Answers to examination-style questions

Answers | **Marks** | **Examiner's tips**

1 (a) Other quantities that are conserved:
- charge
- baryon number
- lepton number
- strangeness

Marks: any 3

Examiner's tip: You are still required to know about particle reactions and the properties of fundamental particles, even though these topics were covered in Unit 1 of *AS Physics A*.

(b) Feynman diagram drawn to show:
- the proton changing to a neutron
- the exchange particle W^+
- β^+ and ν_e as emitted particles
- a correct overall shape, with arrows in correct directions

Marks: 4

Examiner's tip: You should be able to recall the general form of the Feynman diagrams for reactions such as this. This question assists you because it starts by providing the equation representing the reaction.

(c)

	meson	baryon	lepton
proton	✗	✓	✗
neutron	✗	✓	✗
β^+	✗	✗	✓
ν_e	✗	✗	✓

Marks: 4

Examiner's tip: One mark is available for each correct horizontal line in the table. None of these particles are mesons; two are baryons and two are leptons.

2 (a) (i) An ionising radiation removes electrons from atoms … **1**
by colliding with them. **1**

Examiner's tip: Ionisation involves converting neutral atoms into positive ions by releasing negative electrons from them. The positive ion and electron form an 'ion pair'.

(ii) *Relevant points include those listed below.*
- Beta particles make many fewer collisions with air molecules per unit distance travelled.
- Because β particles are much smaller than α particles.
- Therefore β particles lose their energy over a longer distance than α particles.

Marks: any 2

Examiner's tip: β particles have a much **smaller size** than α particles (note that it is size, not mass, that matters here). They are also generally emitted at higher speeds than α particles. Hence β particles have a much lower probability of colliding with air molecules (or of being collided with by them) than α particles.

(b) (i) One correct value determined clearly by construction on graph, for example 52 → 53s **1**
At least one other determination evident from graph. **1**
Average value of half-life calculated. **1**

Examiner's tip: You should draw horizontal and vertical lines on a graph such as this to give evidence of your working. This also helps you to find your values more accurately.

Answers to examination-style questions

Answers	Marks	Examiner's tips
(ii) From the graph, when $t = 72$ s number of atoms $N = (1.08 \rightarrow 1.10) \times 10^{21}$	1	This question spares you from having to calculate λ from $T_{½}$, but you should be able to do it if you had to:
Use of $\frac{\Delta N}{\Delta t} = -\lambda N$ gives activity $A = \frac{\Delta N}{\Delta t} = 1.3 \times 10^{-2} \times 1.10 \times 10^{21}$	1	$\lambda = \frac{\ln 2}{T_{½}} = \frac{\ln 2}{52} = 1.3 \times 10^{-2}\ s^{-1}$.
$= \therefore\ 1.43 \times 10^{19}$ Bq (or s^{-1})	1	You could try to find the activity by measuring the gradient of the graph at $t = 72$ s, but the result would be much less accurate.
(c) (i) *Possible origins of background radiation*: cosmic rays, radiation from the Sun, from other radioactive isotopes, radioactive atoms in rocks or in the air, from the nuclear industry or nuclear testing, from medical sources such as radiotherapy or diagnosis.	any 2	The more specific you can make your answers the better. Radioactivity can be ingested through food, water and drink that may contain traces of radioactive isotopes. Food may be exposed to γ radiation in order to destroy bacteria; this food itself does not become radioactive.
(ii) the background count rate would be much lower than the activity of the source in part **(b)**.	1	A typical background count rate would be 1 count s^{-1} or less, whereas the activity of this source is around $10^{19}\ s^{-1}$.
3 (a) ${}^{240}_{94}Pu \rightarrow {}^{236}_{92}U + {}^{4}_{2}He$	2	One mark for ${}^{236}_{92}U$ and one mark for ${}^{4}_{2}He$ (or ${}^{4}_{2}\alpha$).
(b) (i) Mass difference $\Delta m = (3.98626 - 3.91970 - 0.0664251) \times 10^{-25} = 1.349 \times 10^{-29}$ kg	1	A large number of significant figures are quoted in the question because the mass difference is extremely small. You should retain as many significant figures as you can throughout this kind of calculation until you arrive at the final answer. In the final answer you can limit the number of significant figures that you write down.
Energy released $= (\Delta m)c^2 = 1.349 \times 10^{-29} \times (3.00 \times 10^8)^2$	1	
$= 1.21 \times 10^{-12}$ J	1	
(ii) Decay constant $\lambda = \ln \frac{2}{T_{½}} = \frac{\ln 2}{2.1 \times 10^{11}}$	1	By quoting the result as $3.30 \times 10^{-12}\ s^{-1}$ you have shown that you have worked out a precise value, which is 'about $3 \times 10^{-12}\ s^{-1}$'.
$= 3.30 \times 10^{-12}\ s^{-1}$	1	
(iii) Number of decays per second $\frac{\Delta N}{\Delta t} = -\lambda N = 3.30 \times 10^{-12} \times 3.2 \times 10^{21} = 1.06 \times 10^{10}$	1	In this calculation you should use the value of λ that you calculated in part **(b)(ii)** and the value of the energy released per decay that you calculated in part **(b)(i)**. Since 1 W = 1 J s^{-1}, it turns out that the radioactive source has a power of 12.8 mW.
Energy released per second $= 1.06 \times 10^{10} \times 1.21 \times 10^{-12}$	1	
$= 1.28 \times 10^{-2}$ J	1	

