Pearson

Mark Scheme (Results)

January 2026

Pearson Edexcel International Advanced Level
In Physics
Further Mechanics, Fields and Particles
WPH15/01A

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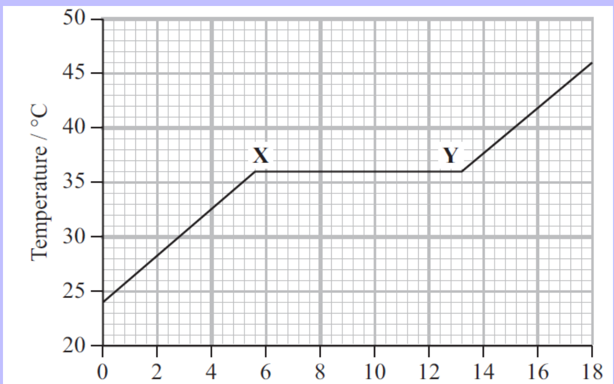
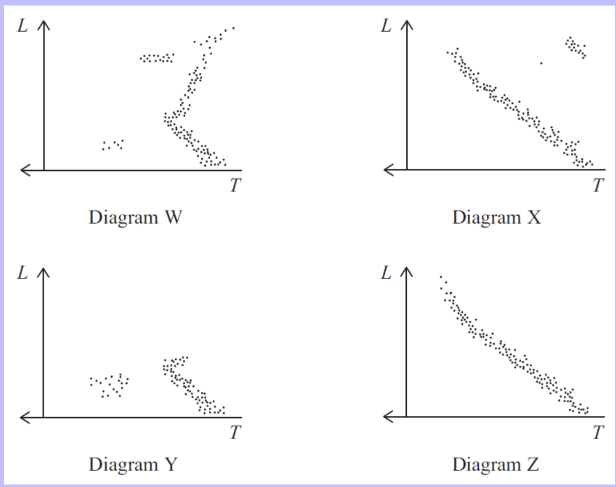
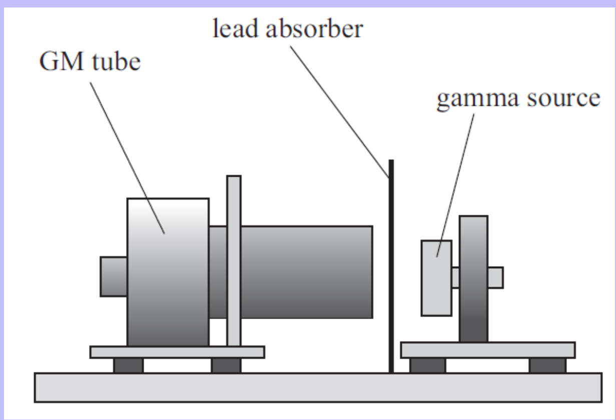
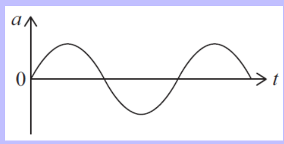
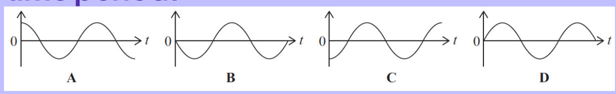
General Marking Guidance

- All candidates must receive the same treatment. Examiners must mark the first candidate in exactly the same way as they mark the last.
- Mark schemes should be applied positively. Candidates must be rewarded for what they have shown they can do rather than penalised for omissions.
- Examiners should mark according to the mark scheme not according to their perception of where the grade boundaries may lie.
- There is no ceiling on achievement. All marks on the mark scheme should be used appropriately.
- All the marks on the mark scheme are designed to be awarded. Examiners should always award full marks if deserved, i.e. if the answer matches the mark scheme. Examiners should also be prepared to award zero marks if the candidate's response is not worthy of credit according to the mark scheme.
- Where some judgement is required, mark schemes will provide the principles by which marks will be awarded and exemplification may be limited.
- When examiners are in doubt regarding the application of the mark scheme to a candidate's response, the team leader must be consulted.
- Crossed out work should be marked UNLESS the candidate has replaced it with an alternative response.

