Particle Physics MS

1. B

[1]

2. D

[1]

3. B

[1]

4. B

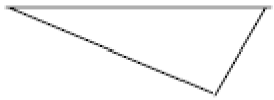
[1]

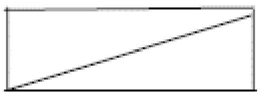
5. C

[1]

6. (a) (Total / sum of) Kinetic energy conserved 1

(b) These diagrams could appear in part c and should be credited in (b) 1





1

[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

(c) KE as formula eg $\frac{1}{2} mu^2 = \frac{1}{2} mv^2 + \frac{1}{2} ms^2$ / $p^2 /2m = p^2 /2m + p^2 /2m$ 1

Recognition of "Pythagoras" 1

(d) (i) Electric field 1

Does work on proton/applies a force /repel/attract 1

qV / Fd / Eq 1

(ii) Mass of incoming proton larger (than rest mass) **(1)**
Due to moving near speed of light/high speed/high energy/relativistic **(1)**

Alt answer : image not in plane of two protons after the event **(2)** Max 2

(e) Out of the plane of paper 1

[11]

7. (a) 2/3 that of a proton / $2/3 \times 1.6 \times 10^{-19}$ (C) 1

(b) Mass = 80 MeV/c^2 1

charge = +1/3 1

(c) Recognition M means 10^6 1

Convert eV to J or divide by c^2 1

eg $4 \times 10^6 \times 1.6 \times 10^{-19}$ or $/9\times10^{16}$
Answer 7.1 × 10-30 (kg) 1

(d) (i) Kaon Meson 1

Omega baryon 1

(ii) $K^- + p$ 1

$= K^+ + K^o + \Omega^-$
[accept p or p^+ ;do not accept K for K^o ;signs must be top right] 1

(iii) Kaon plus = u $\bar{s}$ 1

Kaon neutral = d $\bar{s}$ or s $\bar{d}$ 1

[both marks can be inferred if equation in d(ii) is fully written in quark combinations)

(iv) QWC i and iii – Spelling of technical terms must be correct and the answer must be organised in a logical sequence

Momentum conserved **(1)**
Charge conserved **(1)**
Energy / mass conserved **(1)**
$E = mc^2$ **(1)**
<u>Kinetic</u> Energy (of kaon minus) is responsible **(1)**

Momentum of three particles after = momentum of kaon before **(1)**
Total charge 0 / charge before and after is 0 **(1)**
Conservation of Baryon no, quark no, strangeness **(1)** Max 5

allow only 1 mark max from these 3

[17]

8. C

[1]

9. C

[1]

10. D

[1]

11. **QWC**

QWC i and iii – Spelling of technical terms must be correct and the answer must be organised in a logical sequence

Observations:
Most alpha went straight through **(1)**
Some deflected **(1)**
(Very) few came straight back/large angle **(1)**
Conclusions:
Atom mainly (empty) space **(1)**
Nucleus contains most of the mass **(1)**
(Nucleus) very small/tiny **(1)**
(Nucleus) charged /positive **(1)**

[5]

12. (a) $u\bar{d}$ identified **(1)** 1

(b) Conversion of G **(1)**
Conversion of either eV or divided by c2 **(1)**
2.5×10^{-28} (kg) **(1)**

eg
$m = 0.14 \times 10^{9} \times 1.6 \times 10^{-19} / 9 \times 10^{16}$ 3

(c) **QWC**

QWC i and iii – Spelling of technical terms must be correct and the answer must be organised in a logical sequence

Electric fields:
Electric field provides force on the charge/proton **(1)**
gives energy to /work done / E = qV/ accelerate protons **(1)**

Magnetic fields:
Force on moving charge/proton **(1)**
Produces circular path/centripetal force **(1)** 4

labelled diagram showing Dees
with E field indicated across gap OR B field through Dees **(1)**
E field is reversed/alternates **(1)** Max 1

(d) **QWC**

QWC i and iii – Spelling of technical terms must be correct and the answer must be organised in a logical sequence

momentum **(1)**
Zero / negligible momentum before **(1)**
To conserve momentum (fragments go in all directions) **(1)** 3

[12]

13. (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 mm × 6 mm/4.5 mm 3

(ii) Use of $p = Bqr$ [any two values sub] **(1)**
Answer range 9.1×10^{-21} - 1.4×10^{-20} 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 9.11×10^{-31} kg **(1)**
Answer range $1.0 - 1.6 \times 10^{10}$ m s^{-1} **(1)** 2

(ii) greater than speed of light **(1)**
(impossible) so mass must have increased **(1)** 2

[13]

14. C

[1]

15. C

[1]

16. (a) A baryon is a (sub-atomic) particle made up of 3 quarks**(1)** 1

(b) n (ddu) → **(1)**
p (duu) **(1)** 2

[3]

17. (a) High frequency or high voltage**(1)**
Alternating **or** square wave voltage**(1)** 2

(b) No electric field inside cylinders (due to shielding) **(1)**
so no force (on electrons) **(1)** 2

(c) As speed increases (along the accelerator), **(1)**
cylinders are made longer so that time in each stays the same**(1)** 2

[6]

18. The answer must be clear, use an appropriate style and be organised in a logical sequence **(QWC)**
α-particles fired at (named) metal (film) **(1)**
in a vacuum **(1)**
Most went straight through **or** suffered small deflections. **(1)**
A few were reflected through large angles **or** some were reflected along their original path **(1)**
suggesting the mass **or** charge of the atom was concentrated in a very small volume **(1)** 5

[5]

[6]

19. (a) $_3Li^7 + {}_1p^1 = {}_2He^4 + {}_2He^4$

completing LHS **(1)**
completing RHS**(1)** 2

(b) (i) Charge **(1)**
(mass/) energy **(1)** 2

(ii) Mass of Li + p = 7.0143 u + 1.0073 u = 8.0216 u **(1)**
Mass of 2 α-particles = 2 × 4.0015 u = 8.0030 u **(1)**
Δm = 8.0216 u – 8.0030 u = 0.0186 u
= $0.0186 \times 1.66 \times 10^{-27}$ kg = 3.09×10^{-29} kg **(1)**
$\Delta E = c^2\Delta m = (3.00 \times 10^8 \text{ m s}^{-1})^2 \times 3.09 \times 10^{-29} \text{ kg} = 2.78 \times 10^{-12}$ J **(1)**
[Allow ecf from equation] 4

