Markscheme

May 2017

Physics

Higher level

Paper 3

22 pages

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 ✓ $n = \frac{5\times10^{4}\times1.3\times10^{-3}}{8.31\times300} = 0.026 \approx 0.03$ ✓	*Answer must be to 1 or 2 SF.* *Award **[2]** for a bald correct answer.* *Allow ECF from (b).*	**2**

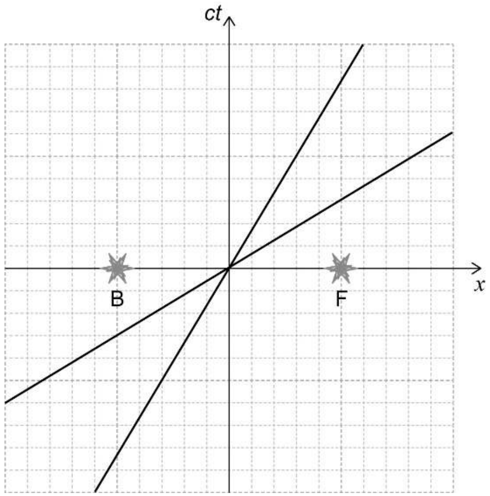
Question			Answers	Notes	Total
1	e		very large $\frac{1}{H}$ means very small volumes / very high pressures ✓ at very small volumes the ideal gas does not apply ***OR*** at very small volumes some of the assumptions of the kinetic theory of gases do not hold ✓		**2**

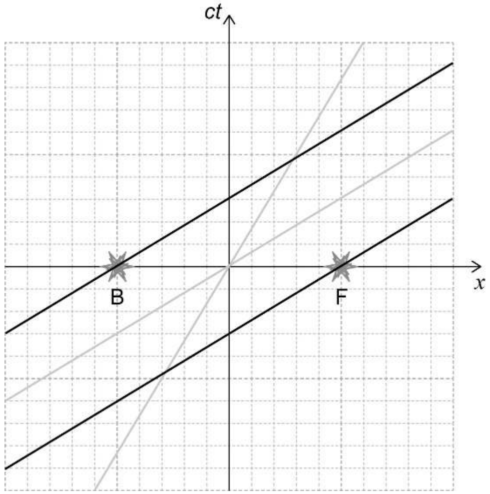
Question			Answers	Notes	Total
2	a		$g=\frac{4\pi^2\times 1.60}{2.540^2}=9.7907$ ✓ $\Delta g=g(\frac{\Delta L}{L}+2\times\frac{\Delta T}{T})=$ «$9.7907\times\left(\frac{0.01}{1.60}+2\times\frac{0.005}{2.540}\right)=$» 0.0997 ***OR*** 1.0 % ✓ hence $g=(9.8\pm 0.1)$ «m s^{-2}» ***OR*** $\Delta g=0.1$ «m s^{-2}» ✓	*For the first marking point answer must be given to at least 2 dp.* *Accept calculations based on* $g_{max}=9.8908$ $g_{min}=9.6913$. $\frac{g_{max}-g_{min}}{2}=0.099\approx 0.1$	**3**
	b		$\frac{T}{T_0}=1.01$ ✓ $\theta_{max}=22$ «°» ✓	*Accept answer from interval 20 to 24.*	**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 ✓ *P* 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		$\gamma = \frac{\Delta t_Q}{\Delta t_P} =$ «$= \frac{1}{0.30}$» $= 3.3$ ✓ to give $v = 0.95c$ ✓		2
	c		$\gamma = 1.25$ ✓ «length of train according Q» = 125/1.25 ✓ «giving 100 m»		2
	d	i	 axes drawn with correct gradients of $\frac{5}{3}$ for ct' and 0.6 for x' ✓	*Award **[1]** for one gradient correct **and** another approximately correct.*	1

4	d	ii	 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 ✓		3
	d	iii	$\Delta t' = 1.25 \times \frac{0.6 \times 100}{3 \times 10^8}$ ✓ «2.5×10^{-7} s»	*Allow ECF for gamma from (c).*	1
	d	iv	according to P: $\left(3 \times 10^8 \times 2.5 \times 10^{-7}\right)^2 - 125^2 =$ «–» 10000 ✓ according to Q: $\left(3 \times 10^8 \times 0\right)^2 - 100^2 =$ «–» 10000 ✓		2
	e		$u' = \frac{-0.7 - 0.6}{1 + 0.7 \times 0.6}$ **c** ✓ $=$ «–» 0.92c ✓		2

