

Markscheme

May 2017

Physics

Higher level

Paper 3

22 pages

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Section A

Question		Answers	Notes	Total
1	a	in order to keep the temperature constant ✓ in order to allow the system to reach thermal equilibrium with the surroundings/OWTTE ✓	Accept answers in terms of pressure or volume changes only if clearly related to reaching thermal equilibrium with the surroundings.	1 max
	b	recognizes b as gradient ✓ calculates b in range 4.7×10^4 to 5.3×10^4 ✓ Pa m ✓	Award [2 max] if POT error in b . Allow any correct SI unit, eg kg s^{-2} .	3
	c	$V \propto H$ thus ideal gas law gives $p \propto \frac{1}{H}$ ✓ so graph should be «a straight line through origin,» as observed ✓		2
	d	$n = \frac{bA}{RT}$ OR correct substitution of one point from the graph ✓ $n = \frac{5 \times 10^4 \times 1.3 \times 10^{-3}}{8.31 \times 300} = 0.026 \approx 0.03$ ✓	Answer must be to 1 or 2 SF. Award [2] for a bald correct answer. Allow ECF from (b).	2

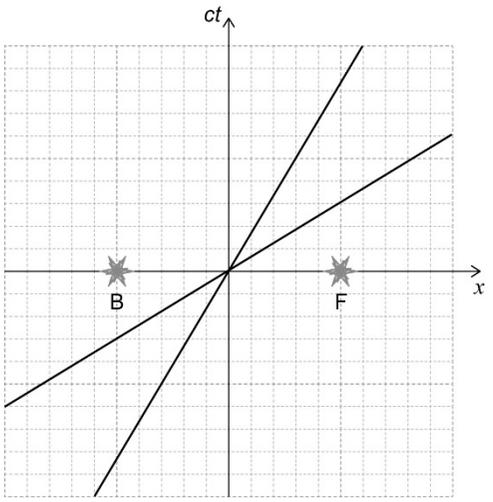
Question		Answers	Notes	Total
1	e	very large $\frac{1}{H}$ means very small volumes / very high pressures ✓ at very small volumes the ideal gas does not apply OR at very small volumes some of the assumptions of the kinetic theory of gases do not hold ✓		2

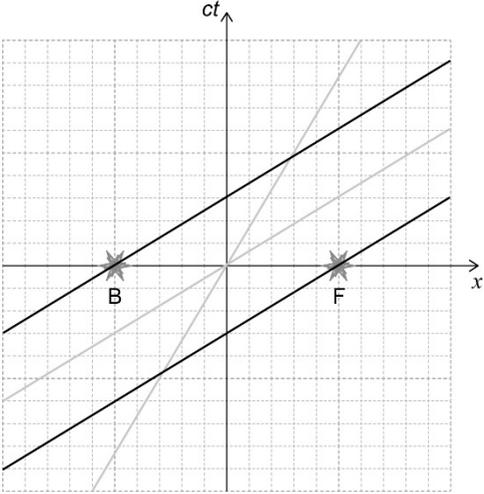
Question		Answers	Notes	Total
2	a	$g = \frac{4\pi^2 \times 1.60}{2.540^2} = 9.7907 \checkmark$ $\Delta g = g\left(\frac{\Delta L}{L} + 2 \times \frac{\Delta T}{T}\right) = 9.7907 \times \left(\frac{0.01}{1.60} + 2 \times \frac{0.005}{2.540}\right) \Rightarrow 0.0997$ <p>OR</p> <p>1.0 % \checkmark</p> <p>hence $g = (9.8 \pm 0.1) \text{ «ms}^{-2}\text{»}$ OR $\Delta g = 0.1 \text{ «ms}^{-2}\text{»}$ \checkmark</p>	<p><i>For the first marking point answer must be given to at least 2 dp.</i></p> <p><i>Accept calculations based on</i></p> $g_{\max} = 9.8908$ $g_{\min} = 9.6913$ $\frac{g_{\max} - g_{\min}}{2} = 0.099 \approx 0.1$	3
	b	$\frac{T}{T_0} = 1.01 \checkmark$ $\theta_{\max} = 22 \text{ «}^\circ\text{»} \checkmark$	<p><i>Accept answer from interval 20 to 24.</i></p>	2

