Pearson Edexcel

Mark Scheme (Results)

Summer 2021

Pearson Edexcel International Advanced Level
In Physics (WPH14)
Paper 01 Further Mechanics, Fields and Particles

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General Marking Guidance

- All candidates must receive the same treatment. Examiners must mark the first candidate in exactly the same way as they mark the last.

- Mark schemes should be applied positively. Candidates must be rewarded for what they have shown they can do rather than penalised for omissions.

- Examiners should mark according to the mark scheme not according to their perception of where the grade boundaries may lie.

- There is no ceiling on achievement. All marks on the mark scheme should be used appropriately.

- All the marks on the mark scheme are designed to be awarded. Examiners should always award full marks if deserved, i.e. if the answer matches the mark scheme. Examiners should also be prepared to award zero marks if the candidate's response is not worthy of credit according to the mark scheme.

- Where some judgement is required, mark schemes will provide the principles by which marks will be awarded and exemplification may be limited.

- When examiners are in doubt regarding the application of the mark scheme to a candidate's response, the team leader must be consulted.

- Crossed out work should be marked UNLESS the candidate has replaced it with an alternative response.

Mark scheme notes

Underlying principle

The mark scheme will clearly indicate the concept that is being rewarded, backed up by examples. It is not a set of model answers.

For example:

(iii) Horizontal force of hinge on table top

66.3 (N) or 66 (N) **and** correct indication of direction [no ue] [Some examples of direction: acting from right (to left) / to the left / West / opposite direction to horizontal. May show direction by arrow. Do not accept a minus sign in front of number as direction.]	✓	**1**

This has a clear statement of the principle for awarding the mark, supported by some examples illustrating acceptable boundaries.

1. Mark scheme format

1.1 You will not see ‘wtte’ (words to that effect). Alternative correct wording should be credited in every answer unless the ms has specified specific words that must be present. Such words will be indicated by underlining e.g. ‘resonance’

1.2 Bold lower case will be used for emphasis.

1.3 Round brackets ( ) indicate words that are not essential e.g. “(hence) distance is increased”.

1.4 Square brackets [ ] indicate advice to examiners or examples e.g. [Do not accept gravity] [ecf].

2. Unit error penalties

2.1 A separate mark is not usually given for a unit but a missing or incorrect unit will normally mean that the final calculation mark will not be awarded.

2.2 Incorrect use of case e.g. ‘Watt’ or ‘w’ will **not** be penalised.

2.3 There will be no unit penalty applied in ‘show that’ questions or in any other question where the units to be used have been given, for example in a spreadsheet.

2.4 The same missing or incorrect unit will not be penalised more than once within one question (one clip in epen).

2.5 Occasionally, it may be decided not to penalise a missing or incorrect unit e.g. the candidate may be calculating the gradient of a graph, resulting in a unit that is not one that should be known and is complex.

2.6 The mark scheme will indicate if no unit error penalty is to be applied by means of [no ue].

3. Significant figures

3.1 Use of an inappropriate number of significant figures in the theory papers will normally only be penalised in 'show that' questions where use of too few significant figures has resulted in the candidate not demonstrating the validity of the given answer.

3.2 The use of g = 10 m s^{-2} or 10 N kg^{-1} instead of 9.81 m s^{-2} or 9.81 N kg^{-1} will be penalised by one mark (but not more than once per clip). Accept 9.8 m s^{-2} or 9.8 N kg^{-1}

4. Calculations

4.1 Bald (i.e. no working shown) correct answers score full marks unless in a 'show that' question.

4.2 If a 'show that' question is worth 2 marks then both marks will be available for a reverse working; if it is worth 3 marks then only 2 will be available.

4.3 **use** of the formula means that the candidate demonstrates substitution of physically correct values, although there may be conversion errors e.g. power of 10 error.

4.4 **recall** of the correct formula will be awarded when the formula is seen or implied by substitution.

