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5.1 Thermal physics

5.1.1 Temperature (page 11)

1

Example	Absolute scale	Celsius scale
Absolute zero	0 K	−273.16 °C
Boiling point of helium	4.26 K	−268.9 °C
Triple point of water	273.16 K	0.01 °C
Hot water bath	343.16 K	70 °C
Surface temperature of the Sun	5700 K	5426.84 °C

- 2 The temperature of the patient's mouth and the temperature of the liquid in the thermometer will initially be different. When the thermometer and the patient's mouth are in contact with each other, energy will be transferred between them until they are at the same temperature (thermal equilibrium). The temperature reading will not be accurate until this point.
- 3 (a) Thermal equilibrium occurs when two objects in contact with each other are at the same temperature and there is no net energy transfer between them.
 (b) The molecules in each liquid are moving: they have kinetic energy. The molecules in the hot tea have greater kinetic energy than the molecules in the cold milk, so energy is transferred from molecules of the hot liquid to molecules of the colder liquid. The temperature of the hot liquid decreases and the temperature of the cold liquid increases. Thermal equilibrium is reached when there is no net energy transfer between the molecules of the two liquids – both liquids are at the same temperature.
- 4 (a) Values around 20–25 °C
 (b) The temperature of the bath water increases and the temperature of the aluminium block decreases. The final temperature must be between 15 and 75 °C. Since the aluminium block is small compared to the amount of water in the bath, the amount of thermal energy it has stored cannot be very large. The amount of energy transferred to the water will be small, so the temperature of the water will not increase by very much.
 (c) Energy transfer between the two bodies does not stop when thermal equilibrium is reached. There will still be energy transfer between the two bodies but there is no **net** energy transfer. The rate at which energy is transferred away from one body equals the rate at which energy is transferred to that body.

5.1.2 Solids, liquids and gases (page 13)

- 1 (a) 64 g contains 6.02×10^{23} atoms, so 1000 g contains $6.02 \times 10^{23} \times \frac{1000}{64}$ atoms = 9.4×10^{24} atoms
 (b) 1.0 m^3 of copper has a mass of 8900 kg, so number of atoms = $9.4 \times 10^{24} \times 8900 = 8.4 \times 10^{28}$ atoms
 (c) Suppose each atom sits in a little box of side equal to its diameter. The volume of one box would be $\frac{1 \text{ m}^3}{8.4 \times 10^{28}} = 1.19 \times 10^{-29} \text{ m}^3$, so the side length of each box is $2.3 \times 10^{-10} \text{ m}$
- 2 Percentage error = $\frac{2.55 \times 10^{-10} - 2.3 \times 10^{-10}}{2.55 \times 10^{-10}} \times 100\% = 10\%$
- 3 (a) $\frac{22.43 \times 10^{-3}}{6.02 \times 10^{23}} = 3.73 \times 10^{-26} \text{ m}^3$
 (b) $\sqrt[3]{3.73 \times 10^{-26}} = 3.34 \times 10^{-9} \text{ m}$
 (c) $3.34 \times 10^{-9} \text{ m}$, more than 10 times the atomic diameter

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- 4 Density of osmium (from Table 1) = $22\,500\text{ kg m}^{-3}$ so mass of block = $22\,500\text{ kg m}^{-3} \times 2\text{ m} \times 3\text{ m} \times 4\text{ m} = 5.4 \times 10^5\text{ kg}$

$$\text{Maximum mass of 1 atom of osmium} = \frac{0.19026\text{kg}}{6.02 \times 10^{23}} \text{ or } 3.1605 \times 10^{-25}\text{ kg}$$

$$\text{Minimum mass of 1 atom of osmium} = \frac{0.19020\text{kg}}{6.02 \times 10^{23}} \text{ or } 3.1595 \times 10^{-25}\text{ kg}$$

$$\text{Maximum number of atoms in block} = \frac{5.4 \times 10^5\text{kg}}{3.1595 \times 10^{-25}\text{kg}} = 1.7091 \times 10^{30}\text{ atoms}$$

$$\text{Minimum number of atoms in block} = \frac{5.4 \times 10^5\text{kg}}{3.1605 \times 10^{-25}\text{kg}} = 1.7086 \times 10^{30}\text{ atoms (i.e. no difference, to 3 s.f.)}$$

Alternatively, assume that the atomic diameter of osmium is the same as that of copper in question 1(c) ($2.55 \times 10^{-10}\text{ m}$) and that in osmium (a metal) the atoms pack closely, touching each other. In a box of dimensions 2 m by 3 m by 4 m the number of atoms will be $\frac{2}{2.55 \times 10^{-10}} \times \frac{3}{2.55 \times 10^{-10}} \times \frac{4}{2.55 \times 10^{-10}} = 1.45 \times 10^{30}$, with a percentage error of 10% (question 2).

5.1.3 Internal energy (page 15)

- 1 When a liquid evaporates, more energetic (faster moving) molecules at the surface of the liquid leave the liquid. The average energy of the remaining liquid molecules is less, so the internal energy of the liquid is reduced. The skin feels cold because energy is transferred from the skin to the liquid on the skin, to reach thermal equilibrium.
- 2 (a) Any situation where friction slows the motion of an object so the internal kinetic energy becomes randomised in the molecules of the object.
(b) Any suitable example, for instance, the internal energy of an exploding air–vapour mixture in the cylinder of an internal combustion engine results in the external energy of the piston motion.
- 3 A burn from steam at $100\text{ }^\circ\text{C}$ is more severe than a burn from water at $100\text{ }^\circ\text{C}$. Steam at $100\text{ }^\circ\text{C}$ has much greater internal energy than boiling water at $100\text{ }^\circ\text{C}$ because additional energy has to be transferred to the boiling water in order to vaporise it to steam. Some of the internal energy of the steam or water is transferred to the skin.
- 4 (a) The gas inside the aerosol can is under greater pressure than the gas expanding into the air, so the kinetic energy of the gas molecules will decrease as the gas expands at constant temperature. Since the potential energy component of the internal energy of a gas is very small, the internal energy will decrease when the gas expands at constant temperature.
(b) The internal energy of the gas particles inside the bottle does not change, because their temperature does not increase and no work is done on the gas.
(c) The temperature of the metal rod will increase as energy is transferred to it by heating, so the kinetic (vibrational) energy of the metal atoms will also increase. The potential energy will also increase slightly. Overall, the internal energy increases.

5.1.4 Brownian motion (page 17)

- 1 Equal KE of smoke particle and air molecule, so $\frac{1}{2}m_{\text{air}}v_{\text{air}}^2 = \frac{1}{2}m_{\text{smoke}}v_{\text{smoke}}^2$

$$\text{Therefore, } v_{\text{air}} = \sqrt{\frac{\frac{1}{2}m_{\text{smoke}}v_{\text{smoke}}^2}{\frac{1}{2}m_{\text{air}}}} = \sqrt{\frac{0.5 \times (1 \times 10^{-16}) \times 0.01^2}{0.5 \times (5 \times 10^{-26})}} = 447\text{ m s}^{-1} = 450\text{ m s}^{-1} \text{ (to 2 s.f.)}$$

- 2 (a) 0.013 s
(b) The molecules travel a much greater distance because they are involved in so many collisions, causing their movement to be random.
(c) The scent molecules are much more massive but have the same energy, so their velocities are small. This means that their rate of diffusion is lower.

An alternative argument is that, because scent molecules are much larger, they are more likely to be involved in collisions. Therefore, the scent molecules change direction more often (their mean free path is shorter) and their rate of diffusion is slower.

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- 3 The rate of diffusion increases with temperature because the particles will have higher velocities at higher temperatures due to their increased kinetic energy. The rate of diffusion will be faster in gases than liquids because there is more space between molecules in a gas and because the molecules in a gas have higher kinetic energies than in a liquid. The rate of diffusion in solids is much slower than in liquids because the particles are very closely packed and a large amount of energy is required for a small particle (atom or ion) to move through the lattice, or for particles to change positions.

5.1.5 Specific heat capacity (page 20)

1

Energy supplied, E/J	Mass, m/kg	Specific heat capacity, $c/\text{J kg}^{-1} \text{K}^{-1}$	Change in temperature, $\Delta\theta/\text{K}$
201 600	2.8	900	80
500 000	450	4200	0.26
8.9×10^6	3×10^3	124	24
4.3×10^5	34	913	14

- 2 A temperature difference of 1 K is identical with a temperature difference of 1 °C.
- 3 In one second the energy transferred to a mass of 0.015 kg is 820 J. Using $E = mc\Delta\theta$:
- $$\Delta\theta = \frac{E}{mc} = \frac{820}{0.015 \times 4200} = 13 \text{ K}$$
- 4 (a) electrical energy supplied = power $\times$ time = $650 \times 2 \times 60 = 78\,000 \text{ J}$
- $$E = mc\Delta\theta \text{ so } \Delta\theta = \frac{E}{mc} = \frac{78\,000}{0.4 \times 4200} = 46 \text{ K}$$
- (b) As the temperature increases, the number of vapour molecules above the soup, and the mean speed of these vapour molecules, will also increase. Therefore, there will be more and harder collisions between the vapour molecules and the lid of the cup. Both of these factors will increase the pressure of the vapour within the cup.
- 5 density = $\frac{\text{mass}}{\text{volume}}$ so $m = d \times v = 1.2 \times 5.5 \times 4.5 \times 2.1 = 62.37 \text{ kg}$
- $$E = mc\Delta\theta = 62.37 \times 993 \times 8 = 495\,000 \text{ J}$$
- electrical energy supplied = power $\times$ time so $t = \frac{495\,000}{1500} = 330 \text{ s}$
- The minimum time required to raise the temperature in the room from 10 °C to 18 °C is 330 s or 5.5 minutes. However, it will actually take much longer than this to heat the room, because the convector heater will transfer only a fraction of its input power to the air passing through it. Some heat will also be lost via energy transfer from the air to the walls and objects within the room.
- 6 Using $E = mc\Delta\theta$, the electrical energy E required from the heater is $4.5 \times 4200 \times 60 = 1\,134\,000 \text{ J}$. If this energy is transferred over 15 minutes and assuming no energy losses (which is unrealistic), the power of the heater = $\frac{1\,134\,000}{15 \times 60} = 1260 \text{ W}$

5.1.6 Specific latent heat (page 23)

- 1 (a) $E = mL = 40 \times 23\,000 = 9.2 \times 10^5 \text{ J}$
- (b) $E = mL = 25 \times 855\,000 = 2.1 \times 10^7 \text{ J}$
- (c) $E = mL = 2 \times 10^4 \times 335\,000 = 6.7 \times 10^9 \text{ J}$
- (d) $E = mL = \frac{30}{1000} \times 2\,356\,000 = 71\,000 \text{ J}$
- 2 $E = mL$ so $L = \frac{E}{m} = \frac{3000 \times 2 \times 60}{1.487 - 1.343} = 2.5 \times 10^6 \text{ J kg}^{-1}$
- 3 The specific latent heat of vaporisation of water is much higher than that of alcohol, so for a given time interval, t , and a given heater, the mass of water vapour condensed and collected will be much less for water than for alcohol.

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- 4 (a) Energy is transferred to the ice from the surroundings (for example, by conduction through the funnel walls) and transferred from the ice to the surroundings. These additional energy transfers affect the mass of ice melted and so alter the figure for the specific latent heat of fusion. A control allows you to estimate the amount of ice melted without the heater, so the calculated value for L_f will be more accurate.
- (b) Insulation or lagging around the funnels would reduce the transfer of energy between the ice and the surroundings.
- (c) The temperature of the ice may initially be below 0°C . By waiting for the ice to start melting you can be confident that most of the ice is at or very close to 0°C .
- 5 (a) All sections from A to F
- (b) AB, CD, EF
- (c) AB, CD, EF

5.1.7 The amount of substance (page 25)

1

Substance	Description	Mass of 1 mole of atoms/g	Mass of substance/g	Number of moles	Number of atoms
helium	monatomic gas	4.0	8	2	$2 N_A$
lithium	metal	7.0	3.5	0.5	$\frac{1}{2} N_A$
argon	monatomic gas	40.0	10.0	0.25	$\frac{1}{4} N_A$

- 2 (a) Number of moles of oxygen atoms = $\frac{\text{mass}}{\text{mass of 1 mole}} = \frac{0.016\text{g}}{16\text{g}} = 0.001$
- (b) Oxygen is a diatomic molecule, so 1 mole of oxygen molecules contains 2 moles of oxygen atoms.
 Number of moles of oxygen molecules = $\frac{0.001}{2} = 0.0005$
 Alternatively, using molar mass of O_2 , number of moles of oxygen molecules = $\frac{0.016\text{g}}{32\text{g}} = 0.0005$
- (c) Number of oxygen atoms = $0.001 \times 6.02 \times 10^{23} = 6.02 \times 10^{20}$
- (d) Number of oxygen molecules = $\frac{6.02 \times 10^{20}}{2} = 3.01 \times 10^{20}$
- 3 (a) Number of moles of oxygen atoms = $\frac{\text{mass}}{\text{mass of 1 mole}} = \frac{48}{16} = 3$ moles
- (b) Number of moles of ozone atoms = $\frac{\text{mass}}{\text{mass of 1 mole}} = \frac{960}{48} = 20$ moles
- (c) Number of moles of nitrogen atoms = $\frac{\text{mass}}{\text{mass of 1 mole}} = \frac{40}{14} = 2.9$ moles
- 4 (a) Argon is monatomic, so 40.0 g is 1 mole of argon atoms
- (b) Number of moles of carbon dioxide molecules = $\frac{\text{mass}}{\text{mass of 1 mole}} = \frac{22\text{g}}{(12\text{g}+16\text{g}+16\text{g})} = 0.5$ moles

5.1.8 The kinetic theory and pressure of a gas (page 28)

- 1 (a) $p = \frac{1}{3} \rho \bar{c}^2$ so $\bar{c}^2 = \frac{3p}{\rho}$
 $\bar{c}^2 = \frac{3 \times (1.0 \times 10^5) \times 0.022}{2.0 \times 10^{-3}} = 3.3 \times 10^6$
 $\bar{c} = 1.8 \times 10^3 \text{ m s}^{-1}$
- (b) $\text{KE} = \frac{1}{2} m \bar{c}^2$ where m is the mass of 1 mole of gas, so $\text{KE} = \frac{1}{2} \times (2.0 \times 10^{-3}) \times (3.3 \times 10^6)$
 $= 3.3 \times 10^3 \text{ J}$
- 2 $p = \frac{1}{3} \rho \bar{c}^2$ so $\bar{c}^2 = \frac{3p}{\rho}$
 $\bar{c}^2 = \frac{3 \times (1.0 \times 10^5) \times 0.022}{0.22} = 3.0 \times 10^4$
 $\bar{c} = 1.7 \times 10^2 \text{ m s}^{-1}$

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- 3 KE of 1 mole of hydrogen molecules = 3.3×10^3 J, so mean KE per molecule = $\frac{3.3 \times 10^3 \text{ J}}{6.02 \times 10^{23}}$
 $= 5.5 \times 10^{-21}$ J

KE of 1 mole of radon gas = $\frac{1}{2} m \overline{c^2}$ where m is the mass of 1 mole of radon, so

$$\text{KE} = \frac{1}{2} \times 0.22 \times (3.0 \times 10^4) = 3.3 \times 10^3 \text{ J}$$

This is the same as the KE of 1 mole of hydrogen, so the mean KE per particle is the same for hydrogen gas and radon gas.

- 4 (a) Mean speed = $\frac{300+450+500+350+400+550}{6} = 425 \text{ m s}^{-1}$
 (b) Take positive direction to the right; mean velocity = $\frac{350+400+550-300-450-500}{6} = 8.3 \text{ m s}^{-1}$ to the right
 (c) r.m.s. speed = $\sqrt{\frac{300^2+450^2+500^2+350^2+400^2+550^2}{6}} = 430 \text{ m s}^{-1}$
 (d) mean momentum = mass of one molecule $\times$ mean velocity = $4.7 \times 10^{-26} \text{ kg} \times 8.3 \text{ m s}^{-1}$
 $= 3.9 \times 10^{-25} \text{ kg ms}^{-1}$
 (e) mean KE = $\frac{1}{2} \times (4.7 \times 10^{-26}) \times \frac{300^2 + 450^2 + 500^2 + 350^2 + 400^2 + 550^2}{6} = 4.4 \times 10^{-21} \text{ J}$

5.1.9 Investigating gases (page 30)

1

Pressure 1 (p_1)	Volume 1 (V_1)	Pressure 2 (p_2)	Volume 2 (V_2)
$3 \times 10^6 \text{ Pa}$	78 m^3	$8 \times 10^7 \text{ Pa}$	2.93 m^3
2.5 atm	4.5 l	18.8 atm	0.6 l
$1.6 \times 10^7 \text{ Nm}^{-2}$	8.0 l	$5 \times 10^8 \text{ Nm}^{-2}$	250 cm^3
$1.5 \times 10^9 \text{ Pa}$	$1.9 \times 10^5 \text{ m}^3$	9 GPa	$3.2 \times 10^4 \text{ m}^3$

- 2 $PV = \text{constant}$, so reducing pressure from 6.4 atm to 1 atm increases the volume by a factor of 6.4
 New volume is 20.48 cm^3
- 3 $PV = \text{constant}$, so reducing volume from 1200 cm^3 to 340 cm^3 increases the pressure by a factor of $\frac{1200}{340}$
 New pressure is $1.2 \text{ atm} \times \frac{1200}{340} = 4.24 \text{ atm}$
- 4 Percentage difference = $\frac{-286.5 - (-273.16)}{273.16} \times 100\% = 4.9\%$
- 5 Uncertainty in measurements may be due to resolution or the smallest division on the scale of the thermometer or pressure gauge. The uncertainty in the measurement is half the smallest scale division.

5.1.10 The ideal gas equation (page 32)

- 1 $pV = nRT$ or, assuming the amount of gas is unchanged, $\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$
 Rearranging to make p_2 the subject of the formula, $p_2 = \frac{p_1 V_1 T_2}{T_1 V_2} = \frac{(1.01 \times 10^5) \times 12 \times 270}{298 \times 28} = 3.90 \times 10^4 \text{ Pa}$
- 2 (a) $pV = nRT$ so $n = \frac{pV}{RT} = \frac{(70 \times 10^5) \times 0.020}{8.31 \times 290} = 58$
 (b) mass of gas = number of moles $\times$ molar mass = $58 \text{ moles} \times 0.028 \text{ kg mol}^{-1} = 1.6 \text{ kg}$
 (c) $PV = \text{constant}$, so reducing pressure from 70 atm to 1 atm increases the volume by a factor of 70
 New volume = $0.020 \text{ m}^3 \times 70 = 1.4 \text{ m}^3$
 (d) 58
- 3 In the equation $pV = nRT$, units of pV are $\text{N m}^{-2} \times \text{m}^3$ or N m , which is equivalent to J.
 Units of nRT are $\text{mol} \times \text{J mol}^{-1} \text{ K}^{-1} \times \text{K}$ or J.

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- 4 (a) $pV = nRT$ so $n = \frac{pV}{RT} = \frac{(3.7 \times 10^5) \times 8.4}{8.31 \times 327} = 1144$ moles or 1.1×10^3 moles to 2 s.f.
 (b) mass of gas = number of moles $\times$ molar mass = $1144 \text{ moles} \times 0.004 \text{ kg mol}^{-1} = 4.6 \text{ kg}$
- 5 $pV = nRT$ so $V = \frac{nRT}{p} = \frac{4 \times 8.31 \times 297}{240\,000} = 4.11 \times 10^{-2} \text{ m}^3$
 $V = \frac{4\pi r^3}{3}$ so $r^3 = \frac{3V}{4\pi}$ and $r = \sqrt[3]{\frac{3V}{4\pi}} = \sqrt[3]{\frac{3 \times 4.11 \times 10^{-2}}{4\pi}} = 0.21 \text{ m}$

5.1.11 The Boltzmann constant (page 35)

1

Symbol	Quantity	Value	Unit	Abbreviation
p	pressure	–	pascal	Pa
V	volume	–	cubic metres	m^3
n	number of moles	–	moles	mol
N	number of particles (atoms/molecules)	–	pure number	–
N_A	Avogadro constant	6.02×10^{23}	per mole	mol^{-1}
k	Boltzmann constant	1.38×10^{-23}	joules per kelvin	J K^{-1}
T	absolute temperature	–	kelvin	K
$\overline{c^2}$	mean square speed	–	metres ² per second ²	$\text{m}^2 \text{s}^{-2}$
$\bar{c}$	root mean square (r.m.s.) speed	–	metres per second	m s^{-1}

- 2 From $pV = nRT$, if the gas is made up N molecules, the number of moles, $n = \frac{N}{N_A}$ so $pV = RT \times \frac{N}{N_A}$
 $\frac{R}{N_A}$ is the gas constant per molecule = k , so $pV = NkT$
 The equation $pV = nRT$ is used for n moles and $pV = NkT$ for N atoms or molecules
- 3 (a) The velocities of particles in each body will have a range of values. The distribution of velocity values will be random in each body, but the shape of the distribution will be similar in each body.
 (b) The kinetic energies of particles in each body will have a range of values, but the mean kinetic energy of the particles in each body will be the same, because the temperature of each body will be the same.
- 4 Mean kinetic energy $E = \frac{3}{2} kT$ so $\frac{E}{T}$ is a constant. If E decreases to $\sqrt{E}$, T also decreases by a factor of $\sqrt{E}$, so
 $T_{\text{new}} = \frac{273+45}{\sqrt{E}} = \frac{318}{\sqrt{E}}$
- 5 $pV = NkT$, so $N = \frac{pV}{kT}$ or $N = \frac{(8 \times 10^6) \times \pi \times 0.2^2 \times 3}{(1.38 \times 10^{-23}) \times 400} = 5.46 \times 10^{26}$
- 6 $\frac{1}{2} m \overline{c^2} = \frac{3kT}{2}$ so rearranging gives $\overline{c^2} = \frac{3kT}{m} = \frac{3 \times (1.38 \times 10^{-23}) \times 480}{5.3 \times 10^{-26}} = 3.75 \times 10^5$
 Therefore $\bar{c} = 610 \text{ m s}^{-1}$
- 7 (a) Mean pressure exerted by each molecule is $5.0 \times 10^{-19} \text{ Pa}$, and number of molecules = N_A (1 mole), so total pressure = $5.0 \times 10^{-19} \times 6.02 \times 10^{23} = 3.0 \times 10^5 \text{ Pa}$
 (b) $pV = nRT$ so $V = \frac{nRT}{p} = \frac{1 \times 8.31 \times 300}{3.0 \times 10^5} = 8.3 \times 10^{-3} \text{ m}^3$
 (c) Yes, the pressure would have been doubled.
- 8 (a) Mean kinetic energy $E = \frac{3}{2} kT$ and can also be expressed as $\frac{1}{2} m \overline{c^2}$
 (i) $E = \frac{3}{2} kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 273 = 5.65 \times 10^{-21} \text{ J}$
 (ii) $\frac{1}{2} m \overline{c^2} = 5.65 \times 10^{-21}$ and $\bar{c} = 490 \text{ m s}^{-1}$ so $m = \frac{2 \times (5.65 \times 10^{-21})}{490^2} = 4.7 \times 10^{-26} \text{ kg}$
 (b) Mean kinetic energy E is proportional to temperature
 (i) At 273 K, KE is the same for helium molecules as for nitrogen molecules, $5.65 \times 10^{-21} \text{ J}$; at 820 K,
 $E = 5.65 \times 10^{-21} \text{ J} \times \frac{820}{273} = 1.70 \times 10^{-20} \text{ J}$

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- (ii) Mean kinetic energy $E = \frac{1}{2}m\overline{c^2}$ so if the mass of helium is $\frac{1}{7}$ that of nitrogen, for the same mean kinetic energy of a molecule, $\overline{c^2}$ increases by 7. At 273 K, $\bar{c} = 490 \text{ m s}^{-1} \times \sqrt{7} = 1300 \text{ m s}^{-1}$; at 820 K, KE has increased by $\frac{820}{273}$ so $\overline{c^2}$ increases by $7 \times \frac{820}{273}$ and

$$\bar{c} = 490 \text{ m s}^{-1} \times \sqrt{7 \times \frac{820}{273}} = 2300 \text{ m s}^{-1}$$

- 9 (a) Mean kinetic energy $E = \frac{3}{2}kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 1000 = 2.1 \times 10^{-20} \text{ J}$

(b) $\frac{1}{2}m\overline{c^2} = 2.1 \times 10^{-20} \text{ J}$

(i) $\overline{c^2} = \frac{2 \times (2.1 \times 10^{-20})}{\frac{0.002}{6.02 \times 10^{23}}} = 1.25 \times 10^7, \bar{c} = 3.50 \text{ km s}^{-1}$

(ii) $\overline{c^2} = \frac{2 \times (2.1 \times 10^{-20})}{\frac{0.004}{6.02 \times 10^{23}}} = 6.23 \times 10^6, \bar{c} = 2.50 \text{ km s}^{-1}$

- (c) No, because r.m.s. speed $> 2.2 \text{ km s}^{-1}$ for both.

