1. No mark scheme available

2. The list gives some quantities and units. *Underline* those which are base quantities of the International (SI) System of units.

coulomb force <u>length</u> mole newton <u>temperature interval</u>

(2 marks)

Define the volt.

Volt = Joule/Coulomb or Watt/Ampere

(2 marks)

Use your definition to express the volt in terms of base units.

Volt = J/C

$= kg\ m^2\ s^{-2}/A\ s$

$= kg\ m^2\ s^{-3}\ A^{-1}$

(3 marks)

Explain the difference between scalar and vector quantities

Vector has magnitude and direction

Scalar has magnitude only

(2 marks)

Is potential difference a scalar or vector quantity?

Scalar

(1 mark)
[Total 10 marks]

3. With the aid of an example, explain the statement "The magnitude of a physical quantity is written as the product of a number and a unit".

Both number and unit identified in an example (1)

followed by the idea of multiplication (1)

(2 marks)

Explain why an equation must be homogeneous with respect to the units if it is to be correct.

If the units on one side differ from those on the other, then the two sides of the equation relate to different kinds of physical quantity. They cannot be equal [or similar positive statements] (1)

(1 mark)

Write down an equation which is homogeneous, but still incorrect.

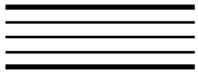
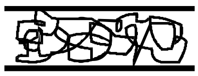
Any incorrect but homogeneous algebraic or word equation :
$2mgh = ½mv^2$, 2 kg = 3 kg, pressure =stress/strain (2 or 0)

(2 marks)
[Total 5 marks]

4. For each of the four concepts listed in the left hand column, place a tick by the correct example of that concept in the appropriate box.

A base quantity	mole	☐	length	✓	kilogram	☐
A base unit	coulomb	☐	ampere	✓	volt	☐
A scalar quantity	torque	☐	velocity	☐	kinetic energy	✓
A vector quantity	mass	☐	weight	✓	density	☐

[Total 4 marks]

5. (a) Straight line parallel to pipe  **(1)**
Two or more parallel lines **(1)**
Muddled/swirly lines  **(1)**
to side of/all over pipe **(1)**
(4 marks)

(b) Critical speed:
Maximum speed for smooth flow/speed at which flow becomes turbulent **(1)**

Initial quietness:
Liquid is undisturbed/still/calm/not moving around (in tank whence it comes) **(1)**

Boundary layer:
Liquid immediately/directly in contact with a surface/cylinder/boundary **(1)**
(3 marks)

(c) Re useful:

Flow of liquid along pipes **(1)**
Flow of liquid past cylinder/pipe **(1)**
Common feature:
Roughness of pipe wall/cylinder surface OR reference to drag **(1)**
(3 marks)

(d) μ must have same units as pvd **(1)**
ρ is kg m^{-3}; v is m s^{-1}; d is m — All **(1)**
∴ μ is kg m^{-1} s^{-1} — (Allow e.c.f) **(1)**
N ≡ kg m s^{-2} **(1)**
∴ N s m^{-2} = (kg m s^{-2}) (sm^{-2})= kg m^{-1} s^{-1} **(1)**
(5 marks)

(e) $v \propto \mu$ **(1)**
and $v \propto 1/\rho$ — (Accept bald answers) **(1)**
Mercury has high ρ/ tomato sauce has low ρ **(1)**
Tomato sauce has high μ / mercury has low μ **(1)**
⇒ v mercury < v tomato sauce (no error carried forward) **(1)**
(5 marks)

(f) (i) $$\frac{\rho v d}{\mu} = \frac{(830\,\text{kg m}^{-3})\,(0.42\,\text{m s}^{-1})\,(0.16\,\text{m})}{9.6\times10^{-2}\ \text{N s m}^{-2}}$$ **(1)**
= 580 **(1)**
(which is less than Re = 1300) ∴ smooth flow **(1)**
(3 marks)

(ii) Sketch:
Section (vertical or horizontal) or 3D **(1)**

Calculation:
Use of $F/l = 4C_D\rho v^2 r$ **(1)**
$= 4 \times 5.0 \times (830\ \text{kg m}^{-3})\ (0.42\ \text{m s}^{-1})^2\ (0.01\ \text{m})$ **(1)**
$= 29\ \text{N m}^{-1}$ **(1)**

(4 marks)

(g) At Re = 10: viscous **(1)**
At Re = 1000: inertial **(1)**
When Re = 10, C_D = 2 to 4. **(1)**
Graph:
Reference to power/log/exponential **(1)**
$\lg c_D = a \lg Re + b$ / $c_D = b\,Re^a$ **(1)**
Attempt to evaluate *a* or *b* **(1)**

(Max 5 marks)
[Total 32 marks]

6. Classify each of the terms in the left-hand column by placing a tick in the relevant box.

[Total 6 marks]

7. (a) (i) Ion pair:
Charged particles **(1)**
Positive and negative **(1)**

(ii) Space charge:
Region/area containing positively charged **(1)**
massive/slow-moving particles/ions **(1)**

(iii) Dead time:
Period/time when GM tube is insensitive to arrival of further particles **(1)**

(5 marks)

Avalanche:
Electrons accelerate/gain energy **(1)**
causing ionisation **(1)**
idea of a cascade, e.g. chain reaction **(1)**

(3 marks)

(b) $\Delta p = (101 - 11) \times 10^3$ Pa **(1)**
Use of $F = Ap$ OR $A\Delta p$ **(1)**
$= \pi(12 \times 10^{-3}\ \text{m})^2\ (90 \times 10^3\ \text{Pa})$ **(1)**
= 41 N **(1)**

(4 marks)

Difficulty:
α-particles easily stopped/have short range/are least penetrating **(1)**
so thin end windows needed **(1)**
but forces/pressures are high **(1)**

(Max 2 marks)

(c) (i) Thickness of mica = $(2 \times 10^{-2}$ kg m$^{-2}) \div (2800$ kg m$^{-3})$ **(1)**
$= 7.14 \times 10^{-6}$ m **(1)**
Therefore number of molecules
$= 7.14 \times 10^{-6}$ m $\div 8.4 \times 10^{-9}$ m **(1)**
= 850 **(1)**
(Max 3 marks)

(ii) α ionises more densely than β **(1)**
as it has twice the charge/is slower than β **(1)**
Therefore β penetrates more/gets through thicker windows than α **(1)**
(3 marks)

(d) Radial lins/parallel lines **(1)**
with arrows outwards **(1)**
± marked/anode-cathode marked consistent with arrows **(1)**
(3 marks)

Calculation:
$F = qE$ **(1)**
$= 1.92 \times 10^{-14}$ N **(1)**
$ma = F$ **(1)**
$a = 2.1 \times 10^{16}$ m s^{-2} **(1)**
(4 marks)

(e) (i) $\ln(r_a/r_c)$ no units/$r_a \div r_c$ no units/ln is number **(1)**
$\varepsilon_0 l$ has unit F m^{-1} × m **(1)**
= F which is unit of capacitance **(1)**
(3 marks)

(ii) Time constant = RC
$= (1 \times 10^5\ \Omega)(10 \times 10^{-12}$ F$)$ **(1)**
$= 1 \times 10^6$ s **(1)**
(2 marks)
[Total 32 marks]

8. Joule: kg m^2 s^{-2} **(1)**
Coulomb: Derived unit **(1)**
Time: Scalar quantity **(1)**
Volt: W × A^{-1} **(1)**

[Total 4 marks]

9. What is meant by "an equation is homogeneous with respect to its units":
<u>Each side/term</u> has the same units 1

Equation $x = ut + ½ at^2$:

ut - (m s^{-1}) s = m

$at^2/2$ (m s^{-2}) s^2 = m

all 3 terms reduce to m 3

[Allow dimensions]

Explanation:

Wrong numerical constant/wrong variables

Units same, numbers wrong/

Units same, magnitudes wrong 1

Example = 1 kg + 2 kg = 5 kg

[5]

10. The joule in base units:

kg m^2 s^{-2} [No dimensions] **(1)** 1

Homogeneity of formula:

ρ kg m^{-3} **(1)**

r m, $f = s^{-1}$ **(1)**

(Right hand side units = (kg m^{-3}) $(m)^5$ $((s^{-1})^2)$ [Correct algebra]

= kg m^2 s^{-2} [Only if 1st two marks are earned] **(1)** 3

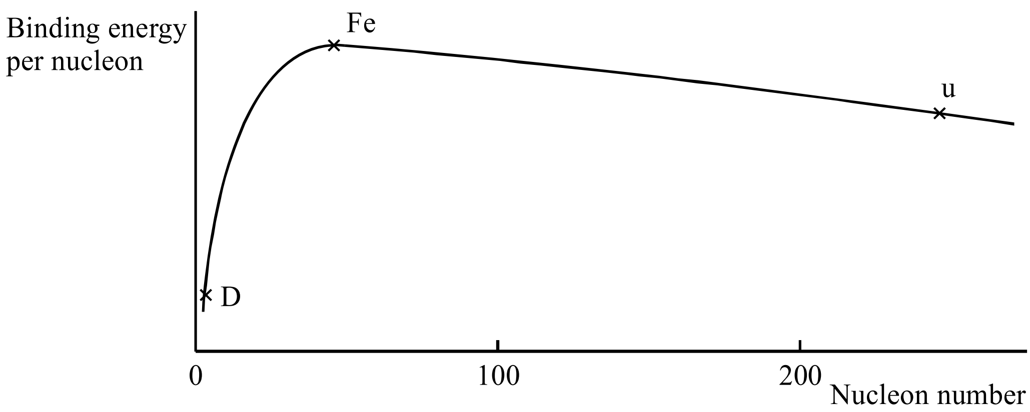
[Ignore numbers; dimensions OK if *clear*]

Why formula might be incorrect:

The $\frac{1}{2}$ could be wrong **(1)** 1

[5]

11. Labels of elements:



D close to O: AND U ≥ 200 **(1)**

Fe at peak **(1)** 2

Meaning of binding energy:

Energy needed to split/separate a nucleus **(1)**

into protons and neutrons/nucleons **(1)**

OR

Energy released when nucleus formed **(1)**

from protons and neutrons/nucleons **(1)**

OR

Energy released due to mass change/defects **(1)**

Sum of masses of protons and neutrons > mass of nucleus **(1)**

[In each of the cases above, the second mark is consequent upon the first]