4.5 The mark scheme will show a correctly worked answer for illustration only.

4.6 Example of mark scheme for a calculation:

'Show that' calculation of weight

Use of L × W × H ✓

Substitution into density equation with a volume and density ✓

Correct answer [49.4 (N)] to at least 3 sig fig. [No ue] ✓
[If 5040 g rounded to 5000 g or 5 kg, do not give 3rd mark; if conversion to kg is omitted and then answer fudged, do not give 3rd mark]
[Bald answer scores 0, reverse calculation 2/3] **3**

Example of answer:

80 cm × 50 cm × 1.8 cm = 7200 cm^3

7200 cm^3 × 0.70 g cm^{-3} = 5040 g

5040 × 10^{-3} kg × 9.81 N/kg

= 49.4 N

5. Quality of Written Expression

5.1 Questions that asses the ability to show a coherent and logically structured answer are marked with an asterisk.

5.2 Marks are awarded for indicative content and for how the answer is structured.

5.3 Linkage between ideas, and fully-sustained reasoning is expected.

6. Graphs

6.1 A mark given for axes requires both axes to be labelled with quantities and units, and drawn the correct way round.

6.2 Sometimes a separate mark will be given for units or for each axis if the units are complex. This will be indicated on the mark scheme.

6.3 A mark given for choosing a scale requires that the chosen scale allows all points to be plotted, spreads plotted points over more than half of each axis and is not an awkward scale e.g. multiples of 3, 7 etc.

6.4 Points should be plotted to within 1 mm.

- Check the two points furthest from the best line. If both OK award mark.
- If either is 2 mm out do not award mark.
- If both are 1 mm out do not award mark.
- If either is 1 mm out then check another two and award mark if both of these OK, otherwise no mark.
- For a line mark there must be a thin continuous line which is the best-fit line for the candidate's results.

Question number	Answer	Mark
1	The only correct answer is B muon Incorrect answers A antiproton is made of antiquarks C neutron is made of quarks D Pion is made of quark-antiquark	(1)

Question number	Answer	Mark
2	The only correct answer is B The nucleus of the atom is positively charged because the deflection could have been caused by a concentration of negative charge Incorrect answers A,C,D these are clear conclusions	(1)

Question number	Answer	Mark
3	The only correct answer is C because lepton number and charge are equal before and after the interaction Incorrect answers A lepton number is not conserved B charge is not conserved D lepton number is not conserved and charge is not conserved	(1)

Question number	Answer	Mark
4	The only correct answer is A Incorrect answers B a baryon cannot mix q and anti-q, a mson cannot be qq C both have the wrong number of quarks D both have the wrong number of quarks	(1)

Question number	Answer	Mark
5	The only correct answer is B increase the anode potential V because this will increase momentum and decrease de Broglie wavelength and decrease the angle Incorrect answers A this does not affect the angle C this does not affect the angle, just the intensity D this will increase the angle	(1)

Question number	Answer	Mark
6	The only correct answer is D because this will decrease the rate of change of flux linkage and therefore the induced emf and therefore the current Incorrect answer A, B, C these will all increase the rate of change of flux linkage and therefore the induced emf and therefore the current	**(1)**

Question number	Answer	Mark
7	The only correct answer is B because each sphere has half of the original kinetic energy and if ke is decreased by a factor of ½, speed is decreased by the square root of this Incorrect answers A,C,D	**(1)**

Question number	Answer	Mark
8	The only correct answer is C because $E = V/d$ so these changes decrease the electric field strength and therefore the force on the particle and therefore the acceleration and therefore the angle Incorrect answers A,B,D – these all increase the electric field strength	**(1)**

Question number	Answer	Mark
9	The only correct answer is B because $F = Bqv$ so $v = F/Bq$ Incorrect answers A,C,D	**(1)**

Question number	Answer	Mark
10	The only correct answer is D because short de Broglie wavelengths are needed to investigate the structure of nucleons at smaller scales Incorrect answers A these experiments are not about the creation of new particles B negative electrons do not experience repulsive electrostatic forces from positive protons or neutral neutrons C particle lifetime is not relevant as all of the particles involved are believed to be stable, as long as neutrons are in a nucleus	**(1)**