- 10 Assuming the work done reduces the kinetic energy of the molecules to zero and ignoring the potential energy of the molecules, KE lost $= \frac{3}{2}kT = 1.1 \times 10^{-20} \text{ J}$. Rearranging and substituting for k :

$$T = \frac{\frac{2}{3} \times (1.1 \times 10^{-20})}{1.38 \times 10^{-23}} = 530 \text{ K}$$

Practice questions (page 38)

1 B

2 D

3 C

4 B

5 A

- 6 Identification of $E = mc\Delta\theta$ for calculating the rise in temperature from -10°C to 0°C and correct substitution of values to obtain $E = 840\,000 \text{ J}$. [1]

Correct identification of $E = mL$ for melting followed by correct substitution of value to obtain $E = 6\,680\,000 \text{ J}$ (or $6.68 \times 10^6 \text{ J}$). [1]

Correct substitution of values into $E = mc\Delta\theta$ to obtain energy value for water being heated from 0°C to 100°C of $8\,400\,000 \text{ J}$ (or $8.4 \times 10^6 \text{ J}$). [1]

Correct use of $E = mL$ and substitution for the vaporisation of water at 100°C to steam at 100°C giving a value of $45\,200\,000 \text{ J}$ (or $4.52 \times 10^7 \text{ J}$). [1]

Final answer as the total of the values above, i.e. $840\,000 + 6\,680\,000 + 8\,400\,000 + 45\,200\,000 = 61\,120\,000 \text{ J}$ (or $6.1 \times 10^7 \text{ J}$). [1]

[Total: 5]

- 7 $E = \text{power} \times \text{time} = 2.2 \times 10^3 \text{ W} \times 180 \text{ s} = 3.96 \times 10^5 \text{ J}$

$$E = mc\Delta\theta \text{ so } m = \frac{E}{c\Delta\theta} = \frac{3.96 \times 10^5}{4200 \times (90 - 25)} = 1.45 \text{ kg}$$

[Total: 5]

- 8 (a) The sum of all the kinetic and potential energies of molecules within a substance. [1]
 (b) The temperature at which a thermodynamic system has minimum energy. It corresponds to -273.16°C on the Celsius temperature scale and 0 K on the Kelvin scale. [1]
 (c) The condition whereby two objects are at the same temperature and so there is no net thermal energy transfer between them. [1]

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- (d) A scale for measuring temperature which is independent of the properties of any specific substance, for instance, the Kelvin scale. [1]

[Total: 4]

- 9 Calculation of the kinetic energy of the tennis ball given by $\frac{1}{2}mv^2$, with correct substitution to give $\frac{1}{2} \times 0.05 \times 4^2$ and correct value for the kinetic energy of 0.4 J. [1]

Calculation that there are 2 moles of gas from $\frac{\text{mass of gas}}{\text{molar mass}}$ [1]

Determining total kinetic energy of gas as being equal to $\frac{3}{2} \times k \times T \times 2 \times N_A$. [1]

Equating kinetic energy value to $\frac{3}{2} \times k \times T \times 2 \times N_A$ to give $0.4 = 25T$. [1]

Final temperature value of 0.02 K. [1]

[Total: 5]

- 10 Refer to official mark scheme for OCR past paper G484/01, June 2013; this is Q4. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.
- 11 Refer to official mark scheme for OCR past paper G484/01, June 2013; this is Q6. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.
- 12 Refer to official mark scheme for OCR past paper G484 January 2012; this is Q6. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.

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5.2 Circular motion

5.2.1 Kinematics of circular motion (page 45)

1

Radius of circle/m	Speed/m s ⁻¹	Angular velocity/rads ⁻¹	Centripetal acceleration/m s ⁻²
3.2	14.8	4.63	68.5
14.9	5.6	0.38	2.1
2×10^6	4000	2×10^{-3}	8

2

- (a) 115°
- (b) The graph should show a triangular shape per cycle.
- (c) The graph should show a square wave, equally above and below the axis per cycle.
- (d) Graph (c) is the gradient of graph (b).

3

- (a) After 2 s: 60°, $\frac{\pi}{3}$
After 6 s: 180°, π
After 9 s: 270°, $\frac{3\pi}{2}$
After 12 s: 360°, 2π
- (b) 3 s
- (c) distance moved = 4 m at speed of 1.5 m s⁻¹, so time taken = 2.7 s. One complete revolution in 12 s, so in 2.7 s, the roundabout will have turned 80°, 0.44π or 1.4 rad.
- (d) (i) $\omega = \frac{2\pi}{12 \text{ s}} = 0.52 \text{ rads}^{-1}$
(ii) $v = \omega r = 2.1 \text{ m s}^{-1}$
(iii) $a = \omega^2 r = 1.1 \text{ m s}^{-2}$

4

- (a) 1.0 km s⁻¹
- (b) $2.7 \times 10^{-3} \text{ m s}^{-2}$

5

- (a) 28 m s⁻¹
- (b) 89 m s⁻², 9.1 g (NB: these figures may vary slightly depending on the equations used)

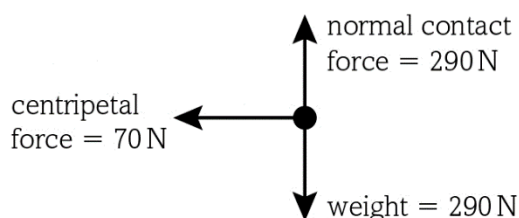
6

- $2.1 \times 10^{13} \text{ m s}^{-2}$

5.2.2 Centripetal force (page 49)

1

- (a) Centripetal force $F = \frac{mv^2}{r} = \frac{29 \times 1.7^2}{1.2} = 70 \text{ N}$
- (b) The centripetal force is provided by the frictional force between the roundabout surface and the child:

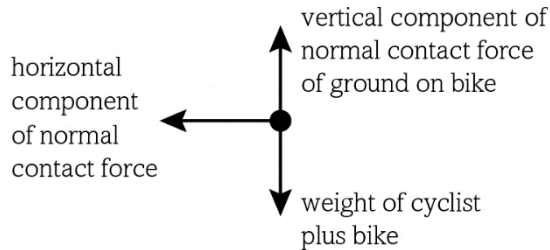


2

- (a) Taking the Equator as the maximum distance from the Earth's rotational axis, centripetal acceleration at the equator $a = \omega^2 r = \left(\frac{2\pi}{8.64 \times 10^4}\right)^2 \times 6.4 \times 10^6 = 3.38 \times 10^{-2} \text{ m s}^{-2}$.
For a person of mass 70 kg, change in weight due to centripetal acceleration = $70 \times 3.38 \times 10^{-2} = 2.4 \text{ N}$
- (b) The measured weight will be lower at the Equator, because some of the gravitational force is being 'cancelled out' by the centripetal force acting outwards. Therefore, the normal contact force is less than your weight because you are accelerating downwards. However, the effect is very small.

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- 3 (a) Centripetal force $F = \frac{mv^2}{r} = \frac{85 \times 4.0^2}{7.0} = 190 \text{ N}$
 (b) Taking moments about the contact point of the tyre, there must be a turning moment towards the centre of the arc as a centripetal force must be created through the centre of mass of the cyclist plus bicycle. This is provided by leaning inwards.



- 4 (a) PE lost = KE gained, $mgh = \frac{1}{2}mv^2$, so $v^2 = 2gh$
 $v^2 = 2 \times 9.81 \times 0.05$, therefore $v = 0.99 \text{ m s}^{-1}$
 (b) Centripetal acceleration, $a = \frac{v^2}{r} = \frac{0.99^2}{0.99} = 0.99 \text{ m s}^{-2}$
 (c) Resultant force of tension and weight provides centripetal acceleration at this point, so $(T - mg) = \frac{mv^2}{r}$
 $T = (0.2 \times 9.81) + (0.2 \times 0.99) = 2.2 \text{ N}$
- 5 Centripetal force, $F = \frac{mv^2}{r} = \frac{7.3 \times 25^2}{2} = 2300 \text{ N}$
- 6 (a) Cyclist is in vertical equilibrium, so resolving forces vertically, $W = R \cos \theta$
 (b) Horizontal component of R , $R \sin \theta$, provides the centripetal force, $\frac{mv^2}{r}$
 $R = \frac{W}{\cos \theta}$ therefore $\frac{mv^2}{r}$ equals $\sin \theta \times \frac{W}{\cos \theta}$
 Hence $\tan \theta = \frac{mv^2}{Wr}$ and as $W = mg$, $\tan \theta = \frac{v^2}{gr}$
 (c) $\tan \theta = \frac{v^2}{gr} = \frac{15^2}{9.81 \times 35}$
 $\theta = 33^\circ$
 (d) $W = R \cos \theta$ so $R = \frac{W}{\cos \theta} = \frac{785}{\cos 33} = 940 \text{ N}$
- 7 If the angle of the string to the horizontal is θ , the centripetal force is given by the horizontal component of the tension in the string, $T \cos \theta$. The radius of circular motion, r , is given by $L \cos \theta$ where L is the length of the string. Equating $T \cos \theta$ with $\frac{mv^2}{r}$, both cosine factors cancel out. (Alternatively, for small angles the cosine of the angle is very close to 1.)

Practice questions (page 52)

- 1 A
 2 B
 3 B
 4 B
 5 C
 6 Explanation that constant speed refers to a constant distance being covered per unit time. [1]
 Explanation that velocity is a vector, so it changes because direction is changing. [1]
 Idea that acceleration is the rate of change of velocity, so acceleration is occurring at a constant speed. [1]

[Total: 3]

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- 7 (a) $\omega = \frac{2\pi}{T}$ so $\omega = \frac{2\pi}{0.25}$ giving $\omega = 8\pi \text{ rad s}^{-1}$ [2 marks: 1 for value of 8π , 1 for units of rad s^{-1}]
 (b) $v = r\omega$, so $v = 1.5 \times 8\pi = 12\pi \text{ m s}^{-1}$ [2 marks: 1 for value of 12π (or equivalent), 1 for units of m s^{-1}]
 (c) $F = mr\omega^2$, so $F = 0.85 \times 1.5 \times (8\pi)^2$, leading to a value of $81.6\pi \text{ N}$ [2 marks: 1 for the correct value, 1 for units of N]
[Total: 6]
- 8 Skater can stretch out arms, increasing their radius of rotation / Pulling in arms decreases radius of rotation. [1]
 Reducing the radius of rotation for the same initial velocity increases the angular frequency. [1]
 Increasing the angular frequency means that the skater rotates more times per second (greater frequency as radius decreases). [1]
[Total: 3]
- 9 Refer to official mark scheme for OCR past paper G484 January 2011; this is Q2. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.
- 10 Refer to official mark scheme for OCR past paper G484 January 2010; this is Q2. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.

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5.3 Oscillations

5.3.1 Simple harmonic motion (page 57)

- 1
 - (a) Displacement is the distance (measured in metres) that an oscillating object moves from its equilibrium (or rest) position. This may be positive or negative. The amplitude of an oscillation is the maximum displacement from the equilibrium position. This is always positive.
 - (b) The time period of an oscillation, measured in seconds, is the time taken for one complete oscillation. Frequency, measured in hertz, is the number of oscillations per unit time and is related to time period by the expression $T = \frac{1}{f}$.
 - (c) The phase difference between two points on an oscillating body is the fraction of one complete cycle of oscillation between those points (where one complete cycle is 2π). It is expressed in degrees or radians and calculated using the equation:

$$\text{phase difference} = \frac{\text{distance between the two points}}{\text{wavelength of the wave}} \times 2\pi.$$

2

Time period/s	Frequency/Hz	Angular frequency/rad s ⁻¹
0.1	10	62.8 or 20π
0.02	50	314 or 100π
8.33×10^{-3}	120	240π

- 3
 - (a) $\text{phase difference} = \frac{\text{distance between the two points}}{\text{wavelength of the wave}} \times 2\pi = \frac{8}{12} \times 2\pi = \frac{4\pi}{3}$ radians
 - (b) $\text{phase difference} = \frac{\text{time between two points oscillating on a wave}}{\text{time period of the wave}} \times 2\pi = \frac{3}{12} \times 2\pi = \frac{\pi}{2}$ radians

5.3.2 The equations of simple harmonic motion (page 59)

- 1
 - (a) The equation shows that the value of the acceleration of an object is proportional to its displacement from its equilibrium position and also that the acceleration is always directed toward its equilibrium position. Any object for which these two conditions are true is undergoing simple harmonic motion.
 - (b) s⁻² or rad⁻²
 - (c) The frequency of oscillation of the second motion is double the frequency of the first oscillation. The first motion oscillates at a frequency of 0.8 Hz.

2

Acceleration/ms ⁻²	Frequency/Hz	Displacement/m
15	0.8	0.6
1.4	1.5×10^{-6}	1.6×10^{10}
-0.3	4.9×10^{-2}	3.2

- 3
 - (a) Maximum velocity = $v_{\max} = \omega A$ or $2\pi fA$. $A = 0.28$ m and $f = 1.2$ Hz so $v_{\max} = 2.1$ m s⁻¹
 - (b) $v = \pm\omega\sqrt{(A^2 - x^2)}$ so when $x = 0.15$ m, $v = \pm 2\pi \times 1.2 \sqrt{(0.28^2 - 0.15^2)} = \pm 1.8$ m s⁻¹
- 4 Timing starts when the pendulum passes through its lowest point, so $x = 0$ when $t = 0$ and we use $x = A \sin \omega t$
 $T = 2.8$ s so $\omega = \frac{2\pi}{2.8} = 2.24$ rad
 $x = A \sin \omega t$ and $A = 4.6$ m, so $x = 4.6 \sin (2.24 \text{ rad}) = 1.1$ m
- 5
 - (a) A, B
 - (b) O
 - (c) O
 - (d) O
 - (e) A

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- 6 (a) (i) 0.050 m (ii) 0.50 Hz (iii) 2.0 s
 (b) (i) At 0.50 s, $x = 0$ m
 At 0.75 s, $x = 0.035$ m up
 At 1.50 s, $x = 0$ m
 At 1.8 s, $x = 0.040$ m down
 (ii) At 0.50 s, $a = 0$ m s⁻²
 At 0.75 s, $a = -0.35$ m s⁻²
 At 1.50 s, $a = 0$ m s⁻²
 At 1.8 s, $a = 0.39$ m s⁻² up
 (c) (i) 0.16 m s⁻¹ up (ii) 0 m s⁻¹

5.3.3 Graphical analysis of simple harmonic motion (page 62)

- 1 The displacement of a body performing simple harmonic motion will be both positive and negative (at different times during the cycle) with respect to the rest or equilibrium position. The graph of displacement against time is sinusoidal with a repeating (periodic) pattern that shows the same variation in displacement for each complete oscillation. The displacement is zero when the velocity is maximum. The velocity of a body performing simple harmonic motion will be both positive and negative (at different times during the cycle) with respect to the rest or equilibrium position. The graph of displacement against time is sinusoidal and repeating (periodic). The velocity is zero at maximum displacement. The acceleration of a body performing simple harmonic motion will be both positive and negative (at different times during the cycle) with respect to the rest or equilibrium position, with a sinusoidal (periodic) pattern. The phase difference between the displacement and acceleration graphs is π rad and the acceleration is maximum when the body is at maximum displacement. For a body performing simple harmonic motion, acceleration is inversely proportional to displacement.
- 2 (a) S
 (b) R
- 3 (a) (i) 0.11 m
 (ii) $f = \frac{1}{T}$ and $T = 0.7$ s, so $f = 1.43$ Hz
 (iii) maximum velocity = maximum gradient (at $t = 0$ or $t = 0.7$)
 Drawing a tangent to the curve at this point, gradient = $\frac{0.2}{0.2} = 1$ m s⁻¹
 (b) $f = 1.43$ Hz and $A = 0.11$ m, so $2\pi fa = 2 \times \pi \times 1.43 \times 0.11 = 0.99$ m s⁻¹, which is approximately equal to the value found from the gradient
- 4 (a) (i) 2.5 m (ii) 2.5 m (iii) 0.08 tides per hour
 (b) 8 hours 30 mins to 10 hours depending on the day
 (c) depth = $c + A \sin 2\pi ft$, where c is a constant, A is the amplitude and f is the frequency

- 5 Only three oscillations are timed. Due to the large size of the student's reaction time in starting the stopwatch, there is likely to be a large percentage uncertainty in the calculated time period. It would be better to time for at least ten oscillations when finding the mean.

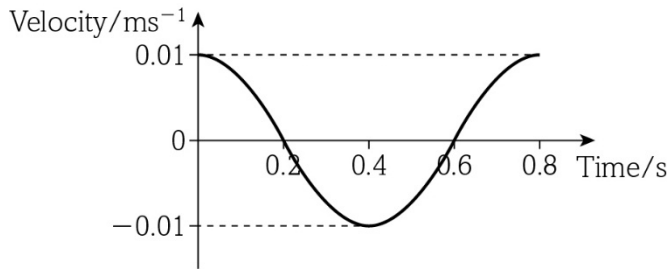
Oscillations are timed from the point at which the pendulum is released. This position is difficult to judge, so it would be better to time the oscillations from the equilibrium (or rest) position at the lowest point of the swing; a fiduciary marker could be placed here as a reference point. The method should also specify that the eye is positioned so that the line of sight is perpendicular to the plane of motion, to avoid parallax error.

Using a stopwatch has limitations due to the resolution of the device (0.01 s) and the random errors that result from the reaction time of the person starting and stopping the stopwatch. Errors are also likely to arise due to the difficulty of judging when the pendulum passes a certain position. It would be better to use a light gate and timer, which starts and stops automatically (eliminating random timing errors and reaction time) and measures time with a greater resolution (0.01 ms).

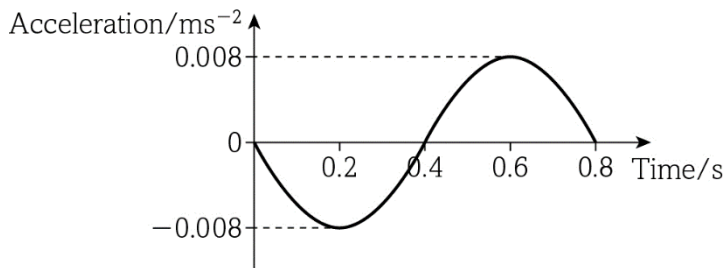
The student started the stopwatch when the pendulum was released but it would be better to let the pendulum settle into a steady periodic oscillation before starting timing, as there may be an initial (transient) period of non-period motion due to a 'push' from the hand releasing the pendulum.

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6 (a)



(b)



5.3.4 Energy in a simple harmonic oscillator (page 65)

1 (a) Sketch to follow shape of KE curve in Figure 1, page 64.

