UNIVERSITY OF CAMBRIDGE INTERNATIONAL EXAMINATIONS

Pre-U Certificate

MARK SCHEME for the May/June 2010 question paper

for the guidance of teachers

9792 PHYSICS

9792/03 Paper 3 (Part B Written), maximum raw mark 140

This mark scheme is published as an aid to teachers and candidates, to indicate the requirements of the examination. It shows the basis on which Examiners were instructed to award marks. It does not indicate the details of the discussions that took place at an Examiners' meeting before marking began, which would have considered the acceptability of alternative answers.

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Section A

1	**(a)**	**(i)**	speed = $2\pi \times 148.1 \times 10^9 / 365.25 \times 86400 = 29.5\ \text{km s}^{-1}$	(1)	[1]
		(ii)	acceleration = v^2 / r with v from **(i)** and r = 148.1×10^9 = $5.87 \times 10^{-3}\ \text{m s}^{-2}$	(1) (1)	[2]
	(b)	**(i)**	1 force = GMM_e / r^2 with correct meaning of symbols = $6.67 \times 10^{-11} \times 200 \times 5.98 \times 10^{24} / (1.51 \times 10^9)^2 = 3.499 \times 10^{-2}$ N	(1) (1)	
			2 force = $6.67 \times 10^{-11} \times 200 \text{ x } 1.99 \times 10^{30} / (148.1 \times 10^9)^2 = 1.210$ N	(1)	[3]
		(ii)	1.210 – 0.035 = 1.175 N	(1)	[1]
	(c)		centripetal acceleration = F / m = 1.175 N / 200 kg = $5.875 \times 10^{-3}\ \text{m s}^{-2}$ (towards the Sun) in agreement with **(a)(ii)**	(1) (1)	[2]
	(d)	**(i)**	the Sun is always visible to it because it does not go into the shadow of the Earth (as an Earth satellite would)	(1) (1)	[2]
		(ii)	it is in unstable equilibrium / not a circular orbit / other influences so small changes of position would increase if not corrected (allow 1 mark for less precise explanations)	(1) (1)	[2]
		(iii)	it has greater potential energy than a geostationary satellite so rocket and fuel costs are greater *Alternatives* greater speed and k.e. / further from Earth than geostationary	(1) (1)	[2]

[Total: 15]

2	**(a)**		the force/acceleration acting is proportional to the displacement the force/acceleration is directed towards a fixed point with – sign	(1) (1)	[2]
	(b)	**(i)**	single sinusoidal waveform constant amplitude	(1) (1)	[2]
		(ii)	bounded on + and – *x*-axis by the amplitude both positive and negative halves symmetrical ellipse/circle	(1) (1) (1)	[3]
	(c)	**(i)**	$T = 2\pi\sqrt{(2.3 / 63)} = 1.20$ s $\omega = 2\pi / T = 2\pi / 1.20 = 5.23\ \text{rad s}^{-1}$ OR directly from $\omega = \sqrt{(k / m)}$	(1) (1)	[2]
		(ii)	correct substitution giving E = $\frac{1}{2} \times 2.3 \times 0.28^2 \times 5.23^2 = 2.47$ J	(1) (1)	[2]
		(iii)	$2.47 = \frac{1}{2} \times 2.3 \times v_{max}^2$ giving $v_{max} = 1.47\ \text{m s}^{-1}$	(1)	[1]

(d)

	kinetic energy / J	gravitational potential energy / J	elastic potential energy / J	total energy / J
top	**0**	**6.32**	–3.85	**2.47**
middle	**2.47**	reference zero	reference zero	**2.47**
bottom	**0**	**– 6.32**	**8.79**	**2.47**

kinetic energy column correct (1)
mgh = 2.3 × 9.81 × 0.28 = 6.32 J (1)
giving +6.32 at top and –6.32 at bottom (1)
total energy constant at 6.32 – 3.85 = 2.47 J (1)
so e.p.e. at bottom = 8.79 J (1) [5]

[Total: 17]

3 (a) the force acting per unit positive charge at the point (1) [1]

(b) with calculus notation OR as follows
for a charge q moving a distance *d* against a field E; work, W = Eqd (1)
potential difference V = W / q therefore potential gradient = V / x = W / qd = E (1) [2]

(c) (i) 200 V / 0.015 m (= 13 000) (1)
$V m^{-1}$ OR $N C^{-1}$ (1) [2]