Answers	Marks	Examiner's tips
(iv) 100 year = $100 \times 365 \times 24 \times 3600$ $= 3.15 \times 10^9$ s	1	*Alternative solutions* to this question are possible. As an example:
Use of activity $A = A_0 e^{-\lambda t}$ where $\lambda = 3.30 \times 10^{-12}$ and $t = 3.15 \times 10^9$	1	Time taken for activity to become 95% of the original is given by $0.95\,A_0 = A_0 e^{-\lambda t}$, from which
gives activity after 100 years $A = 0.990\,A_0$	1	$\lambda t = \ln\left(\dfrac{A_0}{0.95A_0}\right) = 0.0513$, and
which is 99.0% of the original activity, and so the energy release will change by only 1.0%, which is less than 5%.	1	$t = 1.55 \times 10^{10}$ s = 492 years
4 (a) (i) Since $R = r_0 A^{1/3}$ the ratio $\dfrac{R}{A^{1/3}}$ should be the same for all nuclei	1	The ratio $\dfrac{R}{A^{1/3}}$ is equal to the constant r_0.
Be: $r_0 = \dfrac{2.5 \times 10^{-15}}{9^{1/3}} = 1.20 \times 10^{-15}$ m **Na**: $r_0 = \dfrac{3.4 \times 10^{-15}}{23^{1/3}} = 1.20 \times 10^{-15}$ m **Mn**: $r_0 = \dfrac{4.6 \times 10^{-15}}{56^{1/3}} = 1.20 \times 10^{-15}$ m	1	The value obtained for r_0 depends on the technique used to measure R, because nuclei do not have a hard edge.
(ii) Average density of nuclear matter = $= \dfrac{\text{mass of nucleus}}{\text{volume of nucleus}}$ $= \dfrac{A \times \text{mass of a nucleon}}{4\pi R^3/3}$	1	When calculating the volume of a nucleus it is, however, regarded as a hard-edged sphere. You could calculate the density of a particular nucleus such as Be by direct use of the numbers given in the table. All nuclei should have this same average density. In the method shown here the nucleon number A cancels in the working.
$= \dfrac{3A \times \text{mass of a nucleon}}{4\pi r_0^3 A}$ using $R = r_0 A^{1/3}$	1	
$= \dfrac{3 \times 1.7 \times 10^{-27}}{4\pi \times (1.20 \times 10^{-15})^3}$ using values for m, r_0	1	
$= 2.35 \times 10^{17}$ kg m^{-3}	1	
(b) (i) The binding energy is the energy released when a nucleus is formed from its constituent nucleons (or the energy required to break up a nucleus into its constituent nucleons).	1	Forming a nucleus from protons and neutrons causes energy to be given out. The strong nuclear force pulls the nucleons together, decreasing their potential energy.
(ii) Binding energy of sodium-23 nucleus $= 23 \times 8.11 = 187$ MeV	1	Multiply the number of nucleons (A in the table) by the binding energy per nucleon.
$= 187 \times 10^6 \times 1.60 \times 10^{-19}$ $= 2.99 \times 10^{-11}$ J	1	
(iii) Mass-equivalent is given by $\Delta E = (\Delta m)c^2$ $\therefore\ 2.99 \times 10^{-11} = \Delta m \times (3.00 \times 10^8)^2$	1	The mass-equivalent of the binding energy is the mass difference of the nucleus.
gives mass-equivalent $\Delta m = 3.32 \times 10^{-28}$ kg	1	