(b) (i) $KE = 1 - \frac{1}{2} kx^2$ (ii) $A\sqrt{\frac{k}{m}}$ or $\sqrt{\frac{2E}{m}}$

2 (a) $PE = \frac{1}{2} kx^2 = 0.5 \times 10 \times (0.05 \times \cos 0)^2 = 13 \text{ mJ}$

At $t = 0.5 \text{ s}$, $PE = 0.5 \times 10 \times (0.05 \times \cos \frac{\pi}{2})^2 = 0$

At $t = 0.75 \text{ s}$, $PE = 0.5 \times 10 \times (0.05 \times \cos \frac{3\pi}{4})^2 = 6.3 \text{ mJ}$

At $t = 1.25 \text{ s}$, $PE = 0.5 \times 10 \times (0.05 \times \cos \frac{5\pi}{4})^2 = 6.3 \text{ mJ}$

(b) $KE + PE = PE_{\text{max}}$ at all points

At $t = 0$ PE is max so $KE = 0$

At $t = 0.5 \text{ s}$, $PE = 0$ so $KE = 12.5 \text{ mJ}$

At $t = 0.75 \text{ s}$, $PE = 6.3 \text{ mJ}$ so $KE = 6.3 \text{ mJ}$

At $t = 1.25 \text{ s}$, $PE = 6.3 \text{ mJ}$ so $KE = 6.3 \text{ mJ}$

3 Reduced to one quarter, as total energy is proportional to amplitude squared

4 (a) maximum $KE = \frac{1}{2} mv_{\text{max}}^2 = 50 \text{ mJ}$

Therefore, $v_{\text{max}} = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2 \times 50 \times 10^{-3}}{0.4}} = 0.5 \text{ m s}^{-1}$

(b) $v_{\text{max}} = 2\pi fA$ so $A = \frac{v_{\text{max}}}{2\pi f} = \frac{0.5}{2\pi \times 0.5} = 0.16 \text{ m}$

5.3.5 Damping (page 67)

- 1 (a) Light damping occurs when the amplitude of an oscillation decreases gradually with time (decaying exponentially to zero), due to energy being removed from the oscillating system; examples include a child's swing that comes to rest when no driving force is applied, or the decrease in volume/vibration of an oscillating drum skin.
- (b) Natural damping occurs when the forces damping the oscillation are frictional forces within the system, such as air resistance acting on a pendulum, frictional forces at the pivot of a swing or the internal forces in a mass-spring oscillator.

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- (c) Artificial damping occurs when external damping forces are intentionally used to reduce the amplitude of the oscillations, such as the use of shock absorbers in cars, soundproofing, and magnetically induced eddy current damping used in magnetic braking.
- (d) Critical damping occurs when the damping forces cause the displaced system to return to the equilibrium position without oscillating; an example is the design of earthquake-resistant buildings or the Millennium Bridge.
- 2 (a) Yes, yes, by approximately 0.62
- (b) The gradient of the line crossing the x -axis decreases at each crossing.
- 3 There is greater damping because of increased air resistance on the wings. This will cause greater energy loss per oscillation so the amplitude will die away more quickly and the plane will stop oscillating in a shorter time. With greater mass, there will be greater inertia in the system, so the frequency of the oscillation will decrease and the time period will increase.

5.3.6 Resonance (page 71)

1

Statement	True or false?	Corrected statement if wrong
a pendulum swinging is an example of a forced vibration	False	a pendulum swinging is an example of a free vibration
dampers are used to increase the amplitude of vibration	False	dampers are used to decrease the amplitude of vibration
a body will resonate when the driving force matches its natural frequency	True	
Barton's pendulums show that resonance occurs at many different lengths	False	Barton's pendulums show that resonance occurs at fixed string lengths, where the natural frequency of the balls on these strings is equal to the driving frequency
TVs, radios and microwave ovens all make use of resonance	True	

- 2 (a) Resonance occurs when the natural frequency of oscillation of the mirror equals the driving frequency of the engine. When this occurs, maximum energy is transferred between the engine and the mirror, giving the oscillation of the mirror a large amplitude.
- (b) (i) Resonance of the mirror will occur at a lower frequency because of its greater inertia, causing a reduced natural frequency. With the engine at the original frequency, the mirror motion will be smaller.
- (ii) Resonance of the mirror will occur at a higher frequency as there is now a larger restoring force, causing an increase in the natural frequency. With the engine at the original frequency, the mirror motion will be smaller.
- 3 (a) Answers should refer to the following points: When the bridge was originally constructed, resonance occurred at or close to the natural frequency of the oscillating bridge due to the driving force from the pedestrians' footsteps. At this frequency, large energy transfer from pedestrians to the bridge caused large-amplitude oscillations of the bridge.
- (b) Answers should refer to the following points: When soldiers march in unison, all their footsteps fall simultaneously providing a regular repeating force on the bridge. This acts as a driving force. If the frequency of this driving force matches the natural frequency of the bridge, the bridge will resonate – that is, the bridge will oscillate with a large amplitude. Since large-amplitude oscillations of the bridge could cause structural damage or even failure of the bridge, soldiers are advised to break step so that the many small driving forces of their footsteps are not synchronised and do not have a resultant effect.
- (c) In the Barton's pendulums demonstration, a large mass oscillating on a string acts as a driver pendulum for other small masses attached at intervals to the same supporting string. The small mass on a string of the same length as the driver mass has a natural frequency equal to that of the driver pendulum and resonates – it oscillates with a much larger amplitude than any of the other small masses.

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Practice questions (page 74)

- 1 D
- 2 C
- 3 A
- 4 D
- 5 C
- 6 (a) (i) When the pendulum is released from its highest point and the oscillations are timed from that point. [1]
(ii) When the pendulum is released from its highest point and the timing of the oscillations is started at the instant the pendulum is moving through its lowest point. [1]
(b) (i) Correct substitution of numbers into $X = A \cos \omega t$, i.e. $X = 0.45 \cos\left(\frac{2\pi}{1.4} \times 1.8\right)$ [1]
Correct answer of $X = -0.1$ m [1]
(ii) Correct substitution of numbers into $X = A \cos \omega t$, i.e. $X = 0.45 \cos\left(\frac{2\pi}{1.4} \times 23.7\right)$ [1]
Correct answer of $X = 0.40$ m [1]
[Total: 6]
- 7 Graph A: acceleration against displacement [1]
Graph B: displacement against time [1]
Graph C: kinetic energy against displacement [1]
[Total: 3]
- 8 (a) When an object oscillates without a driving force acting to keep it oscillating. Objects undergoing free oscillations vibrate at their natural frequency. [1]
(b) Oscillations in which the kinetic energy is converted into other forms and so the amplitude of the oscillation reduces. [1]
(c) The frequency of the free oscillations of a system (the natural frequency of a pendulum of certain length is the frequency at which the pendulum will swing once released). [1]
(d) When the driving frequency is equal to the natural frequency of an oscillating system. This causes a dramatic increase in the amplitude of the oscillations. [1]
[Total: 4]
- 9 Refer to official mark scheme for OCR past paper G484 June 2011; this is Q2. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.
- 10 Refer to official mark scheme for OCR past paper G484 January 2011; this is Q4. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.

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5.4 Gravitational fields

5.4.1 Gravitational fields (page 80)

1

Gravitational field strength/N kg ⁻¹	Force/N	Mass/kg
9.81	981	100.0
1.67	890	533
3.2×10^4	384	1.2×10^{-2}

2 At the crossing point, the pull on the mass could be in either of two different directions.

3 27 N kg^{-1}

5.4.2 Newton's law of gravitation (page 83)

1 (a) $2F$

(b) $\frac{F}{2}$

(c) $2Fd$

2

Gravitational field strength/N kg ⁻¹	Distance from centre of Earth/m	Distance from centre of Earth/ R_E	Factor of g
9.81	6.4×10^6	1	1
2.45	12.8×10^6	2	$\frac{1}{4}$
9.81×10^{-2}	6.4×10^4	10	$\frac{1}{100}$

3 (a) Gravitational field strength, g , is proportional to $\frac{1}{r^2}$, where r is the distance from the centre of the Earth.

If g is half the value at the Earth's surface, r has increased by $\sqrt{2}$, so $(R_E + h) = \sqrt{2} \times R_E$ and

$$h = (\sqrt{2} - 1) \times 6.4 \times 10^6 \text{ m} = 2.6 \times 10^6 \text{ m}$$

$$\text{Alternatively, } h = \sqrt{\left(\frac{GM}{g}\right)} - r = \sqrt{\left(\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{9.81 \div 4}\right)} - 6.4 \times 10^6 = 2.6 \times 10^6 \text{ m}$$

(b) If g is $\frac{1}{16}$ the value at the Earth's surface, r has increased by 4 and $h = 3R_E = 1.9 \times 10^7 \text{ m}$

$$\text{Alternatively, } h = \sqrt{\left(\frac{GM}{g}\right)} - r = \sqrt{\left(\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{9.81 \div 16}\right)} - 6.4 \times 10^6 = 1.9 \times 10^7 \text{ m}$$

4 g is proportional to $\frac{GM}{r^2}$, so if g decreases from 9.8 to 4.3 N kg⁻¹, $\frac{1}{r^2}$ also decreases by this ratio

$$\frac{g_1}{g_2} = \frac{9.8}{4.3} = \frac{r_2^2}{R_E^2}$$

$$r_2 = R_E + h, \text{ so } R_E^2 \left(\frac{9.8}{4.3}\right) = (R_E + h)^2 = R_E^2 + 2R_E h + h^2$$

$$h^2 = R_E^2 \left(\frac{9.8}{4.3}\right) - R_E^2 - 2R_E h$$

Substitution for $R_E = 6400 \text{ m}$

$$\text{Therefore, } h^2 = 5.24 \times 10^7 \text{ and } h = 7200 \text{ m}$$

5 Mass of planet = $\rho \times \frac{4}{3}\pi R^3$

$$g = -\frac{GM}{R^2} = -\rho \times \frac{4}{3}\pi R^3 \times \frac{G}{R^2} = -\frac{4\rho G\pi R}{3}$$

If circumference = $6 \times 10^5 \text{ km}$, $2\pi R = 6 \times 10^8 \text{ m}$

$$g = -\frac{2}{3} \times 6800 \times 6.67 \times 10^{-11} \times 6 \times 10^8 = -180 \text{ N kg}^{-1}$$

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- 6 Within the interior of a planet, only the mass of the sphere beneath that point has a gravitational attraction on a small mass at that point. So at a distance r from the centre:

$$\text{mass of planet beneath that point} = \rho \times \frac{4}{3}\pi r^3$$

$$g = -\frac{GM}{r^2} = -\rho \times \frac{4}{3}\pi r^3 \times \frac{G}{r^2} = -\frac{4\rho G\pi r}{3}$$

Hence g is proportional to r .

5.4.3 The motion of planets and satellites (page 86)

- 1 From Newton's law of gravitation and using $F = \frac{mv^2}{r}$
- $$\frac{mv^2}{r} = \frac{GMm}{r^2}$$
- Also, $v = \frac{2\pi r}{T}$ so $F = \frac{m4\pi^2 r^2}{T^2 r} = \frac{GMm}{r^2}$
- Leading to $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$
- Hence, $T^2 = kr^3$, where k is a constant and equal to $\frac{4\pi^2}{GM}$
- 2 (a) A geostationary satellite has the same period of rotation around a planet as the planet's own period of rotation, so from Table 1, 5.94×10^7 s.
- (b) From Table 1, 5.20×10^9 s.
- 3 For a satellite orbiting at a height of 400 km:
- $$r = R_E + 4.0 \times 10^5 \text{ m} = 6.4 \times 10^6 \text{ m} + 4.0 \times 10^5 \text{ m} = 6.8 \times 10^6 \text{ m}$$
- $$T^2 = \left(\frac{4\pi^2}{GM}\right)r^3, \text{ so } T^2 = \left(\frac{4\pi^2}{GM}\right)(6.8 \times 10^6)^3 = \left(\frac{4\pi^2}{6.67 \times 10^{-11} \times 6 \times 10^{24}}\right)(6.8 \times 10^6)^3 = 3.10 \times 10^7$$
- $$T = 5600 \text{ s to 2 s.f.}$$
- 4 $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$, so $r^3 = \left(\frac{T^2 GM}{4\pi^2}\right)$
- Substituting $T = 27.3$ days and $M = 6 \times 10^{24}$ kg gives:
- $$r^3 = \left(\frac{(27.3 \times 24 \times 60 \times 60)^2 \times 6.67 \times 10^{-11} \times 6 \times 10^{24}}{4\pi^2}\right) = 5.64 \times 10^{25}$$
- $$r = 3.8 \times 10^8 \text{ m}$$
- 5 Like the planets, comets travel around the Sun in elliptical orbits, so a line joining the Sun to a comet will sweep out equal areas in equal times. Kepler's third law also applies to the orbit of comets, i.e. the time period of the orbit squared is proportional to the mean radius of the orbit cubed. The special case for circular orbits cannot be used but we can still write $T^2 \propto r^3$.
- 6 (a) From the definition of centre of mass, taking moments about the centre of mass, $m_1 r_1 = m_2 r_2$.
Since $d = r_1 + r_2$, rewrite this as $m_1 r_1 = m_2 (d - r_1)$. Collecting like terms and rearranging to make r_1 the subject of the equation, $r_1 \frac{m_2}{m_1 + m_2} \times d$
- (b) $T^2(m_1 + m_2) = d^3$, so the total mass $m_1 + m_2 = \frac{d^3}{T^2} = \frac{(103 \times 1.496 \times 10^{11})^3}{(722 \times 365 \times 24 \times 60 \times 60)^2} = 2 \times 10^{15} \text{ kg}$

5.4.4 Gravitational potential and gravitational potential energy (page 89)

- 1 Gravitational potential, V_g , at a point in a field is the work done in moving a unit mass from infinity (where the gravitational potential is zero) to that point and is defined as $V_g = -\frac{GM}{r}$ where r is the distance of the unit mass from a point mass M .
- Gravitational potential energy, E , is the energy a mass, m , has in a gravitational field of potential V_g , and is given by $E = mV_g$

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2 $V_g = -\frac{GM}{r}$

If the planet's density is ρ and its radius is r : $V_g = -\frac{4G\rho\pi r^3}{3r} = -\frac{4G\rho\pi r^2}{3}$

Substituting the values given, $V_g = -\frac{4}{3} \times 6.67 \times 10^{-11} \times 6800 \times \pi \times (8.9 \times 10^6)^3 = -4.3 \times 10^{14} \text{ J kg}^{-1}$

3 When point A is further from the centre of the planet than point B.

4 (a) For an object to reach escape velocity from the surface of a body, its kinetic energy on leaving the body's surface must be greater than the increase in gravitational potential energy from the body's surface to a point at infinity, so $\frac{1}{2}mv^2 \geq \frac{GMm}{r}$ where r is the radius of the body causing the gravitational field and v is the escape velocity.

At the Schwarzschild radius R_S , the escape velocity is equal to the speed of light, c .

Hence $R_S = \frac{2GM}{c^2}$

(b) $R_S = \frac{2GM}{c^2} = 42 \text{ km}$

5 $\frac{1}{2}mv^2 \geq \frac{GMm}{r}$, where r is the radius of the body causing the gravitational field and v is the escape velocity. The Moon has a mass of $7.35 \times 10^{22} \text{ kg}$ and a radius of 1740 km.

For the Moon, $v^2 \geq \frac{2GM}{r}$ or $v^2 \geq \frac{2 \times 6.67 \times 10^{-11} \times 7.35 \times 10^{22}}{1.74 \times 10^6}$

$v^2 \geq 5.64 \times 10^6$ so $v \geq 2400 \text{ m s}^{-1}$

Practice questions (page 92)

1 B

2 C

3 D

4 A

5 D

6 (a) The gravitational potential at a point in a gravitational field is the work done in moving a unit mass from infinity to that point in the gravitational field. [1]

Measured in joules per kilogram (J kg^{-1}). [1]

A scalar quantity. [1]

(b) Gravitational potential energy is the energy stored in an object (the work an object can do) by virtue of the object being in a gravitational field. [1]

Measured in joules (J). [1]

A scalar quantity. [1]

[Total: 6]

7 (a) Substitution of G , mass of Earth, M , and radius of Earth, R , into the equation $V = -\frac{GM}{R}$ to obtain

$V = -\frac{(6.67 \times 10^{-11}) \times (6 \times 10^{24})}{6.4 \times 10^6}$ [1]

Obtaining the answer and converting it to -62.5 MJ [1]

(b) (i) Use of $V = -\frac{GM}{R}$ to determine the values for the gravitational potential at points A and B, which will be given by $-\frac{GM}{36\,000\,000}$ and $-\frac{GM}{60\,000\,000}$ respectively. [1]

Calculating the difference between the gravitational potential at points A and B, which will be given by $-\frac{GM}{36\,000\,000}$ and $-\frac{GM}{60\,000\,000} - \left(-\frac{GM}{36\,000\,000}\right)$. [1]

Substituting in the values for G and M and then doing the calculation gives a value of $+4.5 \times 10^6 \text{ J}$ [1]

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- (ii) Since moving from point A to point B is moving away from the Earth and requires work to be done, moving from point B to point A will involve a change in gravitational potential of $-4.5 \times 10^6 \text{ J}$ [1]

[Total: 6]

- 8 (a) Substitution of values to obtain $\frac{T^2}{R^3}$ for Mercury and obtaining a value of 0.98 [1]
 Substitution of values to obtain $\frac{T^2}{R^3}$ for Jupiter and obtaining a value of 0.99 [1]
 Determining the ratio as being 0.98 : 0.99 or about 0.99 : 1 [1]
- (b) Use of Kepler's third law equation $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ and substitution of values from both planets [1]
 Rearranging to make M the subject of the equation for both planets and calculating this value for each example. [1]
 Obtaining a mean value by adding both values and halving of $\sim 2 \times 10^{30} \text{ kg}$. [1]

[Total: 6]

- 9 (a) Equate $F = mr\omega^2$ to $\frac{GMm}{r^2}$ i.e. $mr\omega^2 = \frac{GMm}{r^2}$ [1]
 Substitute $\frac{2\pi}{T}$ into the equation for ω and rearrange, cancelling the 'm's. [1]
 Show that $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ and that this is Kepler's third law. [1]
- (b) Rearrange equation to make r the subject of the formula and substitute values for G , M and T into the equation. [1]
 Determine a value for r of $\sim 42\,000 \text{ km}$. [1]
 Subtract the value for the radius of the Earth to obtain a value of $\sim 36\,000 \text{ km}$. [1]

[Total: 6]

- 10 Refer to official mark scheme for OCR past paper G484 June 2011; this is Q3. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.

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5.5 Astrophysics and cosmology

5.5.1 The structure of the Universe (page 97)

- 1 comet, Moon, Earth, Jupiter, Sun, Alpha Centauri, Milky Way, universe (although we don't know if Alpha Centauri is bigger or smaller than the Sun)
- 2
 - (a) $4.24 \text{ light-years} = (4.24 \times 365 \times 24 \times 60 \times 60) \times 3 \times 10^8 \text{ m}$, or $4.0 \times 10^{16} \text{ m}$
 - (b) $25\,000 \text{ light-years} = (25\,000 \times 365 \times 24 \times 60 \times 60) \times 3 \times 10^8 \text{ m}$, or $2.4 \times 10^{20} \text{ m}$
 - (c) Assuming that our Solar System is at the centre of observable Universe, 93 billion light-years $= (93 \times 10^9 \times 365 \times 24 \times 60 \times 60) \times 3 \times 10^8 \text{ m}$, or $8.8 \times 10^{26} \text{ m}$
- 3
 - (a) Students' own research. A planetary satellite. Answers should mention time of orbit around Saturn and possibly composition of Titan.
 - (b) Students' own research. A comet. Answers should mention time of orbit around the Sun, elliptical nature, and possibly composition of the comet.
 - (c) Students' own research. A galaxy. Answers should mention distance in light years and refer to approximate number of stars.
 - (d) Students' own research. A star with a planetary system. Answers should mention planetary satellites, solar system, time of orbit for each satellite, distance in light-years to Kepler-11 and name of galaxy it is in.
 - (e) Students' own research. A spiral galaxy. Answers should mention its distance in light-years from the Sun and refer to approximate number of stars.

5.5.2 Star formation and life cycle (page 101)

- 1
 - (a) Find the number of atoms in the Sun – the nebula contains the same number of atoms. If the number of atoms in the Sun is N and the radius of the Sun is r , the number of particles per unit volume, n , equals $\frac{N}{\frac{4}{3}\pi r^3}$. The number of particles per unit volume can also be expressed in terms of the mean separation of atoms, d , imagining each atom as a cube of side length d and each atom occupying a volume of d^3 . So n can also be written as $n = \frac{1}{d^3}$. Hence $\frac{N}{\frac{4}{3}\pi r^3} = \frac{1}{d^3}$.
 Substituting for $r = 7.0 \times 10^8 \text{ m}$ and $d = 1.0 \times 10^{-10} \text{ m}$ gives:

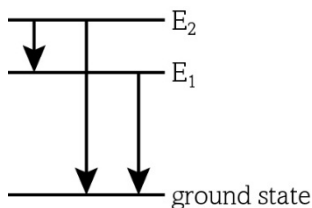
$$N = \frac{4}{3} \times \pi \times \frac{(7.0 \times 10^8)^3}{(1.0 \times 10^{-10})^3} = 1.440 \times 10^{57}$$
 In the nebula, number of particles per unit volume $= \frac{1}{d^3}$ where for the nebula $d = 2.3 \times 10^{-3} \text{ m}$ and number of particles per unit volume $= \frac{\text{total number of atoms}}{\text{volume of nebula}}$.
 Hence volume of nebula $= \text{total number of atoms} \times d^3 = 1.440 \times 10^{57} \times (2.3 \times 10^{-3})^3 = 1.8 \times 10^{49} \text{ m}^3$
 - (b) Mass of the Sun $= \text{density} \times \text{volume} = 1400 \times \frac{4}{3} \pi (7.0 \times 10^8)^3 = 2 \times 10^{30} \text{ kg}$
- 2
 - (a) Power output $= \text{energy transferred per second} = 4 \times 10^{26} \text{ W}$
 From $E = mc^2$, the change in mass per second $= \frac{4 \times 10^{26}}{c^2} = 4.4 \times 10^9 \text{ kg s}^{-1}$
 - (b) Initial mass $= 2 \times 10^{30} \text{ kg}$
 Decrease in mass $= 1\% \times 2 \times 10^{30} \text{ kg} = 2 \times 10^{28} \text{ kg}$
 If rate of loss of mass is $4.4 \times 10^9 \text{ kg s}^{-1}$, time taken to reach this mass $= 4.54 \times 10^{18} \text{ s}$ or 152 billion years.
- 3 Neutron stars are not present on the Hertzsprung–Russell diagram because their temperatures are extremely high and cannot be plotted at the scale of the diagram. Black holes are not present on the Hertzsprung–Russell diagram because they emit no radiation and cannot be seen directly.

