{\sqrt{1-\frac{R_s}{r}}}$$

Option I: Medical physics

$$IL = 10 \lg \frac{I}{I_0} \quad \text{where} \quad I_0 = 1.0 \times 10^{-12}\ \mathrm{W\,m^{-2}}$$

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

$$\mu x_{\frac{1}{2}} = \ln 2$$

dose equivalent = absorbed dose × quality factor

$$Z = \rho c$$

$$\frac{1}{T_E} = \frac{1}{T_P} + \frac{1}{T_B}$$

Option J: Particle physics

$$\Delta E\,\Delta t \geq \frac{h}{4\pi}$$

$$R \approx \frac{h}{4\pi mc}$$

$$E = hf$$

$$E = mc^2 + E_K$$

$$E_a^2 = 2Mc^2E + (Mc^2)^2 + (mc^2)^2$$

$$\lambda = \frac{h}{p}$$

$$E_K = \tfrac{3}{2}kT$$