(iii) $= \dfrac{2.78 \times 10^{-12}\ \text{J}}{1.60 \times 10^{-19}\ \text{J eV}^{-1}}$ = 1.74 × 10^7 eV = 17.4 MeV **(1)**

The incoming proton has an energy of 300 keV = 0.30 MeV **(1)**
So total energy = 17.4 MeV + 0.3 MeV = 17.7 MeV **(1)**
The calculated energy differs by

$\dfrac{17.7\ \text{Mev} - 17.2\ \text{MeV}}{\frac{1}{2}(17.7 + 17.2)\text{MeV}} \times 100\% \approx 3\%$ **(1)**

The experiment therefore provides strong evidence for Einstein's prediction **(1)** 5

[13]

20. (a) Paths of alpha particles
Path A drawn less deflected than B **(1)**

Path A drawn as a straight line **(1)** 2

(b) (i) Why alpha source inside container
Alpha would be absorbed by [accept would not get through] container (material) **(1)** 1

(ii) Why the same kinetic energy?
Either
To restrict observation to two variables / closeness of approach and deflection
or so that speed / velocity / (kinetic) energy does not have an effect (on the observation / deflection /results / contact time) 1

(iii) Why an evacuated container?
Either
so that alphas do not get absorbed by / collide with / get deflected by / stopped by / scattered by / get in the way of / ionise / lose energy to atoms / molecules (of air) [Do not accept 'particles' of the air]

or so that all alphas reach the foil with the same (kinetic) energy 1

[5]

21. **<u>Particle classification</u>**

Neutron: baryon and hadron **(1)**

Neutrino: lepton **(1)**

Muon: lepton **(1)** 3

[3]

22. (i) **<u>Conservation laws</u>**

First reaction, Q: $0 + 0 \neq 1 + 1$ **(1)**

Second reaction B: $1 = 1 + 0$ AND Q: $-1 = -1 + 0$ **(1)**

Hence only Ω^- decay possible [based on B and Q conservation for this decay, accept simple ticks and crosses] **(1)** 3

(ii) **<u>Quark charges</u>**

Use of sss = –1 to show s = –⅓ **(1)**

Hence correct working (from baryons) to show u = ⅔ and d = –⅓ **(1)** 2

[5]

23. (a) (i) $1.2 \text{ keV} = 1.2 \times 10^3 \times 1.6 \times 10^{-19}$ J

OR

Use of $e\Delta V$ with e as 1.6×10^{-19} C and V as 1200 V **(1)**

Use of $\Delta(\frac{1}{2}m_e v^2)$ with m_e as 9.1**(1)** $\times 10^{-31}$ kg. **(1)**

Correct answer $2.0 - 2.1 \times 10^7$ m s^{-1} **(1)** 3

(ii) 1200 × 8/100 = 96 (eV delivered per electron) **(1)**
96/2.4 = 40 **(1)**

Or
2.4 × 100/8 = 30 (incident eV needed per photon) **(1)**
1200/30 = 40 **(1)**

Or
1200 / 2.4 = 500 (photons per electron, ideally) **(1)**
500 × (8/100) = 40 **(1)** 2

(b) Electrons on screen repel electrons in beam / force opposes electron motion/decelerating force **(1)**

Electrons (in beam) decelerated /slowed / velocity reduced/ work done by electrons (against force) **(1)**

Electron (kinetic) energy reduced (not ¯shared¯) **(1)**

Fewer photons (per electron, stated or implied) **(1)**

Trace less bright **(1)**

QoWC **(1)** Max 4

[9]

24. (a) pair of values of k.e. and υ2 read from graph / gradient **(1)**

$\upsilon^2 > 5 \times 10^{16}$ m s^{-2} **(1)**

$\Rightarrow$ mp = 1.62 – 1.69 × 10^{-27} (kg) to 3 s.f. **(1)** 3

(b) (i) (values 1.3 – 1.7, 3.1 – 3.5, 6.0 – 6.5) any **two** correct **(1)(1)**

(ii) $\Delta E = c^2 \Delta m$ / $E = mc^2$ **(1)**

$\Rightarrow$ one value for Δm (× 10–28 kg) **(1)**

use of m_p from (i) [no mark]

$\Rightarrow$ one value of $\Delta m/m_p$: about 10%, 20%, 40% **(1)** 5

[8]

25. (a) Show sum of quark charges in proton = +1
+2/3 +2/3 –1/3 = (+) 1 **(1)**

Show sum of quark charges in neutron = 0
+2/3 –1/3 –1/3 = 0 **(1)**

[ignore references to e] 2

(b) (i)
- baryon **(1)**
- meson **(1)** 2

(ii) baryon: 3 quarks **(1)**
meson: quark/antiquark **(1)**
[1 for answers reversed or baryon/meson not specified] 2

(c) any 4 marks from the following examples:
high speed means high energy/momentum **(1)**
may need to overcome (electrostatic) repulsion **(1)**
more energy available for creating particles **(1)**
higher energy/momentum/speed means shorter wavelength **(1)**
reference to $\lambda = h/mv$ or $\lambda = h/p$ **(1)**
for diffraction/scattering **(1)**
need λ approx equal to particle spacing/internal structure **(1)** max 4

(d) Speeds near the speed of light **(1)**

[11]

26. Recall speed = s/t **(1)**
Use of s = π D **(1)**
Answer for speed **(1)**
Conclusion **(1)**

OR
Use of v = rω
Use of $\omega = 2\pi \times 20\,000$
Answer for speed
Conclusion

$v = s/t$
$s = \pi \times 8000$ (m)
$v = \pi \times 8000 \times 20\,000$ (m/s)
$v = 5 \times 10^8$ m/s

inaccurate/not possible since speed > c

[4]

27. (a) ${}^{18}_{8}\text{O} + {}^{1}_{1}\text{p/H}$ equals ${}^{18}_{9}\text{F} + {}^{1}_{0}\text{n}$ **(1)** **(1)** **(1)**
[omitting the n with everything else correct = 1] 3

(b) Accelerated through 19×10^6 V / MV
Using linear accelerator / cyclotron / particle accelerator / **(1)**
recognisable description **(1)** 2

(c) Time taken for half the original quantity/ nuclei /activity to decay **(1)**

Long enough for (cancer/tumour/body to absorb) and still be active/detected **(1)**