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- 4 Hydrogen comes from the matter created shortly after the Big Bang (as will be explained in Topics 5.5.7 to 5.5.8). In young hot stars that formed under gravitational collapse, fusion of hydrogen nuclei formed helium, and fusion of helium nuclei formed heavier elements such as carbon and oxygen. Other elements, up to iron in the periodic table, were created by fusion in the core of stars like the Sun as they developed. Elements heavier than iron were formed in supernovae, resulting from the collapse of high-mass stars.
- 5 (a) Less than 1.4 times the mass of our Sun
 (b) (i) More than 1.4 times the mass of our Sun
 (ii) More than 4 times the mass of our Sun

5.5.3 Electromagnetic radiation from stars (page 105)

- 1 (a)/(b)



- (c) Radiation is emitted at three frequencies. The three possible transitions are E_2 to E_1 , E_1 to ground state and E_2 to ground state.

$$E_2 = \frac{hc}{\lambda_2} = \frac{6.626 \times 10^{-34} \times 3.00 \times 10^8}{540 \times 10^{-9}} = 3.7 \times 10^{-19} \text{ J}$$

$$E_1 = \frac{hc}{\lambda_3} = \frac{6.626 \times 10^{-34} \times 3.00 \times 10^8}{290 \times 10^{-9}} = 6.9 \times 10^{-19} \text{ J}$$

$$\text{Check: } \frac{hc}{\lambda_1} = \frac{6.626 \times 10^{-34} \times 3.00 \times 10^8}{620 \times 10^{-9}} = 3.2 \times 10^{-19} \text{ J, which equals } E_2 - E_1$$

- (d) Yellow (a mixture of the red and green wavelengths)

- 2 (a) Wavelengths of 589.0 and 589.6 nm

$$\text{Frequencies are } \frac{c}{\lambda} \text{ or } 5.093 \times 10^{14} \text{ Hz and } 5.088 \times 10^{14} \text{ Hz}$$

- (b) $E_1 = hf = 6.626 \times 10^{-34} \times 5.093 \times 10^{14} \text{ J} = 3.375 \times 10^{-19} \text{ J}$

$$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J so } E_1 = 2.109 \text{ eV}$$

$$E_2 = hf = 6.626 \times 10^{-34} \times 5.088 \times 10^{14} \text{ J} = 3.371 \times 10^{-19} \text{ J} = 2.107 \text{ eV}$$

- 3 Ionisation energy is the energy required to remove an electron from an atom completely, i.e. to take it to a point where the energy is zero or positive. For an electron initially in its ground state, the minimum ionisation energy is the energy difference between the ground state and the zero energy level, or 13.6 eV.

$$\text{For } \frac{1}{2}mv^2 \geq 13.6 \text{ eV, } v^2 \geq \frac{2 \times 13.6 \times 1.60 \times 10^{-19}}{9.11 \times 10^{-31}}$$

$$v^2 \geq 4.78 \times 10^{12}$$

$$v \geq 2.2 \times 10^6 \text{ m s}^{-1}$$

- 4 (a) Hot gases produce emission (line) spectra when photons are emitted due to the transition of electrons between discrete energy levels in atoms of the gas. The line spectrum has certain, fixed frequencies related to the differences in energy between the various energy levels of the atoms of the gas.
- (b) Hot sources observed through cold gases produce absorption spectra (dark lines in a continuous emission spectrum), because atoms of different elements in the cold gas absorb energy emitted from the hot source but only at particular energy values. These particular energy values correspond to the differences in energy between the energy levels of a bound electron. (This is the opposite of what happens in line emission in part (a).) This means that particular frequencies of light are absorbed, creating black lines in the continuous emission spectrum.

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- 5 (a) $n\lambda = d \sin\theta$
 $n = 2$, $\theta = 34^\circ$ and $d = \frac{1}{600\,000}$
 $\lambda = \frac{\sin 34}{2 \times 600\,000} = 4.41 \times 10^{-7} \text{ m}$
- (b) This is in the red region of visible light.
- 6 Different atoms produce different spectral lines and so the absorption lines in a star's spectrum can be used to identify elements within that star's atmosphere. As a star evolves, it fuses all the hydrogen into helium and begins to fuse helium into heavier and heavier elements, eventually producing iron. Hence the presence of hydrogen indicates a relatively young star, and the presence of elements from helium to iron indicates the products of nuclear fusion for increasingly older stars.
- However, new stars form from nebulae that have been enriched with heavier elements through supernova explosions, and so the atmosphere of these stars contains atoms and ions of heavier elements, including elements beyond iron in the periodic table. Hence if a star contains a relatively high percentage of heavy elements, it is relatively young.
- 7 (a) Substituting in $\lambda = \frac{4n^2}{n^2-4} \times 91.176 \text{ nm}$
For $n = 3$, $\lambda = 656 \text{ nm}$
For $n = 4$, $\lambda = 486 \text{ nm}$
- (b) In Bohr's model (Figure 3), for the $n = 3$ to $n = 2$ transition:
 $\Delta E = E_3 - E_2 = -1.51 \text{ eV} - (-3.41 \text{ eV}) = 1.90 \text{ eV}$
Using $E = hf$ gives the frequency of the associated photon as:
 $f = \frac{E}{h} = \frac{1.90 \times 1.60 \times 10^{-19}}{6.626 \times 10^{-34}} = 4.59 \times 10^{14} \text{ Hz}$ and $\lambda = 654 \text{ nm}$
From Worked example 1, in Bohr's model the $n = 4$ to $n = 2$ transition has a wavelength of 488 nm. Thus Balmer's model is a good fit to Bohr's model.
- (c) Balmer's formula only works for electrons falling from the n th level into the second level, and there are many other transitions possible, such as into the third or fourth levels, or the ground state.

5.5.4 Wien's law and Stefan's law (page 108)

- 1 (a) The power transmitted per unit area (Wm^{-2})
(b) The total energy that the star emits per second, or power (W)
- 2 (a) $\lambda_{\text{max}} T = \text{constant}$, where the constant has a value of $2.89 \times 10^{-3} \text{ mK}$, T is the star's surface temperature (in K) and λ_{max} is the wavelength that corresponds to the peak intensity of the star's spectrum.
(b) $L = 4\pi r^2 \sigma A T^4$ where L is the star's luminosity (in W), T is the star's surface temperature (in K), r is the star's radius (in m), σ is a constant (value $5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$) and A is the star's surface area (in m^2).
(c) Intensity, I , and luminosity, L , are related by the equation:
 $I = \frac{L}{4\pi d^2}$ where d is the distance from the star
- 3 $T \sim 6000 \text{ K}$, so from $\lambda_{\text{max}} T = 2.89 \times 10^{-3}$, $\lambda_{\text{max}} = \frac{2.89 \times 10^{-3}}{6000} = 482 \text{ nm}$
- 4 (a) $A = 4\pi r^2 = 4\pi (2.07 \times 10^6)^2 = 5.38 \times 10^{13} \text{ m}^2$
(b) $\lambda_{\text{max}} T = 2.89 \times 10^{-3}$ so $T = \frac{2.89 \times 10^{-3}}{118 \times 10^{-7}} = 24\,500 \text{ K}$
(c) $L = 4\pi r^2 \sigma T^4 = 5.38 \times 10^{13} \times 5.67 \times 10^{-8} \times (24\,500)^4 = 1.10 \times 10^{24} \text{ W}$
(d) $I = \frac{L}{4\pi d^2}$ so $d^2 = \frac{L}{4\pi I} = \frac{1.10 \times 10^{24}}{4\pi \times 4.36 \times 10^{-11}} = 2.00 \times 10^{33}$, $d = 4.48 \times 10^{16} \text{ m}$
(e) Time taken = $\frac{\text{distance}}{c} = 1.49 \times 10^8 \text{ s}$, or 4.7 years
- 5 Luminosity is proportional to T^4 , so $\left(\frac{5700}{4500}\right)^4 = \text{about } 3 \text{ times}$

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6 (a) $\lambda_{\max} T = 2.89 \times 10^{-3}$ so Rigel's temperature is 11 560 K

(b) Ratio of luminosities $\frac{L_R}{L_S} = \frac{r_R^2 T_R^4}{r_S^2 T_S^4}$

$$66\,000 = \frac{r_R^2 (11\,560)^4}{r_S^2 (5780)^4}$$

$$\frac{r_R^2}{r_S^2} = \frac{66\,000 \times 5780^4}{14\,450^4} = 4125$$

Rigel has a radius about 64 times that of the Sun

5.5.5 Astronomical distances (page 111)

1

Distance	In astronomical units (AU)	In light-years (ly)	In parsec (pc)
Earth to the Sun	1	1.6×10^{-5}	4.8×10^{-6}
Sun to Alpha Centauri	2.77×10^5	4.37	1.34
Sun to the centre of the Milky Way	1.8×10^9	2.7×10^4	8500

2 For small angles, θ (in rad) $\approx \tan \theta$

$$\tan p = \frac{1 \text{ AU}}{4.5 \text{ ly}} \text{ so } p \approx \frac{1.5 \times 10^{11}}{4.5 \times 9.5 \times 10^{15}} = 3.5 \times 10^{-6} \text{ rad}$$

3 (a) For small angles, $p = \frac{1}{d}$ where d is in parsec and p is in seconds of arc, so $d = \frac{1}{3.6 \times 10^{-4}} = 2780 \text{ pc}$

(b) 1 light-year = $9.5 \times 10^{15} \text{ m}$, so $2780 \text{ pc} = 9072 \text{ ly}$

(c) 1 AU = $1.5 \times 10^{11} \text{ m}$, so $2780 \text{ pc} = 5.7 \times 10^8 \text{ AU}$

(d) 1 pc = $3.1 \times 10^{16} \text{ m}$, so $2780 \text{ pc} = 8.6 \times 10^{19} \text{ m}$

4 (a) Distance from Earth to the Andromeda galaxy $\approx 10^6 \text{ ly}$

$$1 \text{ AU} = 1.5 \times 10^{11} \text{ m}, \text{ so in AU this distance is about } 6 \times 10^{10} \text{ AU}$$

(b) Distance to the Coma cluster $\approx 5 \times 10^8 \text{ ly}$ and distance to the Hydra cluster $\approx 10^{10} \text{ ly}$, so distance between them $\approx 9.5 \times 10^9 \text{ ly}$.

$$1 \text{ pc} \approx 3.1 \times 10^{16} \text{ m} \text{ so } 9.5 \times 10^9 \text{ ly is about } 3 \times 10^{14} \text{ pc}$$

5 Earth's orbit is so small compared to the distances to stars that even the nearest stars have very small angles of parallax / apparent changes in position.

5.5.6 The Doppler effect and red shift (page 114)

1 $\frac{\Delta f}{f} \approx \frac{v}{c}$ so $v = \frac{c \Delta f}{f} = \frac{3.0 \times 10^8 \times (3.6 \times 10^{14} - 3.3 \times 10^{14})}{3.6 \times 10^{14}} = 2.5 \times 10^7 \text{ m s}^{-1}$

2 $\frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$ so $v = \frac{c \Delta \lambda}{\lambda} = 3.0 \times 10^8 \times 0.04 = 1.2 \times 10^7 \text{ m s}^{-1}$

Since the wavelength is shorter (redshifted) the galaxy is moving away from the Earth.

3 The age of the Universe, $t \approx H_0^{-1}$

If $H_0 = 75 \pm 25 \text{ km s}^{-1} \text{ Mpc}^{-1}$, maximum value of t is when $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$

Converting velocities to ms^{-1} and Mpc to metres:

$$\text{maximum age} = \frac{10^6 \times 3.1 \times 10^{16}}{50\,000} = 6.2 \times 10^{17} \text{ s or 20 billion years.}$$

Minimum value of t is when $H_0 = 100 \text{ km s}^{-1} \text{ Mpc}^{-1}$

$$\text{Therefore, minimum age} = \frac{10^6 \times 3.1 \times 10^{16}}{10\,000} = 3.1 \times 10^{17} \text{ s or 9.8 billion years}$$

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- 4 There are large uncertainties in the value of H_0 , and hence in estimates of the age of the Universe, due to random and systematic errors involved when calculating the distance to a star (the distance scale to galaxies is not well calibrated). The calculation also assumes that the galaxy has been travelling at the same speed throughout its existence. In practice it must have gained some gravitational potential energy during its lifetime, which will mean it has lost some kinetic energy. This has the effect of slowing down the rate of expansion of the Universe. The present speed of a galaxy is therefore below its average speed. If the average speed is used in the above calculation, therefore, the time since the Big Bang will be lower. There is also a problem at the time of the Big Bang itself. The galaxies did not form all at once. Any time delay at this stage has been ignored.
- 5 ‘Little’ because the speed of recession of other stars in the galaxy is very small; ‘none’ because the galaxy is rotating, and for one star it could be that it is moving towards the Earth by rotation at the same speed as recession.
- 6 (a) The speed of recession
(b) The rate of rotation of the galaxy
- 7 $\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$ so $v = \frac{c\Delta\lambda}{\lambda} = \frac{3.0 \times 10^8 \times (4.485 \times 10^{-7} - 3.969 \times 10^{-7})}{3.969 \times 10^{-7}} = 3.90 \times 10^7 \text{ m s}^{-1}$

5.5.7 The microwave background and the cosmological principle (page 117)

- 1 (a) For example, a gas such as hydrogen or a piece of lead – the same properties in all directions and from any position.
(b) For example, rocks in the crust of the Earth – properties such as density, Young's modulus varies according to the composition and degree of fracturing of the rock and the distribution of these rocks is irregular so the properties vary in all directions.
(c) For example, the atmosphere near the surface of the Earth – mean temperature, density and pressure are the same in all directions, but composition varies randomly at a microscopic scale due to the presence of different gases and particles such as dust. Also any pattern of concentric circles where each layer has a different pattern.
(d) For example, a uniform electric field; equally spaced stripes. (Also refractive index of a birefringent material.)
- 2 The signal could not be background noise because the same signal level was always detected in any direction and the signal did not vary with time. This meant the signal could not be coming from a radio source on Earth or the Sun and Solar System (which would be an anisotropic signal).
- 3 All objects emit radiation with a range of wavelengths, and the spectrum of wavelengths has a characteristic curve shape that depends on its temperature. For example, a heated iron rod emits infrared radiation and visible light at red wavelengths and as it is heated further its colour changes from red towards white. It is the wavelength of the peak of the spectrum (maximum intensity) that is related to the object's temperature.
- 4 The microwave background provides evidence of thermal radiation (photons moving about randomly in space) everywhere in the Universe and (due to redshift by the expansion of the Universe) the very early Universe had very high temperatures. Hence the Universe had a beginning (a Big Bang). The value of 2.7 K together with the rate of Hubble expansion tells us the age of the Universe by extrapolating the ‘cooling time’ back to the Big Bang. If the Universe was younger, the microwave background temperature would be higher.
- 5 In a steady state Universe, there would be no microwave background radiation as there is no hot beginning to the Universe. When the microwave background was discovered, the steady state theory was shown to be invalid and so a modified steady state theory was proposed to account for the origin of the microwave background radiation. Small creation events (mini Big Bangs) between galaxies would be a source of microwave radiation.

5.5.8 The evolution and expansion of the Universe (page 119)

- 1 (a) If the microwave background temperature was higher, the Universe would be younger (less time for red shift by the expansion of the Universe).
(b) If there was no microwave background radiation, there could have been no hot beginning to the Universe, so no Big Bang, and no beginning of the Universe (the Universe must always have existed).
(c) If galactic red shift was lower, the recessional velocity would be lower and the age of the Universe would be lower.

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- (d) If there was no galactic red shift, the Universe could not be expanding so there could have been no hot beginning to the Universe and no Big Bang.
- 2 Physicists have no models of what might happen under conditions of very high temperature and high energy.
- 3 Any material of uniform composition and properties (homogenous) that has no anisotropy in properties (difference in properties depending on direction, such as the 'grain' in wood which makes it difficult to break across the grain).

5.5.9 Dark matter and dark energy (page 123)

- 1 The possible fates are:
- expansion slows down, stops and Universe contracts down to a Big Crunch
 - expansion continues and galaxies continue to get further apart
 - expansion gradually slow down until galaxies reach a maximum separation, which is maintained.
- The outcome depends on the density of the Universe.
- 2 Dark energy is an unknown form of energy that opposes the attractive force of gravitation between galaxies and so drives the accelerated expansion of the Universe. Dark matter is an unknown form of matter which cannot be seen and does not emit or absorb electromagnetic radiation.
- Similarities: both have been confirmed to exist, from observational evidence, but neither can be detected directly (hence 'dark').
- Differences: dark matter is located in discrete areas of space whereas dark energy is uniformly distributed throughout space and so does not affect 'local' motions of galaxies, only the motion of the Universe as a whole.
- 3 The evidence for dark matter comes from the following points:
- The mass of a galaxy estimated by measuring its luminosity does not correspond with the mass of the galaxy predicted from observations of how fast it rotates.
 - Gravitational lensing of light occurs when a massive object lies on the line of sight to a much more distant star, bending the light that reaches the observer.
- 4 The gravitational field of a galaxy exerts a centripetal force on objects rotating within (i.e. stars within the galaxy) or outside the galaxy. The tangential velocity of the orbiting star around the galactic centre depends on the mass of the galaxy within the radius of the orbiting star. The observed rate of rotation of many galaxies cannot be accounted for by the visible (luminous) mass. Therefore, there must be other mass in the galaxy that is not visible.
- 5 The rate at which the Universe expands is increasing (accelerated expansion) – a long time ago, the Universe was expanding more slowly than it is today. Something must be causing the increased expansion rate, i.e. opposing the gravitational attraction of matter in the Universe.
- 6 Students' own response.
- 7 Having dark matter that was made from normal matter would not appear to fit any agreed models of the Big Bang.
- 8 Solar neutrinos and neutrinos produced in radioactive decay have very small masses. There would have to be a new kind of neutrino with very large mass to contribute enough mass to make up the bulk of the dark matter.
- 9 Students' own research. Einstein's cosmological constant was an addition to his general theory of relativity, and said that empty space (vacuum) could possess its own energy. This form of energy would cause the Universe to expand. Einstein introduced the constant as a form of cosmic repulsion to counteract the force of gravity and thus explain how the Universe could be static and not collapse under gravity. Einstein abandoned the idea of a cosmological constant when Hubble showed the Universe was not static, but expanding. Today, the cosmological constant is a contender for dark energy, causing the Universe to expand faster and faster.

Practice questions (page 126)

- 1 C
- 2 B

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- 3 D
4 D
5 A
6 A – In the main sequence in the middle of the diagram with luminosity equal to 1 [1]
B – In the bottom left hand corner of the diagram [1]
C – Any supergiant [1]
D – A supergiant [1]
E – Any small star in the main sequence or a white dwarf [1]
F – Anywhere in the protostar region in the bottom right hand corner of the diagram [1]

[Total: 6]

- 7 (a) The end product of low-mass stars when the outer layers have dispersed into space. [1]
Formed from main sequence stars with masses less than 1.4 solar masses. [1]
(b) The maximum size of a stable white dwarf, approximately 3×10^{30} kg (about 1.4 times the mass of the Sun). [1]
Stars with mass higher than the Chandrasekhar limit ultimately collapse under their own weight and become neutron stars or black holes. [1]
(c) No two electrons with the same spin can occupy the same energy state, so some are pushed to higher energy states where they exert pressure. [1]
This pressure is known as electron degeneracy pressure and it is the force that supports white dwarf stars against their own gravity. [1]

[Total: 6]

- 8 (a) Atoms contain electron energy levels at fixed or discrete energy values. [1]
Photons are absorbed when their energy is equal to the energy gap between two energy levels in the atom's electron energy levels. [1]
The photon energies corresponding to these energy gaps are not observed, hence a dark line is present on the spectrum. [1]
(b) The electron energy levels in atoms of a particular element are at fixed, discrete values – like a fingerprint for that element. [1]
The pattern of the absorption lines of sodium gas will be in the same position as the emission lines for a sodium lamp. [1]
If sodium gas is present in the Sun, then there will be a pattern of lines in the absorption spectrum that corresponds exactly to the position of the lines in the emission spectrum. [1]

[Total: 6]

- 9 (a) Energy in J = energy in eV $\times 1.602 \times 10^{-19}$ [1]
Energy difference of 10.2 eV, hence energy level difference is 1.63×10^{-18} J [1]
(b) $\lambda = \frac{hc}{E}$ [1]
 $\lambda = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{1.63 \times 10^{-18}}$ giving $\lambda = 1.2 \times 10^{-7}$ m [1]
(c) $f = \frac{c}{\lambda}$ giving $f = \frac{3 \times 10^8}{1.2 \times 10^{-7}}$ [1]
 $f = 2.5 \times 10^{15}$ Hz [1]
(d) Ultraviolet [1]

[Total: 7]

- 10 Refer to official mark scheme for OCR past paper G485 June 2011; this is Q7. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.

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6.1 Capacitors

6.1.1 Capacitors (page 131)

1

Charge, Q/C	Potential difference, V/V	Capacitance, C/F
2.56×10^{-5}	128	200 nF
5.8×10^{-3}	14.0	430 μ F
4.2×10^{-6}	1.4×10^3	3.0×10^{-9}

- 2 $C = \frac{Q}{V}$, units of Q are coulombs (C) and units of V are joules per coulomb ($J C^{-1}$). Hence units of C (farad, F) are equivalent to $\frac{C}{J C^{-1}}$ or $C^2 J^{-1}$.
- 3 $C = \frac{Q}{V}$ so $V = \frac{Q}{C} = \frac{1.8 \times 10^{-5}}{4.0 \times 10^{-6}} = 4.5 V$
- 4 (a) $Q = CV = 200 \times 10^{-3} \times 40 = 8.0 C$
 (b) (i) average current = $\frac{\text{total charge}}{\text{total time}} = \frac{8.0}{100 \times 10^{-6}} = 8 \times 10^4 A$
 (ii) average power = $VI = 40 \times 8 \times 10^4 = 1.6 MW$
- 5 If the resistance was low it would discharge the very small amount of charge on the capacitor.

