

Name: _____

Particle accelerators LEGACY

Mark Scheme

Date:

Time:

Total marks available:

Total marks achieved: _____

Mark Scheme

Q1.

Question Number	Answer	Mark
	C	1

Q2.

Question Number	Answer	Mark
	A	1

Q3.

Question Number	Answer	Mark
	C	1

Q4.

Question Number	Answer	Mark
	A	1

Q5.

Question Number	Answer	Mark
	D	1

Q6.

Question Number	Answer	Mark
	C	1

Q7.

Question Number	Answer	Mark
	B	(1)

Q8.

Question Number	Answer	Mark
	C	1

Q9.

Question Number	Answer	Mark
	C - The particles are losing energy	1
	Incorrect Answers: A – An oscillating field would not produce this track as the force would be switching direction periodically B – The particles would require an increase in magnitude of velocity to gain mass and the force from this field is perpendicular to their velocity D – An increasing speed would produce spirals of increasing radius	

Q10.

Question Number	Answer	Mark
	D	1

Q11.

Question Number	Answer	Mark
	D	1

Q12.

Question Number	Answer	Mark
	C – The new particles have opposite charge	1
	Incorrect Answers: A – without knowing the charges, the direction of the field cannot be deduced B – the particles cannot be deduced from the information given, other oppositely charged particles could produce the same tracks without a scale D – without knowing the direction of the field, the charges cannot be deduced	

Q13.

Question Number	Answer	Mark
	B	1

Q14.

Question Number	Answer	Mark
	C	1

Q15.

Question Number	Answer	Mark
	D – thermionic emission	1
	Incorrect Answers: A – involves electrons moving to higher energy levels in atoms B – involves electrons gaining enough energy to leave atoms C – involves electrons being emitted when energy from photons is absorbed	

Q16.

Question Number	Answer	Mark
(i)	The time spent in each tube must remain constant (as the speed increases) Refers to the tubes switching polarity at fixed time intervals (For MP2 just saying frequency is constant is not sufficient)	(1) (1)
		2

Question Number	Answer	Mark
(ii)	The speed of electrons has become a maximum/constant Or there can be no further increase in the speed of the electrons (do not accept there is no acceleration)	(1)
		1

Q17.

Question Number	Answer	Mark
(i)	C	1
(ii)	A	1
(iii)	D	1

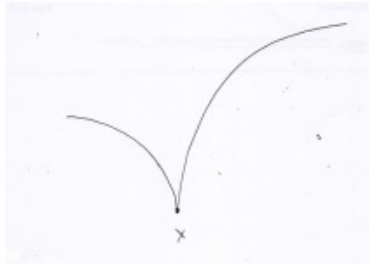
Q18.

Question Number	Answer	Mark
*	<p>(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)</p> <p>proton is accelerated by the electric field (1)</p> <p>The alternating p.d. means that as a proton emerges from one tube the next one is negative (1)</p> <p>length of drift tubes increases because proton travels further during that half period of the cycle as its speed is greater Or size of gap between drift tubes increases because proton travels further during that half period of the cycle as its speed is greater (1)</p> <p>p.d. must switch at constant frequency so time in each drift tube is the same Or p.d. must switch at constant frequency so time between each pair of drift tubes is the same (1)</p>	4

Q21.

Question Number	Answer	Mark
	<p>At X the idea that 2 particles are produced (1)</p> <p>One is uncharged/neutral so no track (1)</p> <p>charged particle has same charge as incident particle to conserve charge Or path of (new) charged particle changes to conserve momentum (1)</p> <p>At Y Neutral particle decays into two charged particles. (1)</p> <p>Tracks curve in opposite directions as particles oppositely charged. Or particles have (equal and) opposite charge to conserve charge Or particles have equal (magnitude of) momenta since their (radius of) curvature is the same. (1)</p>	5

Q22.

Question Number	Answer	Mark
	<p>Diagram: Path curves in opposite sense (1)</p> <p>With a greater radius of curvature (1) [For Mp2 drawn line must start at X , upwards at less than 45° to vertical and go above printed line. Look at curvature close to X, do not penalise if later it curves more/less.]</p>  <p>Explanation: (these marks are independent of the diagram) (Antihelium) has opposite charge (to proton) Or reference to proton +ve and antihelium -ve (1)</p> <p>See $r = p/BQ$ (1)</p> <p>r is doubled Or p/Q is doubled (1)</p> <p>[equation may appear near diagram.]</p>	5
	Total for question	5

Q23.