Explanation:

Uranium **(1)**

Binding energy per nucleon of products is higher
OR
Products/atoms/element/nuclei nearer peak **(1)**

Therefore more stable **(1)** 5

[7]

12. Calculation of the magnitude of the electric field strength:

Correct use of $E = kq/r^2$ [all substitutions, any value of q] **(1)**

$q = 92 \times e$ **(1)**

Magnitude = 2.4×10^{21} N C^{-1} OR V m^{-1} **(1)**

Direction of electric field:

Away from nucleus/outwards/on diagram **(1)** 4

Similarity and difference between electric and gravitational field:

Similarity - Both radial/obey inverse square law/ $\propto 1/r^2$ **(1)**

Difference - Magnitude of g field << E-field

OR G-field direction towards nucleus, E field away from nucleus

OR G-field attractive only, E field attractive OR repulsive **(1)** 2

[6]

13. Estimate of time constant, using graph:

V/3	OR	V/e	OR	$t_{1/2}$
↓ 3 V		↓ 3.3 V		↓ 16 s
26 s		23.24 s		23 s

Method **(1)**

Value 23 → 26 s **(1)** 2

Calculation of resistance and hence capacitance:

$R = \frac{V}{i}$ OR $\frac{9}{0.19 \times 10^{-3}}$ **(1)**

Resistance = 47 kΩ [ue] **(1)**

Substitute in t = RC [e.c.f their t, their R] OR answer 300 μF

Capacitance = 500 μF **(1)** 3

Addition to graph of line showing how potential difference varies with time:

A curve of shape shown below, i.e. getting less steep **(1)**

Any convex curve ending at ≈ 7.5 V, crossing at ≈ 15 s **(1)** 2

[7]

14. (a) *Either*

Bunch of threads/hair **(1)**

Connected to top of sphere **(1)**

Fan out repelling each other **(1)**

Or

Light conductor on insulating thread [e.o.p. plastic sphere] **(1)**

Touch to sphere **(1)**

Hold at side repelled **(1)**

[May all be on labelled diagram] Max 2

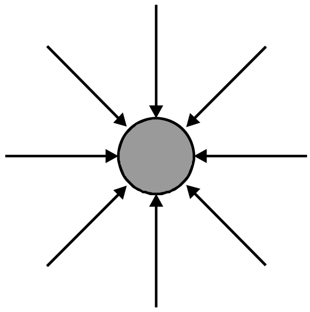
(b) Unit of I, w and v as A, m and m s^{-1} **(1)**

As A s = C **(1)**

unit of X is C m^{-2}

so X may be the charge density/per unit area (on belt) **(1)** 3

(c) (i) Radial lines [be generous] **(1)**
> 4 lines **(1)**
Arrows inward [to surface only] **(1)**



(ii) $E = Q/4\pi\varepsilon_0 r^2 \rightarrow Q = 4\pi\varepsilon_0 r^2 E$ **(1)**

$\therefore Q = 4\pi\ (8.85 \times 10^{-12}\ \text{F m}^{-1})\ (0.15\ \text{m})^2\ (3.6 \times 10^5\ \text{N C}^{-1})$

$= 0.90 \times 10^{-6}$ C OR 0.90 μC **(1)**

$V = Q/4\pi\varepsilon_0 r^2$ OR $V = Er$ **(1)**
Substitution [allow e.c.f for *Q*]
$\rightarrow V = 54 \times 10^3$ V OR 54 kV — 6

(d) (i) Leakage current:

(Fast) random movement **(1)**
(Very) slow drift velocity [down] **(1)**

On belt:

Uniform velocity [up] **(1)**

(ii) Axes showing:

V (up) and 120 s/2 min (along) **(1)**

V/2 OR origin OR 60 s [i.e. zero on one axis implied] **(1)**

Exponential curve from (O s, V) not reaching time axis **(1)** — Max 5

[16]

15. Correct quantities on diagram:

Upper ellipse	capacitance	[**not** energy]	[Accept capacitance^{-1}]	**(1)**
Lower ellipse	resistance	[**not** power]	[Accept conductance/resistance^{-1}]	**(1)**

2

Explanation:

Base quantities/units [**Not** fundamental] **(1)**

Not derived from other (physical) quantities **(1)**

OR other (physical) quantities are derived from them

OR cannot be split up/broken down

2

[4]

16. Calculation of energy released for each fission:

$\Delta m = 0.2035$u **(1)**

Convert their Δm to kg [$\times (1.66 \times 10^{-27})$ kg] OR × 931 **(1)**

Convert their kg to J [$\times (3 \times 10^{8}$ m s$^{-1})^{2}$] OR $\times 1.6 \times 10^{-13}$ **(1)**

= 3.04×10^{-11} (J) **(1)**

4

Calculation of power output:

Energy per mole = 3.04×10^{-11} J $\times 6 \times 10^{23}$ **(1)**

Full e.c.f. their energy = 1.8×10^{13} J

Power = $\frac{\text{Any energy J}}{5 \text{ s}}$ [No e.c.f.] **(1)**

= 3.6×10^{12} W [Accept J s^{-1}] **(1)**

3

[7]

17. (a) (i) Light travels very fast/instantaneous/at 3×10^{9}m s^{-1}
To travel 1.5 km, sound takes 4.4 s
Measuring time enables distance to be found

(ii) Sheet lightning: flash/stroke/discharge
within a cloud/from cloud to cloud 5

(b) Charge negative on cloud
Charge positive on tower
Jagged line from cloud to tower
Negative leader is column of charged ions
Negative leader marked on diagram 5

(c) (i)

Either	Or
$P = 4 \times 10^{10}$W	$P = IV \Rightarrow \frac{p}{l} = I\frac{V}{l}$
$p = IV \to V = \frac{P}{I}$	$E = \frac{V}{l} = \frac{P/l}{I}$
$\Rightarrow V = 2 \times 10^{6}$V	$= 5000\ V$ m^{-1}

3

(ii)

E = $\frac{V}{d}$	$E = Vl$ **(1)**
= 5000 V m^{-1}**(1)**	= 2×10^{6}V **(1)**

Max 2

(d) (i) Thunder
Air heated
Rapid expansion 3

(ii) Air temperature, any value in kelvin

$\frac{p}{T}$ = constant

Assume V constant
$\Rightarrow$ P = around 10 000 kPa 4

(e) Breathing stops (when struck by lightning)
(alone means) no-one to help get it going again 2

(f) The electrical discharge ionises/excites gas/air molecules/particles

which return to their ground state
emitting (a flash of) visible photons

Quality of written communication 4

(g) e.h.t. /Van de Graaf
with voltmeter
Two terminals/spheres/plates
Raise voltage/bring t.s.p closer
Suggestions: atmospheric conditions Max 4

[32]

18. (a) (i) X = 520 N **and** Y = 637 N to 650 N

(ii) moment of weight/650 N and moment of towing force/520 N must be equal
as 520 N varies she must alter its moment *or* that of her weight
by altering the distance of either force from (the point of) the ski
(through which the resultant of X and Y acts) 4

(b) The push of the water on her/the board
inward/towards the centre of the curved path/circle
the only vertical force on her is her weight/gravity 3

[Not "no vertical reaction "]

(c) (65 kg) a = 520 N
$\rightarrow a = 8.0 \text{ m s}^{-2}$

Force X reduces as she slows/X depends on speed 3

(d) Doppler shift (of spectral lines)
Tells us speed of recession (of galaxy)
Nature of emission/absoption (of spectral) lines
Tells us chemical composition (of stars)
Quality of written communication 5

[15]

19. (a) (i) Current in coil produces a magnetic field
$\therefore$ (magnetic) flux through ring changes/field lines are cut by ring
so induced e.m.f. in ring

The current feels a *Bil* force/motor effect/
Fleming/left hand rule

because of opposing B-fields/Lenz's law opposing

Quality of written communication 6

(ii) $P = I^2 R \Rightarrow R = P/I^2$ **(1)**

$= 1.6\ W \div (140\ A)^2$ **(1)**

$= 8.2 \times 10^{-5} \Omega$ **(1)**

$R = \rho l/A$ **(1)**

A calculated as $(2.0 \times 10^{-3}m)(15 \times 10^{-3}m)$

or

l calculated as $2\pi(12 \times 10^{-3}m)$ **(1)**

$\Rightarrow \rho = 3.3 \times 10^{-8} \Omega\,m$ **(1)** Max 5

(b) (i) Measure:

Mass of ring and mass of water
Initial and final temperatures of water/ $\Delta\theta$ water
Look up s.h.c. of aluminium and water 3

(ii) Detail of where/when heat losses occur
Calculated temperature too small 2

[16]

20. (a) (i) (The particles are accelerated through a circular accelerating tube)
The particles are accelerated by passing repeatedly through accelerating voltages. **(1)**
Alternating voltages are used, so the electric field is always attractive **(1)**
The particles travel in a circle therefore a centripetal force is needed **(1)**
This is provided by (large) magnets, because charged particles experience a force when moving in a magnetic field **(1)**
Because it is a circle the particles can go round many times, gaining more energy each time **(1)**
Quality of written communication **(1)** 6

(ii) $m\frac{\upsilon^2}{r} = Bq\upsilon$

$\rightarrow r = \frac{m\upsilon}{Bq}$

Since $\frac{m}{Bq}$ is constant, r increases as υ increases 3

(b) (i) The particles ionise hydrogen atoms
Bubbles form on these ionised atoms
Light shining on/reflecting from the bubbles (makes them visible) 3

(ii) Particle 2 is charged negatively
Particle 3 does not ionise/is neutral 3

(iii) Mass-energy is conserved/mention of $\Delta E = c^2\Delta m$
In this case the mass lost has become kinetic energy 2

[17]