Question number	Answer		Mark
11(a)	• Calculate period = 8.3 s ÷ 10 = 0.83 s **or** calculate f = 10/ 8.3 s = 1.2 Hz • Use of $\omega = 2\pi / T$ **or** Use of $\omega = 2\pi f$ • ω = 7.6 rad s^{-1} <u>Example of calculation</u> T = 8.3 s ÷ 10 = 0.83 s Use of $\omega = 2\pi / T$ ω = 7.6 rad s^{-1}	(1) (1) (1)	3
11(b)	• Use of $F = BIl \sin\theta$ • $F = 2.0 \times 10^{-3}$ N • direction is out of page <u>Example of calculation</u> F = 0.053 T × 1.1 A × 3.5 × 10^{-2} m × sin 80° = 2.0 × 10^{-3} N	(1) (1) (1)	3
	Total for question 11		**6**

Question number	Answer	Mark
12 (a)	• Evidence of $E_k = ½\, mv^2$ **and** $p = mv$ (1) • Correct algebraic link to $E_k = p^2/2m$ (1) <u>Example of derivation</u> $E_k = ½\, mv^2$ $[= m \times mv^2 / 2 \times m]$ $= (mv)^2 / 2m$ $[p = mv]$ $E_k = p^2/2m$	2
12(b)	• Use of $F = Eq$ (1) • Use of $W = Fs$ (1) • Use of $E_k = p^2/2m$ **Or** Use of $E_k = ½\, mv^2$ **and** $p = mv$ in conjunction (1) • Momentum = 9.33×10^{-20} kg m s^{-1} (1) <u>Example of calculation</u> $F = 7.64 \times 10^6$ V m^{-1} $\times 1.60 \times 10^{-19}$ C $= 1.22 \times 10^{-12}$ N $W = 1.22 \times 10^{-12}$ N $\times 5.50 \times 10^{-3}$ m $= 6.72 \times 10^{-15}$ J 6.72×10^{-15} J + 6.42×10^{-15} J = 1.31×10^{-14} J 1.31×10^{-14} J = $p^2 / 2 \times 3.32 \times 10^{-25}$ kg $p = 9.33 \times 10^{-20}$ kg m s^{-1}	4
	Total for question 12	**6**

<table>
<tr><th>Question number</th><th>Answer</th><th></th><th>Mark</th></tr>
<tr><td>13</td><td>

Use of $\Delta E_{grav} = mg\Delta h$
Idea that centripetal force at top of loop equals weight for minimum speed
Use of $F = mv^2/r$
Use of $E_k = ½ mv^2$
Add E_{grav} at top of loop and required E_k
Or Subtract E_{grav} at top of loop from E_{grav} at launch
Or Subtract required E_k from E_{grav} at launch
(ΔE_{grav} at start of) 0.081 J is less than 0.089 J (for sum of E_{grav} at top of loop and required E_k, so insufficient energy), so it does not complete the loop
Or (Height required of) 0.275 m is greater than 0.25 m, (the height of launch position, so insufficient energy), so it does not complete the loop
Or E_k at height of top of loop would be 0.0097 J which is less than the required 0.071 J (so insufficient energy), so it does not complete the loop
Or v at height of top of loop would be 0.77 m s^{-1} which is less than the required 1.04 m s^{-1} so it does not complete the loop
Or mv^2/r = 0.18 N which is less than weight of 0.32 N so it does not complete the loop

Do not credit parts of calculation or derivation unambiguously using the formula for uniform acceleration $v^2 = 2as$, i.e. if the symbols are seen and substitution is from them and not from $mg\Delta h = ½ mv^2$