Question Number	Answer	Mark
	<p>(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Max5</p> <p>Electric fields</p> <ul style="list-style-type: none"> • can be used to accelerate/deflect particles (1) • direction of force/deflection indicates (sign of) charge. (1) • $a = EQ/m$ (1) <p>Magnetic fields</p> <ul style="list-style-type: none"> • produce circular motion Or provides a centripetal force Or causes spirals/arc (1) • Direction of force/curvature/deflection indicates (sign of) charge. (1) • momentum/speed/mass found from radius/curvature (1) • $r = p/BQ$ Or $Bqv = mv^2/r$ (1) 	5
	Total for question	5

Q24.

Question Number	Answer	Mark
(a)	Divide by 1.6×10^{-19} $V = 4.5 \times 10^6 \text{ V}$ <u>Example of calculation</u> $V = \frac{7.2 \times 10^{-13} \text{ J}}{1.6 \times 10^{-19} \text{ C}} = 4.5 \times 10^6 \text{ V}$	(1) (1) 2

Question Number	Answer	Mark
(b)	Line of best fit drawn with maximum speed $< 3 \times 10^8$ Comment that line tends towards c Or comments that the graph levels off close to c .	(1) (1) 2

Question Number	Answer	Mark
(c)	The idea that as electrons travel at speeds close to the speed of light their mass increases $E_k = \frac{1}{2}mv^2$ does not apply Or relativistic equations should be used.	(1) (1) 2

Q25.

Question Number	Answer	Mark
(a)	Only (moving) charged particles are deflected by a magnetic field Or Only charged particles can be accelerated to produce a beam	(1) (1) 1
(b)	Into the page	(1) 1
(c)	Use of $F = mv^2/r$ Or use of $r = p/BQ$ Use of $F = Bqv$ Or use of $p = mv$ $m = 6.64 \times 10^{-26} \text{ kg}$ <u>Example of calculation</u> $mv^2/r = Bqv$ $m = Bqr/v = (0.673 \text{ T} \times 1.6 \times 10^{-19} \text{ C} \times 7.40 \times 10^{-2} \text{ m}) / 1.20 \times 10^5 \text{ m s}^{-1}$ $m = 6.64 \times 10^{-26} \text{ kg}$	(1) (1) (1) 3
(d)	Semicircle drawn starting from same initial point <u>and</u> a smaller radius	(1) 1
Total for question		6

Q26.

Question Number	Answer	Mark
(a)	Photon causes no ionisation (1)	1

Question Number	Answer	Mark
(b)	The ejected electron has higher speed/momentum (1) Refers to $r = mv/BQ$ so r is bigger (1)	2

Question Number	Answer	Mark
(c)	Charge before collision = 0 Or identifies that both photon and hydrogen are neutral (1) Identifies that after collision hydrogen charge = +1 and electron charge = -1 (×2) and positron charge = +1 (1) (do not accept an electron positron pair is neutral)	2

Question Number	Answer	Mark
(d)	Either The velocity/ E_k of the ionised hydrogen atom is very small (accept negligible or zero) after collision Or it is stationary (1) (Compared to other particles in the interaction) the hydrogen atom has a large mass (1) Or The interaction is with the atomic electron not the nucleus (1) so the nucleus doesn't move (1)	2

Q27.

Question Number	Answer	Mark
(a)	To curve the tracks/paths Or to produce a centripetal force/acceleration Or to allow particles to spiral Or to produce an arc Or to produce circular motion So that momentum/energy/charge/ velocity/mass can be investigated	(1) (1) 2
(b)	The <u>radius</u> of curve gets less Or curvature increases (Because) particle slows down Or loses energy Or loses momentum	(1) (1) 2
(c)	(Magnetic field) out of page	(1) 1
(d)(i)	Does not leave a track Or there is only one visible track for μ^+ Clear demonstration of charge conservation in this situation	(1) (1) 2
(d)(ii)	Reference to momentum Reference to change of direction of the visible path (Hence) another particle must have an equal but opposite change of momentum Or another particle produced to conserve momentum	(1) (1) (1) 3
Total for question		10


Q28.

