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	
	(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 $N = nN_A = 3730 \times 6.02 \times 10^{23} = 2.2 \times 10^{27}$ (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 $\rho = (1)\ \frac{M}{V} = \frac{3733\times\frac{29}{1000}(1)}{90}$ [= 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))	2 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 <u>internal</u> energy [of the gas](1) Q = heat <u>supplied</u> [to] the gas (1) U = work done <u>by</u> the gas (1)	3
	(b)		Readings from graph: $p = 120 \pm 2.5$ kPa; $V = 2.0 \times 10^{-3}$ m (1) $T = \frac{pV}{nR}$ (1)= $\frac{120\times10^{3}\times2.0\times10^{-3}}{0.1\times8.31}$ (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

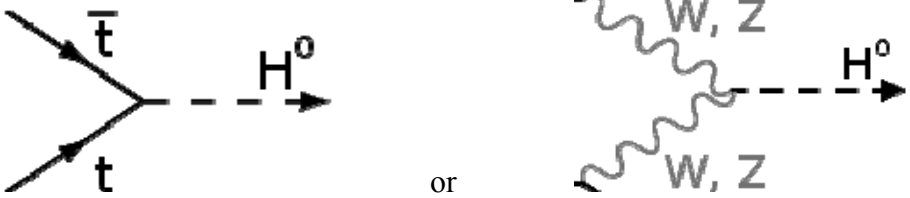
Question			Marking details	Marks Available
A1	*(a)*		${}^{14}_{6}C$ has 8n + 6p [or implied] (1) [8p + 6n → slip, allow e.c.f.] attempt at 8n + 6p – 13.99995 (1) [=0.113026] × 931 and ÷ 14 **or** use of $E = mc^2$ and ÷ 14 (1) $= 7 \cdot 5$ MeV[/nucleon] (1) [or $1 \cdot 2 \times 10^{-14}$ J [/nucleon]] ((**unit**))	4
	(b)		$13 \cdot 99995 - 13 \cdot 999234 - 0 \cdot 000549$ i.e. attempt at mass defect (1) × 931 MeV **or** use of $E = mc^2$ (1) $= 0 \cdot 155$ MeV **or** $2 \cdot 5 \times 10^{-14}$ J (1)	3
	(c)		(from conservation of mom) $v_\beta > v_N$ (1) **or** $v_\beta = 26000 v_N$ (since) $M_N > M_\beta$ (1) **or** $M_N = 26000 M_\beta$ since $E_k = \frac{1}{2}mv^2$, β particle has most of the energy (1) or $E_\beta = 26000 E_N$	3 **10**
A2	*(a)*		137 0 56 -1 Conservation of A and Z (1) All figures correct (1)	2
	(b)		$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$ (**or** $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$) either eq^n by <u>itself</u> or used [e.g. $\frac{0.69}{30}$] (1) $\lambda = \frac{\ln 2}{30 \times 365 \times 24 \times 60 \times 60}$ (1) $\left[= 7.3 \times 10^{10}\right]$	2
	(c)		$A = \pm \lambda N$ stated or used (1) $= 7.3 \times 10^{-10}$ (e.c.f.) $\times \frac{1}{0.137} \times 6 \times 10^{23}$ (1) [= 3.2 × 10^{15} Bq]	2
	(d)		[All] β absorbed [however expressed] ✓ **or** no γ present [implies β absorbed]	1
	(e)		$A = A_0 e^{-\lambda t}$ [or $A = A_0 2^{-n}$] 1000 = 3.2 × 10^{15} $e^{-\lambda t}$ or 3 × 10^{15} $e^{-\lambda t}$ (1) [or 1000 = 3 × 10^{15} × 2^{-n}] taking logs correctly(1) e.g. ln 1000 = ln [3.2 × 10^{15}] – λt or equiv. $t\left[= \frac{1}{\lambda} \ln 3.2 \times 10^{15}\right]$ = 4.1 – 4.9 × 10^{10} s [1240 – 1544 years] (1)	3 **10**