<u>Example of calculation</u>
ΔE_{grav} at release point = 0.033 kg × 9.81 N kg^{-1} × 0.25 m = 0.0809 J
W = 0.033 kg × 9.81 N kg^{-1} = 0.324 N
At minimum speed $W = mv^2/r$
0.324 N = 0.033 kg × v^2 / 0.11 m
v = 1.04 m s^{-1}
E_k = ½ × 0.033 kg × (1.04 m $s^{-1})^2$ = 0.0178 J
ΔE_{grav} at top of loop = 0.033 kg × 9.81 N kg^{-1} × 0.22 m = 0.0712 J
Total energy required to complete loop
= 0.0178 J + 0.0712 J = 0.089 J
0.0809 J < 0.089 J
</td><td>(1)
(1)
(1)
(1)
(1)
(1)</td><td>6</td></tr>
<tr><td></td><td>Total for question 13</td><td></td><td>6</td></tr>
</table>

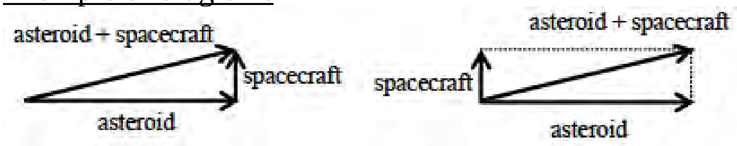
Question number	Answer	Mark
*14	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content	

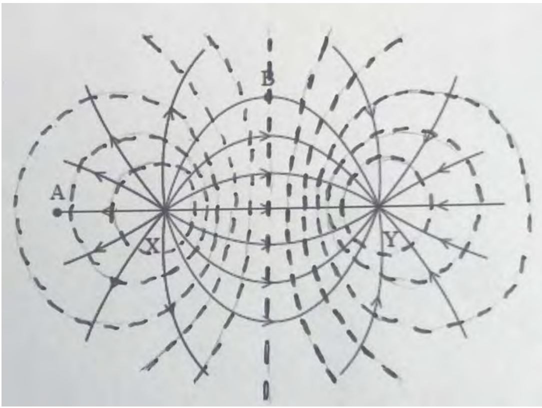
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

The following table shows how the marks should be awarded for structure and lines of reasoning.

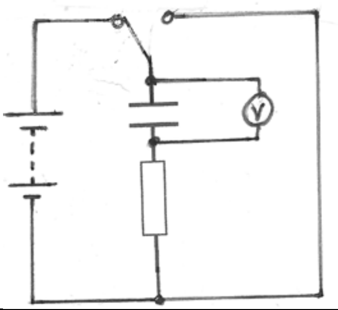
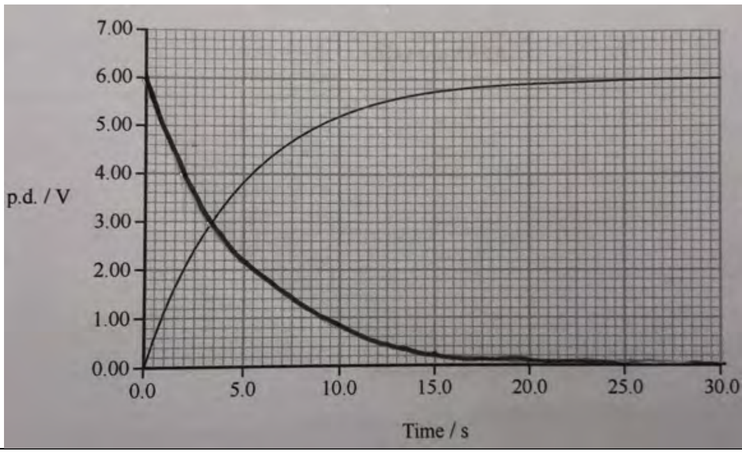
	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages). **Indicative content:** • change of flux linked to surrounding metal **Or** change of flux linked to copper tube • e.m.f induced • full conducting path available, so current in metal • current produces magnetic field • (by Lenz's law the) magnetic field (due to the induced current) produces a force (on the magnet) that opposes the motion of magnet causing it • upward force on magnet, so (increased) downward force on tube	**6**
	Total for question 14	**6**