(ii) 320 (± 10) V (1) [1]

(iii) (400 V – 200 V) × 3.0 × 10^{-6} J (1)
= 6.0 × 10^{-4} J (1) [2]

(d) (i) straight line (tangent to curve and) in opposite direction to arrow (1) [1]

(ii) line parallel to vertical sides and ¼ distance from side to 200 V (1)
curving near corners then flat along the bottom – ¼ distance still (1) [2]

[Total: 11]

4 **(a)** Three from:
no intermolecular attractions
particles in totally random motion
all collisions elastic
contact time negligible
volume of molecules is negligible compared with volume of container
gravitational effects ignored [3]

(b) p is the pressure, V is the volume (1)
N is the number of molecules, m is the mass of one molecule (1)
$<c^2>$ is the mean value of the square of the speed of a molecule (1) [3]

(c) K.E. = $\frac{1}{2}Nm<c^2> = 3pV / 2$ OR working from $\frac{1}{2}m<c^2> = 3kT / 2$ (1)
= 3nRT / 2 (1)
T = 350 + 273 = 623 K (1)
K.E = 3 × 0.36 × 8.31 × 623 / 2 = 2800 J (1) [4]

[Total: 10]

5 **(a)** ${}^{210}_{84}\text{Po} \Rightarrow {}^{206}_{82}\text{Pb} + {}^{4}_{2}\text{He}$
polonium symbol and helium symbol correct (or helium as alpha particle) (1)
lead symbol correct and equation numbers correct (1) [2]
OR top numbers correct (1), bottom numbers correct (1)

(b) 1 eV = 1V × e = 1.6×10^{-19} J (1)
1 MeV = 1.6×10^{-13} J so 5.2 MeV = $1.6 \times 10^{-13} \times 5.2 = 8.32 \times 10^{-13}$ J (1) [2]

(c) 2500 W / 8.32×10^{-13} J (1)
= $3.00 \times 10^{15}\,\text{s}^{-1}$ (1) [2]

(d) **(i)** decay constant λ = ln 2 / time constant: 138 days = 1.192×10^{7} s (1)
decay constant = ln 2 / $1.192 \times 10^{7} = 5.81 \times 10^{-8}\,\text{s}^{-1}$ (1) [2]

(ii) N = rate of decay / λ = $3.0 \times 10^{15} / 5.81 \times 10^{-8} = 5.16 \times 10^{22}$ (1)
210 g of Polonium contain 6.02×10^{23} molecules (1)
mass required = 210 g × 5.16 / 60.2 = 18 g (1) [3]

(e) alpha particles are absorbed in around 7 cm of air so
will be absorbed within a few mm of being produced in polonium
the energy is therefore contained as heat within the polonium
less dangerous radiation emitted for those preparing the satellite
2 comments expected; [1] mark each [2]

	(f)	mass: with a longer half-life (the decay constant will be much smaller) to get the same heating effect will therefore require a much greater mass	(1)	
		half-life: being longer will mean that power is supplied for a longer time (than the mission is likely to last)	(1)	
		the short half-life will mean that the power output will drop significantly (even on a comparatively short mission)	(1)	
		safety: not much difference assuming that the count rate is the same	(1)	[4]

[Total: 17]

6	**(a)**	$\Delta\lambda = 137.6$ nm $= 1.376 \times 10^{-7}$ m	(1)	
		$v = c\Delta\lambda / \lambda = 3.00 \times 10^{8} \times 1.376 \times 10^{-7} / 4.861 \times 10^{-7} = 8.49 \times 10^{7}\,\text{m s}^{-1}$	(1)	[2]
	(b)	The recession velocity of a (distant) galaxy	(1)	
		is directly proportional to its distance	(1)	[2]
		OR $v = HD$ (1) with symbols explained (1)		
	(c)	a unique point at which space and matter started – the Big Bang	(1)	
	+	if everything is moving away from everything else then space is increasing; idea that it is space that is increasing not that the space was there already; the future of the Universe can (in theory) be programmed; when (the computer programme) working backwards in time all the galaxies get closer together and end up at a point; space shrinks; 3 additional comments expected: [1] mark each	(3)	[4]
	(d)	hubble constant is the reciprocal of the age of the Universe	(1)	
		time $= 1 / 2.3 \times 10^{-18} = 4.35 \times 10^{17}$ s (= 13.8 billion years)	(1)	[2]