6.1.2 Capacitors in series and in parallel (page 133)

- 1 (a) (i) Total capacitance of the two parallel capacitors, C , given by:
 $C = C_1 + C_2 = 3.0 \times 10^{-6} + 3.0 \times 10^{-6} = 6.0 \times 10^{-6} F$
 The total capacitance of this in series with the other capacitor, C_{TOT} is given by:
 $\frac{1}{C_{TOT}} = \frac{1}{6.0 \times 10^{-6}} + \frac{1}{6.0 \times 10^{-6}}$ so $C_{TOT} = 3.0 \times 10^{-6} F$
- (ii) For the whole circuit, $Q = CV$ so $Q = 3.0 \times 10^{-6} \times 60 = 1.8 \times 10^{-4}$ or 180 μC .
 Hence there will be a charge of 180 μC on the 6.0 μF capacitor and a charge of 180 μC shared equally across the two 3 μF capacitors in parallel giving 90 μC on each.
- (iii) p.d. across the 6.0 μF capacitor given by $C = \frac{Q}{V}$ so $V = \frac{180 \mu C}{6.0 \mu F}$ or 30 V
 Similarly for each of the 3.0 μF capacitors, $V = \frac{90 \mu C}{3.0 \mu F}$ or 30V
- (b) Total capacitance of the two parallel capacitors, C , given by $C = 3.0 \times 10^{-6} + C_2$
 The total capacitance of this in series with the other capacitor, C_{TOT} is given by:
 $\frac{1}{C_{TOT}} = \frac{1}{6.0 \times 10^{-6}} + \frac{1}{C}$
 If $C_{TOT} = 4.0 \mu F$, $\frac{1}{4.0 \times 10^{-6}} = \frac{1}{6.0 \times 10^{-6}} + \frac{1}{C}$ giving $\frac{1}{C} = \frac{1}{12.0 \times 10^{-6}}$ and $C = 12.0 \times 10^{-6} F$
 Hence $3.0 \times 10^{-6} F + C_2 = 12.0 \times 10^{-6} F$ and $C_2 = 9.0 \mu F$
- (c) (i) For the whole circuit, $Q = CV$ so $Q = 4.0 \times 10^{-6} \times 60 = 2.4 \times 10^{-4}$, or 240 μC
 Hence there will be a charge of 240 μC on the 6.0 μF capacitor and a charge of 240 μC shared unequally across the two capacitors in parallel.
 The 9.0 μF capacitor can store three times the charge of the 3.0 μF capacitor, so the charge on the 9.0 μF capacitor is 180 μC and the charge on the 3.0 μF capacitor is 60 μC .
- (ii) p.d. across the single, 6.0 μF capacitor is $V = \frac{Q}{C} = \frac{240 \mu C}{6.0 \mu F}$ or 40 V
 p.d. across the 3.0 μF capacitor is $\frac{60 \mu C}{3.0 \mu F} = 20 V$
 p.d. across the 9.0 μF capacitor is $\frac{180 \mu C}{9.0 \mu F} = 20 V$

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- 2 (a) (i) Initial charge, Q on the $1000\ \mu\text{F}$ capacitor is $Q = CV = 1000 \times 10^{-6} \times 150.0 = 15\ \text{mC}$
- (ii) Charge is conserved, so the charge present on the capacitors in the second circuit equals the initial charge on the $1000\ \mu\text{F}$ capacitor.
- Total capacitance of the second circuit, C_{TOT} , is given by: $\frac{1}{C_{\text{TOT}}} = \frac{1}{1000\ \mu\text{F}} + \frac{1}{500\ \mu\text{F}}$
- So $C_{\text{TOT}} = \frac{1000}{3\ \mu\text{F}}$
- Charge on the $1000\ \mu\text{F}$ capacitor is given by $Q_1 = C_1 V_1$ and charge on the $500\ \mu\text{F}$ capacitor is given by $Q_2 = C_2 V_2$
- The p.d. across each capacitor is the same, so $\frac{Q_1}{C_1} = \frac{Q_2}{C_2}$ or $Q_1 = 2 \times Q_2$
- Also, $Q_1 + Q_2 = 15\ \text{mC}$, hence $Q_1 = 10\ \text{mC}$
- (b) Initial p.d. across the $500\ \mu\text{F}$ capacitor is zero. Hence change in p.d. across the $500\ \mu\text{F}$ capacitor is:
- $$\frac{Q_2}{C_2} = \frac{5\ \text{mC}}{500\ \mu\text{F}} \text{ or } 10\ \text{V}$$

6.1.3 Energy stored in a capacitor (page 136)

1

Charge (Q)	Potential difference (V)	Capacitance (C)	Energy stored (E)
78 nC	$1.4 \times 10^{-2}\ \text{V}$	$5.6 \times 10^{-6}\ \text{F}$	$5.4 \times 10^{-10}\ \text{J}$
$7.1 \times 10^{-6}\ \text{C}$	15 V	470 nF	$5.4 \times 10^{-5}\ \text{J}$
1.2 C	48 V	25 mF	29 J

- 2 (a) Energy stored, $W = \frac{1}{2} QV = 0.5 \times 3.4 \times 10^{-3} \times 18 = 0.03\ \text{J}$
- (b) Energy stored, $W = \frac{1}{2} CV^2 = 0.5 \times 9.4 \times 10^{-3} \times (80)^2 = 30\ \text{J}$
- 3 If the potential difference across a capacitor is doubled, the charge is doubled. Since $W = \frac{1}{2} CV^2$ the energy stored is proportional to the square of the charge, so the energy stored is four times greater.
- 4 Charging a capacitor can be thought of as similar to inflating a flat tyre. The air in the tyre represents the charge on the capacitor and the pressure is like the potential difference across the capacitor. The volume of the tyre itself is like the capacitance. To charge a capacitor, work must be done to separate the charges on the two plates. Charging the capacitor becomes more difficult as the charge on the plates increases and the p.d. across the plates increases. This is similar to how work must be done to move air into the tyre, and how inflating the tyre becomes more difficult as more air is moved into the tyre and the pressure increases. In the reverse situation, discharging a capacitor is similar to deflating an inflated tyre since air moves rapidly out of the tyre at first (similar to how the rate of discharge of a capacitor is initially high) because the pressure is high (similar to a large p.d. causing a large current to flow).
- 5 (a) Energy is conserved, so the total energy stored on the capacitors in the second circuit equals the initial energy stored on the $12\ \mu\text{F}$ capacitor, equal to $\frac{1}{2} CV^2 = 0.5 \times 12 \times 10^{-6} \times (40)^2 = 0.01\ \text{J}$
- Total capacitance of the second circuit, C_{TOT} is given by $\frac{1}{C_{\text{TOT}}} = \frac{1}{12\ \mu\text{F}} + \frac{1}{80\ \mu\text{F}}$ so $C_{\text{TOT}} = 10.4\ \mu\text{F}$
- For the whole of the second circuit, energy stored $= \frac{1}{2} C_{\text{TOT}} V^2 = 0.01\ \text{J}$
- Hence $\frac{V^2}{2} = \frac{0.01}{10.4 \times 10^{-6}}$ and $V = 43.8\ \text{V}$. V is the total p.d. across the two capacitors.
- The charge present on each capacitor in the second circuit is the same. Call this Q .
- Charge on each capacitor is given by $Q = CV$, hence $C_1 V_1 = C_2 V_2$ and $V_1 = \frac{C_2 V_2}{C_1} = \frac{12 \times V_2}{80}$
- Hence $V_2 + \frac{12 \times V_2}{80} = 43.8\ \text{V}$ and $V_2 = 38.07\ \text{V}$ (across the $12\ \mu\text{F}$ capacitor) and $V_1 = 5.71\ \text{V}$ (across the $80\ \mu\text{F}$ capacitor), or $38\ \text{V}$ and $6\ \text{V}$
- (b) $Q = CV$, so looking at the $80\ \mu\text{F}$ capacitor, $Q = 80 \times 10^{-6} \times 5.71 = 0.5\ \text{mC}$
- (Check: for $12\ \mu\text{F}$ capacitor, $Q = 12 \times 10^{-6} \times 38.07 = 0.5\ \text{mC}$)

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- (c) Let the energy stored in the second circuit on the $12 \mu\text{F}$ capacitor be E_1 and the energy stored in the second circuit on the $80 \mu\text{F}$ capacitor be E_2 .

$$E_1 = \frac{1}{2} C_1 V_1^2 = 0.5 \times 80 \times 10^{-6} \times (5.71)^2 = 0.001 \text{ J}$$

$$E_2 = \frac{1}{2} C_1 V_1^2 = 0.5 \times 12 \times 10^{-6} \times (38.07)^2 = 0.009 \text{ J}$$

(Check: $E_1 + E_2 = 0.01 \text{ J}$)

6.1.4 Charging and discharging capacitors (page 140)

1

Charge, Q	Potential difference, V	Capacitance, C	Resistance, R	Time constant, RC
1.8 mC	12.9 V	140 μF	500 $\text{M}\Omega$	$7 \times 10^4 \text{ s}$
0.56 C	12 V	47 mF	$4.3 \times 10^3 \Omega$	200 s
400 nC	$1.1 \times 10^{-4} \text{ V}$	$3.8 \times 10^{-3} \text{ F}$	80 $\text{k}\Omega$	5 minutes

- 2 As a cup of hot tea cools, the temperature falls quickly at first since there is a large temperature difference between the tea and the air. However, the rate of cooling decreases as the tea approaches room temperature. It can be shown that the rate of change of energy transfer is directly proportional to the difference in temperature between a body and its surroundings. This produces an exponential change, as in the discharge of a capacitor where the charge transferred off the capacitor when its charge decreases by an amount ΔQ is proportional to the charge remaining, Q .

- 3 $Q = Q_f \left(1 - e^{-\frac{t}{CR}}\right)$ where CR is the time constant and Q_f is the final charge on the capacitor when it is fully charged.

$$Q_f = CV = 470 \times 10^{-6} \times 9 = 4.23 \text{ mC}$$

$$\text{Time constant } CR = 470 \times 10^{-6} \times 40 \times 10^3 = 18.8 \text{ s}$$

$$\text{Hence after 5 s, } Q = Q_f \left(1 - e^{-\frac{t}{CR}}\right) = 4.23 \times 10^{-3} \times \left(1 - e^{-\frac{5}{18.8}}\right) = 1.0 \text{ mC}$$

- 4 (a) Initial current $= \frac{V}{R} = \frac{26}{40\,000} = 0.65 \text{ mA}$

- (b) (i) The p.d. has halved in 5.5 s. In exponential decay, the time taken for the quantity to decrease by a certain ratio is fixed so in 5.5 s the p.d. halves again to 6.5 V.

$$(ii) \text{ Time constant, } CR = 200 \times 10^{-6} \times 40\,000 = 8.0 \text{ s}$$

$$\text{At 11 s, } I = I_0 e^{-\frac{t}{CR}} = 0.65 \times 10^{-3} \times e^{-\frac{11}{8}} = 0.16 \text{ mA}$$

- (c) (i) After 8.0 s, p.d. $V = V_0 e^{-\frac{t}{CR}} = 26 \times e^{-\frac{8}{8}} = 9.6 \text{ V}$

$$(ii) I = I_0 e^{-\frac{t}{CR}} = 0.65 \times 10^{-3} \times e^{-\frac{8}{8}} = 0.24 \text{ mA}$$

- (d) Using the exponential expressions for p.d. across the capacitor, ratio of p.d. values at 11 s and 8 s is

$$\frac{e^{-\frac{11}{8}}}{e^{-\frac{8}{8}}} = e^{-\left(\frac{11}{8} - \frac{8}{8}\right)} = e^{-\frac{3}{8}} = 0.69$$

- (e) If V falls to 1.0 V, from $V = V_0 e^{-\frac{t}{CR}}$ so $\frac{1}{26} = e^{-\frac{t}{CR}} = e^{-\frac{t}{8}}$

$$\text{Taking natural logs of both sides, } \frac{t}{8} = \ln 26 \text{ and } t = 26 \text{ s}$$

6.1.5 Graphical and spreadsheet methods (page 143)

- 1 (a) A graph of $\ln V$ against t for a discharging capacitor will show a straight line of the form

$$\ln V = \ln V_0 - \frac{t}{CR}$$

Hence the time constant CR can be found from the gradient (the gradient $= -\frac{1}{CR}$).

- (b) A graph of $\frac{\Delta Q}{\Delta t}$ against Q for a discharging capacitor will show a straight line passing through the origin, with gradient $-\frac{1}{CR}$

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- 2 After each time constant, the p.d. across the capacitor will fall by $\frac{1}{e}$
Hence after a time equal to three time constants, the p.d. across the capacitor will fall by $\frac{1}{e^3}$
- 3 (a) Students' own spreadsheet. After 3.0 s, $Q = 3.04$ s
(b) Students' own graph. Gradient = -0.101 . Since gradient = $-\frac{1}{CR}$ time constant $CR = 9.9$ s.
(c) Calculated CR value = 10 s
Percentage different of graph value from actual value = $\frac{(10-9.9)}{10} \times 100\% = 1\%$
(d) If the iterative model uses a longer time step, such as 1 s, the approximation in the calculation becomes less accurate. The inaccurate values are then carried through to the next iterative step, further increasing the inaccuracy in the calculation. The value obtained from the graph will be much less accurate, and the percentage difference from the true value will be much greater.

Practice questions (page 146)

- 1 B
2 A
3 D
4 B
5 C
6 (a) Charging occurs when the switch is in the charge position. [1]
Electrons flow off the upper plate of the capacitor to the cell and onto the lower plate from the cell, setting up a p.d. [1]
Discharging occurs when the switch is in the discharge position. [1]
Electrons flow off the lower plate and round the circuit towards the upper plate, through the ammeter and the 1 M Ω resistor. [1]
(b) (i) $Q = VC$. Substituting gives $Q = 18 \times 200 \times 10^{-3}$ [1]
Answer of $Q = 3.6$ C [1]
(ii) Time constant = RC . Substituting gives a value of $500 \times 200 \times 10^{-3}$ [1]
Value for the time constant in the charging circuit is 100 s [1]
(iii) Time constant = RC . Substituting gives a value of $10^6 \times 200 \times 10^{-3}$ [1]
Value for the time constant in the discharging circuit is 200 000 s [1]
(iv) Use of $Q = Q_0 e^{-t/RC}$ for the charging circuit, with substitution to give $Q = 3.6 e^{-4/200\,000}$ [1]
Answer for Q of 3.6 C [1]
(c) A circuit where the capacitor can be charged quickly and then discharged slowly. [1]
An example – an LED which can be lit after a short period of charging, a radio which can be charged and then played using a small current. [1]
[Total: 14]
- 7 (a) (i) $Q = VC$ [1]
Substitution of values, i.e. $Q = 470 \times 10^{-6} \times 16$ [1]
Final answer for Q of 7.5×10^{-4} C [1]
(ii) Energy stored, $E = \frac{1}{2} CV^2$ followed by substitution, i.e. $E = \frac{1}{2} 470 \times 10^{-6} \times 16^2$ [1]
Final answer of $E = 0.06$ J [1]

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- (b) Use of equation to calculate total capacitance in series, i.e. $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$ [1]

Substitution of values into equation to obtain new value of 235 μF [1]

New charge value of $Q = 3.75 \times 10^{-4} \text{ C}$ [1]

New energy value of $E = 0.03 \text{ J}$ [1]

[Total: 9]

- 8 Refer to official mark scheme for OCR past paper G485/01 June 2013; this is Q1. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.
- 9 Refer to official mark scheme for OCR past paper G485 June 2011; this is Q2. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk.

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6.2 Electric fields

6.2.1 Electric fields (page 151)

- 1 (a) $E = \frac{F}{Q} = \frac{1.4 \times 10^{-4} \text{ N}}{5.0 \times 10^{-9} \text{ C}} = 2.8 \times 10^4 \text{ N C}^{-1}$
 (b) $1.4 \times 10^{-4} \text{ N}$ towards the positive sphere

2

Electric field strength, $E/\text{N C}^{-1}$	Force, F/N	Charge, Q/C
1800	450	0.25
2×10^{-3}	3.2×10^{-22}	1.6×10^{-19}
400	6×10^{-8}	1.5×10^{-10}

- 3 (a) Like Figure 1 on page 150 but with the arrows pointing in the opposite direction.
 (b) Like Figure 3 on page 151 but with the arrows pointing in the opposite direction.
 (c) Like Figure 6 on page 151 but with the lines beginning at point positive charges, rather than at the surfaces of positively charged spheres.
- 4 (a) Top plate positive, bottom plate negative
 (b) Vertical downward arrows of equal length
 (c) $E = \frac{F}{Q}$ so $F = EQ = 8.0 \times 10^4 \times 1.6 \times 10^{-19} = 1.3 \times 10^{-14} \text{ N}$

6.2.2 Coulomb's law (page 154)

- 1 (a) $2F$
 (b) $4F$
 (c) F
 (d) F
- 2 (a) Similarities: inverse square law with distance, lines of equal field strength for a point source are concentric circles
 (b) Differences: electric field strength can be either positive or negative but gravitational field strength is always positive
- 3 (a) (i) The product of the charges has increased by a factor of $\frac{9}{6} = \frac{3}{2}$ so the force also increases by this factor, to $6.0 \times 10^{-9} \text{ N}$
 (ii) The distance between them has increased by a factor of $\frac{12}{9} = \frac{4}{3}$ so the force decreases by the square of this factor, to $2.3 \times 10^{-9} \text{ N}$
 (b) $E = \frac{F}{Q} = \frac{4.0 \times 10^{-9} \text{ N}}{6.0 \times 10^{-12} \text{ C}}$
 $E = 670 \text{ N C}^{-1}$
- 4 Resultant field strength = field strength due to $+Q$ charge + field strength due to $+2Q$ charge
 Resultant field strength = $\frac{Q}{4\pi\epsilon_0 x^2} + \frac{2Q}{4\pi\epsilon_0 (0.6-x)^2}$
 If the resultant field strength at x is 0, $\frac{Q}{4\pi\epsilon_0 x^2} = \frac{2Q}{4\pi\epsilon_0 (0.6-x)^2}$ so $\frac{1}{x^2} = \frac{2}{(0.6-x)^2}$ and $2x^2 = 0.6^2 + x^2 - 1.2x$
 This can be rewritten as $x^2 + 1.2x - 0.36 = 0$
 Using the quadratic formula, $x = -1.2 \pm \sqrt{1.2^2 - 4 \times (-0.36)}$
 $x = 0.5 \text{ m}$ or -2.9 m

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6.2.3 Uniform electric fields (page 158)

- 1 Similarities: field lines represent the direction in which a positive unit charge would move if placed at that point in the field

Differences: for a radial field, field lines diverge as we move further away from the source, and field strength decreases with distance whereas for a uniform field the field lines are parallel and the field strength is the same at every point

- 2 (a) The equation $E = \frac{V}{d}$ is used for a uniform electric field between the parallel plates of a capacitor with a p.d. of V and a plate separation d .
- (b) The equation $E = \frac{F}{Q}$ is used for any electric field due to a charged body of charge Q .
- (c) The equation $E = \frac{1}{4\pi\epsilon_0} \times \frac{Q}{r^2}$ is used for a point source, where the field is radial.
- 3 (a) $E = \frac{V}{d} = \frac{600}{1.2 \times 10^{-2}} = 5.0 \times 10^4 \text{ N C}^{-1}$
- (b) (i) Forces are balanced so weight = electric force. Therefore, $F = 3.3 \times 10^{-14} \text{ N}$ and the direction of force is upwards.
- (ii) $F = E \times Q$ so $3.3 \times 10^{-14} = 5.0 \times 10^4 \times Q$ and $Q = 6.6 \times 10^{-19} \text{ C}$
- (iii) The sphere will accelerate upwards until it hits the top plate.
- 4 (a) (i) KE gained = work done on the charge against the electric field
The potential difference V is the work done per unit charge, so work done on a charge $e = eV$
 $\frac{1}{2}mv^2 = eV = 1.6 \times 10^{-19} \times 600 = 9.6 \times 1.6 \times 10^{-17} \text{ J}$
- (ii) $\frac{1}{2}mv^2 = eV$ so $v^2 = \frac{2eV}{m} = \frac{2 \times 1.6 \times 10^{-19} \times 600}{9.11 \times 10^{-31}}$ giving $v = 1.5 \times 10^7 \text{ m s}^{-1}$
- (b) (i) $E = \frac{V}{d} = \frac{500}{0.004} = 1.3 \times 10^4 \text{ N C}^{-1}$
- (ii) 1. Students should have sketched five equally spaced vertical lines from top plate to bottom plate.
2. Students should have sketched a parabolic path curving upwards between plates and then a straight path to the screen.
- (iii) The beam will follow a parabolic path curving upwards between the plates: this is because there is no horizontal force (so the horizontal speed is constant) but the vertical force between the plates, due to the electric field, causes the electrons to accelerate upwards. Once outside the field region, there is no force so the beam will follow a straight path to the screen.
- 5 (a) $C = \frac{\epsilon_0 A}{d} = \frac{8.854 \times 10^{-12} \times (0.45 \times 0.45)}{12 \times 10^{-3}} = 1.5 \times 10^{-10} \text{ F}$
- (b) $C = \frac{\epsilon_0 A}{d}$ and $\epsilon = \epsilon_r \epsilon_0$, so $C = \frac{4.6 \times 8.85 \times 10^{-12} \times (0.45 \times 0.45)}{28 \times 10^{-3}}$ or $C = 2.9 \times 10^{-10} \text{ F}$
- (c) $C = \frac{\epsilon A}{d}$ and $\epsilon = \epsilon_r \epsilon_0$, so $C = \frac{2.3 \times 8.85 \times 10^{-12} \times (0.8 \times 0.45 \times 0.45)}{2 \times 10^{-3}}$ or $C = 1.6 \times 10^{-9} \text{ F}$