Question Number	Answer	Mark
	The brightness of a star depends upon its luminosity and	
1	**The only correct answer is B** The brightness or intensity depends on luminosity and distance A is not correct, as brightness or intensity depends on luminosity and distance C is not correct, as brightness or intensity depends on luminosity and distance D is not correct, as brightness or intensity depends on luminosity and distance	1
	Two containers are filled with two gases, A and B. The gases have the same temperature, but the mean squared speed of the molecules in B is twice the mean squared speed of the molecules in A. Which of the following is equal to $\frac{\text{mass of a molecule in B}}{\text{mass of a molecule in A}}$	
2	**The only correct answer is B** as $m < c^2 >$ is constant so $m_A < c^2 >= m_B \, 2 \times < c^2 >$ so $\frac{m_B}{m_A} = 0.5$	1
	The average density of the universe is unknown. Scientists believe that there is a critical value for this density. Which of the following describes the future of the Universe if the density of the Universe is more than the critical density?	
3	**The only correct answer is D** If the density of the universe is more than the critical density then it will reach a maximum size then contract A is not correct because this would only happen if the universe has its critical density. B is not correct because this would only happen if the density of the universe were less than its critical density. C is not correct because observations suggest that the universe is expanding.	1
	A student used a detector and counter to measure the background radiation count for five minutes. He used this value to calculate the background count rate. Which of the following would increase the accuracy of the student's value for the background count rate?	
4	**B is the correct answer** Increasing the count time will increase the accuracy A is not correct, as this will decrease the accuracy	1

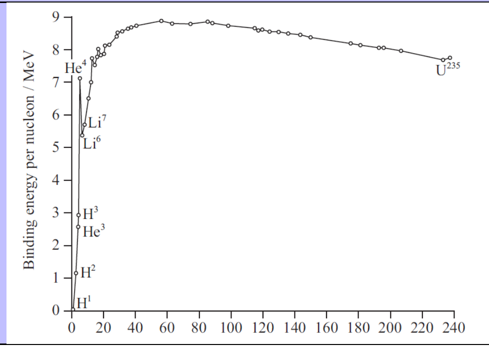
	C is not correct, as this should not change the accuracy D is not correct, as this will decrease the accuracy	
	A sample of radioactive material has a known half-life. Radioactive decay is a random process. Which of the following predictions can be made?	
5	**The only correct answer is D** The half life means that we can predict the fraction of nuclei that decay in a set period of time A is not correct because the half life means that we can predict the fraction of nuclei that decay in a set period of time B is not correct because the half life means that we can predict the fraction of nuclei that decay in a set period of time C is not correct because the half life means that we can predict the fraction of nuclei that decay in a set period of time	**1**
	A piece of chocolate is heated at a constant rate. The graph shows how the temperature of the chocolate varies with time.  Select the correct statement for the time between X and Y.	
6	**The only correct answer is A** The internal energy of the chocolate increases as it changes state. B is not correct because the internal energy of the chocolate increases as it changes state. C is not correct because the internal energy of the chocolate increases as it changes state. D is not correct because the internal energy of the chocolate increases as it changes state.	**1**

	The Hertzsprung–Russell diagrams W, X, Y and Z below show a star cluster at various times when the star cluster is in different stages of evolution.  Which of the diagrams represents the cluster in the final stage of evolution?	
7	**The only correct answer is C** as there are white dwarf stars but no red giants in the cluster	1
	A student investigated the absorption of gamma radiation by lead, as shown.  With no absorber the intensity of radiation was I_O. With an absorber of thickness 3.2 cm the intensity was 0.25 I_O What thickness of absorber would give an intensity of 0.5 I_O ?	
8	**The only correct answer is C** when intensity is reduced to 25% this corresponds to twice the half-thickness of lead between the source and the detector. So a drop of 50% will be 1.6 cm A is not correct because the half-thickness is 1.6 cm B is not correct because the half-thickness is 1.6 cm	1

	D is not correct because the half-thickness is 1.6 cm	
	The graph shows how the acceleration *a* varies with time *t* for an object undergoing simple harmonic motion.  The following graphs show how other quantities for the object may vary over the same time period.  Which graph shows the variation of displacement with time?	
9	**The only correct answer is B** as $a \propto -x$ A is not correct because $a \propto -x$ C is not correct because $a \propto -x$ D is not correct because $a \propto -x$	**1**
	Which graph shows the variation of velocity with time?	
10	**The only correct answer is C** as the gradient of a v - t graph gives $a - t$ graph A is not correct because the gradient of a v - t graph gives a - t B is not correct because the gradient of a v - t graph gives a - t D is not correct because the gradient of a v - t graph gives a - t	**1**

Question Number	Answer	Additional Guidance	Mark
	The Earth is 81 times more massive than the Moon. The gravitational field strength at the surface of t he Earth is 6 times greater than at the surface of the Moon. Calculate the mean radius of the Moon. mean radius of Earth = 6.37×10^6 m		
11	Use of $g = \frac{GM}{r^2}$ **(1)** $R_m = 1.7 \times 10^6$ m **(1)**	Must see 81 and 6 used correctly in solution, don't need to see value for G substituted. <u>Example of calculation</u> $g = \frac{GM}{r^2} \therefore r = \sqrt{\frac{GM}{g}}$ $\frac{R_m}{R_E} = \sqrt{\frac{M_m}{M_E} \times \frac{g_E}{g_m}}$ $\therefore R_m = 6.37 \times 10^6 \text{ m} \times \sqrt{\frac{1}{81} \times 6} = 1.74 \times 10^6 \text{ m}$	**2**
	Total for question 11		**2**