[Total: 10]

Section B

7 **(a)** Recall $\sin c = 1/n$ (1)
$\sin 24° = 0.41322 = 2.42^{-1}$
$n = 2.46$ (2.4586) (1) [2]

(b) **(i)** $n = 2.46 = \frac{\sin\theta_1}{\sin\theta_2} = \frac{\sin\theta_1}{\sin 19}$
$\theta_1 = 53.2°$ [1]

(ii)

Wave Property of the light	Effect			
	Increase	Unchanged	Decrease	
Speed	✓			(1)
Wavelength	✓			(1)
Frequency		✓		(1)

[3]

(c) **(i)** Substitution in $\omega = 2\pi f$ (1)
$$\omega = \frac{2\pi 4000}{60} = 2\pi 66.7 = 418.8$$
[Ignore failure to convert to revs per second i.e., $\omega = 25133$ rads^{-1}]
$\omega = 418.8$ *or* 419 (rads^{-1}) (1) [2]

(ii) Idea that diamond is harder than phosphor-bronze. (1) [1]

(d)

Linear motion	Rotational motion	
Work = force × displacement	Work = torque × angular displacement	(1)
Momentum = mass × velocity	Angular momentum = moment of inertia × angular velocity Allow mass × velocity × distance to centre DO NOT allow angular speed as an alternative to angular velocity	(1) [2]

Answers must be in words, as requested.

(e) **(i)** Expression for mass of one of the concentric rings
$dm = 2\pi rpt.dr$ (1)
Basic expression for the moment of inertia
$I = \int r^2 dm$ (1)
Integration expression for the disc
$I = \int_0^R r^2 2\pi r\rho t.dr = \rho 2\pi t \int_0^R r^3 dr$ (1)

Substitution of $M = \pi R^2 \rho t$ into $I = \frac{R^4 \rho \pi t}{2}$

to give final expression for moment of inertia $I = \frac{MR^2}{2}$ (1) [4]

(ii) Substitution in correct formula for I (ignore errors in powers of 10) (1)
$R^2 = \frac{2I}{M} = 2\frac{1.13 \times 10^{-4}}{35.4 \times 10^{-3}}$
$R = 8.0$ cm or 8×10^{-2} (m) (1) [2]

(iii) RKE = ½ $I\omega^2$ (1)
Substitution RKE = ½[1.13 × 10^{-4} × {418.8 or their value for ω}^{2} (1)
Correct answer only. RKE = 9.9(1) (J) (1) [3]

[Total: 20]

8 **(a)** See both $^{207}_{82}$Pb and $^{0}_{-1}$e [1]

(b) $\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_0^t dt$ Rearrangement (1)

$[\ln N]_{N_0}^{N} = -\lambda t$ Integration (1)
$\ln N - \ln N_0 = -\lambda t$
$\ln N = -\lambda t + \ln N_0$ Either line (1) [3]
($N = N_0 e^{-\lambda t}$)

(c) **(i)** Do not penalise unit errors or omissions

Either For 2 or more values of the ratio A_1/A_2 at fixed time intervals (1)
A values must be ≥ 1 Ms apart (1.70 / 1.60 = 1.60 / 1.51 = 1.51 / 1.42) (1)
Shown to be about the same (1.062 = 1.059 = 1.063 i.e. 1.06) (1)
{similar method could be used to find t values for fixed ratio – unlikely}

Or Use $A = dN / dt = A_0 e^{-\lambda t}$ and find 2 values of λ (1)
A values to be ≥ 1 Ms apart (1)
Shown to be about equal (1)

Or Do first stage (1)
Assume exponantial decay and substitute to predict (1)
Second value of A {or t} (1) [3]

(ii) Use of $\lambda t_{1/2}$ = ln2 to find $t_{1/2}$ (1)
Conversion between seconds and days i.e. either way (1)

$$t_{1/2} = \frac{\ln 2}{5.94 \times 10^{-8}} = 11.67 \times 10^{6}\,\text{s} = \frac{11.67 \times 10^{6}}{60 \times 60 \times 24}\ \text{days}$$

See $\frac{A_0}{4}$ i.e. realisation that 270 days = $2t_{1/2}$ (1) [3]