21. (a) $\upsilon = (u) + at$ Evidence of 183/182.5 × 24 × 3600 s **(1)**

υ = (9.8/10 m s^{-2}) (value of t from above) **(1)**

150 – 160 Mm s^{-1}

= 1.5 – 1.6 × 10^8 m s^{-1}

150 – 16- × 10^6 m s^{-1} [e.c.f. value of t] (1) 3

(b) (i) $E = \frac{V}{d} = \frac{100\ \text{V}}{0.004\ \text{m}}\ /\frac{100\ \text{V}}{4\ \text{mm}}$ **(1)**

= 2.5× 10^4 / 25 000 V m^{-1}/N C^{-1} OR 25 V mm^{-1} **(1)**

(ii) $F = QE$ [Beware $Bq\upsilon \to$ 0/2 e.o.p.] **(1)**

= (1.6 × 10^{-19} C) (value of E from above) **(1)**

= 4.04× 10^{-15} N

(iii) $a = \frac{F}{m}$ **(1)**

Use of m_e = 9.1/9.11 × 10^{-31} kg **(1)**

= 4.4 × 10^{15} m s^{-2} Max 6

(c) (Electron gun at) *high* voltage/potential/p.d. **(1)**

Relative to earth/below earth [Accept anode for earth] **(1)**

Exerts force on/repels electrons **(1)**

(because of large) charge/electrons on hemisphere/dome/belt **(1)** Max 3

(d) Drawing:

Two peaks [up or down or one of each] **(1)**

Narrow [dependent on 2 peaks] **(1)**

About 3 div/cm apart [Award a 3 cm wide rectangle] **(1)**

About 1/3 div/cm wide [Apply to single peak] **(1)**

Time base scale shown **(1)** 4

(e) (i) *m* is mass of disk/B/aluminium **(1)**

c is s.h.c. **(1)**

(ii) 1 volt is a joule per coulomb [owtte]/watt per ampere **(1)**

[Not a definition of p.d.] **(1)**

NeV units are (none) × $C \times \frac{\text{J}}{\text{C}}$ [hence J] 4

(f) (i)

T/MeV	0.25	0.50	1.00	1.50	
$t/10^{-8}$ s	3.85	3.28	3.03	2.92	
$\upsilon/10^8$ m/s	2.18	2.56	2.77	2.88	[all correct]
$\upsilon^2/10^{16}$ m^2/s^2	4.76	6.56	7.68/9	8.27/8	

[may be on graph] [attempted]

[2 s.f. ok] [Table ignore units] **2**

½ $m\upsilon^2$ = eV route: e.o.p. 0/2

(ii) Graph:

[Can be all from their data – sketch OK]

Sensible axes labelled plus units [axes either way] **(1)**

Points correctly plotted e.c.f. [ignore 0,0] **(1)**

Graph smooth curve/best fit line if no zero **(1)**

(iii) Comment:
[No/yes] [From here only credit υ^2 v T graphs] **(1)**
υ^2 v T is not straight line / through zero
υ^2 v T is straight line through zero

(iv) At very high T: line flattens out [owtte] / has max at **(1)**
Reference to c/speed of light/9×10^{16} m^2 s^{-2}/ **(1)**
3×10^8 m s^{-1} 5

(g) (i) Concept of delay **(1)**
For each must be (made) the same
[Beware signals arriving at same time] **(1)**

(ii) To check/confirm that $T = eV$/ to measure T independently
[T or energy or k.e.] **(1)** **Max 3**

[31]

22. (a) (i) (Extending) force, extension [Not displacement, length, distance]
[Accept $l - l_0$ implied] **(1)**
Potential difference/voltage, charge **(1)**

(ii) $W_s = \frac{1}{2} xF / \frac{1}{2} Fx$ **(1)**
$= \frac{1}{2} \frac{F^2}{k}$ [Accept bald answer in correct order] **(1)**

EITHER
$W_s = \frac{1}{2} \frac{(kx)^2}{k}$
$= \frac{1}{2} kx^2$

OR
$W_s = \int_0^x F dx = \int_0^x kx dx$ **(1)**
$= \left[k \frac{x^2}{2} \right] = \frac{1}{2} kx^2$

OR
$W_s = \frac{1}{2} xF = \frac{1}{2} x(kx)$
$= \frac{1}{2} kx^2$

OR
$W_c = \frac{1}{2} \frac{Q^2}{C}$
$= W_s = \frac{1}{2} kx^2$ **(1)** 5

(b) (i) $W_c = \frac{1}{2} CV^2 = \frac{1}{2} (0.0047 \text{ F}) (25 \text{ V})^2$ [Ignore 10^n] **(1)**
$= 1.5$ J / 1.47 J [no e.c.f.] **(1)** 2

Quality of written communication
W_c is (very) small **(1)**
Even at 50 V it is only 6 J **(1)**
Any ΔT is difficult to measure/wire spread out/ **(1)**
something like a thermocouple is needed **(1)**
Wire (might) melt/fuse **(1)**
Heat/energy loss to air/surroundings [not to connecting wires] **(1)** Max 4

(ii) Exponential (decay) **(1)**
Radioactive decay/radioactivity [independent] **(1)**
Use of one of *five* approved methods [Name it] **(1)**
Data off graph appropriate to method [ignore 10^n] **(1)**
Use of RC/use of $R = V/I$ **(1)**
$R = 7.2\ \Omega - 8.5\ \Omega$ [no e.c.f.] **(1)**
[7200 Ω – 8500 gets 3/4] 6

[17]

[Methods:
M1 _RC = time to $Q_0 \div e$ [35 – 39 ms]
M2 $RC \ln 2 = t_{1/2}$ [24 – 28 ms]
M3 RC = where initial tangent hits t axis [32 – 40 ms]
M4 Use of RC in $Q = Q_0 e^{-t/RC}$ with numbers
[≈ correct]
M5 Calculation of T_0 initial current from gradient
[2.7 – 3.0 A]

23. (a) (i) $v = \frac{2\pi r}{T}$ / $\omega = \frac{2\pi}{T}$ [Use of] **(1)**

Use of $a = \frac{v^2}{r}$ / $r\omega^2 = 0.22\ \text{m s}^{-2}$ **(2)**

Centripetal/towards (centre of) Earth **(1)**

(ii) $g = G\frac{m_E}{r^2}$ / $G\frac{m}{r^2}$ with m defined **(1)**

$\Rightarrow m_E = \frac{gr^2}{G}$ or numbers [$\rightarrow 5.3 - 5.8 \times 10^{24}$ kg] **(1)** 6

(b) (i) $18\,000 \times (12 \times 10^{-4}\ \text{m}^2)(1.4 \times 10^3\ \text{W m}^{-2})$ **(1)**
(= 30.24 kW) [Ignore 10^n] **(1)**
$\eta = \frac{4500\ \text{W} / 4.5\ \text{kW}}{\text{their power}}$
$\Rightarrow \eta$ = 15%/0.15 [no e.c.f.] [Beware 0.15%] **(1)** 3

(ii) Evidence of × 60 (series) **(1)**
Evidence of ÷ 300 (parallel) **(1)**
$\Rightarrow R = 8.0\ \Omega/8\ \Omega$ [200 Ω → 1/3 e.o.p.] **(1)**
e.m.f. = 60ε **(1)** 4

(iii) S open: read V to get ε/e.m.f. of cell **(1)**
S closed:
Read mV to get *V/p.d./*voltage across R OR terminal voltage/voltage of cell **(1)**
Current $I = V/R$ **(1)**
Use $\varepsilon = I(R + r)$ / $V = \varepsilon - Ir$/ $Ir = \varepsilon - V$ = lost volts **(1)**
$\varepsilon = V + IR$
Value for R: 10 Ω – 100 Ω **(1)** Max 4

[17]

24. (a) (i) $c = f\lambda \Rightarrow \lambda = c/f$ **(1)**

$\lambda = \dfrac{3.00 \times 10^{8}\ \text{m s}^{-1}}{1.07 \times 10^{9}\ \text{Hz}}$ [Ignore 10^n] **(1)**

= 0.28 m **(1)**

Plane polarised:

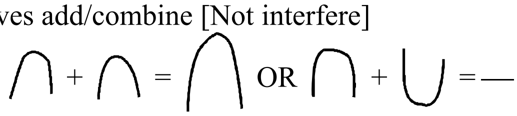
Rotate aerial [Not a grid] **(1)**

about horizontal axis/still pointing to transmitter **(1)**

Note max to min signal (on TV) i.e. change **(1)** — Max 5

(ii) Superposed:

Waves add/combine [Not interfere]

OR 

OR nodes and antinodes **(1)**

Displacements add/vector addition **(1)**

$\dfrac{\lambda}{2}$ /0.14 m OR $\dfrac{\lambda}{4}$ /0.7 m apart OR $n\lambda$ OR $n\dfrac{\lambda}{2}$ **(1)**

so that waves arrive in phase/to get (because) path difference of λ/to get constructive interference/to get the receiving dipole at an antinode **(1)** — 4

(b) (i) I is in W m^{-2} (given) [Unit ≡ kg s^{-3}]

Evidence of B in N A^{-1} m^{-1} **(1)**

Evidence of c in m s^{-1} *and* μ_0 in N A^{-2} (data) **(1)**

Evidence of m N as J/J as kg m^2 s^{-2} **(1)**

Evidence of J s^{-1} as W **(1)** — Max 3

(ii) Connect coil to galvo / datalogger / oscilloscope / ammeter / voltmeter OR current in coil and magnet on top pan balance **(1)**

Move coil (rapidly) out of field/to or from magnet **(1)**

OR detect force

No movement → no reading/current **(1)**

OR steady force means steady field — 3

[15]

25. (a) (i) Force per unit area **(1)**

on a surface/object/body **(1)**

by light/e-m radiation/e-m waves **(1)**

(ii) Away from the Sun/in direction of waves **(1)**

(iii) A bounce/collision (of e.g. molecule or ball or trolley) which conserves k.e./transfers twice its momentum **(1)** — Max 5

(b) (i) LHS: kg m s^{-1}/N s **(1)**

RHS: W/m^2 **(1)**

× m^2 × s ÷ m/s **(1)**

Use of W as J/s OR use of J as N m/kg m^2 s^{-2} **(1)**

OR N as kg, m s^{-2} **(1)** — 4

(ii) $U = IAt$ = (12 W/cm^2) (460 cm^2) (30 × 60 s) [Ignore 10^n]