Question Number	Answer	Additional Guidance	Mark
	Light from either end of the Sun's diameter is analysed and compared to light from the centre of the Sun. A hydrogen line in the light from the centre of the Sun has a wavelength of 490 nm. The shift in wavelength observed from opposite edges of the Sun's diameter is 3.4×10^{-3} nm. Calculate the angular velocity of the Sun. radius of the Sun = 7.0×10^{8} m		
12	Use of $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ **(1)** Use of $\omega = \frac{v}{r}$ **(1)** $\omega = 3.0 \times 10^{-6}$ (rad) s^{-1} **(1)**	Do not credit an attempt to subtract values to find Δλ. Also, must see 490 (to any power) in denominator. Allow use of factor of 2 to give $\omega = 1.5 \times 10^{-6}$ rad s^{-1} Example of calculation $v = c \times \frac{\Delta\lambda}{\lambda}$ $v = 3.0 \times 10^{8}\ \text{m s}^{-1} \times \frac{(3.4 \times 10^{-3}\ \text{nm})}{490\ \ \text{nm}}$ $v = 2.08 \times 10^{3}\ \text{m s}^{-1}$ $\omega = \frac{v}{r} = \frac{1.04 \times 10^{3}\ \text{ms}^{-1}}{7.0 \times 10^{8}\ \text{m}} = 2.97 \times 10^{-6}\ \text{rads}^{-1}$	3
	Total for question 12		2

Question Number	Answer		Additional Guidance	Mark
	The graph shows how the binding energy per nucleon varies with nucleon number for a range of isotopes. Explain why fission reactors use isotopes such as U-235 as fuel and why there is still ongoing research to develop fusion reactors. Your answer should include reference to the graph.			
13	**Any four of the following points:**		Accept 'heavy' for 'massive' Accept 'large/small nucleon number' but not 'large' or 'small'	
	Massive nuclei can undergo fission	**(1)**	Accept massive nuclei can break into fragments	
	(The graph shows that) massive nuclei have less B.E. <u>per nucleon</u> than the nuclei produced in the fission	**(1)**	Accept reference to U-235 in MP2	
	(Hence) energy is released during fission.	**(1)**	This is **not** a dependent mark	
	Low mass nuclei can undergo fusion (into more massive nuclei) releasing energy.	**(1)**	Allow 'light' for low mass. Reference to H or He okay.	
	Fusion would produce more energy per interaction (than fission) **Or** Fusion produces less radioactive waste (than fission) **Or** Fusion uses atoms which are abundant **Or** Reference to containment problems in a practical fusion reactor	**(1)**	Allow converse statements for fission in MP5 Don't allow 'more energy' without some qualification Allow reference to temperature, pressure or need for strong magnetic field	4

	Total for question 13		**4**
	Cocoa powder, milk and hot water are mixed together to produce a 'hot chocolate' drink. The mass of the drink is 275 g, and its initial temperature is 71.5 °C. **Ice at 0.0 °C is added to the drink to reduce its temperature. Research indicates that the maximum serving temperature of any hot drink should be 58.0 °C.** **Deduce whether 4.0 g of ice would be enough to bring the temperature below 58.0 °C.**	**specific latent heat of ice = 3.34×10^5 J kg^{-1}** **specific heat capacity of 'hot chocolate' = 3750 J kg^{-1} °C^{-1}** **specific heat capacity of water = 4190 J kg^{-1} °C^{-1}**	**4**
14	Energy transferred from hot liquid = energy transferred to ice + energy transferred to cold water **(1)** Use of $E = mc\Delta\theta$ **(1)** Use of $E = mL$ **(1)** $m = 2.4 \times 10^{-2}$ kg **Or** 4 g of ice would only reduce the temperature to 69 °C **Or** energy transferred to ice = 2.31×10^3 J **and** energy transferred from drink = 1.39×10^4 J (for drink to reach 58 °C) **(1)** So 4 g would not bring the temperature below the ideal serving temperature. **Or** comparison of calculated value for mass with 4 g with consistent conclusion **Or** comparison of calculated value for final temperature with 69 °C with consistent conclusion **Or** comparison of energy transferred to use with energy transferred from drink with consistent conclusion **(1)**	<u>Example of calculation</u> Energy transferred from hot liquid = energy transferred to ice + energy transferred to cold water $0.275 \text{ kg} \times 3750 \text{ J kg}^{-1}\text{K}^{-1} \times (71.5 - 58.0)\text{K}$ $= \text{m} \times 3.34 \times 10^5 \text{ J kg}^{-1}$ $+ \text{m} \times 4190 \text{ J kg}^{-1}\text{K}^{-1} \times (58.0 - 0)\text{K}$ $\therefore 1.39 \times 10^4\text{J} = \text{m} \times (3.34 \times 10^5 + 2.43 \times 10^5) \text{ J kg}^{-1}$ $\therefore m = \dfrac{1.39 \times 10^4 \text{ J}}{5.77 \times 10^5 \text{ J kg}^{-1}} = 2.41 \times 10^{-2} \text{ kg}$ Look for a comparison of values. A comment such as "not enough" is sufficient, with the values compared.	**5**
	Total for question 14		**5**