Question number	Answer		Mark
15 (a)	• Resultant on correct triangle or parallelogram including arrows with a clear right angle between initial asteroid momentum and initial spacecraft momentum • Fully labelled (dependent on MP1) Example of diagram:  	(1) (1)	2
15 (b)	• Use of $p = mv$ • $p = 1.1 \times 10^7$ (N s) (minimum 2 s.f.) Example of calculation $p = 920\text{ kg} \times 12\,000\text{ m s}^{-1} = 1.1 \times 10^7\text{ N s}$	(1) (1)	2
15 (c)	• Use of correct trigonometry • Angle $= 1.5 \times 10^{-7}$ (rad) (minimum 2 s.f.) Allow ecf from (b) Example of calculation $\tan\theta = 1.1 \times 10^7\text{ N s} \div 7.6 \times 10^{13}\text{ N s} = 1.45 \times 10^{-7}$ ($\theta = 8.3 \times 10^{-6}\,°$) $\theta = 1.45 \times 10^{-7}$ rad (Answer depends on rounding from (b), accept 1.4 or 1.5 rad)	(1) (1)	2
15 (d)	• Apply principle of conservation of momentum along path at 90° to original path of asteroid • Component of velocity $= 3.9 \times 10^{-3}\text{ m s}^{-1}$ Allow ecf from (b) or (c) Example of calculation Component of velocity = spacecraft momentum ÷ (mass of spacecraft + mass of asteroid) $= 1.1 \times 10^7\text{ N s} \div (920\text{ kg} + 2.8 \times 10^9\text{ kg})$ $= 3.9 \times 10^{-3}\text{ m s}^{-1}$	(1) (1)	2
15 (e)	• Use of impulse $= F\,\Delta t = \Delta p$ • Concludes 1.8×10^9 N s change in momentum from rocket engines is greater than 1.1×10^7 N s change from impact Allow ecf from (b) Example of calculation Impulse $= 5.1 \times 10^6\text{ N} \times 6 \times 60\text{ s} = 1.8 \times 10^9\text{ N s}$	(1) (1)	2
	Total for question 15		10

Question Number	Answer		Mark
16 (a)	• Use of $E = Q / 4\pi\varepsilon_0 r^2$ **Or** Use of $E = kQ / r^2$ • Adds E due to X to E due to Y • $E = 2.8 \times 10^6$ V m^{-1} <u>Example of calculation</u> E due to X = 2.5×10^{-7} C / $4 \times \pi \times 8.85 \times 10^{-12}$ F m^{-1} × $(4.0 \times 10^{-2}$ m$)^2$ = 1.4×10^6 V m^{-1} (towards Y) E due to Y = 2.5×10^{-7} C / $4 \times \pi \times 8.85 \times 10^{-12}$ F m^{-1} × $(4.0 \times 10^{-2}$ m$)^2$ = 1.4×10^6 V m^{-1} (towards Y) $E = 1.4 \times 10^6$ V m^{-1} + 1.4×10^6 V m^{-1} = 2.8×10^6 V m^{-1}	(1) (1) (1)	**3**
16 (b) (i)	• Central straight line equidistant from X and Y **and** at least one of the diverging lines between X and the central line **and** at least one of the diverging lines between the central line and Y • At least one line looping X **and** one line looping Y • Line spacing between X and Y smaller than line spacing to the left of X **and** to the right of Y <u>Example of diagram</u> 	(1) (1) (1)	**3**