Section B

Option A — Relativity

Question			Answers	Notes	Total
3	a		a set of coordinate axes and clocks used to measure the position «in space/time of an object at a particular time» OR a coordinate system to measure x,y,z,and t / OWTTE ✓		1
	b	i	magnetic only ✓ there is a current but no «net» charge «in the wire» ✓		2
	b	ii	electric only ✓ <i>P</i> is stationary so experiences no magnetic force ✓ relativistic contraction will increase the density of protons in the wire ✓		3

Question		Answers	Notes	Total
4	a	Δt_p / observer sitting in the train ✓		1
	b	$\gamma = \frac{\Delta t_Q}{\Delta t_p} = \left\langle \frac{1}{0.30} \right\rangle = 3.3 \checkmark$ to give $v = 0.95c \checkmark$		2
	c	$\gamma = 1.25 \checkmark$ «length of train according Q» = $125/1.25 \checkmark$ «giving 100 m»		2
	d i	 <p>axes drawn with correct gradients of $\frac{5}{3}$ for ct' and 0.6 for $x' \checkmark$</p>	Award [1] for one gradient correct and another approximately correct.	1

4	d	ii	 <p>lines parallel to the x' axis and passing through B and F ✓ intersections on the ct' axis at B' and F' shown ✓ light at the front of the train must have been turned on first ✓</p>		3
	d	iii	$\Delta t' = 1.25 \times \frac{0.6 \times 100}{3 \times 10^8} \checkmark$ <p>«2.5×10^{-7} s»</p>	Allow ECF for gamma from (c).	1
	d	iv	<p>according to P: $(3 \times 10^8 \times 2.5 \times 10^{-7})^2 - 125^2 = \text{«-» } 10000 \checkmark$ according to Q: $(3 \times 10^8 \times 0)^2 - 100^2 = \text{«-» } 10000 \checkmark$</p>		2
	e		$u' = \frac{-0.7 - 0.6}{1 + 0.7 \times 0.6} c \checkmark$ <p>= «-» $0.92c \checkmark$</p>		2

Question		Answers	Notes	Total
5	a	$\gamma = 1.96 \checkmark$ $E_k = (\gamma - 1) m_0 c^2 = 900 \text{ «MeV» } \checkmark$ $pd \approx 900 \text{ «MV» } \checkmark$	Award [2 max] if Energy and Potential difference are not clearly distinguished, eg by the unit.	3
	b	energy of proton = $\gamma mc^2 = 1838 \text{ «MeV» } \checkmark$ total energy available = energy of proton + energy of antiproton = $1838 + 1838 = 3676 \text{ «MeV» } \checkmark$ momentum of a one photon = Total energy / $2c = 1838 \text{ «MeVc}^{-1}\text{» } \checkmark$		3

6	a	$f = \left\langle \frac{E}{h} \right\rangle = \frac{14400 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = \text{«}3.475 \times 10^{18} \text{ Hz» } \checkmark$ $\Delta f = \left\langle \frac{g \times \Delta h \times f}{c^2} \right\rangle \approx \text{«}8550 \text{ «Hz» } \checkmark$		2
	b	«as the photon moves away from the Earth, » it has to spend energy to overcome the gravitational field \checkmark since $E = hf$, the detected frequency would be lower «than the emitted frequency» \checkmark		2

Option B — Engineering physics

Question			Answers	Notes	Total
7	a	i	$\frac{M}{3}vR \checkmark$		1
	a	ii	evidence of use of: $L = I\omega = (MR^2 + \frac{M}{3}R^2)\omega \checkmark$		1
	a	iii	evidence of use of conservation of angular momentum, $\frac{MvR}{3} = \frac{4}{3}MR^2\omega \checkmark$ «rearranging to get $\omega = \frac{v}{4R}$ »		1
	a	iv	initial KE = $\frac{Mv^2}{6} \checkmark$ final KE = $\frac{Mv^2}{24} \checkmark$ energy loss = $\frac{Mv^2}{8} \checkmark$		3

Question			Answers	Notes	Total
7	b	i	$\alpha \llcorner = \frac{3 \Gamma}{4 MR^2} \llcorner = \frac{3 \cdot 0.01}{4 \cdot 0.7 \times 0.5^2} \llcorner \checkmark$ <p>«to give $\alpha = 0.04286 \text{ rads}^{-2}$»</p>	Working OR answer to at least 3 SF must be shown.	1
	b	ii	$\theta = \frac{\omega_i^2}{2\alpha} \llcorner \text{«from } \omega_f^2 = \omega_i^2 + 2\alpha\theta \llcorner \checkmark$ $\theta \llcorner = \frac{v^2}{32R^2\alpha} = \frac{2.1^2}{32 \times 0.5^2 \times 0.043} \llcorner = 12.8 \text{ OR } 12.9 \llcorner \text{«rad»} \llcorner \checkmark$ <p>number of rotations $\llcorner = \frac{12.9}{2\pi} \llcorner = 2.0 \text{ revolutions} \llcorner \checkmark$</p>		3