Question Number	Answer	Additional Guidance	Mark
	A weather balloon takes scientific equipment high into the atmosphere to monitor atmospheric conditions. A weather balloon is filled with hydrogen at a temperature of 22.5 °C and a pressure of 1.02×10^5 Pa. The volume of the balloon is 7.50 m^3. The balloon rises through the atmosphere to a maximum height. At the maximum height, the temperature of the hydrogen in the balloon is −48.0 °C and the pressure of the hydrogen in the balloon is 8.40×10^4 Pa. (a) Calculate the volume of the balloon at the maximum height.		
15(a)	Use of $pV = NkT$ **(1)** Temperature converted to kelvin **(1)** $V = 6.9\ \mathrm{m}^3$ **(1)**	<u>Example of calculation</u> $\frac{pV}{T} = \text{a constant}$ $\frac{8.4 \times 10^4\ \mathrm{Pa} \times V}{(273 - 48)\ \mathrm{K}} = \frac{1.02 \times 10^5\ \mathrm{Pa} \times 7.50\ \mathrm{m}^3}{(273 + 22.5)\mathrm{K}}$ $\therefore V = \frac{1.02 \times 10^5\ \mathrm{Pa} \times 7.5\ \mathrm{m}^3 \times (273 - 48)\ \mathrm{K}}{(273 + 22.5)\mathrm{K} \times 8.4 \times 10^4\ \mathrm{Pa}}$ $= 6.93\ \mathrm{m}^3$	3
15(b)	(b) Calculate the decrease in the mean kinetic energy of a hydrogen molecule in the balloon as the balloon rises to the maximum height.		
	Use of $\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$ **(1)** Decrease = 1.5×10^{-21} J **(1)**	<u>Example of calculation</u> $\Delta E_k = \frac{3}{2} 1.38 \times 10^{-23}\ \mathrm{J\ K^{-1}}(-48 - 22.5)\mathrm{K}$ $\therefore \Delta E_k = -1.46 \times 10^{-21}\ \mathrm{J}$	2

	Total for question 15		**5**

	A ‘scuba tank’ is used to store air at high pressure. Explain why the pressure of the air inside the scuba tank increases as the temperature increases. Your answer should refer to the motion of the air molecules.		
***16**	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for structure and lines of reasoning.		

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning

IC points	IC mark	Max linkage mark	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

	Indicative content IC1 As the temperature increases the (average) kinetic energy of the (air) molecules increases IC2 So the (root mean square) velocity of the (air) molecules increases IC3 The change of momentum of the air molecules when colliding with the tank/walls increases IC4 The rate of collision of (air) molecules with the tank/walls increases IC5 So the rate of change of momentum and so the force (on the tank/walls), increases IC6 Hence the pressure exerted by the gas increases, since $p = F/A$	If reference is made to particles instead of molecules/atoms, then withhold IC point on first occasion. Allow E_k for kinetic energy in IC1 Allow 'momentum' for 'velocity' in IC2 Do **not** allow p for momentum (too easy to be confused with pressure) Allow $F = \frac{\Delta p}{\Delta t}$ in IC5	
	Total for question 16		**6**

Question Number	Answer		Additional Guidance	Mark
	A commercial drinks dispenser fills a cup with 0.30 kg of water at a temperature of 5.0 °C after chilling it for 2 minutes. (a) The water enters the dispenser at a temperature of 20 °C. Calculate the electrical power of the heater in the dispenser. specific heat capacity of water = 4200 J kg^{-1} K^{-1}			
17(a)	Use of $\Delta E = mc\Delta\theta$ Use of $P = \frac{\Delta E}{\Delta t}$ P = 160 W [allow J s^{-1}]	**(1)** **(1)** **(1)**	Example of calculation $P = \frac{\Delta E}{\Delta t} = \frac{mc\Delta\theta}{\Delta t}$ $P = \frac{0.3\ \text{kg} \times 4200\ \text{J kg}^{-1}\text{K}^{-1} \times (20-5)\ \text{K}}{120\ \text{s}} = 158\ \text{W}$	3
	Suggest why the actual power of the heater may differ from the value calculated in (a).			
17(b)	Any **TWO** from Energy may be transferred from the surroundings (to the water in the cup) Energy may be required to cool the dispenser 'Heater' may not be 100% efficient	 **(1)** **(1)** **(1)**	 MP1, accept energy may be transferred (from the 'heater') to the surroundings. Accept lost to the surroundings. Do not allow 'power' for 'energy'. MP3, accept the 'heater power' may be greater than the value calculated in (a)	2
	Total for question 16			5