× 0.8

= 7.95/8.0 × 10^6 J **(1)** 3

(c) (i) Step 1: Newton's 2nd law/force = rate of change of momentum
$F = \Delta p/t$ impulse = Ft **(1)**

Step 2: pressure = force,/area $p = F/A$ **(1)**

(ii) 20 N is a small force/produces small acceleration/'needs a vehicle of small mass **(1)**

but operates continually **(1)**

but S falls off **(1)**

as inverse square law **(1)**

control of (2 km^2) sails difficult/subject to damage **(1)** Max 5

(d) (i) Switch light on and off **(1)**

Graph: A against f with a peak and axes labelled **(1)**

f_0/resonant frequency indicated **(1)**

(ii) Any **two** from:

- increase distance MM^1
- use a weaker suspension/thinner suspension
- increase area of mirror
- use longer suspension **(1) (1)** 5

(iii) Mass of (metal) disc **(1)**

Area illuminated/area of disc or mirror **(1)**

s.h.c. of disc **(1)**

Time illuminated **(1)**

(iv) *Either*

Measured v predicted = 0.05 μPa÷7.06 μPa **(1)**

= 0.71%

which is < 1.5% (so confirmed) **(1)**

Or

7.01 μPa ± 1.5% = (7.01 ± 0.11) μPa **(1)**

which is from 6.90 μPa to 7.12 μPa (so confirmed) **(1)** Max 5

(e) (i) Because we don't fall backwards when opening a window [i.e. quote] OR light/e-m waves/photons have no mass **(1)**

(ii) Use of $E = hf$ **(1)**
Use of $f = c/\lambda$ **(1)**

$\Rightarrow p = hc/\lambda c = h/\lambda$

$\therefore$ p = (6.6 × 10^{-34} Js) ÷ (560 × 10^{-9} m) = 1.2 × 10^{-27} Ns **(1)** 4

(f) Sun + comet + orbit/tangential line **(1)**

Tail not along orbit and away from Sun **(1)** 2

[33]

26. (a) (i) Tracks (of alphas) are the same length/alphas travel same or equal distance **(1)**

(ii) H/p + Li $\rightarrow$ 2α/2He **(1)**

$^{1}_{1}$p and $^{4}_{2}$He correctly labelled **(1)**

$^{7}_{3}$Li **(1)** 4

(iii) Mass defect = 0.01865u **(1)**

Either	*Or*
Use of $\times\ 1.66 \times 10^{-27}$	Use of $\times$ 930 **(1)**
Use of $\times\ 9.0 \times 10^{16}$	Use of $\times\ 1.6 \times 10^{-13}$ **(1)**
$\Rightarrow 2.79 \times 10^{-12}$ J	$\Rightarrow 2.78 \times 10^{-12}$ J **(1)**

Assume: proton has zero/very little k.e. **(1)** Max 4

(b) Quality of written communication **(1)**

p/α ionise ,gas/liquid (particle) **(1)**

producing (a line of visible) drops/bubbles **(1)**

Detail e.g sudden drop of temperature/pressure/condensation/boiling, or liquid H/alcohol **(1)** 4

(c) Use of F_{e}, $= kQ_1Q2/r^2$ and $F_g = Gm_1m_2/r^2$ [$k = 1/4\pi\varepsilon_0$ OK] **(1)**

Evidence of *r* cancelling in ratio **(1)**

*Q*s as *e* and 3*e* **(1)**

*m*s as *m* and 7*m* **(1)** 4

[16]

27. (a) 60 m.p.h. = (60 × 1.6 × 1000 m) ÷ (3600 s) **(1)**
= 27 m s^{-1}

a = 27 m s^{-1} ÷ 4.5 s **(1)**
5.9 m s^{-2}

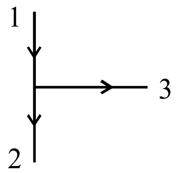
$\therefore$ a/g = 0.60/0.59 OR % OR expressed as fraction **(1)**

(ii) *P*: the forward push/force of the road/ground (on the car) **(1)**

W. the pull/gravitational force of the Earth (on the car) **(1)** 5

(iii) 1 : hot reservoir/source **(1)**
2: cold reservoir/sink (1)
3:work/mechanical energy **(1)** 4

Branching diagram



(b) (i) Change of wavelength/frequency from moving source/surface (**1)**

$\Delta f = 2\upsilon f/c$ = 2/29 m s^{-1}) (1.1×10^{10} Hz) ÷ (3.0×10^{8} m s^{-1}) **(1)**

= 2100 Hz/2.1 kHz [no e.c.f] **(1)** 3

(ii) Any four from:

- Two Slit superposition/stationary waves **(1)**
- Decent diagram (e.g. scale/waves/perpendicular reflector) **(1)**
- What is done **(1)**
- What is measured **(1)**
- How λ is found **(1)** Max 4

[$\frac{xs}{D}$ loses last two marks: screen to detect loses marks 2 and 3]

[16]

28. (a) (i)

Either	*Or*
The (magnetic) flux	The (moving) axle/conductor wire **(1)**
linking OR linkage/trough the circuit/WXYZ changes	cuts (across/trough)/sweeps **(1)** the magnetic field **(1) (1)**

(ii) *d* from 1 m – 4m

υ from 1 m s^{-1} – 30 ms^{-1}

⇒ ε from 48 μV **–** 5.8 mV **(1)** Max 5

(iii) EITHER $\varepsilon = I(R + r)$ OR $\varepsilon = IR + Irl$ OR $V = \frac{R}{R + r}$ **(1)**

⇒$I = \varepsilon /(R + r)$ **(1)**

$P = I^2R$ OR $p = \frac{V^2}{R}$ **(1)** 3

$= \varepsilon^2 R/(R + r)^2$

(b) (i)

Either	*Or*
Ammeter in circuit/series with *R*	Use ohmmeter **(1)**
Voltmeter across R/WZ	Measure R with no current **(1)**
Measure *I* and *V* with axle rolling	Measure *I*/*V* with A/V **(1)**
$P = IV$	$P = I^2R/V^2 \div R$ **(1)**

4

[Direct *P* by heating water: max 2]

(ii) Current in axle ⇒ force / Fleming LHR/two B-fields interact **(1)**

given by $F = B_V Id/BIe$ **(1)**
which is horizontal/parallel to rails/along rails **(1)**
No good F small/huge I needed **(1)** Max 3

[15]

29.	(a)	Terminals/output connected OR component bypassed		1
		by low R / wire / low resistance path		1
	(b)	(i)	d.c	1
		(ii)	Speed/frequency of rotation/disc [**not** f]	1
			Radius/diameter/area [**not** r]	1
			B /B-field / magnetic field	1
		(iii)	To study the properties of matter (under extreme conditions) [**not** to produce large B / as a research tool]	1
			as an electromagnetic gun/to project small masses at high speeds / to study problems of re-entry	1
	(c)	(i)	Method, i.e. attempt to find area under graph / use $Q = It$	1
			5 – 6 squares/triangle as $\frac{1}{2}bh$ / triangles as $\frac{1}{2}bh$ / rectangle I_{av}	1
			Area number 2.4 – 3.3	1
			Area (e.c.f.) × 10^6 C	1
		(ii)	<u>Use</u> of $P = I^2 R$ or $P = I^2 r$ [wrong equation –2 e.o.p.]	
			Peak I as 1.6 (A) or 1.7 (A)	1
			= 3 – 3.5 × 10^8 W [c.e.p. kW/MW e.c.f. no 10^6]	1
	(d)	V as J C^{-1}/Wb as V s / WA^{-1}		1
		B as N A^{-1} m^{-1}/Wb m^{-2}		1
		R OR r as m *and* f as s^{-1} [not if $m^2 - m^2$ which then disappears]		1
		Evidence of J as N m/ A as C s^{-1}/ N as kg m s^{-2} [one only]		1
	(e)	(i)	Chemical energy / electrical energy	1
			kinetic energy /k.e.	1
			[one energy only 0/2]	
		(ii)	Magnetic force on the current/electrons/$F = BIl$ or $BQ\upsilon$ or motor or Fleming / catapult effect [**not** e-m force] / LH rule	1
		(iii)	$\upsilon = 2\pi rf$	1
			$\Rightarrow \upsilon = 2\pi(1.8\text{ m})(15\text{ Hz})$ [**not** 3.6 m]	1
			= 170 m s^{-1}	
			which is less than 200 m s^{-1} [e.c.f. their υ]	1

(f) $\varepsilon - V = IR$ or $I = (\varepsilon - V) \div R$ or $\varepsilon = V + IR$ or $V = \varepsilon - IR$ 1

[do not allow r for R here, then ignore]

As speed increases V / generated e.m.f. increases / generated voltage increases 1

So $\varepsilon - V$ decreases ($\Rightarrow I$ decreases) / net voltage decreases 1

(g) (i) $m\dfrac{\upsilon^2}{r} = G\dfrac{mm_E}{r^2}$ or $\dfrac{\upsilon^2}{r} = G\dfrac{m_E}{r^2}$ 1

[Ignore sloppy use of suffix E]

$r = r_E + h$ 1

$\Rightarrow \upsilon = \left(\dfrac{Gm_E}{r_E + h}\right)^{1/2}$ [No mark]

(ii) Substitute $m_E = 6.0 \times 10^{24}$ kg, $\upsilon = 7\ (\times 10^3)$ m s^{-1} and $G = 6.7 \times 10^{-11}$ N m^2 kg^{-2} 1

1.8 × 106 (m) / 1.77 × 106 (m) 1

[No e.c.f. 7 m s^{-1}**]**

[31]

30. (a) (i) Protons are positively charged / like current 1

refer to Fleming or motor rule / *Rev* / *Bqv* / perpendicular *F* and υ 1

[**not** right hand rule]

(ii) $m\dfrac{\upsilon^2}{r} = Be\upsilon$ $\qquad$ $mr\omega^2 = Be\upsilon$ 2

[accept q for e]

$\upsilon = \dfrac{2\pi r}{T} / \dfrac{\pi r}{t}$ $\qquad$ $\omega = \dfrac{2\pi}{T} / \dfrac{\pi}{t}$ 1

(iii) Quality of written communication 1

Each time it crosses gap/between dees it accelerated / is attracted / is given E 1