Will not be in body for too long **(1)** 3

(d) Use of $E = mc^2$ **(1)**
Use of $E = hf$ **(1)**
Use of $v = f\lambda$ **(1)**
$\lambda = 2.4 \times 10^{-12}$ m **(1)**

eg $9.11 \times 10^{-31} \times 9 \times 10^{16}$ (×2)
$f = 8.2 \times 10^{-14} / 6.6 \times 10^{-34}$ ecf
$\lambda = 3 \times 10^{8} / 1.2 \times 10^{20}$ ecf — 4

(e) Conservation of momentum **(1)**

Before momentum = 0 **(1)**

so + for one photon and – for other **(1)** — 2 max

[14]

28. (a) Calculate the ratio the densities of the atom and the nucleus
Density equation [In symbols or numbers] **(1)**
Show the relationship between density and radius. **(1)**
[Candidates who start by stating that density is inversely proportional to the radius cubed would get both these marks. Candidates who show an expression where the mass is divided by $\frac{4}{3}\pi r^3$ would set both these marks. Candidates who write Ratio = $(1/10^5)^3$ would get both of these marks.]
Factor 10^{-15} established. [Some working must be shown for this mark] **(1)**

Eg $(\text{Density})_{\text{atom}} = \dfrac{m}{\frac{4}{3}\pi r_{\text{atom}}^{3}}$ or Density $\alpha \dfrac{1}{r^3}$

$$(\text{Density})_{\text{nucleus}} = \frac{m}{\frac{4}{3}\pi r_{\text{nucleus}}^{3}}$$

$$\frac{(\text{Density})_{\text{atom}}}{(\text{Density})_{\text{nucleus}}} = \left(\frac{r_{\text{nucleus}}}{r_{\text{atom}}}\right)^3$$

$= (10^{-5})^3$

Assumption – (entire) mass of the atom is concentrated in the nucleus[there must be a reference to the nucleus] **(1)**
[eg mass of the atom =/approx – mass of the nucleus; most / majority of the atom’s mass is in the nucleus. The following would not be awarded marks; The atom is mostly empty space; mass of the electrons is negligible; the nucleus is a very dense.] — 4

(b) <u>Observation</u>
A very small percentage of particles [accept ‘very few’ not just ‘a few’. Do not accept ‘some’] are deflected through angles greater than 90° / are back-scattered / deflected back. **(1)**
[Allow; nearly all / most (alpha) particles pass through (the atom) without being deflected (showing the atom is virtually empty space).]
[Accept ‘nearly all’, not ‘many’ for the word ‘most’.] 1

[5]

29. (a) energy (of proton) converts to mass **(1)**
7 TeV > 251 GeV, (so enough energy present to create Higgs particle) **(1)** 2

(b) (i) calculate rest–mass energy of proton in J **(1)**
comparison with 7 TeV **(1)**

rest mass energy of proton – $E = mc^2 = 1.67 \times 10^{-27} \times c \times c$
$= 1.5 \times 10^{-10}$ J
$= 1.5 \times 10^{-10} / 1.6 \times 10^{-19}$ (eV) $= 9.4 \times 10^{8}$ (eV)
much less than 7 TeV.
OR 7 TeV $= 7 \times 10^{12} \times 1.6 \times 10^{-19}$ (J)
$= 1.12 \times 10^{-6}$ (J)
$>> 1.5 \times 10^{-10}$ J 2

(ii) Appropriate use of 1.6×10^{-19} OR energy from above in J **(1)**
Answer **(1)**

momentum = energy/c $= 7 \times 10^{12} \times 1.6 \times 10^{-19}$ (J)/(3×10^{8} (m/s)) =
3.73×10^{-15} (kg m s^{-1}) 2

(iii) Attempt to use r = p/Bq **(1)**
two correct subs into formula OR rearrangement **(1)**
circumference => radius **(1)**
answer **(1)**

r = p/Bq
B = p/rQ
$= 3.73 \times 10^{-15}$ / [(27000/2_) $\times 1.6 \times 10^{-19}$] (T)
= 5.4 T 4

(iv) Yes (stated or clearly implied) **(1)**
because motion and force both horizontal OR motion/force/B must all be perpendicular **(1)** 2

[12]

30. (i) Add to diagram.

Arrows at A and B, both pointing directly away from the nucleus. **(1)**
[Arrow end (head or tail) need not touch A /B, but direction must be correct. Gauge by eye, accept dotted construction lines as indication of intent] 1

(ii) Calculation of force

Use of $F = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ or $F = \dfrac{kQ_1 Q_2}{r^2}$ **(1)**

[ignore error/omission of '2' and/or '79' or 'e' or '1.6×10^{-19}' for this first mark, providing numerator clearly has a product of charges and denominator a distance value squared. Ignore power of 10 errors in values of Q or r]

2 × 1.6×10^{-19} C **and 79** × 1.6×10^{-19} C seen (**consequential** mark, dependent upon correct use of equation previously) **(1)**

Correct answer = 1.6 – 1.7 N **(1)**

Example of answer:

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2} = \frac{(79 \times 16 \times 10^{-19}\ \text{C}) \times (2 \times 1.6 \times 10^{-19}\ \text{C})}{4\pi \times 8.85 \times 10^{-12}\ \text{F m}^{-1} \times (1.5 \times 10^{-13}\ \text{m})^2}$$

= 1.62 N 3

(iii) Effect on motion of α

Slows down [decelerates] and then speeds up again [accelerates].
(both needed)
[accept 'slows down **at** A and speeds up **at** B] **(1)** 1

[5]

31. (a) (i) Not matter/antimatter pair [stated or implied] **(1)**
particle/antiparticle have same mass OR electron/proton not same mass OR other correct reason (eg electron is fundamental, proton is quarks) **(1)**
antiparticle to proton is antiproton OR antiparticle to electron is positron/antielectron **(1)** 3

(ii) Not matter/antimatter pair [stated or implied] **(1)**
anti to up is anti-up OR anti to down is anti-down **(1)**
up and down have different charge **(1)** any 5

(b) particles/antiparticles carry opposite charge **(1)**
(component of) field perpendicular to travel **(1)**
(magnetic/LH rule) forces act in opposite directions **(1)**
some pairs uncharged so no separation/deflection **(1)**
[not annihilation] any 2

(c) number = 5000 × 10^{-12} kg / 9.11 × 10^{-31} kg = 5.5 (5.488) × 10^{21} **(1)** 1

(d) (i) correct use of $E = mc^2$ [subs] **(1)**
correct use of $E = hf$ and $c=f\lambda$ [rearranged or subbed] **(1)**
correct answer [ue] **(1)**