Or

3 marks for correct answer: activity = 0.425×10^{14} (Bq)

$$\text{Activity} = \frac{A_0}{4} = \frac{1.70 \times 10^{14}}{4} = 0.425 \times 10^{14}\ \text{(Bq)}$$

(d) **(i)** (A region or area in which there is...)
the same (1)
force per unit charge / point charge (1) [2]

(ii) A minimum of 5 reasonably parallel vertical lines (1)
A downwards arrow on a field line (1) [2]

(e) **(i)** Substitution [ignoring powers of 10] (1)

$W = \frac{4}{3}\pi\,(7.80 \times 10^{-7})^3(920)(9.81)$ (N)

$W = 1.79 \times 10^{-14}$ (N) (1) [2]

(ii) Recall $F = EQ$ and $E = V/d$ (1)
Establish that $Q = Wd/V$ and substitute (1)

$$Q = \frac{(1.79 \times 10^{-14})(20 \times 10^{-3})}{746}$$

$Q = 4.8 \times 10^{-19}$ (C) (1) [3]

(iii) 3 times the fundamental charge i.e. $3 \times 1.6 \times 10^{-19}$ (C)
Or
Answer is an integral multiple of the fundamental charge [1]

[Total: 20]

9 **(a)** **(i)** Small displacement / small angle [1]

(ii) $T = 2\pi\sqrt{\frac{0.54}{9.81}} = 1.47$(s)

T = <u>1.47</u>(s) [1]

(b) Recall $\omega = \frac{2\pi}{T}$ (1)

Use to give $\frac{d^2x}{dt^2} = -\frac{g}{l}x$

statement alone scores both marks (1) [2]

(c) Taking logs gives $\ln T = \frac{1}{2}\ln l + \frac{1}{2}\ln(4\pi^2/g)$
Show or state in working that intercept is $\frac{1}{2}\ln(4\pi^2/g)$ (1)
Attempt to use intercept value $\ln T = 0.70$ from graph (1)
$g = 9.73 / 9.7\ (\text{m s}^{-2})$ (1) [3]

(d) (i) 1st differentiation $\frac{dx}{dt} = -A\omega\sin(\omega t)$
Negative sign (1)
Multiplication by ω (1)

2nd differentiation $\frac{d^2x}{dt^2} = -A\omega^2\cos(\omega t)$
Correctly done (1) [3]

(ii) Substitution (ignoring any errors in powers of 10) (1)
$x = A\cos(\omega t) = 3.0\cos\left(\frac{2\pi}{1.47}0.50\right) = -1.61\ (\text{cm})$
Correct answer only, to include the minus sign (1) [2]

(e) Idea that Total energy = Maximum KE
Or that Total energy = $\frac{1}{2}mv_{max}^2$ (1)
Substitution of $v_{max} = A\omega$ into KE = $\frac{1}{2}mv^2$ (1) [2]

(f) (i) Correct substitution (1)
$-\frac{d\Phi}{dt} = \frac{0.025}{200} = 1.25 \times 10^{-4}\ \text{Wb s}^{-1}$
Correct value (–)1.25×10^{-4} (1)
Correct unit Wb s^{-1} or equivalent (1) [3]

(ii) Some relevant reference to energy (1)
- e.g. Energy of pendulum is used to do work or to create current in the coil

Plus any other two points:
- Reference to 'Lenz's law'
- Change in flux linkage produces induced e.m.f. in coil
- There is an induced current in the coil
- A magnetic field is created around the coil
- The motion of the magnet is damped by the interaction of the two magnetic ' fields.
- Amplitude decreases so less flux linkage in same time interval (max 2) [3]

[Total: 20]

10 (a) (i) Description of main features of de Broglie's model – 3 marks max.

Wavelength associated with electrons (1)

Wavelength inversely proportional to momentum (or equation $\lambda = \frac{h}{p}$) (1)

Wave amplitude/intensity related to probability of locating the electron (1) [3]

(ii) Explanation of spreading using wave model – 2 marks max.

Diffraction mentioned. (1)
Amount of spread related to wavelength λ and slit width *w* correctly
(i.e. angular spread related to ratio of wavelength to slit width)* (1) [2]
*They must refer to both λ *and* slit width *w* for this mark.