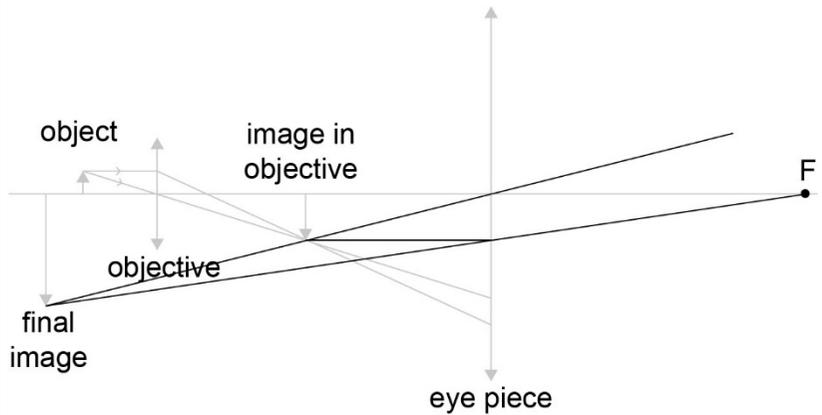
Question		Answers	Notes	Total
8	a	«a process in which there is» no thermal energy transferred between the system and the surroundings ✓		1
	b	A to B AND C to D ✓		1
	c	i $T = \frac{PV}{nR}$ ✓ $T \left(= \frac{512 \times 10^3 \times 1.20 \times 10^{-3}}{0.150 \times 8.31} \right) \approx 493 \text{ «K»}$ ✓	<i>The first mark is for rearranging.</i>	2
	c	ii $P_B = \frac{P_a V_A}{V_B}$ ✓ $P_B = 267 \text{ kPa}$ ✓	<i>The first mark is for rearranging.</i>	2
	d	i «B to C adiabatic so» $P_B V_B^{\frac{5}{3}} = P_C V_C^{\frac{5}{3}}$ AND $P_C V_C = nRT_C$ «combining to get result» ✓	<i>It is essential to see these 2 relations to award the mark.</i>	1
	d	ii $T_C = \left(\frac{P_B V_B^{\frac{5}{3}}}{nR} \right) V_C^{-\frac{2}{3}}$ ✓ $T_C = \left\langle \frac{267 \times 10^3 \times (2.30 \times 10^{-3})^{\frac{5}{3}}}{0.150 \times 8.31} \right\rangle (2.90 \times 10^{-3})^{-\frac{2}{3}} = 422 \text{ «K»}$ ✓		2
	e	the isothermal processes would have to be conducted very slowly / OWTTE ✓		1

Question		Answers	Notes	Total
9	a	<p>ALTERNATIVE 1 pressure in a liquid increases with depth ✓ so pressure at bottom of bubble greater than pressure at top ✓</p> <p>ALTERNATIVE 2 weight of liquid displaced ✓ greater than weight of bubble ✓</p>		2
	b	$\frac{\text{weight}}{\text{buoyancy}} \left(= \frac{V\rho_a g}{V\rho_l g} = \frac{\rho_a}{\rho_l} = \frac{1.2}{1200} \right) = 10^{-3} \checkmark$ <p>since the ratio is very small, the weight can be neglected ✓</p>	Award [1 max] if only mass of the bubble is calculated and identified as negligible to mass of liquid displaced.	2
	c	<p>evidence of equating the buoyancy and the viscous force $\ll \rho_l \frac{4}{3} \pi r^3 g = 6\pi \eta r v_t \gg \checkmark$</p> $v_t = \ll \frac{2 \cdot 1200 \times 9.81}{9 \cdot 1 \times 10^{-3}} (0.25 \times 10^{-3})^2 \gg = 0.16 \text{ ms}^{-1} \gg \checkmark$		2

10	a	the loss of energy in an oscillating system ✓		1
	b	$Q = 2\pi \frac{16^2}{16^2 - 10.3^2} \approx 11 \checkmark$	Accept calculation based on any two correct values giving answer from interval 10 to 13.	1
	c	<p>the amplitude decreases at a slower rate ✓ a higher Q factor would mean that less energy is lost per cycle ✓</p>		2