Idea that p.d. between the dees reverses while the proton completes half a revolution / c.e.p. 1

As energy becomes large the mass/inertia of the proton increases 1
[**not** protons hit edge]

so it cannot exceed the speed of light [i.e. ref to c]/synchronous property breaks down/formula no longer gives constant f 1

(iv) $\Delta E = (1.6 \times 10^{-19}$ C) (12000 V) [allow × 12] 1

$= 1.9/1.92 \times 10^{-15}$ (J) [no e.c.f.] 1

(v) $r^2 = 2m \times$ k.e. $\div B^2e^2r = \sqrt{}$same

Substitute 1.66 / 1.7 × 10^{-27} kg /1860 m_e /2000 m_e *and*
1.6 × 10^{-19} C 1

Use of k.e. = (1.9 × 10^{-15}J) × 850 1
[e.c.f. for 1.9 × 10^{-15} J e.g. 2 × 10^{-15}J ⇒ 1.7 × 10^{-12}J]

⇒ r = 0.575 m /57.5 cm 1

[2 × 10^{-15}J ⇒ 0.59 m]
[9.1 × 10^{-31} kg ⇒ 0.0137 m e.o.p. max 1/3]

(b) (i) $m\frac{\upsilon^2}{r} = T\sin\theta$ is second law / $F = ma$ / $a \propto$: F 1

$mg = T\cos\theta$ is first law 1

[third law ✗ ✗]

(ii) Assumption is that θ is small or $\tan\theta = r/l$ or r/l is small or $\tan\theta = \sin\theta$ or $\tan\theta = \theta$ or $\sin\theta = \theta$ 1

(iii) Give the pendulum bob a push 1

which is tangential/along the direction of motion 1

for any r or υ the time period is unchanged 1

Higher speed/energy ⇒ *bigger radius* 1

[18]

31. (a) (i) $\left({}^{222}_{86}\text{Rn} \rightarrow {}^{4}_{2}\text{He} + {}^{218}_{84}\text{Po}\right)$ 4 + 218 1

2 + 84
[accept α for He but if unlabelled then 218 + 84, 1 mark out of 2] 1

(ii) Gains electron(s) / e^- 1

two 1

(b) (i) $l_A < l_B$ 1

Ratio diameters/ 12:1 1

[Accept 10 – 14]
[$V_A \approx 4$ cm^3; $V_B \approx .025$ cm^3]

⇒ volumes/cross-sectional areas 144:1 OR V_A=150 their V_B calculated 1

[Accept 100:1 to 200:1)

(ii) pV = constant / Boyles' law 1

p = 20 (Pa) ÷ answer to (i) [e.c.f. (comes to 0.13 Pa)] 1

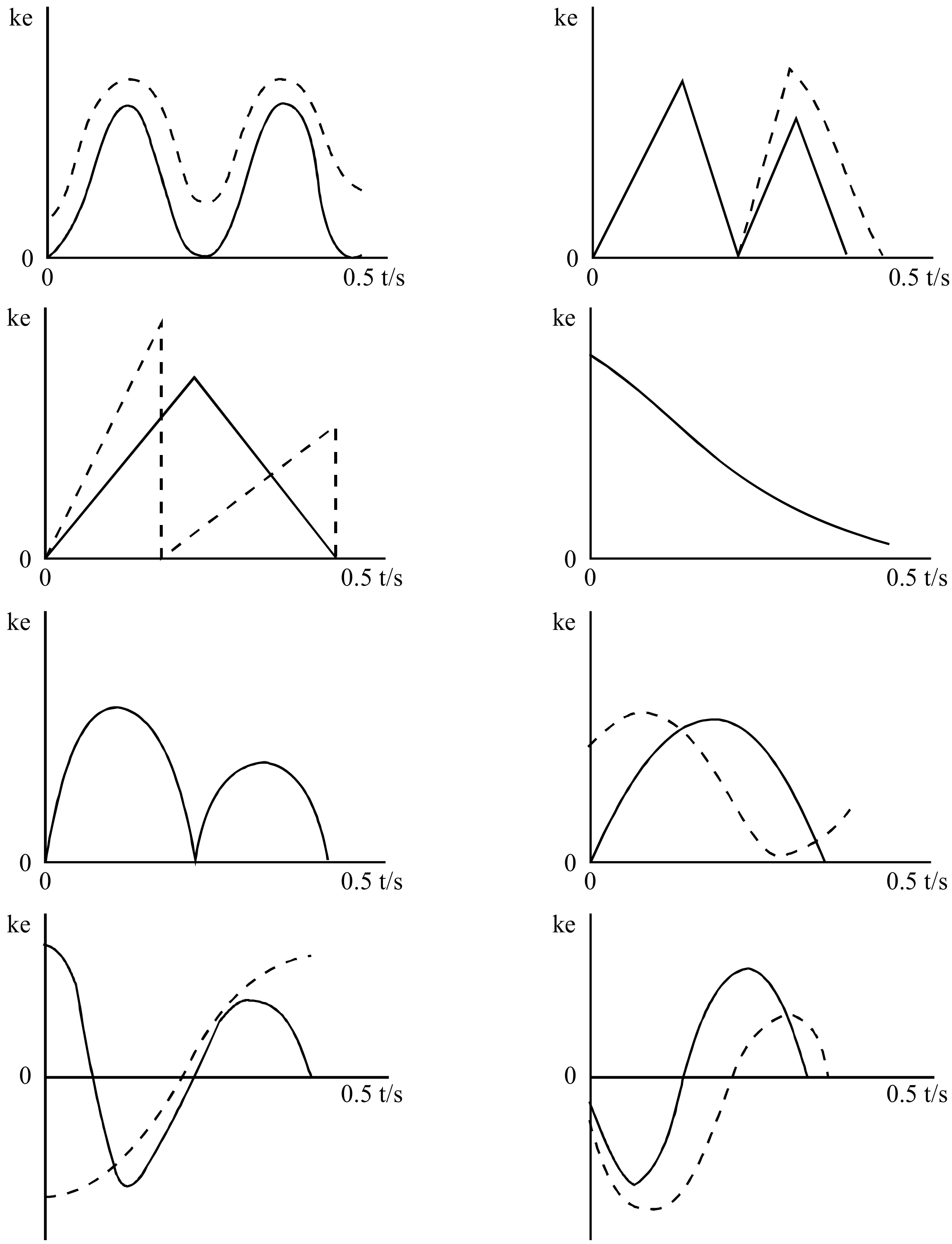
(iii) So that α-particles are not absorbed by/can penetrate them / can , get into tube A 1

	(c)	(i)	View/look through (diffraction) grating / prism / spectroscope / spectrometer	1
			A source, e.g. helium tube / lamp / excited gas / discharge tube OR (absorption) white light through helium	1
			Lines (are seen) [not bands or fringes]	1
		(ii)	Photons of certain frequencies / $E_1 - E_2 = hf/\Delta E = hf$	1
			Reference to energy levels	1
			Electron or atom changes	1
		(iii)	Mercury will produce a unique/different spectrum/ lines [e.c.f. work function from (ii)]	1

[16]

32.	(a)	(i)	*a* is acceleration	1
			f is frequency	1
			x is displacement from equilibrium/centre/mean position	1
			[beware amplitude]	
			Either minus sign means that *a* is always directed to centre/equilibrium position/mean position OR *a* and *x* in opposite directions / *a* opposite to displacement	1
		(ii)	Attempt to use υm = $2\pi fa$	1
			$\upsilon_m = 2\pi(50\text{ Hz})(8.0 \times 10^{-6}\text{ m})$ [$a = 4\times 10^{-6}$ m e.o.p]	1
			$= 2.5 \times 10^{-3}\text{ m s}^{-1}$/ 2.5 mm s^{-1}/$2500\ \mu\text{m s}^{-1}$	1
	(b)	(i)	ρ in kg m^{-3} and g in m s^{-2} / N kg^{-1}	1
			$A\rho g/m$ with units leading to s^{-2}	1
		(ii)	At least three peaks of *y/m* measured [ignore numbers]	1
			EITHER	
			(5.4/5/6 3.7/6/8 2.4 1.6/7 1.2 4.4 2.8/9 2.0/1.9 1.4)	
			Attempt to calculate successive ratios [e.g. 0.67 or 1.5]	1
			Logical statement re ratios and exponential change	1
			OR	
			Read 3 values *of x* and *y* [ignore numbers]	1
			Two half lives between 0.75 s and 0.95 s	1
			Logical statement re half-lives and exponential change	1
			[beware Δy not constant / use of $y = Y_0 e^{-kt}$]	
		(iii)	Starting and ending at k.e. of 0	1
			k.e. always positive	1
			Two positive peaks between origin and marked 0.5 s	1
			Second peak smaller	1

[15]



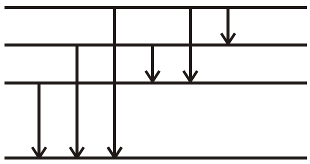
33. (a) (i) Mention of kelvin (scale) **(1)**
Celsius plus 273/(which depends on) ideal gas behaviour **(1)**
[$T/K = \theta/°C + 273$ both marks]

(ii) Change in/broadening of frequency or wavelength/lines **(1)**
caused by motion of source/atom/observer **(1)**

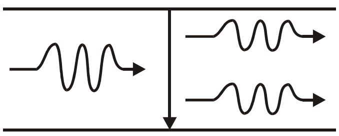
(iii) (process which) happens spontaneously / by chance / unpredictably **(1)** 5

(b) (i) Use of 1.6×10^{-19} **(1)**
$\lambda = hc/E$ OR $f = E/h$ **(1)**
Substitute $h = 6.6 \times 10^{-34}$ J s and $c = 3.0 \times 10^{8}$ m s^{-1} **(1)**
(=> 620/622 nm)
Visible (part of e-m spectrum) [e.c.f.] **(1)** — 4

(ii) Four horizontal lines **(1)**
6 lines drawn **(1)**
Words or diagram to indicate each vertical gives a wavelength/labels E_0E_1 etc plus $\Delta E = E_2 - E_0$ etc **(1)** — 3