Answers	Marks	Examiner's tips
(c) de Broglie wavelength = 9.2×10^{-15} m	1	The nuclear diameter for Mn-56.
Momentum of α particle $p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{9.2 \times 10^{-15}} = 7.21 \times 10^{-20}$ Ns	1	Using the wave-particle duality equation from Unit 1 of *AS Physics A*.
Velocity of α particle $V = \frac{p}{m} = \frac{7.21 \times 10^{-20}}{6.8 \times 10^{-27}} = 1.06 \times 10^{7}$ m s^{-1}	1	Since momentum $p = mv$, you can find the velocity of the α particle by dividing p by its mass.
Energy of α particle $= \frac{1}{2}mv^2$ $= \frac{1}{2} \times 6.8 \times 10^{-27} \times (1.06 \times 10^{7})^2$ $= 3.82 \times 10^{-13}$ J	1	The energy of the α particle is its kinetic energy, $\frac{1}{2}mv^2$
(d) **(i)** Proton number $Z = 26$ Nucleon number $A = 56$	1 1	In β^- decay Z increases by 1 but A is unchanged.
(ii) Decay constant $\lambda = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2}{2.6 \times 3600}$ $= 7.41 \times 10^{-5}$ s^{-1}	1 1	If t is in seconds, λ must be expressed in s^{-1}. 2.6 hours is $(2.6 \times 60 \times 60)$ s
5 **(a)** ${}^{212}_{83}\text{Bi} \rightarrow {}^{4}_{2}\alpha + {}^{208}_{81}\text{Tl}$	2	One mark each for ${}^{4}_{2}\alpha$ and ${}^{208}_{81}\text{Tl}$.
(b) **(i)** 6.1 MeV $= 6.1 \times 10^{6} \times 1.60 \times 10^{-19}$ $= 9.76 \times 10^{-13}$ J	1	The energy of the α particle is given in the question, but in MeV. To use $E_K = \frac{1}{2}mv^2$, this energy must be converted into J and the mass of the α particle must be converted into kg from u.
Mass of α particle $= 4.0 \times 1.66 \times 10^{-27}$ $= 6.64 \times 10^{-27}$ kg	1	
Speed of α particle $v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2 \times 9.76 \times 10^{-13}}{6.64 \times 10^{-27}}}$ $= 1.71 \times 10^{7}$ m s^{-1}	1	
(ii) Momentum is conserved in the emission process, thus $m_{nuc}\, v_{nuc} + m_\alpha\, v_\alpha = 0$	1	Momentum is always conserved in an explosive process, such as the emission of an α particle by a nucleus. In this calculation you can use masses in u on both sides of the equation (rather than converting to kg) because it is the **ratio** of the masses that matters. The negative value for the recoil velocity of the Tl nucleus simply means that it moves in the opposite direction to the α particle.
$\therefore$ 208 $v_{nuc} = -4 \times 1.71 \times 10^{7}$	1	
from which $v_{nuc} = -3.29 \times 10^{5}$ m s^{-1} and recoil speed of Tl nucleus $= 3.29 \times 10^{5}$ m s^{-1}	1	
6 **(a)** **(i)** Power output $P = IV = 2.8 \times 25$ $= 70$ W	1	The question gives values for the current and voltage supplied at the output of the solar panel, so $P = IV$ enables the output power P_{out} to be determined. The input power P_{in} is the power incident on the solar panel, calculated from (power in W m^{-2}) × (area of panel in m^2).
(ii) Incident solar power $= 1400 \times 3.8$ $= 5320$ W	1	
Efficiency of panel $= \frac{P_{out}}{P_{in}} = \frac{70}{5320}$	1	
$= 0.0132$ (= 1.32%)	1	