16 (b) (ii)	• Field lines show direction of force on a (positive) charge • (So) field line shows the direction of acceleration • Point A - Where the line is straight, a charge (initially at rest) will follow the line, so true in this case • Point B - Curved line means acceleration always changing direction but velocity is not in the direction of acceleration so statement not true	(1) (1) (1) (1)	**4**
16 (c)	• Use of $V = Q / 4\pi\varepsilon_0 r$ **Or** Use of $V = kQ / r$ • Applies potential at each point is sum of potential due to charge at X and potential due to charge at Y • Applies p.d. = sum of potentials at D – sum of potentials at C • $V = (-)\ 2.0 \times 10^5$ V <u>Example of calculation</u> V_C due to X= 5.0×10^{-7} C / $4 \times \pi \times 8.85 \times 10^{-12}$ F m $^{-1} \times 2.5 \times 10^{-2}$ m $= 1.8 \times 10^5$ V V_D due to X= 5.0×10^{-7} C / $4 \times \pi \times 8.85 \times 10^{-12}$ F m $^{-1} \times 5.5 \times 10^{-2}$ m $= 0.8 \times 10^5$ V V_D due to Y= -5.0×10^{-7} C / $4 \times \pi \times 8.85 \times 10^{-12}$ F m $^{-1} \times 2.5 \times 10^{-2}$ m $= -1.8 \times 10^5$ V V_C due to Y = -5.0×10^{-7} C / $4 \times \pi \times 8.85 \times 10^{-12}$ F m $^{-1} \times 5.5 \times 10^{-2}$ m $= -0.8 \times 10^5$ V $V_C = 1.8 \times 10^5\ \text{V} - 0.8 \times 10^5\ \text{V} = 1.0 \times 10^5$ V $V_D = -1.8 \times 10^5\ \text{V} + 0.8 \times 10^5\ \text{V} = -1.0 \times 10^5$ V $V_{CD} = V_D - V_C$ $= -1.0 \times 10^5\ \text{V} - 1.0 \times 10^5$ V $= -2.0 \times 10^5$ V	(1) (1) (1) (1)	**4**
	Total for Question 16		**14**

Question number	Answer		Mark
17 (a)	• Battery in series with capacitor and resistor • Voltmeter/datalogger/oscilloscope in parallel with capacitor • Appropriate switching mechanism and discharge circuit completed <u>Example of diagram:</u>  	(1) (1) (1)	**3**
17 (b) (i)	• Exponential decline • Symmetry with charging curve, starts at 6.00 V, curves cross at 3.00 V <u>Example of graph</u>  	(1) (1)	**2**
17 (b) (ii)	• Use of $I = I_0 e^{-\frac{t}{RC}}$ with $V = IR$ • Apply total p.d. = sum of p.d.s • Suitable algebra <u>Example of derivation</u> $I = I_0 e^{-\frac{t}{RC}}$ $V_R = RI_0 e^{-\frac{t}{RC}}$ $I_0 R = V_0$ $V_R = V_0 e^{-\frac{t}{RC}}$ $V_{cap} = V_0 - V_R$ $V = V_0 - V_0 e^{-\frac{t}{RC}}$	(1) (1) (1)	**3**

17 (b) (iii)	• Use of $V = V_0(1 - 1/e) = 0.63\ V_0$ for V at time constant (1) • Read time constant off graph = 4.9 s (allow range 4.5 s to 5.0 s) (1) • Use of time constant = RC (1) • $C = 1.5 \times 10^{-5}$ F, so choose 15 μF capacitor (1) ($C = 1.4 \times 10^{-5}$ F to $C = 1.5 \times 10^{-5}$ F when rounded to 2 s.f.) **Or** • Draws tangent to line at t = 0 s to intercept p.d. = 6.00 V line (1) • Read time constant off graph = 4.9 s (allow range 4.5 s to 5.0 s) (1) • Use of time constant = RC (1) • $C = 1.5 \times 10^{-5}$ F, so choose 15 μF capacitor (1) ($C = 1.4 \times 10^{-5}$ F to $C = 1.5 \times 10^{-5}$ F when rounded to 2 s.f.) **Or** • Record corresponding values of V and t from point (or points) on graph (1) • Use of $V = V_0 - V_0 e^{-\frac{t}{RC}}$ (1) • Convert to correct logarithmic form (1) • $C = 1.5 \times 10^{-5}$ F, so choose 15 μF capacitor (1) ($C = 1.3 \times 10^{-5}$ F to $C = 1.5 \times 10^{-5}$ F when rounded to 2 s.f.) **Or** • $\frac{V_0}{2} = V_0 e^{-\frac{t_{\frac{1}{2}}}{RC}}$ (1) • $RC = t_{½} / \ln 2$ (1) • Records time for V to increase to ½ V_0 (3.4 s) (allow range 3.0 s to 3.5 s) (1) • $C = 1.5 \times 10^{-5}$ F, so choose 15 μF capacitor (1) ($C = 1.3 \times 10^{-5}$ F to $C = 1.5 \times 10^{-5}$ F when rounded to 2 s.f.) <u>Example of calculation</u> V at time constant time = 0.63 × 6.00 V = 3.8 V Time from graph = 4.9 s 4.9 s = $C \times 3.3 \times 10^5\ \Omega$ $C = 1.48 \times 10^{-5}$ F	**4**