$E = mc^2 = 9.11 \times 10^{-31} \times (3 \times 10^8)^2$ J (= 8.199 × 10^{-14} J) **(1)**
$E = hf = hc/\lambda \Rightarrow \lambda = hc/E$ **(1)**
= 6.63 × 10^{-34} × 3 × 10^8/8.199 × 10^{-14} m
= 2.4 (2.426 or 2.42 or 2.43) × 10^{-12} m [ignore omission of both factors of 2] **(1)**
[factor of 2 wrong is a.e. = –1]
[use of $\lambda = h/p$ scores 0] 3

(ii) this wavelength is not visible light
OR this is x-ray or gamma or high energy photon so need shielding **(1)** 1

[12]

32. ***B* in accelerators:**

changes direction of motion of charged particles OR force/B perpendicular to motion of charged particles OR ref to LHR **(1)**1
(moving) charged particles stored in <u>circles</u>/<u>circular</u> path/spirals **(1)**2
$Bqv = mv^2/r$ **(1)**3
cyclotron: $T = 2\pi m/Bq$ **(1)**4
fixed frequency voltage for acceleration **(1)**5
diag/construction detail [probably on diag] **(1)**6
synchrotron: r fixed, B adjusted as needed **(1)**7 (up to 4)

B in detectors:
charged particles ⇒ (detectable) <u>curved</u> paths **(1)**8
find sign of charge from sense of curvature **(1)**9
find momentum/speed/energy/mass from r (= p/Bq) **(1)**10

[5]

33. Deductions

(a) (i) The atom is mainly empty space **(1)**
[The atom must be referred to. The words ‘empty’ and ‘space’ must be qualified eg ‘there is a large amount of space in the atom’ is not sufficient]

(ii) Within the atom there is an area / the nucleus which is positive / charged or more massive than the alpha particle
[If they choose to describe only the mass it must be a comparison ie ‘the nucleus is (much) more massive than the alpha’. ‘The atom has a dense centre,’ ‘the nucleus has a large mass’ are both insufficient.] □**(1)** 2

(b) Explain
(Deflection could have been) repulsion from positive nucleus **(1)**
(Deflection could have been) attraction towards negative nucleus **(1)**
[The words repulsion and attraction can be described eg ‘α deflected away from positive nucleus’, ‘α is deflected towards a negative nucleus’] [Diagrams showing the path of an alpha deflected by both a negatively and a positively charged nucleus would get both marks]□ 2

(c) Value of *n*
(4 – 6) **(1)**
[Allow minus values] 1

[5]

34. (a) Any 2 from:
momentum conserved **(1)**
initial momentum zero **(1)** (Any 2)
⇒ final momentum zero **(1)**
[opposite charges repel ⇒ xx] 2

(b) 0.140 GeV/c^2 **(1)**
– 1.6×10^{-19} C **(1)**
anti-u, d **(1)** 3

(c) Meson **(1)** 1

(d) [**(1)** for 0.14 (alone) **or** correct use of 10^9] **(1)**
Minimum energy = 1.4×10^8 (eV) **or** 0.14×10^9 (eV) **(1)**□ 2
[0.14 G is **(1)**x]

(e) Particles have K.E. (as well as mass) **(1)**□ 1

(f) Use of $\Delta E = c^2\Delta m$ [rearrangement OR one correct line subbed) **(1)**□
correct value **(1)**□

eg $\Delta m = \Delta E / c^2 = 0.14 \times 10^9 \times 1.6 \times 10^{-19}$ J / $(3 \times 10^8$ m s$^{-1})^2$
Mass loss = 2.5×10^{-28} kg — 2
[ecf from (d)]

[11]

35. <u>β – decay equations</u>

(i) n = udd and p = uud **(1)**

β^- and $\bar{\nu}$ have no quarks / are leptons / are fundamental **(1)** — 2

(ii) p → n **(1)**

β^+ and ν [on RHS, allow e^+] **(1)** — 2

[4]

36. <u>Antihydrogen</u>

(i) Antiproton [or anti–up quark, anti–down quark] and positron **(1)** — 1

(ii) $\bar{p}$ = –1 and e^+ = +1 [accept correct $\bar{u}$, $\bar{d}$ charges for $\bar{p}$] **(1)**
$\bar{u}\ \bar{u}\ \bar{d}$ (e^+ fundamental / no quarks) [ecf from (b), credit if in (i)] **(1)** — 2

(iii) zero / neutral **(1)** — 1

<u>Antimatter storage</u>

(iv) <u>Annihilates</u> **(1)**
(On contact) with matter / container / protons / H
OR Not charged: not affected by magnetic fields **(1)** — 2

[6]

37. (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)**
[$5.36/5.38/5.4 \times 10^{-11}$ (J)] [no ue]

Δm = energy $\div$ (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)**

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

38. <u>“The standard model”</u>

Everyday matter/atoms: p,n, e [maybe in two places] **(1)**

Protons / neutrons are made from quarks **(1)**

p: uud and n:udd **(1)**

show charge of either [p: u(+2/3) u(+2/3) d(–1/3) $\Rightarrow$ + 1 OR n: u
(+2/3) d(–1/3) d(–1/3) $\Rightarrow$ 0] **(1)**

All baryons have three quarks **(1)**

Hadrons contain quarks **(1)**

Electron is fundamental/leptons are fundamental **(1)**

Electron-neutrino created during β-decay **(1)** Max 6

[6]

39. <u>Calculation of voltage</u>

Use of $\Delta E = c^2 \Delta m$ **(1)**

Use of eV **(1)**

Correct answer [4.1×10^9 (V)] [no ue] **(1)**

<u>Example of calculation:</u>

$\Delta E = c^2 \Delta m$ = eV

$\Rightarrow V = c^2 \Delta m$ / e = $9 \times 10^{16} \times 8000 \times 9.1 \times 10^{-31} / 1.6 \times 10^{-19}$ V

= 4.1×10^9 V 3

<u>Role of magnets</u>

Field deflects/bends/curves the path **(1)**

Field is at curved parts / field at AD and BC / no field on straight parts **(1)**

Field perpendicular to page / velocity **(1)**

Force perpendicular to velocity or field **(1)**

Force is centripetal / towards centre **(1)** Max 4

<u>Calculation of field strength:</u>

$r = p / Bq$ rearranged to $B = p/rq$ **(1)**

correct substitution of either p OR of r **and** q **(1)**

Correct answer [0.124(T), no ue] **(1)**

<u>Example of calculation:</u>

$r = P / Bq \Rightarrow B = P / qr$

= $8000 \times 9.1 \times 10^{-31} \times 3.0 \times 10^8 / 110 \times 1.6 \times 10^{-19}$ T