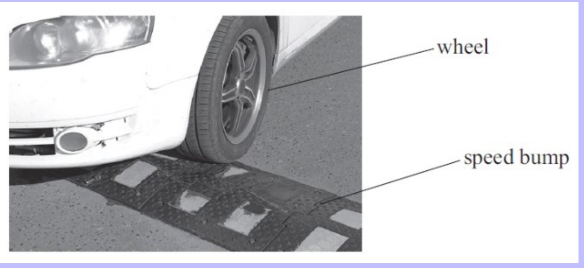
Question Number	Answer	Additional Guidance	Mark
	Superfluid He-3 has been used as a potential dark matter detector. To test the idea, He-3 atoms are bombarded with neutrons. (a) (i) Deduce the identity of particle X by completing the nuclear equation in the answer booklet.	$^{\dots}_{\dots}\mathrm{n} + ^{\dots}_{2}\mathrm{He} \rightarrow ^{\dots}_{1}\mathrm{H} + ^{1}_{\dots}\mathrm{X}$	
18(a)(i)	Top line correct **(1)** Bottom line correct **(1)** X is a proton [allow p, hydrogen or H] **(1)**	Example of equation $^{1}_{0}\mathrm{n} + ^{3}_{2}\mathrm{He} \rightarrow ^{3}_{1}\mathrm{H} + ^{1}_{1}\mathrm{X}$	**3**
	Calculate the total kinetic energy, in MeV, of the reaction products. Assume that the neutron has zero kinetic energy. Mass / u electron 0.000549 proton 1.007276 neutron 1.008665 H-2 2.013553 H-3 3.015501 He-3 3.014932 He-4 4.001506		
18(a)(ii)	Attempt at calculation of mass difference **(1)** Use of $\Delta E = c^2 \Delta m$ **(1)** Conversion of energy to eV and E_k = 0.766 MeV (766 keV) **(1)**	Must see a subtraction of values Example of calculation Δm = [(1.008665 +3.014932) – (3.015501 + 1.007276)] = 0.000820 u $\Delta m = 0.000820 \times 1.66 \times 10^{-27}$ kg $= 1.361 \times 10^{-30}$ kg $\Delta E = c^2\Delta m = (3 \times 10^8 \text{ m s}^{-1})^2 \times 1.361 \times 10^{-30} \text{ kg} = 1.225 \times 10^{-13}$ J $\Delta E = \frac{1.225 \times 10^{-13} \text{ J}}{1.6 \times 10^{-13} \text{ JMeV}^{-1}} = 0.766$ MeV	**3**
18(b)(i)	(b) Tritium (H-3) is an isotope of hydrogen. (i) Define what an isotope is.		
	Atoms that have the same number of protons **(1)** **(1)**	Allow same proton/atomic number	**2**

	but a different number of neutrons	Allow different neutron/nucleon/mass number.	
18(b)(ii)	**(ii) State what is meant by a positron, and suggest why positron emission cannot occur for H-3.**		
	A positron is the antiparticle to the electron **(1)** After positron emission there would be only neutrons in the nucleus (which is not possible) **Or** after positron emission the proton/atomic number would be zero **Or** positron emission is impossible because (mass-) energy would not be conserved. **Or** positron emission is impossible because the mass of ^{3}H is less than the mass of the products **(1)**	Allow tritium nucleus is 'neutron rich', but positron emission occurs for 'proton rich' nucleus.	**2**
	Tritium has a half-life of 12.5 years. At a particular instant a sample of tritium contains 3.2×10^{12} atoms. **(i) Calculate the activity of the sample at this instant.**		
18I(i)	Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ **(1)** Use of $A = -\lambda N$ **(1)** A = 5600 Bq **(1)**	<u>Example of calculation</u> $\lambda = \frac{0.693}{12.5 \text{ x } 365 \text{ x } 24 \text{ x } 3600 \text{ s}} = 1.758 \text{ x } 10^{-9} \text{ s}^{-1}$ $A = \lambda N = 1.758 \text{ x } 10^{-9} \text{ x } 3.2 \text{ x } 10^{12} = 5.623 \text{ x } 10^{3}$ Bq Accept $\lambda = 5.54 \text{ x } 10^{-2}$ year^{-1}; $A = 1.77 \text{ x } 10^{11}$ decays per year.	**3**
	(ii) Determine the activity of the sample 60 years later.		
18I(i)(ii)	λ and t in consistent units **(1)** Use of $A = A_o e^{-\lambda t}$ **(1)** A = 200 Bq (ecf from (i)) **(1)**	Allow a method that uses $A/2^n$ with n = 4.8 <u>Example of calculation</u> $\lambda = \frac{\ln 2}{12.5 \text{ year}} = 0.0555 \text{ year}^{-1}$ $A = 5.62 \text{ x } 10^{3} \text{ Bq x } e^{-5.55 \text{ x } 10^{-2} \text{ year}^{-1} \text{x } 60 \text{ year}}$ A = 201 Bq Accept $A = 6.34 \text{ x } 10^{9}$ decays per year.	**3**

