Question			Marking details	Marks Available
1	*(a)*		Acceleration towards a fixed point [or central / equilibrium](1) and [directly] proportional to the distance from that point (1) Accept $a = -kx$ (1) with x defined	2
	(b)		Smooth curve drawn which extends at least to ± 19.5 mm [i.e. beyond the extreme points] symmetrically on at least 2 extremes.	1
	(c)		$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.5}$ [= 12.57 rad s^{-1}]	1
	(d)		**Either** $v_{max} = r\omega$ [or by impl.] (1) $= 20 \times 10^{-3} \times 12.57$ [r range 19.5 – 21 mm] $= 0.25$ m s^{-1} (1) **Or** tangent drawn (1) $v_{max} = \frac{(30-(-30))\times 10^{-3}}{0.67-0.42}$ $= 0.24$ m s^{-1} (1)	2
	(e)		Squaring $T = 2\pi\sqrt{\frac{m}{k}}$ i.e $T^2 = 4\pi^2\frac{m}{k}$ or following substitution (1) Substitution (1) Rearranging and answer: $k = 6.32$ N m^{-1}	2
				[8]

Question			Marking details	Marks Available
2.	*(a)*		Any 2 × (1) of: • forces between molecules negligible [or no forces…] / molecules travel in straight lines between collisions ✓ • volume [allow "size"] of molecules negligible / collision time small [cf time between collisions] ✓ • molecules behave like perfectly elastically / have elastic collisions ✓ • molecules exert forces [or pressure] on walls of container during collisions ✓ • gasses consist of a large number of particles / molecules in random motion	2
	(b)		amount of gas, $n = \left[\frac{pV}{RT} = \frac{1.01\times10^5\times(6\times5\times3)}{8.31\times293} = \right]$ 3730 mol (1) no. of molecules $N = nN_A$= 3730 × 6.02 × 10^{23} = 2.2 × 10^{27} (1)	2
	(c)		$c_{rms} = \sqrt{\frac{350^2+420^2+550^2}{3}}$ (1) [or by impl.] = 448 m s^{-1} (1)	2
	(d)		Density ρ = (1) $\frac{M}{V} = \frac{3733\times\frac{29}{1000}(1)}{90}$ [= 1.203 kg m^{-3}]. Use of $p = \frac{1}{3}\rho\overline{c^2}$ (1). [c_{rms} = 502 m s^{-1}]. (1) (i.e. use of *M/V* (1); inserting ~3733 for *n* (1); relating *M* to *Mr* (1); use of $p = \frac{1}{3}\rho\overline{c^2}$ and substitution [or by impl.] (1))	4
	(e)	(i)	Time of travel ~ 0.01 – 0.02 s	1
		(ii)	No – time estimated is [far] too short (1) e.c.f from (i) Relay is much longer because of collisions between molecules [or equiv. eg takes time to diffuse / mean free path is very short] (1)	2 **[13]**

Question			Marking details	Marks Available
3	*(a)*		ΔU = increase [accept change / difference] in internal energy [of the gas](1) Q = heat supplied [to] the gas (1) U = work done by the gas (1)	3
	(b)		Readings from graph: p = 120 ± 2.5 kPa; $V = 2.0 \times 10^{-3}$ m (1) $T = \dfrac{pV}{nR}$ (1)= $\dfrac{120\times10^3 \times 2.0\times10^{-3}}{0.1\times8.31}$ (1) [= 289 / 290 K]	3
	(c)		Work Done = 'area' under graph (1) Any reasonable method used correctly to estimate area, (1) e.g 27 × 1 cm squares × 'area' of 1 cm square → 169 J **or** [approximating AB to straight line] area ~ 1.0 × ½ × [120 + 240] → 180 ∴ a bit less than 180 J ~ 170 J.	2
	(d)	(i)	$\Delta V = 0$ along AP (1) So $W = p\Delta V = 0$ (1)	2
		(ii)	Work done **on** gas (1) = $p\Delta V$ = 240 J (1)	2
	(e)		Temperature at A and B are the same: $U_A = U_B$ so $\Delta U = 0$, so $Q = W$ [from 1st law] (1) W is different for the two paths so Q is different. (1)	2 **14**
4.	*(a)*		Concentric equipotentials drawn (1) At least 3 outward radial electric field lines drawn symmetrically(1) [No labelling →−1; no arrows on field lines → −1]	2
	(b)	(i)	KE = 8.3×10^{-14} J	1
		(ii)	At closest approach, all KE lost [or by impl.] (1) KE lost [or PE gained] = $q\Delta V_E$ (1) $\Delta V = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{r}$ (1) Subst, manip + ans → $r = 1.6 \times 10^{-13}$ m (1) [e.c.f. on KE from (i)]	4
		(iii)	[It retraces its path] with electric PE decreasing (1) and KE increasing (1) or equiv.	2
		(iv)	Smooth symmetric curve drawn curving away from nucleus	1 **10**