(b) The detection/counting of electrons. (1)
Electrons are detected/counted discretely. (1) [2]

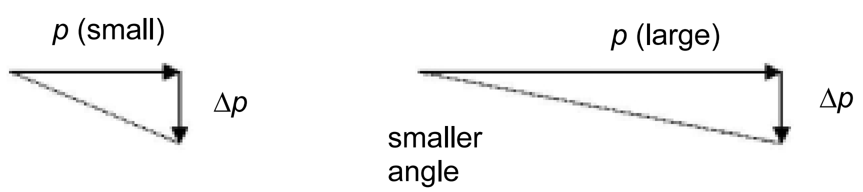
(c) (i) Δy is uncertainty in position (1)
Linked to slit width (1) [2]

(ii) Δp is uncertainty in momentum (1)
In the *y*-direction. (1) [2]

(d) (i) The uncertainty in *y*-momentum gives each electron a momentum (velocity) perpendicular to the original direction. (1)
The process is random so the beam spreads out with some electrons going to +*y* and some to –*y*. (1) [2]

(ii) If *w* is smaller then Δy is smaller. (1)
Δp is therefore larger (1)
so more electrons scatter through larger angles. (1) [3]

(iii) Uncertainty in *y*-momentum is still the same. (1)
momentum in original direction is larger. (1)
Use of vector diagram to show that this results in smaller deflection angles:



(2) [4]

Accept equivalent written explanations.
Do not award marks for explanations based on wave theory that do not refer to HUP.

11 (a) Candidates **do not** need to derive the time dilation equation in order to gain full marks on this question, although a clear derivation could gain full marks.

Key marking points:
relevant reference to the Principle of Relativity – e.g. The speed of light is the same for all (uniformly moving) observers, (1)
use of this principle (e.g. with light clocks) to show that clocks in relative motion 'tick' at different rates, (2)
convincing demonstration that the satellite clock ('moving' clock) **runs slow** when observed from the Earth clock. (1) [4]

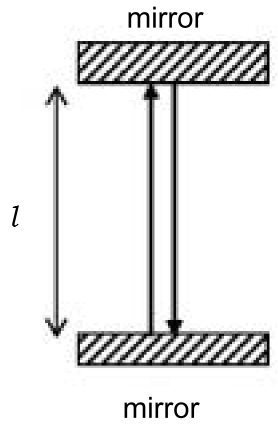
Note: examples of *possible* approaches to this question given underneath.

1. Example based on light clocks:

Diagrams could be used to compare a light clock 'at rest' with a moving light clock.

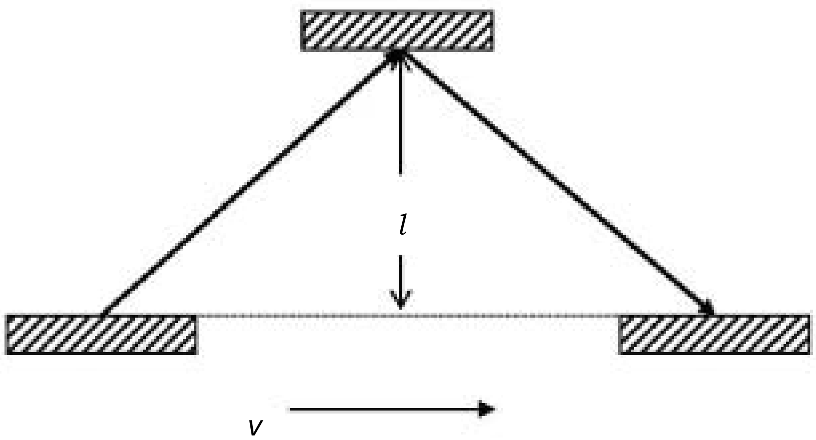
The key ideas (which can be gained from a labelled diagram) are:
- the speed of light relative to the observer is the same in both cases
- the light path in the 'moving' clock is longer
- the time between 'ticks' on the moving clock is longer so it runs slow

Light path in 'rest' or Earth-based clock



l = separation of mirrors in the light clock
v = relative velocity of satellite clock

Extended light path in moving or satellite clock



Candidates may go on to compare the light path lengths and derive the equation for time dilation, but this is not required for the marks.

2. Example based on the Lorentz transformation (this is not expected, and goes further than is required by the question, but some candidates may use it).