= 0.124 T 7

[10]

40. Conservation laws

Baryon **(1)**

– 1 **(1)**

Q: (–1) + (+1) = (0) + (+1) + (X) **(1)**

B: (0) + (+1) = (0) + (0) + (X) **(1)** 4

Quark content

uud **(1)**

$u\bar{s}$ **(1)** 2

[6]

41. Conserved quantities

Momentum, charge, (mass-)energy, lepton number **(1) (1)** 2

[2 right gets 1 mark; all 3 right get 2 marks]
[Do not credit kinetic energy]

Charge of the pentaquark

$$2 \times \frac{+2}{3} + 2 \times \frac{-1}{3} + \frac{1}{3}$$

= (+) 1(e) **(1)** 1

Charge on X

Positive since pentaquark was positive, neutron neutral [ecf] **(1)** 1

[Reasoning needed]

Possible quark composition for X with explanation

u $\bar{s}$ **(1)**

Left behind (after removing neutron/udd) **(1)** 2

Mass of pentaquark

Conversion from GeV to J or substitution of c^2 **(1)**

answer [no ue] **(1)**

$1.54 \times 10^9 \times 1.6 \times 10^{-19}/(3 \times 10^8)^2$ 2

$= 2.7 \times 10^{-27}$kg

[8]

42. Approximate energy of alpha particle in MeV

1. $r = 0.09$ (m) [accept in range 0.07 – 0.12] **(1)**
   [must have unit if given in cm]

2. $q = 2 \times 1.6 \times 10^{-19}$ (C) **(1)**

3. $m = 4 \times 1.7 \times 10^{-27}$(kg) **(1)**

4. $r = p/Bq \Rightarrow p = rBq$ or $v = rBq/m$ **(1)**
   [see equation or substitution]

   [$p = 0.09 \times 3.7 \times 3.2 \times 10^{-19}$ N s]

5. $=1.07 \times 10^{-19}$ (Ns) **OR** $v = 1.6 \times 10^{7}$ (m s^{-1}) **(1)**

6. $E = p^2/2m$ or use of ½ mv^2 **(1)**
   [$E = (1.07 \times 10^{-19})^2 / (2 \times 4 \times 1.67 \times 10^{-27})$J]

7. $8.6 \times 10”^{13}$J **(1)**

(5.4 MeV/5.4 × 10^6 eV) 7

[7]

43. Base units of eV

(i) Reference to joule **(1)**

Useful energy equation / units shown [e.g. ½mv^2, mgh, mc^2, *Fd, not* *QV or Pt*] **(1)**

Algebra to J = kg m^2 s^{-2} shown (e.g. kg (m s^{-1})^2 or kg m s^{-2} m) **(1)** 3

(ii) Energy released

146 shown or used **(1)**
Δm calculation [1.9415, ecf] **(1)**
Multiply by 930 [allow $E = mc^2$ with mass in kg] **(1)**
1800 MeV [no ue] **(1)** 4

[7]

44. (i) Decay numbers

$^1_1$p and $^1_0$n **(1)**

$^0_1\beta^+$ and $^0_0\nu$ **(1)** 2

(ii) Tick the boxes

Proton: baryon and hadron only **(1)**

neutron: baryon and hadron only **(1)**

β^+: lepton and antimatter only **(1)**

ν: lepton only **(1)** 4

[only penalise once for including meson] [if both baryon correct but no hadrons 1 mark out of 2 and vice versa]

[6]

45. Explanation

energy gained by electron accelerated through 1 V/$W = QV$ **(1)**

$W = 1.6 \times 10^{-19}$ C × 1 V = 1.6×10^{-19} J **(1)** 2

Unit of mass

$\Delta E = c^2\Delta m$ so $\Delta m = \Delta E/c^2$ **(1)**

GeV is energy ⇒ GeV/c^2 is mass **(1)** 2

Mass of Higgs boson

$m = 115 \times [10^9] \times 1.6 \times 10^{-19}/(3 \times 10^8)^2$ **(1)**

$= 2.04 \times 10^{-25}$ kg **(1)** 2

Antiparticle

Same mass and opposite charge **(1)**
[Accept Particle and its antiparticle annihilate (→ photons)] 1

Explanation of need for a magnetic field and why it can be small

Force deflects particles/force produces circular motion **(1)**

Force is perpendicular to motion/force provides centripetal force **(1)**

r is large or curvature is small/gentle **(1)**

reference to $B = p/rQ$ to show why small B is needed **(1)** 4

[11]

46. Particle X

Positive **(1)** 1

Is a baryon **(1)** 1

Quark compositions

Proton uud; neutron udd BOTH **(1)** 1

Explanation and deduction of identity of X

Quality of written communication **(1)**

Strong / not weak interaction **(1)**

One strange quark on each side / no flavour change **(1)**

X is a proton **(1)** 4

[7]

47. Results of experiments and conclusions

Most pass straight through/undeflected **(1)**

A few deflect/reflect (at large angles) **(1)**

Small nucleus/mostly empty space **(1)**

Concentrated mass and/or positive charge **(1)** 4

How to determine *x* graphically

Plot log *N* v. log (sin $\theta/2$) [OR ln on both sides] [Any base] **(1)**

Gradient = *x* **(1)** 2

Meaning of numbers in the symbol for the gold nucleus

Bottom number: 79 protons **(1)**

Top number: 197 ns + ps)
OR)
197 nucleons) **(1)**
OR)
197 – 79 = 118 ns) 2

Mass of alpha particle

Mass of alpha particle ≈ $4 \times m_p$

$= 4 \times 1.67 \times 10^{-27} = 6.7$ [or 6.68] $\times 10^{-27}$ kg **(1)** 1

Calculation of electric force

$F = kq_1q_2/r^2$ OR $q_1q_2/4\pi\varepsilon_o r^2$ **(1)**

$q_1 = 79 \times 1.6 \times 10^{-19}$ C *and* $q_2 = 2 \times 1.6 \times 10^{-19}$ C **(1)**

[stated or subbed]

$\rightarrow F = 14.56$ N **(1)** 3

[12]