Answers to examination-style questions

Answers	Marks	Examiner's tips
(b) (i) Energy of each α particle $= 4.1 \times 10^6 \times 1.60 \times 10^{-19}$ $= 6.56 \times 10^{-13}$ J	1	85 J of energy are produced in each second by the source, and one emission gives 6.56×10^{-13} J. The activity is the number of emissions per second, which is simply found by division.
Activity of isotope $A = \dfrac{\text{energy absorbed s}^{-1}}{\text{energy of } \alpha \text{ particle}} = \dfrac{85}{6.56 \times 10^{-13}} = 1.30 \times 10^{14}$ Bq	1	
(ii) Decay constant $\lambda = \dfrac{\ln 2}{T_{½}} = \dfrac{\ln 2}{200 \times 3.15 \times 10^7}$	1	In this question you are helpfully provided with the number of seconds in a year, saving a step in the calculation.
$= 1.10 \times 10^{-10}$ s^{-1}.	1	
(iii) Activity $A = \dfrac{\Delta N}{\Delta t} = -\lambda N$ gives $1.30 \times 10^{14} = 1.10 \times 10^{-10} \times N$ from which number of radioactive atoms $N = 1.18 \times 10^{24}$	1	Once you know the activity (from part **(b)(i)**) and the decay constant (from part **(b)(ii)**) it is straightforward to find the number of atoms in the isotope.
Mass of isotope $= N \times$ mass of one atom $= N \times \left(\dfrac{209 \times 10^{-3}}{6.02 \times 10^{23}}\right)$	1	There are N_A atoms in 1 mole of the isotope, whose molar mass is 209×10^{-3} kg mol^{-1} (because its nucleon number A is 209).
$= 0.410$ kg	1	
7 (a) (i) The daughter nucleus in the equation should be written as $^{40}_{20}$Ca	1	In β$^-$ decay, a neutron changes into a proton in the nucleus in the presence of the weak interaction. The particles emitted by the nucleus are the β$^-$ particle (a high energy electron) and an electron antineutrino.
(ii) Feynman diagram drawn to show: • a neutron changing into a proton • W$^-$ as the exchange particle • β$^-$ (or e$^-$) and $\overline{\nu_e}$ emerging from the interaction	3	
(b) (i) The daughter nucleus in the equation should be written as $^{40}_{18}$Ar	1	In electron capture, one of the atom's innermost orbital electrons is captured by the nucleus. In the nucleus the electron combines with a proton to produce a neutron. This is accompanied by the emission of an electron neutrino by the nucleus. The weak interaction is again responsible.
(ii) Feynman diagram drawn to show: • a proton changing into a neutron with W$^+$ (left to right) or W$^-$ (right to left) as the exchange particle • e$^-$ entering and ν_e leaving the interaction	2	
(c) (i) For every argon atom now present, number of $^{40}_{19}$K atoms present originally = 9 + the 4 $^{40}_{19}$K atoms still present = 13	1	Nine $^{40}_{19}$K atoms must have been present originally to produce one Ar atom now (because these nine atoms became eight Ca atoms and one Ar atom).

Answers to examination-style questions

Answers	Marks	Examiner's tips
(ii) Decay constant λ for $^{40}_{19}K$ $= \frac{\ln 2}{T_{½}} = \frac{\ln 2}{1250 \times 10^6}$ $= 5.55 \times 10^{-10}$ year^{-1}	1	Part **(d)** illustrates a practical application of radioactive emissions: to find the age of an ancient rock sample using $^{40}_{19}K$ dating. Probably the difficult aspect of this calculation is seeing how to arrive at values for N_0 (the original number of atoms of $^{40}_{19}K$ present in the rock sample) and N (the number present now).
If original number of atoms of $^{40}_{19}K$ was $13N$, number present now is $4N$	1	
$N = N_0 e^{-\lambda t}$ gives $4N = 13Ne^{-\lambda t}$	1	
from which $5.55 \times 10^{-10}\ t = \ln\left(\frac{13}{4}\right)$	1	
$\therefore$ age of rock $t = 2.12 \times 10^9$ years (2120 million years)	1	
8 (a) *Relevant points include these listed here.* **(i)** • The strong nuclear force acts equally on both protons and neutrons. • The strong nuclear force can equal (or exceed) the electrostatic repulsion of the protons. **(ii)** • The neutrons increase the average separation of the protons, thereby reducing their electrostatic repulsion. **(iii)** • The strong nuclear force has a short range. • It acts only on the immediately adjacent nucleons. • Its attractive nature means that the nucleons are closely packed. • If its range were larger, bigger nuclei would have lower densities. • The strong nuclear force becomes repulsive at very small separations. • This prevents nuclei from becoming more dense.	any 6	The gravitational attraction between protons is much too small to balance their Coulomb repulsion. Hence some other force must act on them to keep them stable in a nucleus – the strong nuclear force. However, even this force cannot balance the Coulomb repulsion unless there are also some neutrons in the nucleus. Only the nucleus ^1_1H (which is a single proton) can exist without neutrons. The strong force is short-range; it has no effect beyond separations of 3 fm (1 fm = 10^{-15} m). Between 3 fm and about 0.5 fm it is attractive and at smaller separations than this it becomes repulsive. Therefore it acts only on the nearest neighbours in a nucleus, since the separation of nucleons is about 1 fm. This means that all nuclei have the same density.