The key ideas are:
the Lorentz transformation follows from the principle of relativity,
the Lorentz transformation can be used to compare time measurements for observers in relative motion:

$$t = \gamma\left(t' + \frac{vx'}{c^2}\right)$$

where t is the time elapsed on the Earth clock while a time t' is observed (from Earth) to elapse on the moving clock onboard the satellite.
If the moving clock is at the origin of the moving reference frame then $x' = 0$ and:

$t = \gamma t'$

where $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ which is greater than 1

so $t > t'$ meaning that more time passes on the Earth clock and therefore the moving clock on the satellite appears to run slow.

(b) **(i)** Substitution of $v = 3.5 \times 10^3$ ms^{-1} and $c = 3.0 \times 10^8$ ms^{-1} in the equation:

$$t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}} \approx t\left(1+\frac{1}{2}\left(\frac{v^2}{c^2}\right)\right) \quad (1)$$

t' identified as time on the moving (satellite) clock as measured by the clock on Earth and t as time on the stationary (handset) clock* (1)
*This equation can be interpreted in different ways – the essential point is that the candidate recognises that it compares clock rates between the two reference frames.
Calculation of $(t' - t) = 6.8 \times 10^{-11}$ s (1) [3]

(ii) $60 \times 6.8 \times 10^{-11} = 4.1 \times 10^{-9}$ s $\approx$ 4 ns [1]

(c) The error will change with time (becoming larger with a greater time between measurements). (1)
This will lead to a different value for distance from the reference satellite so the two measurements will differ. (1) [2]

(d) **(i)** Difference used (e.g. 30 – 4 = 26 ns per minute). (1)
260 ns (1) [2]
Allow one mark for (34 × 10 = 340 ns)

(ii) Distance = $260 \times 10^{-9} \times 3.0 \times 10^8 = 78$ m [1]

(iii) The error can be large and significant (1)
One good practical example: (1) [2]
E.g. sat. nav. giving wrong information leading to a ship hitting a reef at sea

(e) Newtonian view (2 marks max.).
Idea of absolute time explained. (2)
E.g.
All observers have the same time regardless of position or movement.
Time progresses at the same rate for everyone.
Time is independent of motion or gravity.

Einsteinian view (2 marks max.).
Idea of relativistic time explained. (2)
E.g.
The laws of physics are the same for all observers so time and space measurements are not.
Time passes at different rates for observers in relative motion.
The 'present moment' for one observer might lie in the future or past for another.
The rate at which time passes depends on the gravitational field.

Use of one relevant example (or GPS) – (must show relevance). (1) [5]
E.g. in a Newtonian universe we would not have to apply corrections to clocks onboard GPS satellites.

12 **(a)** An arrow that points from the past to the future (distinguishes past from future) (1)
Linked to 'one-way' processes (example correctly given) (1) [2]

(b) **(i)** Newton's first law – still applies. (1)
Example correctly given (1) [2]
E.g. reversing time reverses velocities but does not introduce any new forces, so objects that are moving at constant positive velocity in positive time are moving at constant negative velocity in negative time.

(ii) The first law of thermodynamics still applies. (1)
Example correctly given (1)
E.g. Description of a process in which heat and work done on a system increase internal energy becomes one in which loss of heat and work done by the system decrease internal energy.
Idea that energy is conserved in both directions of time. (1) [3]

(iii) Newton's second law – still applies (1)
Example correctly given (1) [2]
E.g. Reversing time reverses the apparent direction of forces, so that gravity becomes (for example) a repulsion, but $F = ma$ still applies because no additional forces have been introduced.

(iv) The second law of thermodynamics – is violated. (1)
Explanation correctly given
E.g. Entropy / Disorder decreases (1)
Example correctly given
E.g. Mixtures separate spontaneously. (1) [3]

(c) **(i)** Linking entropy to the distribution of energy or particles amongst states (1)
Quantitative link – e.g. to number of ways
(or to classical equations such as $\Delta S = \dfrac{\Delta Q}{T}$) (1) [2]

(ii) Idea that there are lots of ways of achieving disordered states but only a small number of ways of achieving ordered states. (1)
Link 'order' to low probability (or disorder to high probability). (1) [2]

(d) If the universe were to collapse in the future (1)
Then the direction of entropy increase would be opposite to the direction of expansion. (1) [2]

(e) It had very low entropy (1)
It had a very low probability (1) [2]
Accept answers that explain the idea of low probability – e.g. of all the ways that the universe might have formed the actual distribution of matter and energy was highly unlikely.