Question			Answers	Notes	Total
5	a		$\gamma = 1.96$ ✓ $E_k = (\gamma - 1)\ m_0c^2 = 900$ «MeV» ✓ $pd \approx 900$ «MV» ✓	*Award **[2 max]** if Energy and Potential difference are not clearly distinguished, eg by the unit.*	**3**
	b		energy of proton $= \gamma mc^2 = 1838$ «MeV» ✓ total energy available = energy of proton + energy of antiproton = 1838 + 1838 = 3676 «MeV» ✓ momentum of a one photon = Total energy / 2c = 1838 «MeVc^{-1}» ✓		**3**

6	a		$f =$ «$\frac{E}{h} =$» $\frac{14\,400 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} =$ «3.475×10^{18} Hz» ✓ $\Delta f =$ «$\frac{g \times \Delta h \times f}{c^2} \approx$» 8550 «Hz» ✓		**2**
	b		«as the photon moves away from the Earth, » it has to spend energy to overcome the gravitational field ✓ since $E = hf$, the detected frequency would be lower «than the emitted frequency» ✓		**2**

Option B — Engineering physics

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

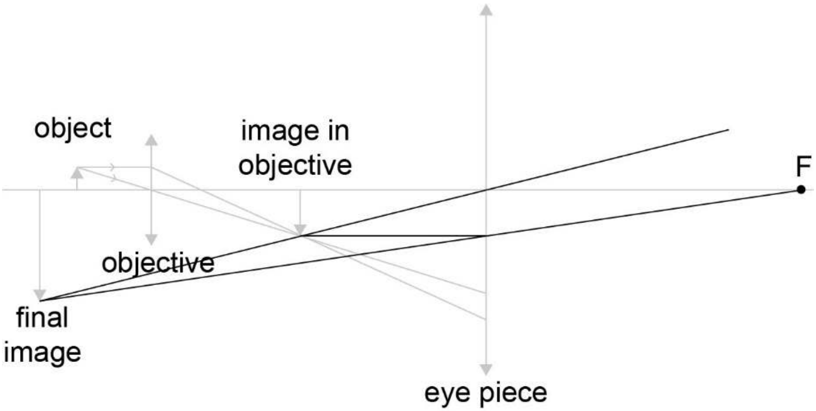
Question			Answers	Notes	Total
7	b	i	α «$= \frac{3}{4}\frac{\Gamma}{MR^2}$» $= \frac{3}{4}\frac{0.01}{0.7\times 0.5^2}$ ✓ «to give $\alpha = 0.04286\ \text{rad s}^{-2}$ »	*Working **OR** answer to at least 3 SF must be shown.*	**1**
	b	ii	$\theta = \frac{\omega_i^2}{2\alpha}$ «from $\omega_f^2 = \omega_i^2 + 2\alpha\theta$» ✓ θ «$= \frac{v^2}{32R^2\alpha} = \frac{2.1^2}{32\times 0.5^2\times 0.043}$» $= 12.8$ ***OR*** 12.9 «rad» ✓ number of rotations «$= \frac{12.9}{2\pi}$» $= 2.0$ revolutions ✓		**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	$T=\frac{PV}{nR}$ ✓ $T\left(=\frac{512\times10^{3}\times1.20\times10^{-3}}{0.150\times8.31}\right)\approx 493$ «K» ✓	*The first mark is for rearranging.*	**2**
	c	ii	$P_B=\frac{P_aV_A}{V_B}$ ✓ $P_B=267\ \text{kPa}$ ✓	*The first mark is for rearranging.*	**2**
	d	i	«B to C adiabatic so» $P_BV_B^{\frac{5}{3}}=P_CV_C^{\frac{5}{3}}$ ***AND*** $P_CV_C=nRT_C$ «combining to get result» ✓	*It is essential to see these 2 relations to award the mark.*	**1**
	d	ii	$T_C=\left(\frac{P_BV_B^{\frac{5}{3}}}{nR}\right)V_C^{\frac{-2}{3}}$ ✓ $T_C=$ «$\left(\frac{267\times10^{3}\times(2.30\times10^{-3})^{\frac{5}{3}}}{0.150\times8.31}\right)(2.90\times10^{-3})^{\frac{-2}{3}}$» $=422$ «K» ✓		**2**
	e		the isothermal processes would have to be conducted very slowly / OWTTE ✓		**1**