48. How properties of particles and antiparticles compare

Same mass/properties, opposite charge **(1)** 1

Energy

$E = mc^2 = 1.67 \times 10^{-27} \times (3 \times 10^8)^2$ J [m or c subbed correctly] **(1)**

$= 1.503 \times 10^{-10}$ J [u.e. if comparison made here]

$= 1.503 \times 10^{-10}/10^9 \times 1.6 \times 10^{-19}$ GeV **(1)**

$= 0.94$ GeV **(1)** 3

[jump to "≈ 1 GeV" omitting last line scores **(1)(1)**×]

Survival of anti-atom

Anti–proton meets proton OR positron meets electron OR (anti-atom) meets atom **(1)**

(leads to) annihilation **(1)** 2

Table 2

	Meson	Baryon	Lepton	
proton		✓		**(1)**
antiproton		✓		
electron			✓	**(1)**
positron			✓	

Quark structure

Antiproton: $2 \times -2/3$ (anti u) + $1 \times + 1/3$ (anti d) **(1)**

= –1 (e not needed) **(1)**

[$3 \times d \Rightarrow -1$ scores ××] 2

[10]

49. Rutherford scattering experiment

Most went (nearly) straight through **(1)**

A small proportion deflected through large angles **(1)** 2

Arrows to diagram

Two arrows directed away from N **(1)** 1

Sketch graph

Speeds equal at A and B **(1)**

A non-zero minimum at P **(1)** 2

Shape of graph

A to P: Force (component) against velocity so decelerates **(1)**

P to B: Force (component) in direction of velocity so accelerates **(1)** 2

Add to diagram

Same initial path but deflected through larger angle **(1)** 1

Observations

More alpha particles deflected/ alphas deflected through larger angles/fewer pass straight through **(1)** 1

[9]

50. Comparison between antiparticle and its particle pair

Similarity: same mass as its particle pair (magnitude of charge) **(1)**

Difference: opposite charge/baryon number/(Iepton number / spin) **(1)** 2

Quark composition

$\bar{u}\ \bar{u}\ \bar{d}$ [OR anti-down etc] **(1)** 1

Baryon number

–1 **(1)** 1

Why difficult to store antiprotons

As soon as they contact protons/matter **(1)**

they annihilate **(1)** 2

Maximum possible mass

×2 **(1)**

÷ 0.93 or equivalent [OR by using $E = mc^2$ to 1.6×10^{-25} kg] **(1)**

96 (u) OR 97 (u) **(1)** 3

[48u x **(1)** **(1)**]

Two reasons why interaction cannot take place

Q/charge not conserved **(1)**

B/baryon number not conserved **(1)** 2

[11]

51. Explanation

Diffraction **(1)**

Molecular/atomic separation ≅ 1nm/de Broglie wavelength **(1)** 2

Kinetic energy

Use of $\lambda = h/mv$ **(1)**

Use of k.e. = $1/2mv^2$ OR $p^2/2m$ **(1)**

k.e. = 9.1-9.2 × 10^{-23} J [no ecf] **(1)** 3

[5]

52. Comparison of positron with electron

Same mass **(1)**

Opposite charge **(1)** 2

Minimum energy

Use of $E = mc^2$ **(1)**

$= 2 \times 9.11 \times 10^{-31} \times (3 \times 10^8)^2$ J
= 1.6398×10^{-13} J **(1)**

[Factor 2 omitted: lose second tick]

$= 1.6398 \times 10^{-13}/1.6 \times 10^{-19}$ $(\times 10^6)$ MeV
= 1.02 MeV **(1)** 3

How process releases energy

Annihilation **(1)** 1

Any two from:

- $\Rightarrow$ em radiation/photon(s)
- 2 photons
- 0.51 MeV each **(1) (1)** Max 2

[8]

53. Alpha particle scattering experiment

Quality of written communication **(1)**

Most alpha went straight through/deflected very little **(1)**

A tiny minority were deflected through large angles / > 90° **(1)**

Atom had a dense/massive nucleus **(1)**

Most of the atom was empty space/small nucleus **(1)**

[5]

54. Classification of particles

Ξ^- is a baryon **(1)**
Λ is a baryon **(1)**
π^- is a meson **(1)** 3
[Allow bbm]

Charge of strange quark

Show that –1 = –1/3(d) + –1/3(s) + –1/3 (s) **(1)** 1

Λ particle

Λ is neutral **(1)**
+2/3 + –1/3 + –1/3 = 0 and uds
OR charge conservation (–1) = 0 + (–1) **(1)** 2

[6]

55. Corrected errors

line 3 **Mesons** are made from q and antiq **(1) (1)**
OR leptons are **fundamental/not made from smaller etc.**

line 4 as line 3 [only one **(1)** for same correction made twice]
OR **quarks, leptons, neutrinos**, and others **(1)**
line 6 Neutron is made from **3 q s (1) (1)**
OR **meson** is made from q and antiq [with restriction as in line 4]

line 10........... **energy** .... [instead of momentum] **(1) (1)** Max 6

[6]

56. Table

(i) particle	(ii) quark content	(iii) antiparticle	(iv) quark content	
proton	**uud**	$\bar{\mathbf{p}}$	$\bar{\mathbf{u}}\bar{\mathbf{u}}\bar{\mathbf{d}}$	**(2)**
π^-	$d\bar{u}$	π^+	$\mathbf{u}\bar{\mathbf{d}}$	**(1)**
K^0	$d\bar{s}$	$\bar{\mathbf{K}}^0$	$\mathbf{s}\bar{\mathbf{d}}$	**(2)**

Shaded boxes show answers: *circled* terms count as one.