17 (b) (iv)	• Use of $Q = CV$ (ecf for C from (iii)) (1) • $Q = 9.0 \times 10^{-5}$ C (1) <u>Example of calculation</u> 1.5×10^{-5} F × 6.00 V = 9.0×10^{-5} C	**2**
17 (b) (v)	• Use of $W = ½ CV^2$ (ecf for C from (iii)) **Or** Use of $W = ½ QV$ (ecf for Q from (iv)) **Or** Use of $W = ½ Q^2/C$ (ecf for C from (iii), for Q from (iv)) (1) • $W = 2.7 \times 10^{-4}$ J (1) <u>Example of calculation:</u> $W = ½ \times 1.5 \times 10^{-5}$ F × (6.00 V)^2 = 2.7×10^{-4} J	**2**
	Total for question 17	**16**

Question number	Answer		Mark
18(a)	• Mass equal (to mass of electron) • Charge equal and opposite (to charge of electron) • Lepton number (equal and) opposite (to lepton number of electron)	(1) (1) (1)	3
18 (b)	• Curvature more in top half of picture • Particle moving slower after passing through lead plate because energy lost, so moving from lower half to top half • (Applying FLHR,) field into page (mark dependent on an indication of correct direction of positron motion)	(1) (1) (1)	3
18 (c) (i)	• Use of conversion factor 1.6×10^{-19} C • Use of $E_k = ½\ mv^2$ • Calculated speed = 2.8×10^9 (m s^{-1}), which is greater than the speed of light (so it must be relativistic) <u>Example of calculation</u> $E_k = 23 \times 10^6$ eV × 1.6×10^{-19} C = 3.7×10^{-12} J 3.7×10^{-12} J = 0.5 × 9.11×10^{-31} kg × v^2 $v = 2.8 \times 10^9$ m s^{-1}	(1) (1) (1)	3
18 (c) (ii)	• Use of $E = pc$ (ecf for E from (c)(i)) • Use of $r = p/Bq$ • B = 2.1 T Do not award MP1 if $p = mv$ calculated using v from part (i) <u>Example of calculation</u> 3.7×10^{-12} J = p × 3.00×10^8 m s^{-1} $p = 1.2 \times 10^{-20}$ N s 0.037 m = 1.2×10^{-20} N s / B × 1.6×10^{-19} C B = 2.1 T	(1) (1) (1)	3

18 (d)	• Use of $E_k = ½ mv^2$ • Use of $\Delta E = c^2 \Delta m$ • Use of $E = hf$ • $f = 1.2 \times 10^{20}$ Hz <u>Example of calculation</u> $E_k = 2 \times 0.5 \times 9.11 \times 10^{-31}$ kg $\times (1.5 \times 10^7$ m s$^{-1})^2$ $= 2.0 \times 10^{-16}$ J $\Delta E = (3.00 \times 10^8$ m s$^{-1})^2 \times 2 \times 9.11 \times 10^{-31}$ kg $= 1.64 \times 10^{-13}$ J Total energy = 1.64×10^{-13} J + 2.0×10^{-16} J = 1.64×10^{-13} J Energy for one gamma photon = 8.2×10^{-14} J 8.2×10^{-12} J = 6.63×10^{-34} J s $\times f$ $f = 1.2 \times 10^{20}$ Hz	(1) (1) (1) (1)	**4**
	Total for question 18		**16**

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