	Total for question 18		16
Question Number	**Answer**	**Additional Guidance**	**Mark**
	Salyut 1 was the first Earth-orbiting space station. It was built by the Soviet Union and launched into a low Earth orbit fifty years ago. **(1)** Salyut 1 orbited at an average height above the surface of the Earth of 211 km. mass of Salyut 1 = 18 400 kg mass of Earth = 5.98×10^{24} kg radius of Earth = 6.37×10^{6} m	**(1)** A textbook claims that for astronauts in Salyut 1, there would be a sunrise 16 times every day. Assess the validity of this claim. 1 day = 8.64×10^{4} s	
19(a)(i)	Equate $F = \frac{GMm}{r^2}$ with $F = m\omega^2 r$ **Or** Equate $F = \frac{GMm}{r^2}$ with $F = \frac{mv^2}{r}$ **(1)** Use of $\omega = \frac{2\pi}{T}$ **Or** Use of $v = \frac{2\pi r}{T}$ **(1)** $T = 5300$ s **(1)** **Or** In 1 day Salyut 1 would make 16.3 orbits which greater than [accept equal to] 16, so the claim is correct. **Or** Comparison of calculated number of orbits with 16 and consistent conclusion. **Or** Textbook claim gives T = 5400 (s) which is greater than 5300 (s), so claim is correct. **Or** Comparison of calculated T with T for 16 orbits and consistent conclusion. **(1)**	Calculated number of orbits must be greater than 16, or calculated time must be less than 5400 s, for (at least) 16 sunrises to be seen. Allow responses that say 16.3 ≈ 16 or 5400 ≈ 5310 as a comparison. If Kepler's law is used without derivation, MP1, MP2 and MP3 allowed if value calculated is correct. Otherwise nothing for these 3 MP. <u>Example of calculation</u> $m\omega^2 r = \frac{GMm}{r^2}$ $\therefore \left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3}$ $\therefore T = 2\pi\sqrt{\frac{r^3}{GM}}$ $= 2\pi \times \sqrt{\frac{(6.37 \times 10^6 \text{m} + 2.11 \times 10^5 \text{ m})^3}{6.67 \times 10^{-11} \text{N m}^2 \text{ kg}^{-2} \times 5.98 \times 10^{24} \text{ kg}}}$ $= 5311$ s	4

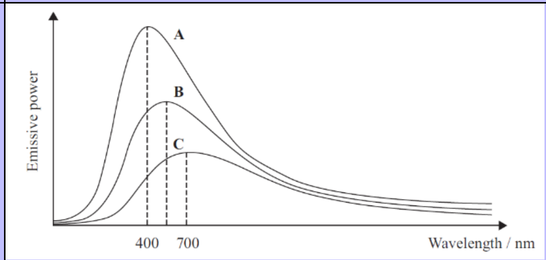
		Number of orbits $= \frac{8.64 \times 10^4\ \text{s}}{5310\ \text{s}} = 16.3$	
	(ii) Salyut 1 made almost three thousand orbits before falling back to Earth. Calculate the change in gravitational potential energy of Salyut 1 as it fell back to Earth		
19(a)(ii)	Use of $V_{grav} = -\frac{GM}{r}$ with M = mass of Earth (5.98×10^{24} kg) **(1)** Calculation using $\Delta E_{grav} = m \times \Delta V_{grav}$ **(1)** $\Delta E_{grav} = (-)3.7 \times 10^{10}$ J **(1)**	Don't credit use of mass of Earth twice. Example of calculation $\Delta V_{grav} = -\frac{GM}{r_1} + \frac{GM}{r_2}$ $\Delta V_{grav} = GM\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$ $\Delta V_{grav} = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 5.98 \times 10^{24}\ \text{kg}\left(\frac{1}{6.58 \times 10^6\ \text{m}} - \frac{1}{6.37 \times 10^6 \text{m}}\right)$ $\therefore \Delta V_{grav} = 2.00 \times 10^6\ \text{J kg}^{-1}$ $\therefore \Delta E_{grav} = -2.00 \times 6\ \text{J kg}^{-2} \times 18400\ \text{kg} = -3.67 \times 10^{10}$ J	**3**
19(b)	**(b) Salyut 1 burned up over the Pacific Ocean as it re-entered the Earth's atmosphere. Explain why Salyut 1 burned up.**		
	Any TWO from Frictional forces did work (on spacecraft) **Or** Frictional forces transfer energy (to spacecraft) **(1)** Internal energy (of spacecraft) increased **(1)** High temperature (so Salyut 1 burned up) **(1)**	Accept 'air resistance', 'drag' for 'frictional forces' Accept 'thermal energy increased', 'energy transferred to thermal' 'heat'	**2**