Proton is **uud** 1

antiproton or $\bar{\mathbf{p}}$ is $\overline{\mathbf{uud}}$ [allow $\bar{p}^-$ or p-bar] 1

π^+ 1

Anti K^0 is $\bar{\mathbf{K}}^0$ [allow K^0-bar] 1

Quark composition is $\mathbf{u}\bar{\mathbf{d}}$ **and** $\mathbf{s}\bar{\mathbf{d}}$ 1

[5]

57. <u>Outline of evidence from Geiger's and Marsden's scattering experiment</u>

Most alpha particles went (almost) straight through **(1)**

Some or a few deflected at larger angles/>90°/rebounded **(1)**

A tiny minority [e.g. 1 in 8000] were deflected at angles > 90° OR rebounded **(1)** 3

<u>Suggestion</u>

No large deflections/all go (almost) straight through **(1)**

<u>Explanation</u>

No concentrated charge/mass OR no massive object (to hit) no dense object to hit [consequent] **(1)** 2

[5]

58. <u>Fundamental particle</u>

A particle which cannot be further divided/which has no "parts" inside it/one of the 12 particles of which all matter is made **(1)**

[Not "one which cannot decay to another particle"]

<u>Circled fundamental particles in list</u> **(2)**

Positron and muon

[If more than two circled, –1 for each extra one] 3

<u>Explanation</u>

Any three from:

Quality of written communication **(1)**

Mesons are composed of a q and an $\bar{q}$ **(1)**

These have charges ± 2/3 and ± 1/3 **(1)**

Shows all possibilities (+1, 0, – 1) OR other convincing arithmetic to show max +1 **(1)** Max 3

[6]

59. <u>Cathode Ray Tube</u>

Electron emission

- Heating effect (due to current) **(1)**
- (Surface) electrons (break free) because of energy gain **(1)** 2

[Thermionic emission scores both marks]

Electron motion towards anode

The electrons are attracted to/accelerated by the positive anode **(1)** 1

Energy

Electron energy = $(10 \times 10^3\ \text{V})\ (1.6 \times 10^{-19}\ \text{C})$

$=1.6 \times 10^{-15}$ J

Correct use of 1.6×10^{-19} OR use of 10×10^3 **(1)**
Answer **(1)** 2

Number of electrons per second

Number each second = $\dfrac{1.5 \times 10^{-3}\ \text{A}}{1.6 \times 10^{-19}\ \text{J}}$

$9.4 \times 10^{15}\text{s}^{-1}$

Correct conversion mA $\rightarrow$A
Answer **(1)** 2

Rate

Energy each second = $(9.4 \times 10^{15}\ \text{s}^{-1})\ (1.6 \times 10^{-15}\ \text{J})$ **(1)**

= 15 Js^{-1} (W) / 14.4 Js^{-1} **(1)** 2

[ecf their energy]

[9]

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

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

^1_1p and ^4_2He correctly labelled **(1)**

^7_3Li **(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

[8]

61. How diagram confirms pion is negatively charged

Any two from:

- bends opposite way to proton
- reference to magnetic interaction/Fleming's left-hand rule
- proton + $\Rightarrow$ pion – **(1) (1)** 2

Charge carried by lambda particle

Neutral **(1)**

because charge conserved OR +1 – 1 $\Rightarrow$ 0 OR λ not ionising/no track **(1)** 2

Deduction

$r_{\text{pion}} < r_{\text{proton}}$ / straighter / less curved **(1)**

$\Rightarrow$ since $r = p / BQ$ ($P_{\text{pion}} < P_{\text{proton}}$) **(1)** 2

Scale drawing

2 straight lines $l_{pr} > l_{pi}$ **(1)**
Orientation of lines (49°) joined correct way **(1)**
Answer 10 ± 1 kg m s^{-1} **(1)** 3

Classification of particles

	baryon	meson
pion		✓ **(1)**
lambda	✓ **(1)**	

2

Charge of a down quark

–1 / 3 (e) **(1)** 1

[12]

62. Topic C – Nuclear and Particle Physics

Similarly
Same mass

Difference
Charge OR baryon number OR uud quarks $\rightarrow \overline{u}\overline{u}\overline{d}$ **(1)** 2

Any two lepton pairs from the following:

$$\left.\begin{array}{l} e^- \, e^+ \\ \mu^- \, \mu^+ \\ \tau^- \tau^+ \end{array}\right\}$$ NOT e.g. muon and antimuon/$\mu\,\overline{\mu}$

$$\left.\begin{array}{l} \nu_e \, \overline{\nu}_e \\ \nu_\mu \overline{\nu}_\mu \\ \nu_\tau \, \overline{\nu}_\tau \end{array}\right\}$$ 0R just $\nu \; \overline{\nu}$ **(2)** 2

Collision
Particle and antiparticle annihilate/produce a burst of energy/of photons /of gamma rays **(1)** 1

[5]

63. Speed of electron
Selection of $\lambda = h/p$ and $p = m\upsilon$ **(1)**
$m = 9.11 \times 10^{-31}$ **(1)**
$7.2 - 7.3 \times 10^6$ m s^{-1} **(1)**

Kinetic energy
Use of $E_k = 1/2\, m\upsilon^2$ **(1)**
147 – 152 [ecf] **(1)** 5

High energy electron
Nucleus tiny/a lot smaller so λ very small **(1)**
υ or p very large [consequent] **(1)** 2

[7]

64. Quarks: What is meant by “charge = + 2/3”

sign: +/positive/sign same as proton/sign opposite to electron **(1)**

size: 2/3 charge on a proton / electron **(1)** 2

Mass of strange quark in kilograms

$m = 0.2\ \text{GeV}/c^2$

$= 0.2 \times 10^9 \times 1.6 \times 10^{-19}$ **(1)**

$/\ 9 \times 10^{16}$

$= 3.6 \times 10^{-28}$ kg **(1)** 2

Charge and mass of anti–particle to the charmed quark

Charge: $-\dfrac{2}{3}$ **(1)**

Mass: 1.3 GeV/c^2 [No unit penalty for omitting GeV/c^2] **(1)** 2

Prediction of top quark

Symmetry of the model / 3rd generation partner / other valid statement 1

Reason for length of time to find experimental evidence for top quark

High energy needed (to create it) / needs a big accelerator/other valid reason 1

Use of conservation law to explain prediction

Momentum (in context)

Total momentum = 0 OR $m_t \upsilon_t = m_b \upsilon_b$ OR in words

$m_t >> m_b \rightarrow \upsilon_t \ll \upsilon_b$ / greater mass ($\rightarrow$ lower velocity) 3

[11]

65. Atom is neutral **(1)**
Quark composition is $\overline{u}\overline{u}\overline{d}$ **(1)**
Antiproton is (–2/3) + (–2/3) + (+1/3) (= –1) **(1)** 3

Explanation:
As soon as it touches the container/matter **(1)**
(Matter and antimatter) annihilate **(1)**
[Not "cancel"; not "react"] 2

Completion of table:

Quarks			Charge
up	charm	**TOP**	+2/3
down	strange	**BOTTOM**	–1/3

1

[OR TRUTH & BEAUTY]
[Both needed for 1 mark]

(i) Neutral strange meson: $s\bar{d}$ OR $d\bar{s}$ **(1)**

(ii) Positive charmed meson: $c\bar{d}$ OR $c\bar{s}$ **(1)**

(iii) Neutral strange baryon: uss/css/uds/cds OR any of their antiparticles, e.g. $\bar{u}\,\bar{s}\,\bar{s}$ **(1)** 3