Answers to examination-style questions

Answers	Marks	Examiner's tips
(b) (i) Force of electrostatic repulsion $= \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ $= \frac{(1.60 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times (1.2 \times 10^{-15})^2}$ $= 160$ N force of gravitational attraction $= \frac{Gm_1 m_2}{r^2}$ $= \frac{6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2}{(1.2 \times 10^{-15})^2}$ $= 1.3 \times 10^{-34}$ N	1 1 1 1	The earliest thoughts on nuclear stability were that the gravitational attraction of nucleons might be sufficient to balance the Coulomb repulsion of the protons. A few calculations based on the experimental findings about nuclei soon dispelled that myth! This calculation shows that the gravitational force is about 10^{36} times weaker than the electrostatic force. The need for a 'new' force to explain nuclear structure – the strong nuclear force – then began to emerge.
(ii) The gravitational force is very much weaker than the electrostatic force; its strength is negligible compared to the strong nuclear force.	1	
9 (a) (i) mass = density × volume $= 1000 \times 1.3 \times 10^{-4} = 0.13$ kg	1	Part **(i)** relies on your retention of very early experiences in science: density $= \frac{\text{mass}}{\text{volume}}$.
(ii) Energy to change temperature: $\Delta Q = mc\Delta\theta = 0.13 \times 4200 \times 18 = 9.83 \times 10^3$ J Energy to turn water to ice: $\Delta Q = m\,l = 0.13 \times 3.3 \times 10^5 = 4.29 \times 10^4$ J Average energy removed per second $= \frac{(9.83 \times 10^3) + (4.29 \times 10^4)}{1700}$ $= \frac{5.27 \times 10^4}{1700} = 31.0$ J s^{-1} (or W)	1 1 1	Changing water at 18 °C completely into ice at 0 °C is a two-stage process. To find the average rate of removal of energy you must find the total energy removed and then divide by the time. To simplify the calculation, the energy that has to be removed from the beaker is regarded as negligible. In practice the rate of removal of energy is likely to decrease as the temperature of the water falls towards 0 °C. Can you explain why?
(b) Electrical energy passed to surroundings by the freezer $= Pt = 25 \times 1700 = 4.25 \times 10^4$ J Total energy passed to surroundings $= (4.25 \times 10^4) + (5.27 \times 10^4)$ $= 9.52 \times 10^4$ J	1 1	All of the electrical energy supplied to the freezer is converted into thermal energy, which is passed to the surroundings together with the energy that is removed from the water.
10 (a) When tube is inverted lead particles fall and lose gravitational potential energy … which is converted into kinetic energy. The kinetic energy is converted into thermal energy on impact with the bottom of the tube.	1 1 1	From your elementary studies in science these ought to be three very easy marks. This type of experiment finally convinced scientists that what they had called 'heat' (thermal energy) is just another form of energy, into which other forms of energy may be completely converted.

Answers	Marks	Examiner's tips
(b) (i) Loss of potential energy $\Delta E_p = mg\Delta h$ $= 0.025 \times 9.81 \times 1.2 = 0.294$ J	1	When the lead particles come to rest again at the bottom of the tube, all of the gravitational potential energy they have lost is converted into thermal energy. Note that this calculation assumes that none of this thermal energy is lost to the surroundings. In practice the lead particles will lose energy once their temperature exceeds that of their surroundings.
(ii) Total loss of potential energy after 50 inversions $= 50 \times 0.294 = 14.7$ J	1	
(iii) $\Delta Q = mc\Delta\theta$	1	
$\therefore\ 14.7 = 0.025 \times c \times 4.5$ gives specific heat capacity of lead $c = 131$ J kg^{-1} K^{-1}	1	
11 (a) (i) *Consider 1s*: mass of water flowing = density × volume $= 1000 \times 5.2 \times 10^{-5}$	1	Flow problems are usually solved most easily by considering what happens in a time of 1 second. This question states that all of the electrical energy supplied should be assumed to become thermal energy in the water. Hence the power supplied to the shower is equal to the thermal energy gained by the water in one second, since power is the rate of supply of energy.
$= 5.2 \times 10^{-2}$ kg s^{-1}	1	
(ii) Thermal energy gained by water $\Delta Q = m\ c\ \Delta\theta = 5.2 \times 10^{-2} \times 4200 \times 32$	1	
$= 6.99 \times 10^3$ J s^{-1} $\therefore$ power supplied to shower = 6.99 kW	1	
(b) Time t taken to reach the floor is given by $s = ut + \frac{1}{2}at^2$ $\therefore\ 2.0 = 0 + (\frac{1}{2} \times 9.81 \times t^2)$	1	The particles of water in the jet behave as tiny projectiles. Projectile motion is covered in Unit 2 of *AS Physics A*. Remember that the horizontal and vertical components of the motion of a projectile are treated separately. The vertical motion is subject to the acceleration due to gravity, whilst the horizontal motion is at constant speed.
… from which $t = 0.639$ s	1	
Horizontal distance travelled $= v_{hor} \times t$ $= 2.5 \times 0.639$ $= 1.60$ m	1	
12 (a) (i) Charge stored by capacitor $Q = CV = 0.25 \times 9.0$	1	A 0.25 F capacitor is a very large capacitor, so it stores a large amount of charge and a significant amount of energy!
$= 2.25$ C	1	
(ii) Energy stored by capacitor $= \frac{1}{2}CV^2 = \frac{1}{2} \times 0.25 \times 9.0^2$	1	*Alternatively*: energy $= \frac{1}{2}QV = \frac{1}{2} \times 2.25 \times 9.0 = 10.1$ J
$= 10.1$ J	1	
(iii) Use of $V = V_0\ e^{-t/RC}$ gives $0.10 = 9.0\ e^{-t/(8.5\times0.25)}$	1	Although the capacitor discharge is exponential (and therefore never completely accomplished) it appears that this capacitor discharges almost fully in about 10 s.
from which $\frac{t}{(8.5 \times 0.25)} = \ln\left(\frac{9.0}{0.10}\right)$	1	
gives time taken $t = 9.56$ s	1	