6.2.4 Electric potential and electric potential energy (page 161)

- 1 Electric potential at a point is the work done in bringing a unit charge from infinity to that point. The unit is J C^{-1} or V. Electric potential energy is the work done on a charge to move it in a direction opposite to the direction of the electric field. The unit is J.
- 2 $V = \frac{Q}{4\pi\epsilon_0 r} = \frac{36}{4\pi \times 8.85 \times 10^{-12} \times 0.48} = 3.2 \times 10^{11} \text{ V}$
- 3 At 1.2 m from a point source of charge +60 mC, the electric potential
- $$V = \frac{1}{4\pi\epsilon_0} \times \frac{Q}{r} = \frac{1}{4\pi\epsilon_0} \times \frac{60 \times 10^{-3}}{1.2} = 4.49 \times 10^8 \text{ J C}^{-1}$$
- The work done to bring an electron from infinity to this point = $eV = 1.6 \times 10^{-19} \times 4.49 \times 10^8 = 7.2 \times 10^{-11} \text{ J}$

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- 4 At a point that is 45 cm away from a point charge of +9 nC, the electric potential

$$V = \frac{1}{4\pi\epsilon_0} \times \frac{Q}{r} = \frac{\frac{1}{4\pi\epsilon_0} \times 9 \times 10^{-9}}{0.45} = 180 \text{ V}$$

At a point that is 36 cm away from the point source, the electric potential the electric potential

$$V = \frac{1}{4\pi\epsilon_0} \times \frac{Q}{r} = \frac{1}{4\pi\epsilon_0} \times \frac{9 \times 10^{-9}}{0.36} = 225 \text{ V}$$

Potential difference between these points = $(225 - 180) \text{ V} = 45 \text{ V}$

- 5 (a) $C = 4\pi\epsilon_0 R = 4\pi \times 8.85 \times 10^{-12} \times 0.52 = 5.8 \times 10^{-11} \text{ F}$
 (b) $C = \frac{Q}{V}$ so $Q = CV = 5.8 \times 10^{-11} \times 120 = 6.9 \times 10^{-9} \text{ C}$
 (c) Electric potential $V = \frac{Q}{4\pi\epsilon_0 r}$ so at a point 68 cm from the surface of the isolated sphere,

$$V = \frac{\frac{1}{4\pi\epsilon_0} \times 6.9 \times 10^{-9}}{0.68} = 92 \text{ V}$$

 (d) Electrical energy stored by the sphere = $\frac{1}{2} QV = 0.5 \times 6.9 \times 10^{-9} \times 92 = 3.2 \times 10^{-7} \text{ J}$

Practice questions (page 164)

- 1 C
 2 D
 3 A
 4 A
 5 D
 6

Gravitational field	Electric field
The force between two masses is always attractive in nature	The force between two charges can be either attractive or repulsive in nature [1]
$F = (-) \frac{GMm}{r^2}$ [1]	$F = \frac{Qq}{4\pi\epsilon_0 r^2}$
Will cause a mass within it to accelerate [1]	Will cause a charge within it to accelerate
Has infinite range	Has infinite range [1]

[Total: 4]

- 7 (a) (i) Use of the equation $C = \frac{\epsilon_0 A}{d}$ [1]
 Substitution of values: $C = \frac{8.85 \times 10^{-12} \times 0.12^2}{0.05}$ [1]
 Final answer (must have unit) of $C = 2.5 \times 10^{-12} \text{ F}$ (or 2.5 pF) [1]
 (ii) Use of $Q = VC$ and substitution of values [1]
 Correct answer of $3.1 \times 10^{-11} \text{ C}$ [1]
 (iii) Use of $E = \frac{1}{2} CV^2$ and substitution (or another equation for calculating the stored energy) [1]
 Calculation of correct answer of $1.8 \times 10^{-10} \text{ J}$ [1]
 (b) Use of, or reference to $\epsilon = \epsilon_r \epsilon_0$ [1]
 Comment that increasing the relative permittivity increases the permittivity by the same factor [1]
 Both the charge and the energy stored will increase by a factor of 2.7 [1]

[Total: 10]

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- 8 (a) Field lines between the plates are parallel, equally spaced and have a direction from + to – [1]
Field lines are arcs at the edges and not straight [1]
- (b) (i) Substitution of correct values into $E = \frac{V}{d}$ [1]
Leads to $E = \frac{120}{0.05}$ which gives an answer of 2400 V m^{-1} [1]
- (ii) Parabolic / curved path [1]
Moving from the negative to the positive plate [1]
- (iii) Use of $\frac{F}{Q} = \frac{V}{d}$ [1]
Use of $F = ma$ and rearranging of equation to obtain a value for the change in velocity of the electron given by $at = \frac{VQ}{md} \times t$ [1]
Substitution of values to obtain change in velocity = $\frac{12 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31} \times 0.05} \times 2 \times 10^{-6}$ giving a final answer of $8.4 \times 10^7 \text{ m s}^{-1}$ [1]
- (c) (i) The path taken would still follow a parabolic or curved path. [1]
The motion would be in the opposite direction (from positive to negative plate). [1]
- (ii) The velocity of the alpha particle would be less. [1]
Refer to greater mass (or inertia) for the same sized electric field. [1]

[Total: 13]

- 9 (a) Reference to potential due to charged sphere being $V = \frac{Q}{4\pi\epsilon_0 r}$ [1]
Reference to $C = \frac{Q}{V}$ [1]
Substitution leads to $C = 4\pi\epsilon_0 R$ [1]
- (b) Use of $Q = VC$ [1]
Substitution of values to obtain $Q = 1.2 \times 10^3 \times 4 \times \pi \times 8.85 \times 10^{-12} \times 0.3$ [1]
Correct answer of $4.0 \times 10^{-8} \text{ C}$ [1]
- (c) Use of $V = \frac{Q}{4\pi\epsilon_0 r}$ [1]
Substitution of correct values into the equation [1]
Final answer of $V = 200 \text{ C}$ [1]

[Total: 9]

- 10 Refer to official mark scheme for OCR past paper G485/01 June 2013; this is Q2. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk

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6.3 Electromagnetism

6.3.1 Magnetic fields (page 169)

- 1
 - (a) Like Figure 5 on page 169
 - (b) Like Figure 3 on page 168
 - (c) Like Figure 1a on page 168
 - (d) Like Figure 2 on page 168
- 2 Accept any suitable answer. For example, on one complete loop of a field line, the direction of the field inside the solenoid (and far from the ends) is opposite to the direction of the field on the same field line outside the solenoid (and far from the ends).
- 3
 - (a) At B and C the field strength is similar to that at A (field lines are almost uniformly close together), so still 2.0 mT. At D the field lines are beginning to diverge so field strength will be reduced, perhaps 1.0 mT.
 - (b) The field strength at A will double and the density of field lines will double.
 - (c) North
 - (d) Magnetic field lines point from a north pole to a south pole, so if the north pole is at D this matches the direction of the field lines leaving the right hand end of the solenoid and entering the left-hand end of the solenoid.
- 4 In arrow notation for magnetic field lines, a dot represents the tip of the front of an arrow as you would see it coming towards you (i.e. a dot is used to represent a magnetic field line coming out of the page) and a cross represents the feathers of the back of an arrow as it moves away from you (i.e. a cross is used to represent a magnetic field line going into the page). This is useful because it allows a 3D field to be represented in 2D.
- 5 The magnetic field is created by moving charges in the wire, so if there is no current (i.e. no moving charges) the magnetic field will disappear.
- 6 The magnetic permeability of a material is the ability of the material to become magnetised and support the formation of a magnetic field within itself, in response to an applied magnetic field. Materials with a high value of magnetic permeability include 'soft' iron, cobalt and steel. Materials with a high value of magnetic permeability are required for the core of electromagnets and transformers.

6.3.2 Magnetic flux and magnetic flux density (page 171)

- 1 Magnetic flux is the product of magnetic flux density, B , and the area, A , at right angles to the flux. Magnetic flux density is a vector quantity, and is a measure of the strength of a magnetic field.
- 2
 - (a) The units of magnetic flux are weber (Wb). The units of magnetic flux density are Tesla (T).
 - (b) From the definition of magnetic flux, $\phi = BA$
 Since the units of ϕ are Wb and the units of area are m^2 , the units of magnetic flux density B must equal Wb m^{-2}
 Since the units of magnetic flux density, B , are also Tesla (T), it follows that 1 T is equal to 1 Wb m^{-2} .
 - (c) Magnetic flux density is defined by the equation for the force, F , on a current-carrying conductor in a magnetic field, $F = BIL\sin\theta$ (where θ is the angle between wire and the field lines).
 Hence $B = \frac{F}{IL\sin\theta}$
 The units of F are N, units of I are A and units of L are m so the units of B (T) must equal $\text{N A}^{-1} \text{m}^{-1}$
 The unit of force (N) can be written as kg ms^{-2} , hence 1 T = 1 $\text{kg ms}^{-2} \text{A}^{-1} \text{m}^{-1}$ or 1 T = 1 $\text{kg s}^{-2} \text{A}^{-1}$
- 3
 - (a) (i) $\phi = BA\cos\theta$, where θ is the angle between the field lines and the normal to the surface
 When the coil is perpendicular to the magnetic field, $\theta = 0$ so:
 $\phi = 1.7 \times 10^{-6} \times \pi(0.25)^2 = 3.3 \times 10^{-7} \text{ Wb}$
 (ii) $\theta = 36^\circ$ so $\phi = 3.3 \times 10^{-7} \cos 36 = 2.7 \times 10^{-7} \text{ Wb}$
 - (b) Magnetic flux through the coil will be zero when the coil is parallel to the field lines ($\theta = 90^\circ$).

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4 $\phi = BA \cos \theta$, so assuming the field is normal to the area, $B = \frac{\phi}{A} = \frac{3.2 \times 10^{-3} \text{ Wb}}{40 \times 10^{-6} \text{ m}^2} = 80 \text{ Wb m}^{-2}$ or 80 T

5

Magnetic flux, ϕ /Wb	Magnetic flux density, B /T	Area, A /m ²	Angle, θ
3.2×10^{-4}	8.2×10^{-3}	4.3×10^{-2}	24°
5×10^{-6}	7×10^{-3}	7.3×10^{-4}	12°
1.0×10^6	5.2×10^{-3}	4×10^8	60°
7.8	2×10^{-3}	10^4	67°

6

- (a) The magnetic field is in the vertical direction so $\theta = 90$

$$\phi = BA \cos \theta = 60 \times 10^{-6} \times 25 \times \cos 90^\circ$$

$\cos 90^\circ = 0$, so the magnetic flux through the wing is also 0

- (b) The magnetic field is directed at 66° below the horizontal, or 33° to the vertical.

$$\phi = BA \cos \theta = 50 \times 10^{-6} \times 25 \times \cos 33^\circ = 1.0 \times 10^{-3} \text{ Wb}$$

6.3.3 Forces on a current-carrying wire (page 175)

1

- (a) Field lines go from N to S so from U to V. The magnetic field lines, the direction of the current through the wire and direction of movement of the wire from the force acting on it are all mutually perpendicular. From Fleming's left-hand rule the force will be downwards.

- (b) Field lines go from N to S so from V to U. From Fleming's left-hand rule the force will be upwards.

2

Force/N	Magnetic flux density/T	Current/A	Length of wire in field/m	Angle wire makes with field/ θ
2.4×10^{-3}	2×10^{-3}	0.5	2.4	90°
3.2×10^{-3}	1.4×10^{-3}	0.8	4.2	42°
40×10^{-6}	6.3×10^{-5}	1.2	0.75	45°

3

There is a magnetic field from the N to S poles of the magnet, i.e. from right to left. When current flows in the loop of wire, a force acts on the wire when the direction of the current through the wire is perpendicular to the field lines. Hence the two (long) sides of the coil perpendicular to the field experience a force. The direction of current is opposite in each of these two sides so the forces acting on each side of the coil are in opposite directions (upwards on the left side and downwards on the right). The current through the two (short) sides of the coil is always parallel to the field direction, so there is no force acting on these two sides. The two forces on the long sides of the coil produce a turning effect, rotating the coil clockwise.

6.3.4 Motion of charged particles in magnetic and electric fields (page 178)

1

$$F = BQv = 7.3 \times 10^{-3} \times 1.6 \times 10^{-19} \times 30\,000 = 3.5 \times 10^{-17} \text{ N perpendicular to the electron's path.}$$

2

Radius, r /m	Mass, m /kg	Velocity, v /ms ⁻¹	Flux density, B /T	Charge, Q /C
5.22	1.67×10^{-27}	3×10^3	6×10^{-6}	1.6×10^{-19}
0.02	3.84×10^{-29}	5×10^3	3×10^{-5}	3.2×10^{-19}
18.0	9.11×10^{-31}	2×10^6	1.58×10^{-7}	6.4×10^{-19}

3

A fine beam of charged particles from the vaporised sample enters a region of uniform magnetic field directed at right angles to the path of the charged particles. A force acts on the charged particles, and since the force is perpendicular to the direction of the charged particles, the particles move in a circular path. The radius of the particle's motion, r , is given by $r = \frac{mv}{BQ}$ so the radius is directly proportional to the particle's mass, m divided by its charge Q .

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6.3.5 Electromagnetic induction (page 181)

- 1 (a) Flux linkage = $N\phi = 6.0 \times 10^{-4}$ Wb turns, and $N = 300$
Hence $\phi = \frac{6.0 \times 10^{-4}}{300} = 2.0 \times 10^{-6}$ Wb.
- (b) $\phi = BA \cos \theta$
In a long solenoid the field is perpendicular to the coils so $\theta = 0$
Hence $B = \frac{\phi}{A} = \frac{2.0 \times 10^{-6}}{4.0 \times 10^{-5}} = 5 \times 10^{-2}$ T
- 2 (a) When the coil is at right angles to the field, $\theta = 0^\circ$
Flux through coil = $BA \cos \theta = 3.6 \times 10^{-3} \times (0.124 \times 0.056) = 2.5 \times 10^{-5}$ Wb
Flux linkage = $N\phi = 280 \times 2.5 \times 10^{-5} = 7.0 \times 10^{-3}$ Wb turns
- (b) When the coil has moved through an angle of 28° , $\theta = 28^\circ$
Flux through coil = $BA \cos \theta = 3.6 \times 10^{-3} \times (0.124 \times 0.056) \times \cos 28^\circ = 2.2 \times 10^{-5}$ Wb
Flux linkage = $N\phi = 280 \times 2.2 \times 10^{-5} = 6.2 \times 10^{-3}$ Wb turns
- (c) When the coil is parallel to the field, $\theta = 90^\circ$
Flux through coil = 0, as $\cos 90^\circ = 0$
Flux linkage = $N\phi = 0$
- 3 (a) For an electric current to be induced in the coil, there must be a change in magnetic flux in the region around the coil. If the coil is rotating in a plane such that the magnetic flux through the coil does not change, there will be no induced current.
- (b) If the number of turns on the coil is increased, the magnetic flux linking the coil will increase. We would expect that when this flux is changed, the induced current will be greater.
- (c) If the area of the coil is increased, the flux through the coil will increase. We would expect that when this flux is changed, the induced current will be greater.
- (d) If the magnetic field strength is increased, the flux through the coil will increase. We would expect that when this flux is changed, the induced current will be greater.
- (e) If the coil is moved faster through the magnetic field, the flux through the coil will change more quickly. We would expect that if the flux is changed more quickly, the induced current will be greater.

6.3.6 Faraday's law and Lenz's law (page 184)

- 1 e.m.f. induced = $\frac{\text{change in flux}}{\text{time taken}} = \frac{0.2 \text{ Wb}}{0.048 \text{ s}} = 4.2 \text{ V}$
- 2 (a) (i) e.m.f. induced = $\frac{\text{change in flux}}{\text{time taken}} = \frac{(200 \times 0.2 \times 4.0 \times 10^{-4})}{0.040} = 0.4 \text{ V}$
(ii) current in coil = $\frac{\text{e.m.f.}}{R} = \frac{0.4}{32} = 13 \text{ mA}$
- (b) Clockwise; the current in the coil will try to keep the magnetic field in existence, from Lenz's law.
- 3 (a) Maximum gradient = 7.5 ± 0.1 mWb per ms giving 7.5 V
(b) Cosine curve with amplitude 7.5 V, period 8 ms
(c) Peak e.m.f. = $200 \times 7.5 \text{ V} = 1500 \text{ V}$
(d) Accept any suitable answer, e.g. insert an iron core; increase area of coil; rotate the coil faster or in a stronger field
- 4 (a) (i) Flux change per second = $B \times \text{area swept out in } 1 \text{ s} = 0.40 \times (0.08 \times 0.2) = 6.4 \text{ mWb}$
(ii) e.m.f. induced = rate of change of flux = $\frac{6.4 \text{ mWb}}{1 \text{ s}} = 6.4 \text{ mV}$
(iii) These sides are moving parallel to the field.

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- (b) (i) Current in the loop = $\frac{\text{e.m.f.}}{R} = \frac{6.4 \times 10^{-3}}{2.0} = 3.2 \text{ mA}$
- (ii) Energy dissipated as heat in the circuit per second = electric power developed in circuit = $\frac{I^2}{R} = \frac{(3.2 \times 10^{-3})^2}{2.0} = 2 \times 10^{-5} \text{ W or } 20 \text{ } \mu\text{W}$
- (c) (i) To induce an e.m.f. in the circuit, work must be done to move the circuit relative to the magnetic field. Work done per second = force $\times$ distance moved per second, and this must equal the electric power developed in circuit.
Rectangle moves to the right at 0.2 ms^{-1} so force $\times 0.2 = 2 \times 10^{-5}$, force = $1 \times 10^{-5} \text{ N}$
- (ii) Work done per second to move the wire = $20 \text{ } \mu\text{W}$
- 5 (a) When the aircraft is flying horizontally over the Earth's surface, there is a component of the Earth's magnetic field directed vertically downwards so there is magnetic flux through the aircraft's fuselage and wings and the flux changes as the aircraft flies over the Earth's surface. As the wings are conducting, an e.m.f. is induced so long as the aircraft is moving. The e.m.f. is maximum when the direction of movement is perpendicular to the magnetic field and the wings are perpendicular to the field lines.
- (b) Since the Earth's magnetic field strength is very low ($50 \times 10^{-6} \text{ T}$), the induced e.m.f. will be very small.

6.3.7 The a.c. generator (page 187)

- 1 In an a.c. generator, the slip rings and brushes maintain continuous electrical contact between the external circuit and the rotating coil of wire without the wires tangling as the coil rotates. The continuous electrical contact means the coil is part of a complete circuit in which induced current can flow.
- 2 (a) (i) At $t = 0.25 \text{ s}$ the coil has made one quarter of a turn so the coil is vertical and the flux linking the coil is maximum. Induced e.m.f. = 0 as the rate of change of flux linkage is zero.
- (ii) At $t = 0.25 \text{ s}$ the coil is again horizontal so rate of change of flux linkage is maximum as it was at $t = 0 \text{ s}$. However the side of the coil that was moving upwards is now moving downwards (and vice versa) so the direction of the induced e.m.f. is reversed. Induced e.m.f. = -0.4 V .
- (iii) At $t = 1.75 \text{ s}$ the coil is vertical again, induced e.m.f. = 0.
- (iv) At $t = 3.0 \text{ s}$ the coil is horizontal again, and at the same position as at $t = 0 \text{ s}$ so induced e.m.f. = $+0.4 \text{ V}$.
- (b) 3 cycles of a cosine curve of amplitude 0.4 V and period 1.0 s
- (c) (i) Amplitude becomes 0.8 V , period unchanged
- (ii) Amplitude becomes 0.2 V , period unchanged
- (iii) Amplitude becomes 0.6 V , period becomes 0.67 s
- 3 Increasing the number of coils, increasing the strength of the magnet, increasing the speed of rotation.
- 4 (a) (i) The rotor is a simple bar magnet, so field line loops pass through the centre of the bar magnet from N to S poles and loop round to the other end.
- (ii) Accept any suitable answers, e.g. a larger magnetic field is produced; iron is easily demagnetised as well; iron conducts flux lines through the coil, so provides magnetic circuit for flux.
- (b) The flux linkage of the coil changes as the magnet rotates, so by Faraday's law an e.m.f. is generated.
- (c) When the rotor is (i) horizontal (ii) vertical.
- (d) Accept any suitable answers, e.g. increasing the number of coils/cross-sectional area of core/strength of the magnet to increase the flux linkage; decreasing the air gap to increase the field; laminating the core to reduce eddy currents and increase the flux through the coil.

6.3.8 Transformers (page 191)

1

N_p	N_s	V_p	V_s	Step up or down?
3000	12 000	6000	24 000	step up
40 000	8000	24	4.8	step down
64	1250	22.5	440	step up

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- 2 The ratio of $I_s : I_p$ is the inverse of the ratio of $V_s : V_p$
- 3 (a) Frequency of the output supply is the same as the input frequency. The supply comes from the mains so has a frequency of 50 Hz.
- (b) $\frac{N_s}{N_p} = \frac{V_s}{V_p}$ so $\frac{48}{N_p} = \frac{6.0}{230}$ so $N_p = 1850$
- 4 (a) $\frac{N_s}{N_p} = \frac{V_s}{V_p}$ so $N_s = \frac{N_p V_s}{V_p} = \frac{400 \times 12}{230} = 21$
- (b) $\frac{V_s}{V_p} = \frac{I_p}{I_s}$ so if maximum primary current is 0.5 A, $I_s = \frac{I_p V_p}{V_s} = \frac{0.5 \times 230}{12}$ or about 10 A
- This is only an estimate because no transformer is 100% efficient and the equation assumes that the output power equals the input power.
- 5 (a) Magnetic flux
- (b) Every cross-section of the core, if solid, would act as a single-turn secondary coil and draw a large current (eddy currents) – the transformer would be very inefficient and become very hot.