Question			Marking details	Marks Available
5.	*(a)*	(i)	N m^{-2} / Pa [or equiv.]	1
		(ii)	Mass = $1.2 \times 2.0 \times 10^{-4} \times 1.00 \times 10^{3}$ [= 0.24 kg]	1
		(iii)	Change in momentum = [0 –] 0.24 × 1.2✓ [= –0.29 N s ~ 0.3 N s]	1
		(iv)	Force = $\frac{\Delta mv}{t} = \frac{0.3\text{(e.c.f.)}}{1}$ / 0.3 N [equal and opposite force on wall implied] (1) Pressure = $\frac{F}{A} = \frac{0.3}{2.0 \times 10^{-4}}$ = 1500 Pa [1450 Pa if 0.29 N s used] (1)	2
	(b)	(i)	$\lambda = 660 \times 10^{-9}$ m [or equiv – unit conversion] (1) $p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{660 \times 10^{-9}}$ (1) [e.c.f. on unit conv.] = 1.0×10^{-27} N s (1)	3
		(ii)	Photon energy $E = hf = \frac{hc}{\lambda}$ (1) = 3.01×10^{-19} J [or by impl.] Number of photons in 1 s = $\frac{\text{Power}}{\text{energy of 1 photon}}$ (1) [= 3.32×10^{13}] Force = $\frac{\Delta p}{t}$ = 3.32×10^{-12} N (1) [e.c.f. if only 1 photon used] Pressure = 3.3×10^{-6} Pa (1) [NB $F = \frac{P}{c} \rightarrow$ 1st 3 marks by impl] [If pressure = 1×10^{-21} Pa given specified "per photon" – or equiv – then 1 mark]	4
				[12]

Question			Marking details	Marks Available
6	*(a)*		$r = 1.0 \times 10^8$ m [unit conversion] (1) $g = \frac{GM_E}{r^2} = \frac{6.67\times10^{-11}\times6.0\times10^{24}}{(1.0\times10^8)^2}$ (1) [e.c.f. for this mark only] $= 0.04$ N kg^{-1} , Statement "agreement with graph" or equiv (1)	2
	(b)		Moon has a [much] smaller <u>mass</u> than the Earth. [or converse]	1
	(c)		3.45 [± 0.05] <u>× 10^5 km</u> (from graph) (1) No resultant gravitational field [or fields of Earth and Moon equal <u>and opposite</u>] or fields balance at this point. [or equiv](1)	2
	(d)		From M to point of intersection / at start $F_{moon} > F_{earth}$ (1) At point of intersection: $F_{moon} = F_{earth}$ (1) From point of intersection to earth / at end $F_{earth} > F_{moon}$ (1) [– 1 for fields rather than forces; – 1 not using resultant at least once]	3
	(e)		More (1) because gravitational fields of Earth and Moon <u>reinforce</u> [or equiv] and act towards centre of moon <u>opposite to rocket motion</u>. (1) Or [if considering escape from the E/M system] Less because of initial greater PE [less negative] due to Earth's field.	2
				[11]

Question			Marking details	Marks Available
7.	*(a)*		$T = 1090 \times 24 \times 60 \times 60$ [$= 9.42 \times 10^7$ s] [unit conversion] (1) $r_S = \frac{Tv_S}{2\pi}$ (1) or equiv e.g. $v = \frac{d}{t}$ and d $\pi r = 6.82 \times 10^8$ m (1)	3
	(b)	(i)	$T = 2\pi\sqrt{\frac{d^3}{G(M_S + M_P)}}$ (equation selection) (1) [or by impl] ($M_S >> M_P$) [or by impl]$\rightarrow$ $T = 2\pi\sqrt{\frac{d^3}{GM_S}}$ (1) $d = \sqrt[3]{\frac{T^2 GM_S}{4\pi^2}}$ (rearrangement) (1) [or with numbers] Substitution and convincing calculation(1) [to give = 3.21×10^{11}m]	4
		(ii)	Use of $M_P = \frac{M_s r_s}{d}$ [in any orientation] or $m_1 r_1 = m_2 r_2$ (1) $= \frac{2.2 \times 10^{30} \times 6.8 \times 10^8}{3.2 \times 10^{11}} = 4.7 \times 10^{27}$ kg (1)	2
	(c)		Find $\Delta\lambda$ in star's spectral lines arising from motion of star / Doppler shift (1) Find velocity of star using $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$	2 **[11]**