Answers	Marks	Examiner's tips
(b) (i) mass of wire = density × volume $= 8900 \times 2.2 \times 10^{-7} = 1.96 \times 10^{-3}$ kg	**1**	All of the energy stored by the capacitor is assumed to be passed to the bundle of wire. In the wire it becomes thermal energy, raising the temperature of the bundle.
$\Delta Q = mc\Delta\theta$ $\therefore\ 10.1 = 1.96 \times 10^{-3} \times 420 \times \Delta\theta$	**1**	
… gives temperature rise $\Delta\theta = 12.3\,°C$ (or K)	**1**	
(ii) *Possible explanations include those listed below.* • Some energy is required to raise the temperature of the thermometer. • Some energy is lost to the surroundings. • Some energy is converted into thermal energy in the other wires in the circuit.	**any 2**	Any energy that is not transferred to the bundle of wire will cause its rise in temperature to be lower than that calculated in part **(b)(i)**.
13 (a) (i) Electrical energy supplied = Pt $= 3000 \times 320 = 9.60 \times 10^5$ J	**1**	This is a more realistic calculation than some earlier examples, because the electrical energy supplied is not all converted into thermal energy in the water.
(ii) Thermal energy supplied to water $\Delta Q = mc\Delta\theta = 2.4 \times 4200 \times 84$	**1**	
$= 8.47 \times 10^5$ J	**1**	
(iii) Possible explanations include: • some energy is required to heat the kettle itself • some energy is lost to the surroundings	**any 1**	Because the water is in contact with the kettle material, the kettle will also experience a rise in temperature of 84 °C. As soon as the kettle is at a higher temperature than its surroundings, some of the energy that has been supplied will be lost.
(b) (i) Resistance of element $R = \frac{V^2}{P} = \frac{230^2}{3000}$	**1**	*Alternatively*: current $I = \frac{P}{V} = \frac{3000}{230} = 13.0$ A
$= 17.6\ \Omega$	**1**	resistance $R = \frac{V}{I} = \frac{230}{13.0} = 17.7\ \Omega$
(ii) Cross-sectional area of wire $A = \frac{\pi d^2}{4} = \frac{\pi \times (0.65 \times 10^{-3})^2}{4}$ $= 3.32 \times 10^{-7}$ m²	**1**	You could calculate the cross-sectional area using $A = \pi r^2 = \pi \times (0.325 \times 10^{-3})^2$. The unit of resistivity regularly causes problems for students. It is Ω m, not $\Omega\ m^{-1}$ (which is the unit of resistance per unit length).
Resistivity $\rho = \frac{RA}{l} = \frac{17.6 \times 3.32 \times 10^{-7}}{0.25}$	**1**	
$= 2.34 \times 10^{-5}\ \Omega$ m	**1**	