Option C — Imaging

Question			Answers	Notes	Total
11	a	i	an image formed by extensions of rays, not rays themselves OR an image that cannot be projected on a screen ✓		1
	a	ii	$\frac{1}{v} = \frac{1}{3.0} - \frac{1}{4.0} \checkmark$ «v = 12 cm»		1
	a	iii	$u = 18 - 12 = 6.0 \text{ «cm»} \checkmark$ $v = -24 \text{ «cm»} \checkmark$ $\left\langle \frac{1}{f} = \frac{1}{6.0} - \frac{1}{24} \Rightarrow \right\rangle f = 8.0 \text{ «cm»} \checkmark$	Award [2 max] for answer of 4.8 cm. Minus sign required for MP2.	3
	a	iv	line parallel to principal axis from intermediate image meeting eyepiece lens at P ✓ line from arrow of final image to P intersecting principal axis at F ✓		2



Question			Answers	Notes	Total
11	b	i	object is far away so intermediate image forms at focal plane of objective ✓ for final image at infinity object must also be at focal point of eyepiece ✓ «hence 87.5 cm»	<i>No mark for simple addition of focal lengths without explanation.</i>	2
	b	ii	angular magnification = $\frac{85.0}{2.50} = 34$ ✓ angular diameter $34 \times 7.8 \times 10^{-3} = 0.2652 \approx 0.27$ «rad» ✓		2
	c		chromatic aberration is the dependence of refractive index on wavelength ✓ but mirrors rely on reflection OR mirrors do not involve refraction ✓ «so do not suffer chromatic aberration»		2

Question			Answers	Notes	Total
12	a	i	longer distance without amplification ✓ signal cannot easily be interfered with ✓ less noise ✓ no cross talk ✓ higher data transfer rate ✓		2 max
	a	ii	infrared radiation suffers lower attenuation ✓		1
	b		$\text{loss} = 10 \log \frac{2.4}{15} \llcorner = -7.959 \text{ dB} \llcorner \checkmark$ $\text{length} = \llcorner \frac{7.959}{0.30} \Rightarrow 26.53 \approx 27 \llcorner \text{«km»} \llcorner \checkmark$		2
	c		a thin core means that rays follow essentially the same path / OWTTE ✓ and so waveguide (modal) dispersion is minimal / OWTTE ✓		2

Question		Answers	Notes	Total
13	a	bone and tissue absorb different amounts of X-rays OR bone and tissue have different attenuation coefficients ✓ so boundaries and fractures are delineated in an image ✓		2
	b	$\frac{I_{\text{bone}}}{I_{\text{tissue}}} = \frac{I_0 e^{-\mu_b x}}{I_0 e^{-\mu_t x}} = e^{-(\mu_b - \mu_t)x} \checkmark$ $\frac{I_{\text{bone}}}{I_{\text{tissue}}} = e^{-1.2 \times 10^{-2} \times (1.9 - 1.1) \times 10^3 \times 5.4 \times 10^{-2}} \checkmark$ $\frac{I_{\text{bone}}}{I_{\text{tissue}}} = 0.60 \checkmark$		3
	c i	to split the energy level of protons in the body OR to cause protons in the body to align with the field / precess at Larmor frequency ✓		1
	c ii	to force/excite protons that are in the spin up/parallel state ✓ into a transition to the spin down/antiparallel state ✓		2
	c iii	the emitted radio frequency signal has a frequency that depends on the magnetic field ✓ with a gradient field different parts of the body have different frequencies and so can be identified ✓		2