(c) (i) One photon in **(1)**
Two photons out **(1)**



(ii) A photon entering gas **(1)**
Mention of population inversion/negative temperature **(1)**
produces an extra/a stimulated photon **(1)** — Max 4
[Allow 1/3 for "by stimulated emission of radiation"]

(d) Mention of $N_1 < N_2$ / $N_2 > N_1$ **(1)**
i.e. number of atoms / electrons in higher level is more than number of atoms / electrons in lower level **(1)** — 2
[Allow excited state/ground state for N_2 / N_1]

(e) (i) Use of k.e. = $\frac{1}{2} m\upsilon^2$ **(1)**
=> υ = 420/423 m s^{-1} **(1)**

(ii) Use of $\frac{\Delta\lambda}{\lambda} = \frac{\upsilon}{c}$ **(1)**
with $c = 3/3.0 \times 10^{8}$ (m s^{-1}) **(1)**
=> $\Delta\lambda = 8.46/8.5 \times 10^{-13}$ (m) **(1)**

(iii) Idea of $\upsilon \rightarrow$ and $\upsilon \leftarrow$ *OR* υ used is an average speed/energy **(1)** — 6

(f) (i) Temperature

(ii) (By) thermal agitation / heating / raising temperature **(1)** — 2

(g) (i) $\Delta E/kT$ calculated using given values **(1)**
(i.e. 1.06×10^{-19} J, 1.38×10^{-23} J K^{-1}, 1150 K) => 6.68 **(1)**
Negative exponent × 2 000 000 => N_4 = 2513/2510/2500 **(1)**

(ii) Use of N_4 = 2513/2510/2500 [e.c.f.] **(1)**
=> N_5 = 114/115 **(1)** — 5

[31]

34. (a) (i) k.e. 3.0 MeV = $3.0 \times 10^6 \times 1.6 \times 10^{-19}$ J **(1) (1)**
use of $\Delta E = c^2 \Delta m / E = mc^2$ **(1)**
=> $\Delta m/m = 5.3 \times 10^{-30}$ (kg)
Use of u = $1.66/1.7 \times 10^{-27}$ kg **(1)**
so $m_{Li} = 7.0 \times 1.66 \times 10^{-27}$ kg / $\Delta m = 0.0032$ u
=> Δm / m_{Li} = 0.0445 – 0.0459% / 0.046%/0.05%/0.04% **(1)**

(ii) Use of k.e. = ½ $m\upsilon^2$ with correct m **(1)**
=:> $\upsilon = 9.1 \times 10^6$ m s $^{-1}$ [e.c.f. no 10^6 for m] **(1)** — 7

(b) (i) Quality of written communication **(1)**
Vacuum **(1)**
Mention of (drift) tubes / cylinders **(1)**
With different lengths/which get longer OR reference to synchronous condition **(1)**
Reference to alternating voltage **(1)**
[Could all be on a diagram]

(ii) Quarks/structure of protons or neutrons **(1)** — Max 5

(c) (i) $1/C_T = N/C$ **(1)**
Total capacitance = C/N **(1)** — 2

(ii) Place N springs in parallel **(1)**
So total force = Nkx [e.c.f. series => kx/N] **(1)** — 2

[16]

35. (a) (i) $T_h - T_c$. temperatures outside-inside fridge **(1)**
Q_h (thermal/ internal) energy (supplied) to kitchen/room **(1)**
Q_c ditto from fridge **(1)**
[Energy transfer related to Q_h and Q_c => 1/2]

(ii) $Q_h = W + Q_c$ **(1)**

(iii) Use of $P = IV/W = IVt$ **(1)**
I= 42 000 J ÷ (230 V) (3.5 × 60 s) **(1)**
= 0.87 A/870 mA **(1)** — 7

(b) Diagram:
Identical structure (i.e. outline) [Beware 'upside down'] **(1)**
Arrow out labelled W/work **(1)**
Arrow/arrows from hot to cold **(1)** — 3

(c) (i) Use of $H = ml/\Delta H = l\Delta m$ **(1)**
=> $l = 26 \times 10^6$ J ÷ 60 kg [Allow 10^n errors] **(1)**
= 4.3×10^5 J kg^{-1}/430 kJ kg^{-1} **(1)** — 3

(ii) Use of electrical heater **(1)**
Sensible way of finding Δm **(1)**
Measurement of I and V **(1)**
OR
Mixing ice with (warm) water **(1)**
Measure θ before and after (melting) **(1)**
Masses known **(1)** — 3

[16]

36. (a) More than four radial lines/four symmetric lines **(1)**
Arrows inwards **(1)** — 2

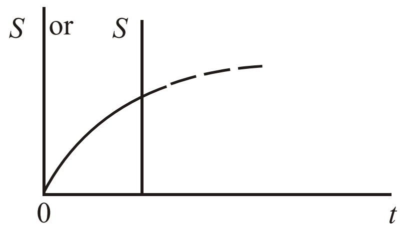
(b) Reference to speed of (gas) molecules [e.g. > 10 m s^{-1}] **(1)**
Greater than escape speed/υ_e **(1)** — 2

(c) (i) m_A in kg *and* r_A in m **(1)**
N (in *G)* in kg m s^{-2}

(ii) $m_A = r_A \upsilon_e{}^2/2G$ **(1)**
$\Rightarrow m_A = 5.8 \times 10^{15}$ (kg) **(1)**
Use of $\rho = m/V$ *and* $V = 4/3\ \pi r^3$ **(1)** — 5

$\Rightarrow \rho = 2900$ kg m^{-3} / 2940 kg m^{-3} [3018 kg m^{-3} from 6×10^{15} kg]

(d) (i) Size or volume of Universe/distance between galaxies against *t*/time **(1)**
Line rising which does not level off **(1)**
Big Bang/*t* = 0 labelled **(1)**



(ii) Average **(1)**
Density/mass-density (of Universe) **(1)** — Max 4

(e) (i) Use of $\Delta p/m\Delta\upsilon = F\Delta t$ **(1)**
$\Delta\upsilon = (2 \times 10^6\text{N})\ (7000\text{ s}) \div 5.8/6 \times 10^{15}$ kg **(1)**
$= 2/2.3 \times 10^{-6}$ m s^{-1} **(1)**

(ii) Will/will not alter asteroid's course [No mark]
Justification: refer to $\Delta s = t\Delta\upsilon\ /s = \upsilon\, t$ **(1)** — 4

[17]

37. (a) (i) Number of protons and neutrons (in nucleus) **(1)**

(ii) Mention of (chemical) elements **(1)**

(iii) Beam of one/speed/velocity energy ions or particles/ions of same energy **(1)**

(iv) Mention of like charges repelling **(1)** — 4

(b) (i) Two protons and two neutrons/labelled sketch **(1)**

(ii) 2 MeV = $(2 \times 10^6$ eV$)\ (1.6 \times 10^{-19}$ J $eV^{-1})$ [Ignore 10^6] **(1)**
Equate energy to $\frac{1}{2}\, m\upsilon^2$ **(1)**
$\Rightarrow \upsilon = 9.8 \times 10^6$ m s^{-1} **(1)**

(iii) α-particles come randomly/o.e.p. **(1)** — 5

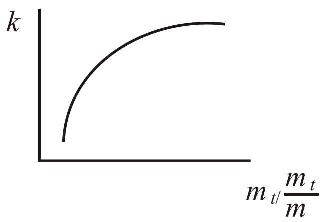
(c) (i) After momentum = – $4m \times 3u/5 + 16m \times 2u/5$ **(1)**
(± vectors)
$\Rightarrow 4\ mu$ **(1)**

(ii) Using $k = T/T_0 = ½\ 4\ m\ (3u/5)^2 \div ½\ 4\ mu^2$ **(1)**
$= 0.36/\ \frac{9}{25}$
Using $k = (m_t - m_i)^2 \div (m_t + m_i)^2 = (16\ m - 4\ m)^2 \div$
$(16\ m + 4\ m)^2 = 0.36/\frac{9}{25}$ [u.e. once only] **(1)** 5

(d) (i)

m_t	$12m$	$24m$	$48m$	$120m$
k	0.25	0.51	0.72	0.88

[–1 each wrong]
Table **(1)** **(1)**
Graph: [Can be sketch]



Axes labelled **(1)**
Curve **(1)**

(ii) Δk becomes smaller for given Δm_t at high m_i OWTTE **(1)** **(1)** 4
[Gradient becomes smaller ⇒ ½]

(e) Quality of written communication **(1)**
Elastic: k.e. conserved **(1)**
uses ions/α-particles **(1)**
Inelastic k.e. not conserved/mass-energy conserved **(1)**
uses electrons **(1)**
new particles/mass/matter/appear (after) **(1)**
Compare: energy greater inelastic (GeV) than elastic
(MeV) **(1)** Max 5

(f) (i) $T = ½\ m\upsilon^2 \Rightarrow \sqrt{\frac{2T}{m}}$ **(1)**
$\lambda = h/m\upsilon$ OR $\lambda = h/p$ and $p = m\upsilon$ **(1)** 2

(ii) Series of tubes [not plates] **(1)**
a.c. between tubes/± alternating in diagrams **(1)**
Ion spends equal time in each tube **(1)**
as the tubes get longer/plates get further apart **(1)**
Mention of vacuum **(1)** Max 4

[31]

38. (a) (i) Activity: (the number of) nuclei/atoms/particles **(1)**
decaying per unit time **(1)**
Unit: bequerel/Bq/s^{-1} [Not s^{-1} if above] **(1)**

(ii) $I \propto Q$ **(1)**
$1/RC$ [dependent on 1st mark] **(1)**
A and *I* both involve rate of change/change with time **(1)**
A of nuclei atoms/particles/decays and *I* of charge **(1)** 7

(iii) EITHER
E- and *g*- fields/forces **(1)**
Both involve inverse square laws **(1)**
$E = kq/r^2$ and $g = Gm/r^2$ / $F = \frac{kq_1q_2}{r^2}$ + $F = \frac{Gm_1m_2}{r^2}$ **(1)**
OR
Springs and capacitors **(1)**
$F = kx$ and $V = Q/C$ OR $E = ½ Fx = ½ VQ$ **(1)**
An action produces a change OR energy stored **(1)**
OR
Other analogy spelled out in a similar manner, but **not** radioactive decay and the discharge of a capacitor. 3