Answers to examination-style questions

Answers	Marks	Examiner's tips
14 (a) (i) Temperature of air = 22 + 273 = 295 K	1	It is essential to realise that the temperature must be expressed in K whenever $pV = nRT$ is to be applied. The size of the room in this question is typical of the rooms in modern houses or apartments. The pressure is normal atmospheric pressure, and the temperature would be comfortable for an evening in winter.
(ii) Use of $pV = nRT$ Gives $105 \times 10^3 \times 27.0 = n \times 8.31 \times 295$ $\therefore$ number of moles of air in room $n = \dfrac{105 \times 10^3 \times 27.0}{8.31 \times 295} = 1160$ mol	1 1	
(iii) Number of molecules in room $= 1160\ N_A = 1160 \times 6.02 \times 10^{23}$ $= 6.98 \times 10^{26}$	 1 1	
(b) *Relevant points include these listed here.* When the temperature *falls* . . . **(i)** The mean square speed of the gas molecules *decreases* because the mean square speed is proportional to the temperature. **(ii)** The pressure of the gas *decreases* • because the number of collisions per second against the walls decreases . . . • and the change in momentum per collision is smaller on average.	**any 4**	*Alternatively (and more mathematically)*: **(i)** Using $\frac{1}{2}mc_{rms}^2 = \frac{3}{2}kT$, m and T are constant. Hence $c_{rms}^2 \propto T$. $\therefore c_{rms}^2$ decreases when T falls. **(ii)** using $pV = \frac{1}{3}Nmc_{rms}^2$, V, N and m are constant and $c_{rms}^2 \propto T \therefore p \propto T$ $\therefore p$ decreases when T falls.
15 (a) *Graph plotted to have*: • axes labelled $E_k/\times 10^{-21}$ J and T/K with a scale occupying more than half of the area of the graph paper • correct plotting of all 6 points • a best fit straight line	3	It is good practice to plot graphs in pencil, because any errors during the plotting are then easily corrected. The line itself is also best drawn with a sharp pencil, using a 300 mm transparent ruler.
(i) Reading from the graph, at 350 K $E_k = 7.23\ (\pm\ 0.05) \times 10^{-21}$ J	1	To be consistent with the data in the table, you should quote this value to three significant figures. Do not overlook the '$\times 10^{-21}$ J'.
(ii) Gradient of graph $= \dfrac{(8.28 - 6.21) \times 10^{-21}}{(400 - 300)}$ $= 2.07\ (\pm 0.08) \times 10^{-23}$ J K^{-1} The equation of the line is $E_k = \frac{3}{2}k\ T$ $\therefore$ gradient of graph $= \frac{3}{2}k$ $\frac{3}{2}k = 2.07 \times 10^{-23}$ gives Boltzmann constant $k = 1.38\ (\pm 0.05) \times 10^{-23}$ J K^{-1}	1 1 1 1	This question becomes a further exercise in applying the properties of a straight line graph of the form $y = mx$, where m is the gradient. The Boltzmann constant k is the universal gas constant *per molecule*, as opposed to R, which is the universal gas constant *per mole*, $k = \dfrac{R}{N_A}$
(b) (i) An elastic collision is one in which there is no loss of *kinetic* energy.	1	'No loss of energy' is not a satisfactory answer because *energy is always conserved* in any physical process.

Answers to examination-style questions

Answers	Marks	Examiner's tips
(ii) *Other possible assumptions listed below.* • The motion of the molecules is random. • Intermolecular forces are negligible (except during collisions). • The volume of the molecules is negligible (compared to volume of container). • The duration of collisions is negligible (compared to time between collisions). • The molecules are identical. • A gas consists of a very large number of molecules. • The molecules behave according to the laws of Newtonian mechanics.	**any 1**	One mark for *any one* of these should not be too taxing!
(iii) *Relevant points include*: • temperature is proportional to the average kinetic energy of the molecules • at the absolute zero of temperature the kinetic energy of the molecules would be zero.	**2**	If the graph were extrapolated to lower temperatures, a point would be reached at which $E_k = 0$. This would be $T = 0$ (i.e. 0 K), at which temperature the graph suggests that molecules would stop moving.
16 (a) (i) *Possible assumptions listed below.* • Molecular collisions are elastic. • The motion of the molecules is random. • The duration of collisions is negligible (compared to time between collisions). • The molecules move with a range of speeds. • Each molecule moves at constant velocity between collisions.	**any 3**	Be careful to read questions carefully. This is not the usual question asking for *any* three assumptions of the kinetic theory. You have to give assumptions that relate to the *motion* of the molecules. The last point listed here follows from the fact that intermolecular forces are negligible.
(ii) Mean kinetic energy of a molecule $= \frac{3}{2}kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 300$ $= 6.21 \times 10^{-21}$ J	 **1** **1**	You are required to show that this energy is 6.2×10^{-21} J because the same energy value is needed in part **(b)** of this question.
(b) (i) Use of $E_k = \frac{1}{2}mv^2$ gives 6.2×10^{-21} $= \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$ from which speed of an electron $v = 1.17 \times 10^5$ m s^{-1}	**1** **1**	The value calculated here is the *mean speed of the random motion* of the electrons. Do not confuse this with the *drift speed* of the electrons through the conductor. Frequent scattering of the electrons by ions in the crystal lattice cause the drift speed to be much lower than this.