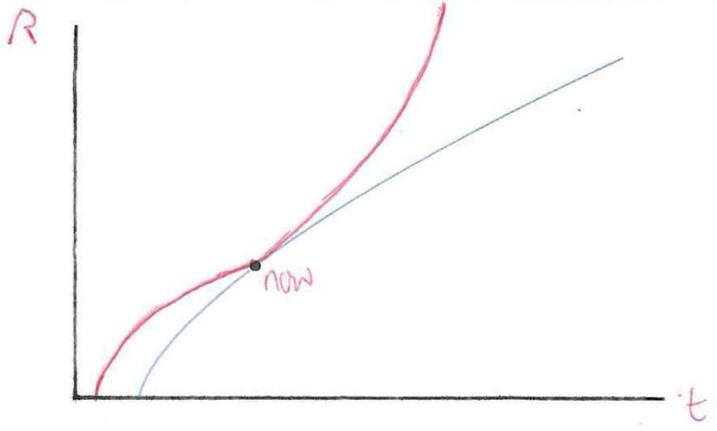
Option D — Astrophysics

Question			Answers	Notes	Total
14	a	i	stars fusing hydrogen «into helium» ✓		1
	a	ii	$M = M_{\odot} (4 \times 10^5)^{3.5} = 39.86 M_{\odot}$ ✓ « $M \approx 40 M_{\odot}$ »	Accept reverse working.	1
	a	iii	$4 \times 10^5 = 13^2 \times \frac{T^4}{6000^4}$ ✓ $T \approx 42000$ «K» ✓	Accept use of substituted values into $L = \sigma 4\pi R^2 T^4$.	2
	a	iv	$4 \times 10^{-11} = 4 \times 10^5 \times \frac{1 \text{AU}^2}{d^2}$ ✓ $d = 1 \times 10^8$ «AU» ✓	Accept use of correct values into $b = \frac{L}{4\pi d^2}$.	2
	b		the gravitation «pressure» is balanced by radiation «pressure» ✓ that is created by the production of energy due to fusion in the core / OWTTE ✓	Award [1 max] if pressure and force is inappropriately mixed in the answer. Award [1 max] for unexplained "hydrostatic equilibrium is reached".	2

Question		Answers	Notes	Total
14	c	the Sun will evolve to become a red giant whereas Theta 1 Orionis will become a red super giant ✓ the Sun will explode as a planetary nebula whereas Theta 1 Orionis will explode as a supernova ✓ the Sun will end up as a white dwarf whereas Theta 1 Orionis as a neutron star/black hole ✓		3

Question			Answers	Notes	Total
15	a	i	black body radiation / 3 K ✓ highly isotropic / uniform throughout OR filling the universe ✓	<i>Do not accept: CMB provides evidence for the Big Bang model.</i>	2
	a	ii	$\ll \lambda = \frac{2.9 \times 10^{-3}}{2.8} \gg \approx 1.0 \text{ «mm» } \checkmark$		1
	b		the universe is expanding and so the wavelength of the CMB in the past was much smaller ✓ indicating a very high temperature at the beginning ✓		2
	c	i	$\ll z = \frac{v}{c} \Rightarrow v = 0.16 \times 3 \times 10^5 \text{ «} = 0.48 \times 10^5 \text{ km s}^{-1} \gg \checkmark$ $\ll d = \frac{v}{H_0} \Rightarrow v = \frac{0.48 \times 10^5}{68} = 706 \gg \approx 710 \text{ «Mpc» } \checkmark$	<i>Award [1 max] for POT error.</i>	2
	c	ii	$z = \frac{R}{R_0} - 1 \Rightarrow \frac{R}{R_0} = 1.16 \checkmark$ $\frac{R_0}{R} = 0.86 \checkmark$		2

Question		Answers	Notes	Total
16	a	<p>a star will form out of a cloud of gas ✓</p> <p>when the gravitational potential energy of the cloud exceeds the total random kinetic energy of the particles of the cloud</p> <p>OR</p> <p>the mass exceeds a critical mass for a particular radius and temperature ✓</p>		2
	b	<p>number of reactions is $\frac{10^{10} \times 365 \times 24 \times 3600 \times 3.8 \times 10^{26}}{4.3 \times 10^{-12}} = 2.79 \times 10^{55}$ ✓</p> <p>H mass used is $2.79 \times 10^{55} \times 4 \times 1.67 \times 10^{-27} = 1.86 \times 10^{29}$ «kg» ✓</p>		2
	c	<p>nuclear fusion reactions produce ever heavier elements depending on the mass of the star / temperature of the core ✓</p> <p>the elements / nuclear reactions arrange themselves in layers, heaviest at the core lightest in the envelope ✓</p>		2

Question	Answers	Notes	Total
17 a	curve starting earlier, touching at now and going off to infinity ✓ 		1
b i	there is dark matter that does not radiate / cannot be observed ✓	<i>Unexplained mention of "dark matter" is not sufficient for the mark.</i>	1
b ii	$\rho_\Lambda = 0.68\rho_c = 0.68 \times 10^{-26} \text{ «kgm}^{-3}\text{»} \checkmark$ energy in 1 m^3 is therefore $0.68 \times 10^{-26} \times 9 \times 10^{16} \approx 6 \times 10^{-10} \text{ «J»} \checkmark$		2