Question			Marking details	Marks Available
B6	*(a)*		See next page for details 3 × (1) points for Higg's Boson or 3 × (1) points for Dark energy / dark matter or 3 × (1) points for Grand Unified Theories	3
	(b)	(i)	$\frac{1}{2}mv^2 = 50$ MeV (1) $v = \sqrt{\frac{2\times 50\times 10^6\times 1.6\times 10^{-19}}{1.67\times 10^{-27}}} = 9.8 \times 10^7$ m s^{-1} (1) [ans]	2
		(ii)	$v = 3\cdot 7\times 10^{10}\ ms^{-1}$ ✓	1
		(iii)	2nd calculation not valid [**or** 1st <u>is</u> valid] (1) Because $v_2 > 3 \times 10^8$ m s^{-1} [**or** c] (1)	2
	(c)		Keeps superconductors at low temperature (1) so that high currents [are maintained] (1)	2
	(d)	(i)	Accept ~ 10^{-4} m $\rightarrow$ ~10^{-3} mm [be generous] (1) $V = 10^{-12}$ m^3 $\rightarrow 10^{-9}$ mm^3 [ecf on side] (1)	2
		(ii)	$pV = nRT$ (1) number of moles = $\frac{1\times 10^{-9}}{1}$ [accept $\frac{1\times 10^{-9}}{2}$] (1) $V = 2.4 \times 10^{-11}$ m^3 and compared with d(ii) (1) (large range: check)	2
	(e)		Any 2 × (1) from • Gravitational pull small (only 2 protons) ✓ • Tiny probability of collision (with small object) ✓ • Shrinks in size ✓ due to Hawking radiation ✓ • etc. [any sensible answer]	3
	(f)		(protons would) collide with soot particles	2
	(g)		Annihilated mass = 2 × 3.1 × 10^{-6} kg [**or** by implication] (1) E [= mc^2 = 6.2 × 10^{-6} × (3 × 10^8)^2]= 5.6 × 10^{11} J (1) [1 mark for 2.8 × 10^{11} J]	1 2
				20

In each case, any 3 × (1) – no combining marks for different subjects

Higgs Boson Marking Points

- Last particle of standard model
- Related to mass (origin of mass of Universe etc.) / gives mass to matter
- Breaking electroweak gauge symmetry
- Has no spin/angular momentum
- Any prediction for mass with the unit GeV/c^2 [100–300 GeV/c^2 or(100–300)m_p or m_n]



(i.e. means of production)

- Possible solution to dark matter problem
- Possibly more than one Higgs predicted

Dark energy/dark matter

- Dark matter related to 'missing' mass (of Universe)
- Evidence from motion of (spiral) galaxies (ph4) {accept from clusters, gravitational lensing etc.)
- Possibly affects anisotropy of cosmic microwave background
- Possible role in galaxy formation
- Does not interact with light (e-m radiation) – not "can't be seen", but "can't be detected
- Possibly accounts for 80% [majority]of mass of Universe
- Higgs boson could be responsible for dark matter
- Dark energy possibly related to accelerated expansion of Universe
- Universe made of ~74% [majority] dark energy
- Evidence for accelerated expansion from (class 1a) supernovae
- Recent evidence also for dark 'flow' or 'fluid' – any mention
- Dark flow/fluid possibly explains both dark matter/dark energy (no marks for details)

Grand Unification Theories

- Based on unification of force [l]aws
- Specifically weak, strong and electromagnetic (accept gravity as well even though this is theory of everything TOE)
- Electric & magnetic already unified (Einstein)
- Electro-weak unification
- Anything to do with greater gauge symmetry or unified coupling constant
- Unification at high energies
- Not possible to check with particle colliders (i.e. too high an energy)
- Observation through proton decay or neutrino properties