Question Number	Answer	Mark
(i)	Outward spiral from centre in either direction, minimum of two complete loops (1)	1
(ii)	Direction consistent with diagram: Clockwise path, field out of page Anticlockwise path, field into page (1)	1
(iii)	Electric field/p.d. between dees causes (resultant) force/acceleration (1) Proton makes half a revolution in half a cycle of the a.c. Or facing dee (always) negative when proton reaches gap. Or whenever the proton gets to a gap, the p.d. has reversed (1) k.e./speed (only) increases each time the proton crosses the gap Or work done by the field in the gap increases the k.e. (1)	3
(iv)	$Bev = mv^2/r$ Or $r = p/Be$ (1) $v = 2\pi r/T$ (1) $T = 1/f$ (seeing $f = v/(2\pi r)$ scores MP2 & 3) (1) Or $Bev = mr\omega^2$ (1) $v = r\omega$ (1) $\omega = 2\pi f$ (seeing $v/r = 2\pi f$ scores MP2 & 3) (1)	3
(v)	Use of $B = 2\pi fm/e$ with mass of proton (1) $f = 1.8 \times 10^4$ Hz (1)	2
	<u>Example of calculation</u> $f = eB/2\pi m$ $f = (1.6 \times 10^{-19} \text{ C} \times 1.2 \times 10^{-3} \text{ T}) / (2\pi \times 1.67 \times 10^{-27} \text{ kg})$ $f = 1.8 \times 10^4$ Hz	

Q29.

Question Number	Answer	Mark
(a)	Force on (charged) particles at right angles to motion (1) Causes circular motion [not spiral / curved] (1) OR force/acceleration is centripetal (1) [credit first mark if clear from diagram]	2
(b)(i)	Momentum: $p=mv$ or $r = mv/Be$ (1) $v = 2\pi r/T$ or $v = r\omega$ or $\omega = Be/m$ (1) Use of $f = 1/T$ or $\omega/2\pi$ (1) [allow q for e] <u>Example of calculation</u> $Be r = mv$ $Be r = m2\pi r/T$ $Be = m2\pi f$	3
(b)(ii)	(Protons) accelerated / given energy, in the gaps / between D's/from one D to the other (1) Every half rotation/semicircle later (polarity of D's) needs a change (1)	2
(b)(iii)	Relativistic effect / v approaching c /mass increases so frequency decreases (1) [second mark consequent on first] (1)	2
(c)	must be accelerating due to circular motion (1) (Speed constant but) direction/velocity changing (1)	2
Total for question		11

Q30.

Question Number	Answer	Mark
(a)	(Total / sum of) Kinetic energy conserved	(1)
(b)	<p>These diagrams could appear in part c and should be credited in (b)</p>  <p>[allow first mark for any triangle or parallelogram ie do not insist on right angle] right angle labelled or approximately by eye / diagonal should be labelled "before" or "initial" or appropriately recognisable as incoming particle</p>	(1) (1)
(c)	<p>KE as formula eg $\frac{1}{2} mu^2 = \frac{1}{2} mv^2 + \frac{1}{2} ms^2$ / $p^2 / 2m = p^2 / 2m + p^2 / 2m$ Recognition of "Pythagoras"</p>	(1) (1)
(d)(i)	<p>Electric field Does work on proton/applies a force /repel/attract qV / Fd / Eq</p>	(1) (1) (1)
(d)(ii)	<p>Mass of incoming proton larger (than rest mass) Due to moving near speed of light/high speed/high energy/relativistic</p> <p>Alt answer : image not in plane of two protons after the event</p>	(1) (1) (2) (max 2)
(e)	Out of the plane of paper	(1)
	Total for question	11

Q31.

Question Number	Answer	Mark
(a)	$u\bar{d}$ identified (1)	1
(b)	<p>Conversion of G (1) Conversion of either eV or divided by c^2 (1) 2.5×10^{-28} (kg) (1)</p> <p>eg $m = 0.14 \times 10^9 \times 1.6 \times 10^{-19} / 9 \times 10^{16}$</p>	3

(c)	<p>QWC i and iii - Spelling of technical terms must be correct and the answer must be organised in a logical sequence</p> <p>Electric fields: Electric field provides force on the charge/proton (1) gives energy to /work done / $E = qV$/ accelerate protons (1)</p> <p>Magnetic fields: Force on moving charge/proton (1) Produces circular path/centripetal force (1)</p> <p>labelled diagram showing Dees with E field indicated across gap OR B field through Dees (1) E field is reversed/alternates (1)</p>	<p>QWC</p> <p>4</p> <p>1 max</p>
(d)	<p>QWC i and iii - Spelling of technical terms must be correct and the answer must be organised in a logical sequence</p>	<p>QWC</p>

	<p>momentum (1) Zero / negligible momentum before (1) To conserve momentum (fragments go in all directions) (1)</p>	<p>3</p>
Total for question		12

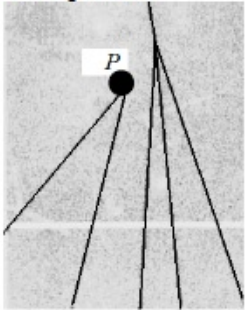
Q32.