[9]

66. <u>Conservation laws</u>:

(i) Charge: (–1) + (+1) = (0) + (–1) + (+1) + (0) **(1)**
Baryon number: (0) + (+1) = (+1) + (0) + (0) + (0) **(1)**
[So possible, no mark]

(ii) Charge: (+1) + (+1) = (+1) + (+1) + (+1) + (–1) **(1)**
Baryon number: (+1) + (+1) = (+1) + (+1) + (+1) + (–1) **(1)** 4
[So possible, no mark]

[4]

67. <u>Isotope of lead</u>:

$^{206}_{82}$Pb 1

<u>Other particles:</u>

(82) electr
ons 1

<u>How appropriate number of quarks can combine:</u>

3 quarks involved **(1)**

2 × + 2/3 + 1 × –1/3 = + 1 **(1)** 2

<u>Explanation:</u>

High energy is needed/high temperature/high speed **(1)**

Mention of $E \rightarrow m$ OR $E = mc^2$ **(1)** 2

<u>Description:</u>

Relates to electron **(1)**

e.g. charge +1/antiparticle/annihilates with **(1)** 2

[8]

68. Charge on strange quark = – 1/3 **(1)** 1

Conservation law:

Charge – (–1) + (+1) $\rightarrow$ (0) + X/by charge conservation **(1)**

X is neutral **(1)** 2

Particle X is a meson **(1)**

Baryon number conservation (0) + (+1) $\rightarrow$ (+1) + (0) **(1)** 2

OR discussion in terms of total number of q + $\bar{q}$ = 5 OR Σq – $\bar{q}$ = 3

Composition of X is s$\bar{d}$ [0/3 if not q$\bar{q}$]**(1)**

Justify S quark:

This is not a weak interaction/only a weak interaction can change quark type/this is a strong interaction/strangeness is conserved/ quark flavour cannot change **(1)**

Justify $\bar{d}$ quark:

X neutral; s – 1/3; $\bar{d}$ + 1/3. [e.c.f. if s = – 1/3 in first line.]

For the third mark accept any q$\bar{q}$ pair that creates a meson of the charge deduced for X above. **(1)** 3

[The justification for both q and $\bar{q}$ can be done also by tracking individual quarks]

[8]

69. Velocity of protons:

$p = Bqr \quad => \quad \upsilon = \frac{Bqr}{m}$ **(1)**

$\upsilon = \frac{0.2 \times 1.60 \times 10^{-19} \times 1.5}{1.67 \times 10^{-27}} = 2.9 \times 10^7 \text{ ms}^{-1}$ **(1)**

[must have 2.9]

$\approx \quad \frac{3 \times 10^8}{10}$ (ms^{-1}) **(1)** 3

Time for last semi-circle of orbit:

$t = \dfrac{d}{\upsilon} = \dfrac{\pi \times 1.5}{2.87 \times 10^{7}}$ **(1)**

$1.6(4) \times 10^{-7}$ s **(1)** 2

Frequency of accelerating p.d.

$f = \dfrac{1}{t}$ = 3.0 MHz [allow ecf] **(1)** 1

[6]

70. Wavelength of photon:

$2E$ **(1)**

$= 135 \times 10^{6} \times 1.6 \times 10^{-19}$ **(1)**

$\Rightarrow E = 1.08 \times 10^{-11}$ J **(1)**

$E = hf = \dfrac{hc}{\lambda}$ **(1)**

$\Rightarrow \quad \lambda = \dfrac{hc}{E}$

$\lambda = 1.84 \times 10^{-14}$ m **(1)** 5

[5]

71. Completion of nuclear equation:

One mark for top line all correct **(1)**

One mark for bottom line all correct

$^{7}_{3}\text{Li} + {}^{1}_{1}\text{p} \rightarrow {}^{7}_{4}\text{Be} + {}^{1}_{0}\text{n}$ 2

Calculation of energy transfer

$P = V \times I = 2.8 \times 10^{6}$ V $\times 2.0 \times 10^{-3}$ A $= 5.6 \times 10^{3}$ W OR 5.6 kW

One mark for value **(1)**

One mark for power of ten and unit **(1)** 2

Demonstration that energy is absorbed at rate of 17 GW per cubic metre:

$$\frac{\text{Power}}{\text{Volume}} = \frac{5.6 \times 10^3 \text{ W}}{280 \times 10^{-6} \text{ m} \times 1.2 \times 10^{-3} \text{ m}^2} = 1.66 \times 10^{10} \text{ W m}^{-3}$$

$= 17$ GW m^{-3}

Substitution **(1)**
Calculation **(1)** 2

Suggested problem:

Very hot/target overheats/vaporises/difficult to cool OR other good relevant physics **(1)** 1

[7]

72. Explanation of how it can be deduced that magnetic field acts out of the plane:

Current flow in opposite direction to e^- movement/same as e^+ movement **(1)**

(Force acts into spiral) hence Fleming's left-hand rule (gives field out of paper) **(1)** 2

Explanation of which e^- moves faster:

(the "atomic" electron) since path is straighter so *r* larger and

$r = \frac{mv}{BQ}$ **(1)** 1

Calculation of momentum:

$p = BQr = 5.4 \times 10^{-3}$ T $\times 1.6 \times 10^{-19}$ C $\times 0.048$ m **(1)**

$= 4.1 \times 10^{-23}$ N s **(1)** 2

Explanation of why path of the positron is a spiral:

Positron continually losing speed/energy (by ionising) 1

Discussion of conservation of *two* properties:

Charge:

e^+ and e^- **(1)**

recoiling electron and stationary positive ion **(1)**

Energy:

e^+ and e^- creation **(1)**

since $E = mc^2$ **(1)**

E_K of recoiling electron **(1)**

E_K of e^+ and e^- pair **(1)**

Ionisation energy **(1)**

Momentum:

Incoming photon momentum goes to recoil electron (mostly) **(1)**

After collision:

Momentum up = momentum down **(1)**

2 go up (one slightly) and only one goes down so down one is faster **(1)** Max 5

[11]

73. In this experiment **alpha particles** were
scattered by thin films of metals such as gold.

The experiment led to the conclusion that the atom had a
positively charged nucleus of diameter approximately **10^{-15} m**
and containing

most of the mass of the atom

[5]