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

10	a		the loss of energy in an oscillating system ✓		**1**
	b		$Q = 2\pi\frac{16^2}{16^2 - 10.3^2}\approx 11$ ✓	*Accept calculation based on any two correct values giving answer from interval 10 to 13.*	**1**
	c		the amplitude decreases at a slower rate ✓ a higher Q factor would mean that less energy is lost per cycle ✓		**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**	$\frac{1}{v}=\frac{1}{3.0}-\frac{1}{4.0}$ ✓ «$v=12$ cm»		**1**
	a	**iii**	$u=18-12=6.0$ «cm» ✓ $v=-24$ «cm» ✓ «$\frac{1}{f}=\frac{1}{6.0}-\frac{1}{24}\Rightarrow$» $f=8.0$ «cm» ✓	*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»	*No mark for simple addition of focal lengths without explanation.*	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		$\text{loss} = 10\log\frac{2.4}{15}$ «$= -7.959$ dB» ✓ $\text{length} =$ «$\frac{7.959}{0.30} =$»$26.53 \approx 27$ «km» ✓		**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		$\frac{I_{\text{bone}}}{I_{\text{tissue}}} = \frac{I_0 e^{-\mu_b x}}{I_0 e^{-\mu_t x}} = e^{-(\mu_b - \mu_t)x}$ ✓ $\frac{I_{\text{bone}}}{I_{\text{tissue}}} = e^{-1.2\times10^{-2}\times(1.9-1.1)\times10^{3}\times5.4\times10^{-2}}$ ✓ $\frac{I_{\text{bone}}}{I_{\text{tissue}}} = 0.60$ ✓		**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**

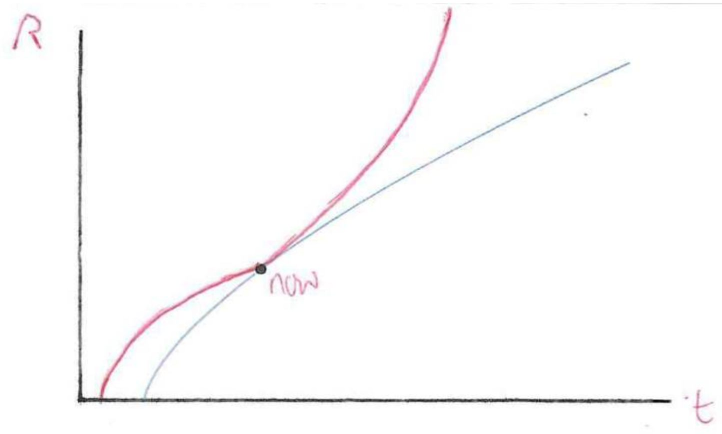
Option D — Astrophysics

Question			Answers	Notes	Total
14	**a**	**i**	stars fusing hydrogen «into helium» ✓		**1**
	a	**ii**	$M = M_{\odot}(4\times10^5)^{\frac{1}{3.5}} = 39.86M_{\odot}$ ✓ «$M \approx 40M_{\odot}$»	*Accept reverse working.*	**1**
	a	**iii**	$4\times10^5 = 13^2 \times \frac{T^4}{6000^4}$ ✓ $T \approx 42000$ «K» ✓	*Accept use of substituted values into $L = \sigma 4\pi R^2 T^4$.*	**2**
	a	**iv**	$4\times10^{-11} = 4\times10^5 \times \frac{1\text{AU}^2}{d^2}$ ✓ $d = 1\times10^8$ «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 ✓	*Do not accept: CMB provides evidence for the Big Bang model.*	**2**
	a	ii	«$\lambda = \frac{2.9\times10^{-3}}{2.8}$» ≈ 1.0 «mm» ✓		**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	«$z=\frac{v}{c}\Rightarrow$» $v=0.16\times3\times10^5$ «$=0.48\times10^5\,\mathrm{km\,s^{-1}}$» ✓ «$d=\frac{v}{H_0}\Rightarrow v=\frac{0.48\times10^5}{68}=706$» ≈ 710 «Mpc» ✓	*Award **[1 max]** for POT error.*	**2**
	c	ii	$z=\frac{R}{R_0}-1\Rightarrow\frac{R}{R_0}=1.16$ ✓ $\frac{R_0}{R}=0.86$ ✓		**2**

Question			Answers	Notes	Total
16	a		a star will form out of a cloud of gas ✓ when the gravitational potential energy of the cloud exceeds the total random kinetic energy of the particles of the cloud ***OR*** the mass exceeds a critical mass for a particular **radius and temperature**✓		**2**
	b		number of reactions is $\frac{10^{10}\times 365\times 24\times 3600\times 3.8\times 10^{26}}{4.3\times 10^{-12}}=2.79\times 10^{55}$ ✓ H mass used is $2.79\times 10^{55}\times 4\times 1.67\times 10^{-27}=1.86\times 10^{29}$ «kg» ✓		**2**
	c		nuclear fusion reactions produce ever heavier elements depending on the mass of the star / temperature of the core ✓ the elements / nuclear reactions arrange themselves in layers, heaviest at the core lightest in the envelope ✓		**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 ✓	*Unexplained mention of "dark matter" is not sufficient for the mark.*	1
	b	ii	$\rho_\Lambda = 0.68\rho_c = 0.68 \times 10^{-26}$ «kgm^{-3}» ✓ energy in 1 m^3 is therefore $0.68 \times 10^{-26} \times 9 \times 10^{16} \approx 6 \times 10^{-10}$ «J» ✓		2