Question Number	Answer	Mark
(a)(i)	measured thickness of lead 4-5 mm (1) measured radius 32 - 38 mm (1) Value between 38 - 57 mm (1) Eg actual radius = $35 \text{ mm} \times 6 \text{ mm} / 4.5 \text{ mm}$	3
(a)(ii)	Use of $p = Bqr$ [any two values sub] (1) Answer range $9.1 \times 10^{-21} - 1.4 \times 10^{-20} \text{ N s}$ or kg m s^{-1} [allow ecf](1)	2
(b)	Track gets more curved above lead / r smaller above lead (1) Must be slowing down / less momentum / loses energy (1) Up [dependent on either answer above] (1)	3
(c)	Into page (1) [ecf out of page if down in b]	1
(d)(i)	Division by $9.11 \times 10^{-31} \text{ kg}$ (1) Answer range $1.0 - 1.6 \times 10^{10} \text{ m s}^{-1}$ (1)	2
(d)(ii)	greater than speed of light (1) (impossible) so mass must have increased (1)	2
	Total for question	13

Q34.

Question Number	Answer	Mark
(a)	Observations: Most alpha went straight through / undeflected (1) [Do not credit just "alphas go through"] Some / few deflected [not "reflected"] (1) Very few / < 1 in 1000 came straight back / were deflected through very large angles (>90°) / were reflected (1)	3
(b)(i)	Any mention of tubes (1) Alternating p.d. / a.c. p.d. /alternating electric field (1) Length of tubes increases (1)	3
(b)(ii)	Use of $p = E/c$ with $c = 3 \times 10^8$ (1) (Use of de Broglie) $\lambda = h/p$ with $h = 6.6 \times 10^{-34}$ (1) wavelength = 6.2×10^{-17} m (1) <u>Example of answer</u> $p = 20 \times 1.6 \times 10^{-10} \text{ J} / 3 \times 10^8 \text{ m s}^{-1} = 1.1 \times 10^{-17} \text{ N s}$ Correct sub of h and p i.e. $\lambda = 6.6 \times 10^{-34} / 1.1 \times 10^{-17} \text{ N s}$	3
(b)(iii)	Wavelengths need to be smaller than nuclei [allow same as / similar to – must be comparative] (1)	1
(b)(iv)	Proton is not uniform / has space (1) Contains quarks (1) [ignore any reference to charge]	2
(b)(v)	Kinetic energy is not conserved (1) [K.E. and momentum not conserved – do not credit]	1
	Total for question	13

Q35.

Question Number	Answer	Mark
(a)	to keep the time spent in each tube the same Or so that frequency of <u>alternating</u> pd/voltage constant (do not accept reference to ac currents)	(1) 1
(b)(i)	At top of Δ 	(1) 1
(b)(ii)	No <u>track/trail</u> to this point (as no charge) Then two tracks (as two charged particles)	(1) (1) 2
(b)(iii)	$D^0 \rightarrow k^+ + \pi^-$ Correct symbols, do not accept pi as a word Correct charge symbols as above, top right of each term. Wrong position or extra ones loses this mark (any extra particles or gamma 0/2)	(1) (1) 2
*18(b)(iv)	(QWC- Work must be clear and organised in a logical manner using technical wording where appropriate.) Charge: +1 -1 = 0 (the positive sign must be used, 1 -1 = 0 is not enough) Or reference to positive and negative charges cancelling. Energy/mass/mass-energy: of D is equal to that of the new particles Momentum: Of D is equal to sum/total of momentum of new particles	(1) (1) (1) (1) (1) (1) 6
(c)(i)	$c \bar{u}$	(1) 1
(c)(ii)	$u\bar{d}$ or $u\bar{s}$ or $c\bar{d}$ or $c\bar{s}$ (allow words)	(1) 1
Total for question		14