Practice questions (page 194)

- 1 D
- 2 B
- 3 A
- 4 A
- 5 B
- 6 (a) (i) Magnetic flux is the amount of magnetic field passing through a surface. [1]
SI unit is the weber, Wb. [1]
- (ii) Magnetic flux density is the magnetic flux passing, perpendicular, through unit area. [1]
SI unit is the tesla, T. [1]
- (iii) Magnetic flux linkage is the product of the magnetic flux and the number of turns on the coil it passes through. Given by magnetic flux linkage = $N\phi$ [1]
Measured in weber turns, Wb. [1]
- (b) Refer to use of the equation $F = BIL$ with quantities defined. [1]
Reference to/explanation of the current, I , force, F , and length of wire, L , in the region of the field all being determined. [1]
Use of $B = \frac{F}{IL}$ to determine the magnitude of the magnetic flux density. [1]
- [Total: 9]**
- 7 (a) (i) Has a high magnetic permeability [1]
Acts to concentrate the magnetic field or flux [1]
- (ii) Thinner sheets of iron in the core [1]
Leads to less energy loss from heat losses (due to eddy currents) [1]
- (iii) The closer the coils are, the more the changing magnetic field in the primary coil will induce an alternating current in the secondary coil. [1]
This leads to greater efficiency / less energy loss. [1]
- (b) (i) Use of $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ [1]
Substitution of values and rearrangement to obtain $V_s = \frac{8000 \times 300\,000}{24\,000}$ [1]
Final value for V_s of 100 kV or 100 000 V [1]
- (ii) Use of $\frac{V_s}{V_p} = \frac{I_p}{I_s}$ [1]
Substitution of values to obtain final value of 3.6 A [1]

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- (iii) Step down transformer [1]
 Secondary voltage is smaller than the primary voltage [1]
- (c) Both values would be 85% of their values stated above [1]
 Only 85% of the input energy / power is being converted [1]

[Total: 15]

- 8 (a) Magnet provides magnetic flux [1]
 Carbon brushes establish electrical contact with the slip rings [1]
 Slip rings ensure that the output is alternating [1]
 Coil cuts through magnetic flux so that e.m.f. is induced [1]
- (b) e.m.f. is greatest when rate of cutting of flux lines is greatest [1]
 e.m.f. is zero when the coil is perpendicular to the lines of magnetic flux [1]
 e.m.f. varies from positive to negative over one complete cycle [1]
 Variation is sinusoidal in nature [1]

[Total: 8]

- 9 (a) (i) The magnitude of the induced e.m.f. [1] is equal to the rate of change of flux linkage. [1]
 (ii) The direction of any induced current [1] is in a direction that opposes the flux change that causes it. [1]
- (b) (i) Change in flux linkage is equal to $N\Delta\phi$ [1]
 Substitution leads to $1000 \times (3.2 - 0.3) \times 10^{-3}$, giving an answer of 2.9 Wb turns. [1]
- (ii) Induced e.m.f. = change in flux linkage per second or $\frac{N\Delta\phi}{\Delta t}$ [1]
 This leads to an answer of $\frac{2.9}{0.025}$ or 116 V [1]

[Total: 8]

- 10 Refer to official mark scheme for OCR past paper G485 January 2011; this is Q3. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk

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6.4 Nuclear and particle physics

6.4.1 The nuclear atom (page 200)

- 1 (a) The vast majority of the mass of the atom is contained within a small volume (the nucleus); the nucleus has a positive charge; the nuclear diameter is considerably smaller than the diameter of the atom.
 (b) Evidence for most of the mass being in a small volume and the nuclear diameter being very small – the vast majority of the alpha particles travelled straight through the gold foil without being deflected and only a small number were deflected while a very tiny percentage were scattered right back. Evidence for nucleus having positive charge – alpha particles have a positive charge and would be deflected (repelled) by another positive charge.
- 2 From Coulomb's law, $F = \frac{Qq}{4\pi\epsilon_0 r^2}$ so $F = \frac{(1.6 \times 10^{-19})^2}{4 \times \pi \times 8.85 \times 10^{-12} \times (5.3 \times 10^{-11})^2} = 8.1 \times 10^{-8} \text{ N}$
- 3 (a) Charge-to-mass ratio of electron = $\frac{-e}{\frac{1}{1840u}} = \frac{-1840e}{u}$
 In units of C and kg, $\frac{1840e}{u} = \frac{1840 \times 1.6 \times 10^{-19}}{1.66 \times 10^{-27}} = 1.8 \times 10^{11} \text{ C kg}^{-1}$
 (b) Charge-to-mass ratio of proton = $\frac{e}{u}$
 In units of C and kg, $\frac{1e}{u} = \frac{1.6 \times 10^{-19}}{1.66 \times 10^{-27}} = 9.6 \times 10^7 \text{ C kg}^{-1}$
 (c) Charge-to-mass ratio of helium nucleus = $\frac{2e}{4u}$
 In units of C and kg, $\frac{e}{2u} = \frac{1.6 \times 10^{-19}}{2 \times 1.66 \times 10^{-27}} = 4.82 \times 10^7 \text{ C kg}^{-1}$
- 4 $\text{KE} = \frac{1}{2}mv^2$ so $v^2 = \frac{2\text{KE}}{m} = \frac{2 \times 4.8 \times 10^6 \times 1.6 \times 10^{-19}}{1.66 \times 10^{-27}} = 9.27 \times 10^{14}$, $v = 3.0 \times 10^7 \text{ ms}^{-1}$
- 5 At distance of closest approach, $\text{KE} = 0$ and $\text{KE lost} = \text{work done against the electric field} = \text{electrical potential energy gained}$. Initial $\text{KE} = 4 \text{ MeV} = 4 \times 10^6 \times 1.6 \times 10^{-19} \text{ J} = 6.4 \times 10^{-13} \text{ J}$
 PE at distance r from nucleus = $\frac{Qq}{4\pi\epsilon_0 r}$ so:

$$r = \frac{2e \times 74e}{4\pi\epsilon_0 \times 6.4 \times 10^{-13}} = \frac{148 \times (1.6 \times 10^{-19})^2}{4\pi \times 8.9 \times 10^{-12} \times 6.4 \times 10^{-13}} = 5.3 \times 10^{-14} \text{ m}$$
- 6 (a) 20 protons, 20 neutrons, 20 electrons
 (b) 43 protons, 56 neutrons, 43 electrons
 (c) 79 protons, 118 neutrons, 79 electrons
 (d) 92 protons, 146 neutrons, 92 electrons

The number of electrons always equals the number of protons. However, as the atoms become more massive, the number of neutrons relative to the number of protons increases.

6.4.2 The strong nuclear force (page 202)

- 1 (a) Around 0.5 fm
 (b) From Coulomb's law, $F = \frac{Qq}{4\pi\epsilon_0 r^2}$ so $F = \frac{(1.6 \times 10^{-19})^2}{4 \times \pi \times 8.85 \times 10^{-12} \times (2.4 \times 10^{-15})^2} = 40 \text{ N}$
 (c) Almost no difference in value from the value for two neutrons in equilibrium. Just very slightly larger than 0.5 fm.
- 2 (a) It changes from positive to negative.
 (b) Attraction
 (c) $Ax^4 = B$

Particles and medical physics

- 3 The accuracy is limited by the resolution of the technique, which depends on the wavelength of the radiation being used. Both alpha particles and electrons can behave as particles or waves and waves will be diffracted by a nucleus (similar to the diffraction of waves around a spherical object). Electrons have a de Broglie wavelength ($\lambda = h/mv$) that is of the same order as the size of a hydrogen atom, so they can be diffracted by objects with dimensions similar to interatomic spacing. However, more massive and faster-moving particles (such as alpha particles) have much shorter de Broglie wavelengths, which will be much smaller than the size of the atom. Therefore, alpha particles will not be diffracted by the nucleus. Hence, using diffraction methods, the diameter of a nucleus can only be determined by electron diffraction.

6.4.3 Nuclear density (page 204)

- 1 Mass = $m_n \times A$ where A is the nucleon number and m_n is the mass of a nucleon (the mass of a proton or neutron).
 Mass = $1.673 \times 10^{-27} \times 11 = 1.84 \times 10^{-26} \text{ kg}$
 Radius of nucleus, $R = r_0 A^{\frac{1}{3}}$ where r_0 is a constant. Using $r_0 = 1.4 \times 10^{-15} \text{ m}$, $R = 3.11 \times 10^{-15} \text{ m}$
 Volume of nucleus = $\frac{4\pi R^3}{3} = 1.26 \times 10^{-43} \text{ m}^3$
 Density = $\frac{\text{mass}}{\text{volume}} = \frac{1.84 \times 10^{-26} \text{ kg}}{1.26 \times 10^{-43} \text{ m}^3} = 1.5 \times 10^{17} \text{ kg m}^{-3}$
- 2 Radius of nucleus, $R = r_0 A^{\frac{1}{3}}$ where r_0 is a constant. Using $r_0 = 1.4 \times 10^{-15} \text{ m}$, $R = 8.64 \times 10^{-15} \text{ m}$
- 3 $R = r_0 A^{\frac{1}{3}}$ so $R^3 = r_0^3 A$. If the relationship holds, a plot of R^3 against A will give a straight line of gradient r_0^3 . Assuming R can be found (e.g. from electron diffraction studies) this plot could be used to verify that the nuclear radius is proportional to the cube root of the mass number, and obtain a value for the unknown constant r_0 .
- 4 The density of the gold nucleus is greater than the density of gold by a factor of $\frac{10^{17}}{10^4}$. This shows that the vast majority of the mass of the atom is contained within a small volume (the nucleus) and the greatest part of the atom is empty space (a vacuum).
- 5

	carbon atom	O ⁻ ion	polonium nucleus
Mass number	12	16	210
Proton number	6	8	84
Number of neutrons	6	8	126
Number of electrons	6	9	84
Mass of nucleus/kg	2.00×10^{-26}	2.68×10^{-26}	3.51×10^{-25}
Radius/m	3.21×10^{-15}	3.53×10^{-15}	8.32×10^{-15}
Volume of nucleus/m³	1.38×10^{-43}	1.84×10^{-43}	2.41×10^{-42}
Density of nucleus/kgm⁻³	1.45×10^{17}	1.46×10^{17}	1.46×10^{17}

6.4.4 Fundamental particles (page 207)

- 1 (a) matter: proton, electron, neutrino
 antimatter: positron
 (b) hadron: proton, positron
 lepton: electron, neutrino
 (c) proton +e, electron -e, neutrino uncharged, positron +e
- 2 (a) up $+\frac{2}{3}e$, down $-\frac{1}{3}e$
 (b) three
 (c) proton uud, neutron udd

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- 3 antiparticle of electron is positron (+e)
antiparticle of neutrino is antineutrino (uncharged)
antiparticle of proton is antiproton (−e)
antiparticle of neutron is antineutron (uncharged)
antiparticle of up quark is anti-up $-\frac{2}{3}e$
antiparticle of down quark is anti-down $(+\frac{1}{3}e)$

6.4.5 Radioactivity (page 209)

- 1 Spontaneous means that there is no known cause of emission and the decay is not affected by temperature or other physical conditions, or by chemical reaction. Random means that it is not possible to predict when any particular radioactive nucleus will decay.
- 2 In the early days of radioactivity research, the Geiger counter had not been invented so initially there was no way to determine when a radioactive decay occurred; it was only possible to identify that radiation had been emitted during the time that the photographic plate or film was close to the radioactive source. Using zinc sulphide as a detector meant that it was possible to identify individual emissions. This made it possible to compare count rates (the number of radioactive decays per minute) for different radioactive substances.
- 3 Moving charges are deflected in a magnetic field (provided the direction of movement is perpendicular to the field direction). Gamma rays are uncharged so would not be deflected. Alpha and beta particles have opposite charge, so would be deflected in opposite directions.

The radius of the curved path depends on the mass, speed and charge of the particle ($r = \frac{mv}{BQ}$). Alpha particles are much more massive, so would generally be deflected into a path with a larger radius (difference in speed or in charge is not as great as difference in mass). However, speed of emission depends on the source so there is no strict rule about which is deflected more.

- 4 Minimise time of exposure, increase distance from their body to the radioactive source (e.g. by using tongs), shield sources when not in use, such as in a lead-lined box. Avoid direct contamination of hands and clothing by using tongs to handle specimens and/or gloves and other protective clothing.
- 5 Radioactive decay is random and it is impossible to predict when a particular nucleus will decay. By recording the count over a long period of time it is possible to calculate and compare a mean number of counts per minute, which will be more accurate. Also, the background count fluctuates randomly over time, so recording over a long period of time smooths out random variations of the background count.
- 6 Place the Geiger counter detector a fixed distance (less than 5 cm) from the source. In turn, place a sheet of paper then a thin sheet of aluminium between the source and the detector. Compare the mean count rate for each absorbing material.

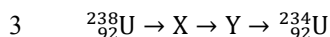
If the count rate drops to zero when the sheet of paper is placed between the source and detector, the source emits only alpha particles. If the count rate is not reduced by the sheet of paper, the source is not an alpha emitter. If the count rate is reduced but not zero when the sheet of paper is placed between the source and detector, the source emits alpha particles but also either beta or gamma radiation.

If the count rate drops to zero when the sheet of aluminium is placed between the source and detector, the source emits beta particles but not gamma rays. If the count rate is reduced but not zero when the sheet of aluminium is placed between the source and detector, the source emits beta particles but also gamma rays.

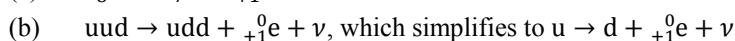
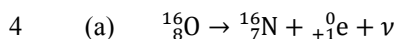
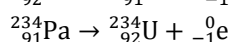
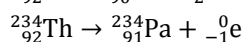
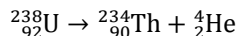
6.4.6 Radioactive decay (page 212)

- 1 Moving charges are deflected in an electric field (provided the direction of movement is perpendicular to the field direction). Both beta-minus and beta-plus particles will move in a parabolic curve in a uniform field. As they have opposite charges, they will be deflected in opposite directions.
- 2
 - (a) ${}_{94}^{242}\text{Pu} \rightarrow {}_2^4\text{He} + {}_{92}^{238}\text{U}$
 - (b) ${}_{15}^{32}\text{P} \rightarrow {}_{16}^{32}\text{S} + {}_{-1}^0\text{e} (+\bar{\nu})$
 - (c) ${}_{8}^{15}\text{O} \rightarrow {}_7^{15}\text{N} + {}_{+1}^0\text{e}$

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Overall the mass number decreases by 4 and the proton number is unchanged. This suggests one alpha particle decay (${}_{2}^4\text{He}$) and two beta-minus decays (${}_{-1}^0\text{e}$, twice).



charge: $+\frac{2}{3} = -\frac{1}{3} + 1 + 0$ (i.e. charge is conserved)

6.4.7 Radioactive decay equations and half-life (page 216)

1 Activity is the rate at which a radioactive source decays, or the number of nuclear decays per unit time. The decay constant λ is the probability that an individual nucleus will decay per unit time and is related to the activity, A , and the number of undecayed nuclei, N , by the equation $A = \lambda N$.

2 $A = \lambda N = 4.3 \times 10^{-2} \times 8.4 \times 10^{28} = 3.6 \times 10^{27} \text{ Bq}$

3 (a) Using $N = N_0 e^{-\lambda t}$, and using the ratio of undecayed masses rather than the ratio of the number of undecayed nuclei, $\frac{M}{M_0} = e^{-\lambda t}$

Taking logs of both sides, $\ln \frac{M}{M_0} = -\lambda t$

$$\text{Hence } t = \frac{-\ln \frac{38}{45}}{9.2 \times 10^{-3}} = 18 \text{ s}$$

(b) Molar mass = 14 g, so number of moles in 38 kg = $\frac{38 \text{ kg}}{14 \text{ g}} = 2714$

$$\text{Hence number of atoms in 38 kg} = 2714 \times N_A = 2714 \times 6.02 \times 10^{23} = 1.6 \times 10^{27}$$

4 (a) $A = \lambda N$ so $N = \frac{A}{\lambda} = \frac{16\,000}{4.88 \times 10^{-18}} = 3.28 \times 10^{21}$

(b) Mass of one uranium atom = $3.95 \times 10^{-25} \text{ kg}$, so 3.28×10^{21} atoms have a mass of 1.30 g

5 (a) Molar mass = 40 g, so mass of 1 atom = $\frac{40}{6.02 \times 10^{23}} = 6.64 \times 10^{-23} \text{ g}$ or $6.64 \times 10^{-26} \text{ kg}$

(b) In 0.0013 kg number of atoms $N = \frac{0.0013}{6.64 \times 10^{-26}} = 1.96 \times 10^{19}$

$$A = \lambda N = 9.15 \times 10^{-17} \times 1.96 \times 10^{19} = 1.8 \times 10^6 \text{ Bq}$$

6 (a) 4

(b) 9

(c) 11

(d) Between 11 and 12

7 (a)

Time/hours	Activity of materials/Bq	Activity of nuclide X/Bq	Activity of nuclide Y/Bq
0	4600	4200	400
6	3713	3334	379
12	3002	2646	356
18	2436	2100	336
24	1984	1667	317
30	1619	1323	296
36	1333	1050	283

(b) 72 hours

(c) The combined graph is the sum of two exponential decays. This is not an exponential decay. The half-life of X dominates at the start and the half-life of Y dominates after a long time; the mixture does not have a constant half-life.

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8 (a) $\ln 2 = \lambda t_{\frac{1}{2}}$
 If $\lambda = 3.7 \times 10^{-11} \text{ s}^{-1}$, $t_{\frac{1}{2}} = 1.87 \times 10^{10} \text{ s}$. In years, this is 590 years.

(b) From $A = A_0 e^{-\lambda t}$, if $\frac{A}{A_0} = 0.34$ then $\ln(0.34) = -\lambda t$
 Therefore, $t = \frac{-\ln(0.34)}{3.7 \times 10^{-11}} = 2.92 \times 10^{10} \text{ s}$ or 930 years

9 $N = N_0 e^{-\lambda t}$ so $\frac{N}{N_0} = e^{-\lambda t}$
 $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$ so $\lambda t = \frac{t \ln 2}{t_{\frac{1}{2}}} = \frac{23 \ln 2}{17}$ and $e^{-\lambda t} = (e^{-\ln 2})^{\frac{23}{17}} = (0.5)^{\frac{23}{17}} = 0.39$

This means 39% of the original radioactive atoms will still be radioactive after 17 years.

One in every five of the atoms was initially radioactive, so $\frac{4}{5}$ of the rock was not initially radioactive. Of the other $\frac{1}{5}$, 61% is no longer radioactive, or 0.122 of the whole.

Hence the total fraction remaining unradioactive is $\frac{4}{5} + 0.122 = 0.922$, or 92%

6.4.8 Radioactive dating (page 217)

1 $\lambda t = \frac{t \ln 2}{t_{\frac{1}{2}}}$ so $e^{-\lambda t} = (e^{-\ln 2})^{\frac{100000}{5730}} = (0.5)^{\frac{100000}{5730}} = 5.58 \times 10^{-6}$

Hence $\frac{N}{N_0} = 5.6 \times 10^{-6}$

With such a tiny fraction of the original carbon-14 remaining, it would be very difficult to measure accurately either the mass of carbon-14 atoms or the activity. This would give very large percentage errors in the calculation of the time elapsed (i.e. the age of the sample).

2 (a) $\lambda = 1.21 \times 10^{-4} \text{ year}^{-1}$
 $\ln \frac{A}{A_0} = \ln(e^{-\lambda t}) = -\lambda t$, so $\ln \frac{2.74 \times 10^{-13}}{1.30 \times 10^{-12}} = 0.211 = -1.21 \times 10^{-4} \times t$
 Hence $t = \frac{-\ln 0.21}{1.21 \times 10^{-4}} = 13\,000 \text{ years}$

(b) Use a specimen from an accurately dated event, e.g. a piece of wood from Pompeii. Then work backwards to find the decay constant.

(c) Fossil fuels are too old.

3 If no argon was present initially, each argon atom now present must have decayed from one potassium ion. Therefore, the ratio of potassium now to original potassium must have been 1 : (1 + 6.7) or 1 : 7.7.

Using $N = N_0 e^{-\lambda t}$ gives $t = 3.7 \times 10^9 \text{ years}$. As a sense check, the ratio is about 1 : 8 or 3 half-lives.

6.4.9 Mass–energy conservation (page 219)

1 (a) ${}^{240}_{94}\text{Pu} \rightarrow {}^{236}_{92}\text{U} + {}^4_2\text{He}$
 (b) $0.0056 \text{ u} = 9.3 \times 10^{-30} \text{ kg}$
 (c) Use $\Delta E = \Delta mc^2$

$\Delta E = 8.37 \times 10^{-13} \text{ J}$, this is the maximum KE of the alpha particle emitted.

(d) This assumes all the energy of the nuclear reaction is transferred to the alpha particle. The uranium nucleus will have a very small amount of the energy released, but it has a much greater mass than the alpha particle so will have much less KE.

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- 2 The particle–antiparticle pair is created from a high-energy photon.
Minimum photon energy required, $E = mc^2$ where m is the combined mass of the particle–antiparticle pair ($m = 2 \times 9.31 \times 10^{-31}$ kg)
Hence $E = 2 \times 9.31 \times 10^{-31} \times (3.0 \times 10^8)^2 = 1.68 \times 10^{-13}$ J
Since $1 \text{ eV} = 1.60 \times 10^{-19}$ J, this energy is equal to 1.1 MeV
- 3 All the other nuclei have a smaller binding energy per nucleon, so these nuclei cannot release any energy by fusion with other nuclei or by fission into smaller nuclei.
- 4 (a) mass defect = mass of nucleons – mass of nucleus
mass defect = $[(29 \times 1.00728 \text{ u}) + (34 \times 1.00867 \text{ u})] - 62.91367 \text{ u} = 0.59223 \text{ u}$
(b) $1 \text{ u} = 1.67 \times 10^{-27}$ kg, so mass defect = 9.89×10^{-28} kg
(c) binding energy = mass defect (u) $\times 931 \text{ MeV} = 551 \text{ MeV}$
(d) binding energy = mass defect $\times c^2 = 9.89 \times 10^{-28} \times (3.0 \times 10^8)^2 = 8.90 \times 10^{-11}$ J
- 5 For the alpha particle, using the data for helium-4 in Q1, $\Delta m = [(2 \times 1.00728 \text{ u}) + (2 \times 1.00867 \text{ u})] - 4.0015 \text{ u}$
 $\Delta m = 0.0304 \text{ u}$ which gives a binding energy of 28.3 MeV or about 7 MeV per nucleon.
Looking at the graph of binding energy per nucleon, at 7 MeV the binding energy per nucleon of helium-4 is significantly larger than that for nearby nuclides. The helium-4 nucleus is thus unusually stable, and so by emitting an alpha particle an unstable nucleus can very easily become more stable.