(b) (i) Use of $\lambda t_{1/2} = \ln 2/0.69/0.693$ **(1)**
with $t_{1/2} = 18 \times 365 \times 24 \times 60 \times 60$ **(1)**
Use of $P = A \times$ energy per decay OR use of $\lambda N \times$ energy per decay **(1)**
$\Rightarrow P = 22.7$ (W) OR $N = 1.76 \times 10^{22}$ **(1)** 4

(ii) Use of $e^{-\lambda t}$ (with *P, A* or *N*) **(1)**
15 W ÷ 20 W = 0.75 **(1)**
$\Rightarrow t = 7.6$ y/2800 a/67 000 h/2.3 or 2.4×10^8 s 3

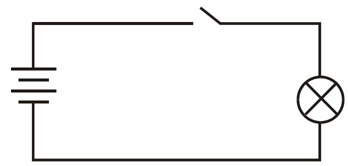
[17]

39. (a) System A: chemical energy → e-m energy/light **(1)**
System B: mechanical energy → e-m energy/light **(1)**
[not kinetic]
EITHER: intermediate electrical energy **(1)** 3
OR: (finally) internal/thermal energy [Not heat]

(b) (i) System A: same power/brightness all the time **(1)**
System B: poor power/brightness/efficiency going up hill/slowly [Not energy] **(1)**

(ii) System A: energy in cell/battery runs out/decreases **(1)**
[Not power]
System B: no change with time **(1)** 4

(c) (i) Two cells in series **(1)**
Switch and lamp **(1)**



(ii) $E = IVt$ = (0.80 A) (1.2 V) (3600 s)/$Q = It$ = 2880 C **(1)**
= 3460 J/3500 J OR $E = QV$= 3460 J **(1)**
Two cells ⇒ E = 6900 J/6.9 kJ **(1)** 5

(d) (i) Magnetic flux **(1)**
changing through coil/magnetic field cuts coil **(1)**
so an e.m.f /voltage/p.d. is induced/produced **(1)**

(ii) Graph + and – on axes of I against t **(1)**
Sinusoidal shape **(1)** 5

[17]

40. (a) (i) Use of $t = s/\upsilon$ **(1)**
Use of × 2 **(1)**
= 7.9×10^{-8} s/7.895×10^{-8} s **(1)** 3

(ii) Answer above ÷ 2×10^{n} **(1)**
= 0.0395 cm/0.395 mm/≈ 0.4 mm OR ½ of this **(1)**
Probably not/just noticeable [ecf] **(1)**

(iii) The time base (of the oscilloscope) moves from left to right **(1)** 4

(b) (i) Complete radial lines > 2 **(1)**
Symmetrically spaced **(1)**
[Arrows either way]
No field outside sheath **(1)**

(ii) (Inside) B-field is circular/clockwise/anticlockwise/ perpendicular E-field **(1)**
Outside B-field is zero Max 4

(c) (i) C = (7.5 m) (120 pF m^{-1})
= 900 pF/9×10^{-10} F/0.90 nF [cao] **(1)**

(ii) Use of Hz as s^{-1} **(1)**
EITHER
Use of F as C V^{-1} **(1)**
Unit of X = 1/C s^{-1} V^{-1} use of C s^{-1} as A **(1)** 4
OR
RC has unit s/F Ω = s **(1)**
∴ s ÷ F = Ω **(1)**

[15]

41. (a) (i) $E = F/q$ Force divided by charge **(1)**
[must define F and q]
Small / point (test) charge OR E parallel to F **(1)**

(ii) A graph with straight line through origin **(1)**
one increases by factor N, other increases by factor N
OR $y = mx$ $y = kx$ / $I = kE$ where m, k is a constant
Charges produced/separated by <u>E–field</u> **(1)** 4

(b) (i) (Produced) when two different materials / insulators
rub together / a cloth rubs a polythene rod / other **(1)**
explicit example / thundercloud [not lightning] / belt of
V der G

(ii) (Used to) check for E-field under power lines/ (build
up) of <u>atmospheric</u> charges **(1)** 2

(c) (i) Use of $E = V/d$ **(1)**
$V = Ed = (240 \text{ N C}^{-1})(60 \times 10^3 \text{ m})$ **(1)**
$= 1.4(4) \times 10^7$ V/14 MV **(1)**
Assume that <u>field</u> is uniform / constant / parallel field lines **(1)**

(ii) $q = CV \Rightarrow C = q/V$ **(1)**
$\therefore C = 1.1 \times 10^6 \text{ C} \div 14.4 / 14 \times 10^6$ V e.c.f. **(1)**
[$\Rightarrow$ 77 mF / 79 mF]

(d) (i) Positive charge collects in ionosphere **(1)**
Negative charge collects on Earth / surface / ground **(1)**
[Because the atmosphere acts as a giant capacitor
$\Rightarrow$ 1 out of 2 – consolation mark]

(ii) Ionosphere and Earth's surface labelled **(1)**
[could be concentric circles/parallel lines]
Field lines reaching Earth's surface **(1)**
Arrows towards Earth's surface **(1)** 5

(e) (i) Attempt to draw plates one above the other **(1)**
Holes not overlapping at all **(1)** 2

(ii) Aware that $q = \varepsilon_0 EA$ is relevant **(1)**
$I = q/t$ $\Delta q \div \Delta t$ / rate of flow of charge **(1)**
For $I \propto E$, there must be no other variable – so speed constant **(1)** 3

(iii) Curve: period (shown as) 0.01(s) **(1)**
symmetric + and − **(1)** 2

(f)

Either	*Or*	
Unit for E: N C^{-1}	Unit for E: V m^{-1}	**(1)**
Unit for ε_0: F $\text{m}^{-1} \Rightarrow$ C V^{-1} m^{-1}	Unit for ε_0 & A: F m^{-1} and m^2	**(1)**
Unit: V = J C^{-1} or J = N m	Unit: F as C V^{-1}	**(1)**

[or look for $\varepsilon_0 \equiv \text{kg}^{-1}\,\text{m}^{-3}\,\text{s}^4\,\text{A}^2 \Rightarrow 2/3$; $E \equiv \text{kg m s}^{-3}\,\text{A}^{-1} \Rightarrow 2/3$;
if both 3/3]

(g) Resistor/R in series with electrostatic mill **(1)**
Voltmeter / oscilloscope across R **(1)**
(Measure) I as (peak) V/R [not $V = IR$] **(1)**
$R \geq 10$ kΩ **(1)**
R in kΩ/MΩ → V in μV/mV **(1)** — Max 4
[battery in circuit, first two marks only]

[31]

42. (a) (i) QOWC **(1)**
Link track to bubbles **(1)**
Which reflects light / are illuminated **(1)**
(produced as) the electron / it <u>ionises</u> liquid / particles / **(1)**
H_2 / air — 4

(ii) Mention of B–field/$F = Bq\upsilon$/ $F = Be\upsilon$/ FLHR **(1)**
B is perpendicular to υ/ direction of motion / in or out **(1)**
of page
Electron loses energy/slows down **(1)**
Colliding with / interacting with / ionising liquid particles / H_2 **(1)** — 4

(b) (i) & (ii)

	r/m	r/mm	p/kg m s^{-1}	m/kg
P	$62 - 67 \times 10^{-3}$	62 – 67	$1.2 - 1.3 \times 10^{-20}$	$4.0 - 4.3 \times 10^{-29}$
Q	$43 - 48 \times 10^{-3}$	43 – 48	$0.83 - 0.92 \times 10^{-20}$	$2.8 - 3.1 \times 10^{-29}$
R	$28 - 33 \times 10^{-3}$	28 – 33	$0.54 - 0.63 \times 10^{-20}$	$1.8 - 2.1 \times 10^{-29}$

Values for r in range above [ignore 10^n and units] **(1)**
$p = Ber \Rightarrow$ any one correct p [ignore 10^n but must have **(1)**
unit] [ecf] **(1)** — 3

All ps correct numerically [no ue] **(1)**
$p = m\upsilon \Rightarrow m = p/\upsilon$ **(1)**
Any one correct m [ignore 10^n but must have unit]

EITHER
Comment [e.c.f.]: any reference to 9×10^{-31} kg/rest **(1)**
mass (of electron) / electron mass
Because electron is moving close to / at the speed of
light
OR
(effective) mass (of electrons) is decreasing **(1)**
reference to $E = mc^2$ / $\Delta E = c^2\Delta m$ / mass–energy **(1)**
conservation — 4

[15]

43. (a) (i) Lead shot loses <u>g.p.e.</u> (which becomes k.e.) **(1)**
(which becomes/lost to/transfers to) internal **(1)** — 2
energy/heat

(ii) Use of 60 $mg\Delta h$ [allow between 0.70 m and 0.80 m] **(1)**
Use of $mc\Delta\theta$/ $mc\Delta T$ **(1)**
= 3.6 K [$\Rightarrow$ 3.2 K] / 3.6 °C **(1)** — 3

(iii) Expect ΔT to be less **(1)**
Any 2 of: Tube/plastic warms up; cork/air warms up;
because lead falls < 80 cm; energy lost to
surroundings/tube/cork/air ; poor thermal contact with
thermocouple **(1) (1)** — 3

(iv) As *m* cancels / mass does not matter **(1)**
but as *c* is higher **(1)**
ΔT will be lower **(1)** — 3

(b) (i)

Either	*Or*
$I = (1.50\text{ V} \div 47\,025\Omega)$	
$V_{25} = (3.19 \times 10^{-4}\text{ A})(25.0\ \Omega)$	$\dfrac{V_{25}}{1.50V} = \dfrac{25.0\,\Omega}{47\,025\,\Omega}$

Correct method [ignore no k / no 25 Ω] **(1)**
Using k and 25 Ω in correct method **(1)**
= 0.797 or 0.798 or 0.799 × 10^{-3} V [n.b. 3 s.f.] **(1)**
Assume resistance of (micro)ammeter negligible [not **(1)**
resistance cell / wires negligible] — 4