	Total for question 19		9

Question Number	Answer	Additional Guidance	Mark
	The suspension system of a car is a set of springs that allows the body of the car to move vertically up and down relative to the wheels. A car is driven along a long straight road that has a series of ‘speed bumps’. Speed bumps are raised parts in a road, as shown. At a particular speed of the car resonance occurs. The amplitude of vibration of the car body on the suspension system becomes much larger. (a) Explain why the amplitude of vibration increases at a particular speed.		
20(a)	The car body is driven/forced into oscillation at its natural frequency **(1)** There is a maximum transfer of energy to the car body **(1)**	Accept driving frequency is equal to natural frequency Accept energy transfer is most efficient	2
	(b) A car suspension system can be thought of as a mass-spring system. The natural frequency of the system is determined by the force constant of the suspension *k* and t total mass of the system *m*. (i) A car is set into vertical oscillation by applying a momentary downwards force. Show that the frequency of oscillation *f* is given by $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$		
20(b)(i)	**EITHER** Use of Hooke’s law with Newton’s 2nd law **(1)** **(1)**	Example of full derivation $ma = -k\Delta x$ So $a = -\left(\frac{k}{m}\right)\Delta x$	2

	Identify $\omega^2 = \dfrac{k}{m}$ and use ω = 2π f to obtain required result. **(1)** **OR** $T = 2\pi\sqrt{\dfrac{m}{k}}$ **(1)** $f = \frac{1}{T}$ with algebra to obtain required result.	$a = -\omega^2 x$ so $\omega^2 = \dfrac{k}{m}$ $\omega = 2\pi f$ so $f = \dfrac{1}{2\pi}\sqrt{\dfrac{k}{m}}$	
20(b)(ii)	A person of mass 75 kg steps into the car, the vertical height of the car above the road decreases by 1.5 cm The mass of the empty car is 1450 kg. The car is driven along the road at a speed of 13.4 m s^{-1} Adjacent speed bumps are a distance of 14.9 m apart. Deduce whether resonance will occur. You should consider the car as a mass-spring system.		
	Use of $F = mg$ **(1)** Use of $\Delta F = (-)k\Delta x$ **(1)** Use of $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ **Or** use of $T = 2\pi\sqrt{\frac{m}{k}}$ **(1)** Use of $s = ut + \frac{1}{2}at^2$ with $a = 0$ **(1)** T = 1.11 s for forced **and** natural, so resonance occurs **Or** f = 0.90 Hz for forced **and** natural, so resonance occurs **Or** Speed of car for driving frequency to be 0.90 Hz is 13.4 m s^{-1} and actual speed of car is 13.4 m s^{-1}, so resonance occurs **(1)**	Correct values for T or f or v must be seen in MP5 Example of calculation $k = \dfrac{75\ \text{kg} \times 9.81\ \text{N kg}^{-1}}{1.5 \times 10^{-2}\ \text{m}} = 4.91 \times 10^4\ \text{N m}^{-1}$ $f = \dfrac{1}{2\pi} \times \sqrt{\dfrac{4.91 \times 10^4\ \text{N m}^{-1}}{(1450 + 75)\text{kg}}} = 0.90\ \text{Hz}$ $t = s/u = 14.9/13.4 = 1.11\ \text{s}$ $f = \dfrac{1}{t} = \dfrac{1}{1.11\ \text{s}} = 0.90\ \text{Hz}$	**5**