6.4.10 Nuclear fission (page 222)

- 1 Start with $mu - mv = mV$ and $\frac{1}{2}mu^2 - \frac{1}{2}mv^2 = \frac{1}{2}mV^2$
Then cancel $\frac{1}{2}$ and divide one equation by the other to show that $V = u$ and hence $v = 0$
- 2 (a)
- | left-hand side/u | | right-hand side/u | |
|------------------|----------|-------------------|----------|
| neutron | 1.0086 | barium-143 | 142.9365 |
| uranium-235 | 235.044 | krypton-90 | 89.9394 |
| | | 3 neutrons | 3.0258 |
| Totals | 236.0526 | | 235.9109 |
- mass difference = 0.151 u
- (b) Energy equivalence = mass defect $\times c^2 = 0.151 \times 1.661 \times 10^{-27} \times (3.0 \times 10^8)^2 = 2.26 \times 10^{-11}$ J, or 140 MeV
- 3 The function of the moderator is to slow down fast-moving neutrons without absorbing them. Reducing the kinetic energy of the moving neutrons means that the neutrons have a better chance of causing fission reactions with uranium-235 nuclei. The function of the control rods is to absorb some of the neutrons and prevent an uncontrollable chain reaction within the reactor.
- 4 Nuclear power produces radioactive waste. This waste undergoes radioactive decay. Some of it has a long half-life and if leaks of radioactive material occur to the environment, the ionising radiation will harm plants and animals.

6.4.11 Nuclear fusion (page 225)

- 1 (a) mass difference = $(2 \times 2.01355 \text{ u}) - (3.01550 \text{ u} + 1.00728 \text{ u}) = 0.00432 \text{ u}$
energy equivalence = mass defect $\times c^2 = 0.00432 \times 1.661 \times 10^{-27} \times (3.0 \times 10^8)^2 = 6.46 \times 10^{-13}$ J, or 4.0 MeV
- (b) Mass of reactants is 2 kg, or 1 kg of each nuclei. In 1 kg of nuclei, there are $\frac{1000}{2.01355} = 497$ moles
The number of reactions that takes place is therefore $497 \times 6.02 \times 10^{23}$
For every two nuclei of deuterium that fuse, 4.0 MeV is released. Therefore, the total energy output is:
 $497 \times 6.02 \times 10^{23} \times 4 \text{ MeV} = 1.20 \times 10^{27} \text{ MeV}$

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(c) Total energy output for power output of 500 MW for one year = $500 \times 10^6 \times 365 \times 24 \times 60 \times 60$
 $= 1.57 \times 10^{16} \text{ J} = \frac{1.57 \times 10^{16}}{1.60 \times 10^{-13} \text{ MeV}} = 9.86 \times 10^{28} \text{ MeV}$

So if 2 kg produces = $1.20 \times 10^{27} \text{ MeV}$, amount of deuterium required in one year = $\frac{2 \times 9.86 \times 10^{28}}{1.20 \times 10^{27}} = 170 \text{ kg}$

2 $E = \frac{3kT}{2}$ where k has a value of $1.38 \times 10^{-23} \text{ J K}^{-1}$

$T = \frac{2E}{3k} \sim \frac{2 \times 6.46 \times 10^{-13}}{3 \times 1.38 \times 10^{-23}} = 3 \times 10^{10} \text{ K}$

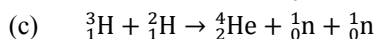
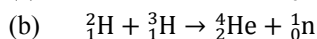
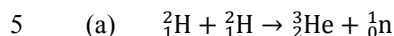
3 Mass difference = $(2 \times 2.01355 \text{ u}) - (\text{mass of } {}^3_2\text{He} + 1.00728 \text{ u})$

Energy equivalence = mass defect (u) $\times 931 \text{ MeV} = 3.3 \text{ MeV}$

Hence = $3.01982 \text{ u} - \text{mass of } {}^3_2\text{He} \text{ (in u)} = \frac{3.3 \text{ u}}{931}$

Mass of ${}^3_2\text{He} = 3.01628 \text{ u}$

4 3 deuterons produce a helium-4 nucleus together with a proton and a neutron and $\frac{21}{6} \text{ MeV}$ of energy



Practice questions (page 228)

1 C

2 D

3 A

4 B

5 C

6 (a) [4]

Element	Nucleon number	Proton number	Number of neutrons	Number of electrons
sodium	23	11	12	11
carbon	12	6	6	6
carbon	14	6	8	6
uranium	238	92	146	92

(b) An isotope is an atom of an element that has a fixed number of protons [1] but a varying number of neutrons; must refer to carbon as the example in the table. [1]

(c) (i) Positive nuclear charge [1]

Contains over 99% of the mass of the atom [1]

Small in comparison to the atomic diameter [1]

(ii) Nucleons are held together by the strong interaction or strong nuclear force [1]

The atom is held together by the electrostatic force between the nucleus and the electrons [1]

(iii) Density of the nucleus is much higher than the density of the atom [1]

Density of the nucleus is independent of nucleon number [1]

Density of the nucleus is around $10^{17} \text{ kg m}^{-3}$ [1]

[Total: 14]

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7 [1 mark for each correct row] [Total: 5]

Particle	Fundamental?	Baryon?	Lepton	Charge
quark	yes	yes	no	$\pm\frac{1}{3}e$
neutrino	yes	no	yes	0
proton	no	yes	no	+1
neutron	no	yes	no	0
positron	yes	no	yes	+1

- 8 (a) (i) The number of nuclear disintegrations per unit time [1]
Measured in Bq [1]
- (ii) The average time taken for the activity of a radioactive isotope to fall to half of its original value [1]
Measured in seconds, hours or years [1]
- (iii) The probability of radioactive decay [1]
Given by $\lambda = \Delta N / \Delta t$ and measured in s^{-1} [1]
- (b) (i) Evidence of a calculation, e.g. $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times 1$ [1]
Answer of $\frac{1}{8}$ of the original activity [1]
- (ii) Evidence of use of the equation $\lambda = \frac{\ln 2}{t_{1/2}}$ [1]
Answer of 0.12 h^{-1} or $3.2 \times 10^{-5} \text{ s}^{-1}$ [1]
- (iii) Use of the equation $A = A_0 e^{-\lambda t}$ [1]
Substitution to obtain $A = A_0 e^{-(0.000032 \times 84 \times 60)}$ [1]
Final answer of 85% [1]

[Total: 13]

- 9 (a) Nuclear fusion [1]
Hydrogen nuclei fuse to form helium nuclei with a higher binding energy per nucleon [1]
- (b) Alpha particles have an unusually high binding energy per nucleon value [1]
This means that they are (more) stable and so are emitted readily by unstable nuclei [1]
- (c) Iron-56 [1]
At the highest point on the curve, with the greatest binding energy per nucleon value [1]
- (d) Uranium has a lower binding energy than iron-56 and is heavier than it [1]
It will undergo fission by undergoing radioactive decay in order to increase its binding energy per nucleon [1]

[Total: 8]

- 10 Refer to official mark scheme for OCR past paper G485 June 2010; this is Q7. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk

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6.5 Medical imaging

6.5.1 X-rays (page 233)

- 1 (a) Power supplied = $86\,000 \times 2.2 \times 10^{-3} = 189\text{ W}$
 (b) Output power = $\frac{189 \times 0.8}{100} = 1.5\text{ W}$
- 2 (a) Energy transferred to electron = $eV = 1.6 \times 10^{-19} \times 83\,000 = 1.32 \times 10^{-14}\text{ J}$
 (b) $E = hf$ so $f = \frac{E}{h} = \frac{1.32 \times 10^{-14}}{6.63 \times 10^{-34}} = 2 \times 10^{19}\text{ Hz}$
 (c) $f = \frac{c}{\lambda}$ so $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2 \times 10^{19}} = 1.5 \times 10^{-11}\text{ m}$
- 3 (a) (i) Maximum KE = $eV = 1.6 \times 10^{-19} \times 100\,000 = 1.6 \times 10^{-14}\text{ J}$
 (ii) Minimum wavelength λ from $E = \frac{hc}{\lambda}$ so $\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{1.6 \times 10^{-14}} = 1.2 \times 10^{-11}\text{ m}$
 (b) (i) Electrons are removed from inner shells; outer electrons fill vacancies; emitted photon has energy equal to the difference in levels.
 (ii) **1:** E_{max} increases, minimum wavelength decreases, peak intensity moves to higher energy and area under graph increases
2: only the area under the graph (the total intensity) increases

6.5.2 Attenuation of X-rays (page 236)

- 1 (a) It becomes kinetic energy of the positron and electron.
 (b) This would give the positron and electron a speed greater than the speed of light. The theory of relativity forbids this. The masses of the positron and electron increase as their speed increases.
- 2 It becomes extra kinetic energy of the scattered electron.
- 3 Intensity is the power transmitted per unit cross-sectional area. Using the values calculated in question 1 in topic 6.5.1 for a tube of 86 000 V, power supplied = 189 W
 Efficiency is only 0.80% so power output = 1.5 W
 If the target area of the beam is the mouth (for a dental X-ray), this area is about $10\text{ cm} \times 10\text{ cm}$ or 0.01 m^2
 Hence intensity = $\frac{1.5}{0.01} = 150\text{ W m}^{-2}$
 X-ray tube powers can vary from a few hundred watts to several thousand watts. Most are about 0.5% efficient, so X-ray output might vary from 0.5 W to 100 W. The smaller machines will be used for imaging smaller areas, say 20 cm^2 , the larger machines for imaging larger areas, say 200 cm^2 . Hence intensities could range from 250 W m^{-2} to 5000 W m^{-2} .
- 4 Initial intensity $I_0 = 4.8 \times 10^3\text{ W m}^{-2}$. At a distance x in a medium of attenuation μ , $I = I_0 e^{-\mu x}$
 - For $x = 3.0\text{ cm}$ and $\mu = 53$, $I = 4.8 \times 10^3 e^{-1.59} = 980\text{ W m}^{-2}$
 - For $x = 15\text{ cm}$ and $\mu = 6.9$, $I = 4.8 \times 10^3 e^{-1.035} = 1700\text{ W m}^{-2}$
 - For $x = 2.0\text{ cm}$ and $\mu = 90$, $I = 4.8 \times 10^3 e^{-1.8} = 790\text{ W m}^{-2}$
- 5 Using $I = I_0 e^{-\mu x}$
 If $\frac{I}{I_0} = 0.37$ then $e^{-\mu x} = 0.37$ Therefore $\ln(0.37) = -1 = -\mu x$
 If $x = 25\text{ mm}$, $\mu = \frac{1}{25 \times 10^{-3}} = 40\text{ m}^{-1}$
- 6 Either plot a graph of transmitted intensity against thickness, draw a smooth curve of best fit and find the average half-value thickness $x_{\frac{1}{2}}$ from which $\mu x_{\frac{1}{2}} = \ln 2$ OR plot a graph of $\ln$ transmitted intensity against thickness and find the gradient of the straight line.
- 7 Some soft tissue organs do not show up on X-rays because the organ has a similar attenuation coefficient to other tissues in the same area. Iodine is injected because it is a good absorber of X-rays (it has a large attenuation coefficient). Hence when iodine is injected into the organ, the image of the organ is enhanced.

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6.5.3 Computerised axial tomography (CAT) (page 238)

- Diagram should show a block of lead with a slit in it placed close to the X-ray source.
- Better contrast between different soft tissues; CAT scan produces 3D images; the image can be processed to view the internal organs from a number of angles or to remove organs with the density of bone or air by making them transparent.
- No, not unless it was an emergency and the mother's life was in danger, as X-rays are ionising radiation and could harm the fetus.

6.5.4 The gamma camera (page 241)

- Time elapsed = 6 hours + 24 hours = 5 half-lives. Activity after 5 half-lives = 15.6 Bq
 - After 6 half-lives, activity = 7.81 Bq

After 7 half-lives, activity = 3.91 Bq

After 8 half-lives, activity = 1.95 Bq

After 9 half-lives, activity = 0.95 Bq

9 half-lives is 54 hours
- $$\text{Time difference} = \frac{0.07-x}{2.0 \times 10^8} - \frac{x}{2.0 \times 10^8} = 0.10 \times 10^{-9} \text{ s}$$

$2x = 0.05 \text{ m}, x = 2.5 \text{ cm}$
- The syringe is shielded to reduce radiation exposure to the medical personnel.
- Technetium-99 is injected into patients before they have a scan with a gamma camera. The technetium is radioactive with a half-life of about 6 hours. The tracer circulates inside the body and is absorbed by a particular organ. The gamma camera is placed above the patient's organs and detects the gamma radiation emitted by the tracer.

6.5.5 Positron emission tomography (PET) scanning (page 243)

- Gamma ray photons travel at the speed of light so the distance from source to detector is very small.
- A positron / beta-plus emitting tracer / source is used, for example glucose with radioactive fluorine-18. The fluorine-18 is produced in a particle accelerator before being incorporated into the glucose that is injected into the patient. When a positron is emitted it immediately annihilates with an electron inside the patient, producing two gamma ray photons which travel in opposite directions. A ring of gamma detectors surrounds the patient. The difference in arrival times of the two photons at the detector is calculated and from this the distance to the gamma ray is found. A 3-D image is created.
- Advantages of PET scans in comparison to CAT scans: PET scans are functional rather than structural – they can show where glucose is being used in metabolic activity, for example, to locate areas of abnormally high metabolic activity or to map, in real-time, the levels of metabolic activity in the brain when performing different activities. PET scans can show the precise location of any concentration of the radioisotope.

Disadvantages of PET scans in comparison to CAT scans: The radioactive tracer may cause allergic reaction in some people. The PET scanner may cause some people to feel claustrophobic, compared to gamma camera, X-ray or ultrasound imaging.
- Annihilation is the process when a particle and antiparticle interact and their combined mass is converted to energy, resulting in the disappearance of the matter. To calculate where the gamma rays are coming from, we use the fact that a pair of gamma rays is produced at exactly the same instant, and these travel at the same speed in the body but in opposite directions. The difference in arrival times of the two photons at the detector thus gives the distance to where the photons were produced, if the speed is known.
- A PET scan relies on selective uptake of the radioactive tracer, i.e. the tracer is absorbed by and becomes concentrated in a certain organ or tissue type in the body. If the molecule used is not biologically active, it will not concentrate in certain areas of the body but will be equally distributed.

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6.5.6 Ultrasound (page 246)

- 1 Ultrasound waves are produced by a piezoelectric crystal, and pulses of ultrasound are transmitted into the patient's body by placing the ultrasound transducer directly on the skin. The pulses of ultrasound waves are reflected from surfaces in the body and the time of each reflected pulse is used to find the depth of the reflecting layer.

- 2 Small wavelength means finer detail can be seen / greater resolution

- 3 $I = I_0 e^{-\mu x}$ so if $\frac{I}{I_0} = 0.50$ when $x = 70 \text{ mm}$, $e^{-\mu x} = 0.5$

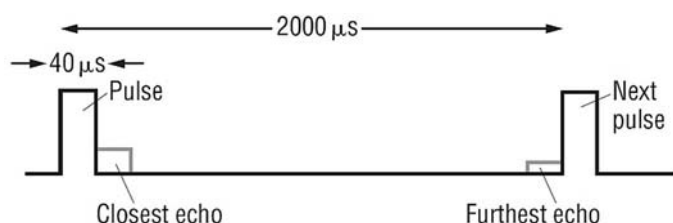
$$\text{Therefore } \ln(0.5) = -\mu \times 70 \times 10^{-3} \text{ and } \mu = \frac{\ln 2}{70 \times 10^{-3}} = 9.9$$

Hence after travelling 28 cm through the same soft tissue, for the same frequency of ultrasound,

$$\frac{I}{I_0} = e^{-\mu x} = e^{-9.9 \times 0.28} = 0.06$$

The percentage reduction in intensity is 94%.

- 4 (a)



$$\text{Number of waves within one pulse} = \frac{40 \mu\text{s}}{\text{time period}} = \frac{40 \times 10^{-6}}{\frac{1}{1.2 \times 10^6}} = 48$$

- (b) Shortest distance (closest echo) is for $t = 40 \times 10^{-6} \text{ s}$, so $d = 1600 \text{ m s}^{-1} \times 40 \times 10^{-6} \text{ s} = 64 \text{ mm}$
 This is for an echo so depth to reflector = 0.032 m
 Longest distance (furthest echo) is for $t = 2000 \times 10^{-6} \text{ s}$, so $d = 1600 \text{ m s}^{-1} \times 2000 \times 10^{-6} \text{ s} = 3.2 \text{ m}$
 This is for an echo so depth to reflector = 1.6 m

6.5.7 Acoustic impedance (page 249)

- 1 (a) From the expression $Z = \rho c$, units of Z are the same as the units of ρc , i.e. $\text{kg m}^{-3} \times \text{m s}^{-1} = \text{kg m}^{-2} \text{ s}^{-1}$
 (b) The units on the top of the expression are divided by the same units on the bottom. By squaring the expression, negative values are eliminated.
- 2 (a) X: $(0.007 \text{ ms} + 0.019 \text{ ms}) \times 2 = 0.052 \text{ ms}$
 Y: $(0.007 \text{ ms} + 0.019 \text{ ms} + 0.006 \text{ ms}) \times 2 = 0.064 \text{ ms}$
 (b) fat–muscle = muscle–fat = 0.0044 ≈ 0
 muscle–bone = bone–muscle = 0.31
 (c) X: 31% returns
 Y: 14% returns

6.5.8 The Doppler effect (page 251)

- 1 Accept any suitable answers, e.g. the wash of a boat, an aircraft going faster than the speed of sound

$$2 \quad \frac{\Delta f}{f_0} = \frac{2v}{c}$$

Here c is the speed of sound and v is the speed of the train

$$\Delta f = \frac{f_0 \times 2v}{c} = \frac{400 \times 2 \times 60}{340} = 141 \text{ Hz}$$

The frequency heard is higher (because the train is moving towards you), so:

$$\text{frequency heard} = 400 + 141 \text{ Hz} = 541 \text{ Hz}$$

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- 3 Cross-sectional area of artery in $\text{cm}^2 = \pi r^2 = \pi(0.25)^2 = 0.196 \text{ cm}^2$
Volume of blood passing any point in 1 s = $0.196 \text{ cm}^2 \times 13 \text{ cm s}^{-1} = 2.6 \text{ cm}^3$
- 4 (a) Accept any suitable sketch.
- (b) A variation from maximum to minimum and back to maximum over five cycles of one wave and four of the other.
- (c) The frequency of this oscillation equals the difference in frequency between the two waves. The same happens with the ultrasound waves. A so-called beat frequency of 975 Hz is obtained. This will vary with the speed of the blood and so can be monitored.

Practice questions (page 254)

- 1 A
- 2 B
- 3 D
- 4 C
- 5 D
- 6 (a) A radioactive nuclide either ingested by, or injected into, a patient [1]
The nuclide emits gamma photons to be detected by a gamma camera [1]
- (b) Pure gamma emitters [1] with a half-life in the region of hours [1]
Non-toxic [1]
- (c) (i) Low (biological) half-life [1]
Low dose [1]
Useful for diagnostic purposes / not therapeutic purposes (e.g. looking at kidney function) [1]
Used with a gamma camera as it is a gamma emitter [1] **[Any 3 for 3 marks]**
- (ii) Positron emitter [1]
Half-life of around 110 minutes / short half-life [1]
Used in PET scans [1]

[Total: 11]

- 7 (a) (i) Electrons are accelerated [1] towards a metal target [1]
X-rays are produced when the electrons collide with the nuclei and atoms of the target atoms [1]
X-rays pass through flesh and soft tissue but are absorbed by denser materials such as bone [1]
- (ii) Piezoelectric transducer [1] transmits and detects ultrasound waves over 20 000 Hz [1]
Used for diagnostic and imaging purposes (or give example) [1]
Image is based on the amount of ultrasound that is reflected between two media [1]
- (b) (i) Reference to $I = I_0 e^{-\mu x}$ and explanation of terms [1]
Attenuation coefficient is the reduction of X-ray intensity and is dependent on the material's density or atomic number, and its thickness [1]
Caused by the absorption of scatter of photons as they pass through matter [1]
- (ii) Reference to the equation that describes how the fraction of reflected ultrasound is dependent on the acoustic impedance of the two media in question [1]
Explanation that acoustic impedance is given by $Z = \rho c$ [1]
Explain that a large difference in the acoustic impedance (of the adjacent media that the ultrasound is travelling between) will result in large amounts of reflection (using equation to demonstrate) [1]
- (c) (i) A material that is used to enhance the contrast of structures in the human body when undergoing an X-ray [1]
Example of use, e.g. use of barium / barium meal to see the gastrointestinal tract in detail. Must refer to the nature of the difference in density between the contrast media and the surrounding part of the body that is being investigated. [1]

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- (ii) A coupling gel is used to match the acoustic impedance of the point of contact of the transducer on the skin with human tissue. [1]

If the air is not displaced between the transducer and the skin, then all of the ultrasound will be reflected and no image will be seen, e.g. of a fetus. [1]

[Total: 18]

- 8 3D image can be constructed [1]

Image is of a higher quality (reduces need for further exploratory surgery) [1]

Image can be obtained quickly [1]

A large portion of the body can be viewed [1]

Better diagnosis of, e.g., cancer [1]

Any 4 of the above **[Total: 4]**

- 9 (a) The change in wavelength (or frequency) [1]

Caused by the relative motion between the wave source and an observer / moving object [1]

- (b) Reference to the Doppler ultrasound equation, i.e. $\frac{\Delta f}{f_0} = \frac{2v \cos \theta}{c}$ [1]

Definition of terms in the equation [1]

- (c) Correct explanation of how the value detected for the speed of the blood, v , is dependent on the angle θ [1]

Worked example to show the effect of changing θ or $\cos \theta$ [1]

[Total: 6]

- 10 Refer to official mark scheme for OCR past paper G485 June 2010; this is Q10. All past papers and mark schemes are available on the OCR website, www.ocr.org.uk