(ii) 0.797 mV / 0.799 mV [e.c.f. value from (i)] **(1)**

(iii) Advantage:
Low heat capacity/low energy needed to warm up/ can
detect small ΔTs / more sensitive
OR can be a transducer sensor for datalogging
OR no parallax problem with thermocouple **(1)** — 2

[17]

44. (a) (i) Its chemical composition / <u>surface</u> temperature **(1)**
(not velocity) — 1

(ii) Use of $\Delta\lambda/\lambda = \upsilon/c$ [some substitution or rearrange] **(1)**
see λ = 440 or 400 **(1)**
= 1.36 × 10^{7} m s^{-1} **(1)**
[if bald answer: 1.43 × 10^{7} **(1)xx**; 1.4 × 10^{7} **(1)xx ;**
1.50 × 10^{7} **(1) (1)x;** 1.5 × 10^{7} **(1) (1)x**]
towards the Earth / us **(1)** — 4

(b) (i) Electrons (are removed) from P / photoelectric effect **(1)**
Current is from P to capacitor / left to right / opposite **(1)**
to emitted e^- — 2

(ii) P/plate becomes positively charge/voltage of P rises **(1)**
until electrons can no longer escape/don't have k.e. to **(1)**
escape — 2

(iii) Use of $Q = CV = [(22 \times 10^{-12}\ \text{F})\ (0.58\ \text{V})]$ **(1)**
[Ignore 10^n until the final answer]
$= 1.28 \times 10^{-11}$ C/ 1.3×10^{-11} C / 12.8 pC [no ue] **(1)**
Their $Q \div 1.6 \times 10^{-19}$ C **(1)**
$\Rightarrow N = (1.28 \times 10^{-11}\ \text{C}) \div (1.6 \times 10^{-19}\ \text{C})$
$= 8.0 \times 10^7$ / 80 million [79–81 million] **(1)** — 4
[2.4×10^8 electrons $\Rightarrow$ 2/4 from $q = C \div V$]

(c) Photocell in envelope with two electrodes **(1)**
Variable applied power supply / potential divider[not rheostat] **(1)**
Emitter as positive [emitter labelled or light on it] **(1)**
(micro)ammeter in series [only if a power supply included] **(1)**
Voltmeter across photocell/power supply **(1)** — Max 4
[no power supply – max 2/4]

[17]

45. (a) <u>Graph</u>

Line from origin curving towards (horizontal) **(1)**

becoming horizontal and terminal velocity marked **(1)**

(i) Fluid/liquid/gas [do **not** accept air] **(1)**
Resistive/drag forces for (movement) through it **(1)**

(ii) Charge comes in multiples of a basic charge/e **(1)** — 5

(b) (i) Use of $\frac{4}{3}\pi r^3 \rho g$ **(1)**

Correct answer [$W = 1.86 / 1.9 \times 10^{-14}$ (N)] to at least 2sf **(1)**
[Watch out for 10^{-5} followed by 'right' answer – loses second mark]
[Do not credit bald answer] [no ue]

(ii) Use of $4/3\pi r^3\ \rho' g$ as buoyant force [could be implied] **(1)**
Recognition of $\rho' \div \rho$ *OR* $U = 2.4 \times 10^{-17}$ N **(1)**

Hence $U/W = 0.13(\%)$ [no ue]
[allow use of 2×10^{-14} giving 0.12%]

(iii) $4/37\pi r^3(\rho - \rho')g = 6\pi r \eta \upsilon$ **(1)**
Hence $r = \sqrt{\dfrac{9\eta v}{2g(\rho - \rho')}}$ **(1)** — 7
[accept any equivalent of 9/2 e.g. 18/4; accept substitution
into $(\rho - \rho')$]

(c) (i) Sketch: ≥ 3 vertical lines **(1)**
[ignore curved lines at edges and central gap]
Arrows down/consistent with $\pm$ **(1)**

(ii) Rearrangement *of* $E=V/d \Rightarrow V = Ed$ **(1)**

$\Rightarrow V = 780$ V **(1)**

(iii) E.m.f. = 2 × 780 V / 1560 V [ecf their *V*] **(1)**

Assume: (power) supply has zero resistance or no internal **(1)** resistance **or** voltmeter has infinite resistance — 6

(d) > 2 sets of values correctly read from graph
[eg (7.4, 5) (8.5 or 8.6, 4) (10.2, 3) (13.8–14.0, 2)
eg (8, 4.4) (10, 3.1) (12, 2.3–2.4) (14, 2.0) (7, 5.4)]

Range of at least 2 N **(1)**

Correct method [e.g. multiplied together / calculate *k* and use to compare predicted to actual value] [ignore 10^n error] **(1)**

Hence conclusion: not proportional **(1)** — 4
[consequent mark, no ecf from using close values or wrong method]

(e) [Accept symbols/words/formulae throughout part (e)]

Identify weight **down AND** buoyancy (force) **up** on **(1)** **both** diagrams [do **not** accept gravity]

Identify electric (force) **up** on (i) [Allow electric field] **(1)**

Identify viscous (force) **up** on (ii) **(1)**

[Accept 2 labels on 1 **up** arrow]

(i) $W = B + F_e$ **(1)**
[Accept any correct rearrangement]

(ii) $W = B + V$ **(1)** — 5
[Accept any correct rearrangement]

(f) Mention of ionising/ionisation **(1)**

Comment on a relevant property of α **and** γ **(1)** — 2

(g) Diagram: Downward **drift** [curves/wiggles OK] **(1)**
[not straight down] **(1)**
Non-equal straight lines **(1)**
At random angles **(1)**

Explanation: Droplet is bombarded **(1)**
by air molecules — 5
[1/2 for stating Brownian motion without further detail]

[34]

46. (a) Quality of written communication **(1)**
Protons drift/move uniformly inside tubes **(1)**
Accelerate **between** the tubes/in the **gaps (1)**
Alternating p.d. reverses while p is **in** tube **(1)**
The tubes must get longer as p speeds up **(1)**
For time inside tube to be constant or to synchronise movement with the pd **(1)** — Max 5

(b) (i) Multiply by 419 or 420 **(1)**

Multiply by 1.6×10^{-19} **(1)**

Correct answer to at least 2 sf **(1)**
[5.36/5.38/5.4 × 10^{-11} (J)] [no ue]

Δm = energy ÷ (9.0×10^{16} m^2 s^{-2}) **(1)**
[ecf their energy or 5×10^{-11}] **(1)**

$\Delta m \div 1.01 \times 1.66 \times 10^{-27}$kg [ecf their Δm] **(1)**

Correct answer **(1)**
[0.36 or 36%] [Use of 5×10^{-11} gives 33%] **(1)** — 6

[Accept routes via Δm in u and m_p in J]

(ii) Use of $1/f$ **(1)**

∴ time down linac = $420 \div 3.9 \times 10^8$ s^{-1}
or $210 \div 3.9 \times 10^8$ s^{-1} **(1)**
[t = 1.07/1.08/1.1 × 10^{-6}(s) or 0.54×10^{-6} (s)] — 2

(c) (i) Fixed target:
Large(r) number of /more collisions **or** more likely to get collisions
[not easier to get collisions] **(1)**

Other particle beams produced **(1)**

(ii) Colliding beams:
More energy available for **new particles (1)**
p = 0 so all energy available **(1)** — Max 2

[15]

47. (a) Mention of natural frequency (of water molecules) **(1)**

At f_0 there is a large/increased **amplitude (1)**

and hence max energy transfer / max power transfer / max efficiency / max heating **(1)** — 3

(b) (1.2 kg)(3200 J kg^{-1} K^{-1})(75 K) seen **(1)**
⇒ 288 kJ
+ 600 s to give a power in W [⇒ 480 W] **(1)**
Efficiency 480 W e.c.f ÷ 800 W [= 60%] **(1)**

There will be heat/energy/power losses from the meat/to the **(1)** surroundings or water evaporation needs LHV or water evaporation leaves fewer molecules to vibrate — 4

(c) (i) See c = 3×10^8 (m s^{-1}) used in $c = f\lambda$ **(1)**
[⇒ λ = 0.12 m/12 cm/120 mm]

(ii) Measure SQ[34 mm], QP[34 mm] and SP[32 mm] and multiply readings by 5 [170 mm, 170 mm, 160 mm] **(1)**
[No tolerance on measurements, no ue]

Add SQ and QP [ecf their values] **(1)**

Mention of path difference or attempt to find path difference **(1)**
e.g. (SQ+QP) – SP

Conversion of any length to wavelengths **(1)**
Correct discussion of superposition/phase difference **(1)** relevant to their path difference

[Allow maximum if mention π phase shift on reflection] 6

(iii) Mention of nodes/antinodes **(1)**
[not constructive/destructive interference]

Energy at antinodes/no energy at nodes **(1)**
[Accept heating at antinodes]

Rotate meat (plate)/reflect waves from (metal) **(1)** paddle/move meat several times 3

[16]

48. (a) Push end of slinky in **suddenly/quickly (1)**
Time how long to reach end **(1)**
Measure length of slinky and use

$\upsilon = \textit{defined length}/\textit{defined time}$ **(1)**

Reliability: repeat **and** average/use very short pulse **(1)** 4

(i) LHS: m s^{-1}
RHS: l is m and m is kg } **(1)**

k is N m^{-1}

N is kg m s^{-2}

[k is kg s^{-2} is last 2 marking points]

(ii) k is double (that of a spring) **(1)** 4

(c) (i) Rearrangement of $B = \mu_0 nI \Rightarrow n = B/\mu_0 I$ **(1)**
$\therefore\ n = (0.34 \times 10^{-3}\ \text{N A}^{-1}\ \text{m}^{-1}) \div (4\pi \times 10^{-7}\ \text{N A}^{-2})(5\ \text{A})$ **(1)**
$= 54\ \text{m}^{-1}$ **(1)** 3

(ii) Mention of magnetic flux/flux/ϕ **(1)**
[Do not accept magnetic flux density]

Increasing/changing ϕ (as pulse reaches coil) **(1)**
[Accept decreasing]

Because ϕ or B depends on n **(1)**
[can be symbols or words]

Reference to Faraday /rate of change of ϕ or B **(1)** Max 4
Producing induced e.m.f./voltage in coil **[not** current] **(1)**

[15]