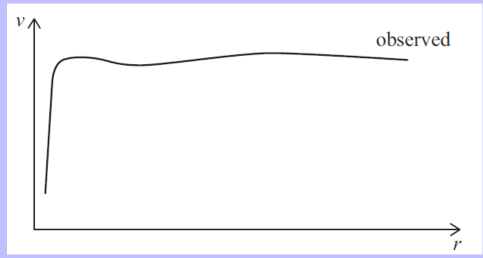
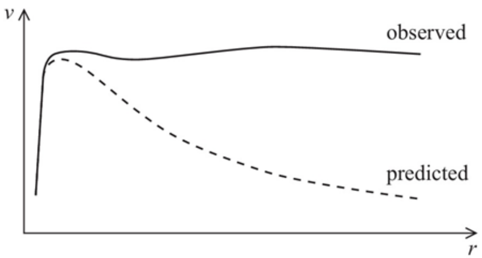
20(c)	**Explain how damping reduces the large amplitude of vibration of the car on its suspension, and how it could be achieved in practice.**		
	Damping removes energy from the oscillating system **(1)** <u>Kinetic</u> energy is dissipated as internal energy (of the dampers) **(1)** Damping provides a resistive force. **Or** Damping provides a force that opposes the motion **(1)**	Accept energy is transferred to the surroundings Accept 'thermal energy', 'heat' for 'internal energy' Allow examples such as oil-filled damper, shock absorber	**3**
	Total for question 20		**12**

Question Number	Answer	Additional Guidance	Mark
	Curves A, B and C show the radiation spectra of stars with three different surface temperatures. **(a) Curve B represents radiation from the Sun.** **(i) State what evidence from the graphs suggests that this might be so.**		
21(a)(i)	The curve has a peak in the middle of the visible region of the electromagnetic spectrum **Or** The curve has a peak between 400 nm and 700 nm. **Or** The curve has a peak at (about) 500 nm **(1)**	Accept λ_{max} for 'curve has a peak' Allow maximum/peak wavelength for λ_{max}	**1**
	(ii) State, with a reason, which curve represents a star with a lower surface temperature than the Sun.		
21(a)(ii)	Curve C (as λ_{max} is larger) **(1)**		**1**
	(iii) Explain, using the graphs, how the radiation from the star identified in (ii) differs from the radiation from the Sun.		

21(a)(iii)	The curve peaks at a longer wavelength so the star emits more red/IR radiation (allow ecf from (ii)) **(1)**	Allow maximum/peak wavelength or λ_{max} for 'peaks at a longer wavelength' Allow the peak (emissive) power is lower so the brightness/intensity is lower	1
	(iv) Determine, using curve B, the surface temperature of the Sun.		
21(a)(iv)	Use of $\lambda_{max}T = 2.9 \text{ x } 10^{-3}\text{Km}$ **(1)** T = 5300 K (allow 5200 → 6000 K, if the approach is correct) **(1)**	Example of calculation $T = \frac{2.9 \text{ x } 10^{-3} \text{ mK}}{550 \times 10^{-9} \text{ m}} = 5270 \text{ K}$	2
	Total for question 21		**5**

Question Number	Answer	Additional Guidance	Mark
	Almost fifty years ago, a physicist called Vera Rubin found evidence for the existence of dark matter from her observations of nearby spiral galaxies. Her observations seemed to contradict Newton's laws. **(a) Show that the velocity *v* of a star of mass *m*, in an orbit of radius *r* about a larger mass *M*, is given by** $$v = \sqrt{\frac{GM}{r}}$$		
22(a)	Equate $F = \frac{GMm}{r^2}$ and $F = \frac{mv^2}{r}$ **(1)** Algebra leading to $v = \sqrt{\frac{GM}{r}}$ **(1)** Example of calculation:	Allow equating $g = \frac{GM}{r^2}$ and $a = \frac{v^2}{r}$	2

	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ $\therefore \frac{GM}{r^2} = \frac{v^2}{r}$ $\therefore v = \sqrt{\frac{GM}{r}}$		

	Stars orbit the centre of their galaxies. Most of the visible mass of a galaxy is concentrated at its centre. The graph shows how the velocity *v* of stars varies with distance *r* from the centre of the galaxy. (i) Sketch, on the same graph in the Answer Book, how the predicted velocity of stars varies with distance *r* from the centre of the galaxy. Label it with the word 'predicted'.		
22(b)(i)	**(1)** 		**1**
	(ii) Explain how dark matter may account for the difference between the observed velocity and the predicted velocity of stars far away from the centre of the galaxy. You may assume that, for a star orbiting at radius *r*, all the matter inside the sphere of radius *r* acts like a point mass at the centre.		
22(b)(ii)	Dark matter increases the mass **Or** dark matter has mass **(1)** If mass at centre of galaxy increases, then as *r* increases *v* may stay constant **(1)**		**2**

	(c) The exact amount of dark matter in the Universe is unknown. **Explain how the amount of dark matter might be expected to determine the ultimate fate of the Universe.**		
22(c)	Amount of dark matter determines the mass of the universe **(1)** So the density (of universe) depends upon the amount of dark matter **(1)** If the density is greater than the critical density then the universe will reach a maximum size and then start to contract **(1)**	Accept universe will be closed, but do not accept references to a 'big crunch' Accept argument for less dark matter leading to open universe or flat universe	**3**
	Total for question 22		**8**