Answers	Marks	Examiner's tips
(ii) *Relevant points include*: • The applied pd causes a force on each conduction electron that is directed towards the positive end of the wire. • Conduction electrons gain kinetic energy when they accelerated by the applied pd. • They collide with ions in the crystal lattice of the metal … • losing some of the kinetic energy they had acquired. • This process happens repeatedly and slows down their progress through the conductor. • This drift motion is superimposed on the random motion they would have if no pd were applied.	**any 4**	This is the 'free electron gas' model of metallic conduction. In metallic conduction two factors are at work: the usual random motion of the free electrons, and their drift motion caused by an applied electric field. At higher temperatures the random motion is more energetic; therefore there is more scattering and the drift motion of the conduction electrons is hindered still further. Consequently the resistivity of the metal increases when the temperature is increased.
17 (a) Mean kinetic energy of an air molecule $= \frac{3}{2}kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 300$ $= 6.21 \times 10^{-21}$ J	**1** **1**	The mean molecular kinetic energy depends only on the absolute temperature of the gas.
(b) Combining $pV = \frac{1}{3}Nmc_{rms}^2$ with density $\rho = \frac{Nm}{V}$ gives $p = \frac{1}{3}\rho c_{rms}^2$ $\therefore\ 1.01 \times 10^5 = \frac{1}{3} \times 1.24 \times c_{rms}^2$ leading to mean square speed of air molecules $c_{rms}^2 = 2.44 \times 10^5$ m^2 s^{-2} *Note that*: • c_{rms} is the square root of the mean square speed; therefore the mean square speed is c_{rms}^2 • root mean square speed c_{rms}= 494 m s^{-1}	**1** **1** **1**	*Alternatively (and rather more tediously)*: Consider 1.0 m^3 of air. Substitution of given values into $pV = nRT$ gives $n = 40.5$ mol. ∴ The mass of 40.5 N_A molecules is 1.24 kg, and the molecular mass $m = 5.08 \times 10^{-26}$ kg. Using $E_k = \frac{1}{2}mc_{rms}^2$, $6.21 \times 10^{-21} = \frac{1}{2} \times 5.08 \times 10^{-26} \times c_{rms}^2$ giving $c_{rms}^2 = 2.44 \times 10^5$ m^2 s^{-2}.
(c) Gas molecules always move with a range of speeds. At 320 K many molecules will be moving much faster than 494 m s^{-1} but many will also be travelling at much lower speeds than this.	**1** **1**	Raising the temperature from 300 K to 320 K will increase the *mean* square speed. At *any* temperature, the random motion means that there are many molecules travelling at both higher and lower speeds than the mean value.

Answers to examination-style questions

Answers			Marks	Examiner's tips
18 (a)	**(i)**	For a point on the surface of a planet of mass M and radius R the gravitational potential $V_S = -\frac{GM}{R}$ and field strength $g_S = \frac{GM}{R_2}$	1	It is not advisable to attempt to show this result by starting from the equation $g = -\frac{\Delta V}{\Delta r}$, because ΔV and Δr represent small **changes in** the values V and r. In this question V_S and R are the **absolute** values of gravitational potential and radius.
		$\therefore \frac{g_s}{V_s} = -\frac{1}{R}$ and $V_S = -g_S R$	1	
	(ii)	Gravitational potential at a point on the surface of the moon $V_S = -g_S R$ $= 1.6 \times 1.70 \times 10^6 = 2.72 \times 10^6$ J kg^{-1}	1	The result from part **(a)(i)** allows you to determine the gravitational potential without having to go back to first principles.
		Mass of an oxygen molecule $m = \frac{0.032}{6.02 \times 10^{23}} = 5.32 \times 10^{-26}$ kg	1	One mole of any substance contains N_A molecules.
		Gravitational potential energy of molecule $= mV_S = -5.32 \times 10^{-26} \times 2.72 \times 10^6$ $= -1.45 \times 10^{-19}$ J	1	This value is negative because gravitational potential is defined to be zero at an infinite distance from the source of the gravitational field. Due to this convention **all** absolute gravitational potential energy values are negative.
(b)	**(i)**	Mean kinetic energy of an oxygen molecule $E_k = \frac{3}{2}kT$ $= \frac{3}{2} \times 1.38 \times 10^{-23} \times 400$	1	The surface temperature of the Moon can be much higher than that of the Earth. At first sight it may appear that the gas molecules do not have enough kinetic energy to escape. The fact that they move with a vast range of speeds means that, in any population of molecules, some will always have a speed in excess of the escape speed. The Moon has no atmosphere because **all** gas molecules eventually gain enough energy to escape.
		$= 8.28 \times 10^{-21}$ J	1	
	(ii)	In order to escape the molecule will require more than 1.45×10^{-19} J of kinetic energy.	1	
		Molecules have a range of speeds; many will have more kinetic energy than 8.28×10^{-21} J (and enough to escape) because $\frac{3}{2}kT$ is only a mean value.	1	

Nelson Thornes is responsible for the solution(s) given and they may not constitute the only possible solution(s).