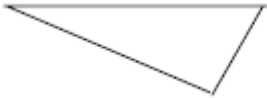
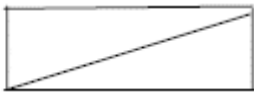


Particle Physics MS

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 = $80 \text{ MeV}/c^2$ 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 $/9 \times 10^{16}$
 Answer 7.1×10^{-30} (kg) 1

- (d) (i) Kaon Meson 1
 Omega baryon 1

- (ii) $K^- + p$ 1
 $= K^+ + K^0 + \Omega^-$
 [accept p or p^+ ;do not accept K for K^0 ;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)

Kinetic 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 c^2 (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 = $35 \text{ mm} \times 6 \text{ mm} / 4.5 \text{ mm}$ 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) ${}_3\text{Li}^7 + {}_1\text{p}^1 = {}_2\text{He}^4 + {}_2\text{He}^4$
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 \times 4.0015 u = 8.0030 u (1)
 $\Delta m = 8.0216 \text{ u} - 8.0030 \text{ u} = 0.0186 \text{ u}$
 $= 0.0186 \times 1.66 \times 10^{-27} \text{ kg} = 3.09 \times 10^{-29} \text{ kg}$ (1)
 $\Delta E = c^2 \Delta m = (3.00 \times 10^8 \text{ m s}^{-1})^2 \times 3.09 \times 10^{-29} \text{ kg} = 2.78 \times 10^{-12} \text{ J}$ (1)
[Allow ecf from equation] 4

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

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

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

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. **Particle classification**

Neutron: baryon and hadron (1)

Neutrino: lepton (1)

Muon: lepton (1)

3

[3]

22. (i) **Conservation laws**

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) **Quark charges**

Use of $sss = -1$ to show $s = -\frac{1}{3}$ (1)

Hence correct working (from baryons) to show $u = \frac{2}{3}$ and $d = -\frac{1}{3}$ (1)

2

[5]

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

OR

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

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

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

3

(ii) $1200 \times 8/100 = 96$ (eV delivered per electron) (1)

$96/2.4 = 40$ (1)

Or

$2.4 \times 100/8 = 30$ (incident eV needed per photon) (1)

$1200/30 = 40$ (1)

Or

$1200 / 2.4 = 500$ (photons per electron, ideally) (1)

$500 \times (8/100) = 40$ (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 v^2 read from graph / gradient (1)

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

$$\Rightarrow m_p = 1.62 - 1.69 \times 10^{-27} \text{ (kg) to 3 s.f. (1)}$$

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 ($\times 10^{-28}$ 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

$$+2/3 + 2/3 - 1/3 = (+) 1 \text{ (1)}$$

Show sum of quark charges in neutron = 0

$$+2/3 - 1/3 - 1/3 = 0 \text{ (1)}$$

[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 $s = \pi D$ (1)
 Answer for speed (1)
 Conclusion (1)

OR

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

$$v = s/t$$

$$s = \pi \times 8000 \text{ (m)}$$

$$v = \pi \times 8000 \times 20\,000 \text{ (m/s)}$$

$$v = 5 \times 10^8 \text{ m/s}$$

inaccurate/not possible since speed $> c$

[4]

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

- (b) Accelerated through $19 \times 10^6 \text{ V / MV}$
 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 $9.11 \times 10^{-31} \times 9 \times 10^{16}$ ($\times 2$)
 $f = 8.2 \times 10^{-14} / 6.6 \times 10^{-34}$ 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)

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

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

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

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

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

- (ii) Appropriate use of 1.6×10^{-19} OR energy from above in J **(1)**
 Answer **(1)**
 momentum = energy/c = $7 \times 10^{12} \times 1.6 \times 10^{-19} \text{ (J)} / (3 \times 10^8 \text{ (m/s)}) =$
 $3.73 \times 10^{-15} \text{ (kg m s}^{-1}\text{)}$ 2

- (iii) Attempt to use $r = p/Bq$ **(1)**
 two correct subs into formula OR rearrangement **(1)**
 circumference => radius **(1)**
 answer **(1)**
 $r = p/Bq$
 $B = p/rQ$
 $= 3.73 \times 10^{-15} / [(27000/2_) \times 1.6 \times 10^{-19}] \text{ (T)}$
 $= 5.4 \text{ T}$ 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

$$\text{Use of } F = \frac{Q_1 Q_2}{4\pi\epsilon_0 r^2} \text{ or } F = \frac{kQ_1 Q_2}{r^2} \text{ (1)}$$

[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:

$$F = \frac{Q_1 Q_2}{4\pi\epsilon_0 r^2} = \frac{(79 \times 1.6 \times 10^{-19} \text{ C}) \times (2 \times 1.6 \times 10^{-19} \text{ C})}{4\pi \times 8.85 \times 10^{-12} \text{ F m}^{-1} \times (1.5 \times 10^{-13} \text{ m})^2}$$

$$= 1.62 \text{ N} \quad 3$$

- (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 = $5000 \times 10^{-12} \text{ kg} / 9.11 \times 10^{-31} \text{ kg} = 5.5 (5.488) \times 10^{21}$ (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)

$$E = mc^2 = 9.11 \times 10^{-31} \times (3 \times 10^8)^2 \text{ J} (= 8.199 \times 10^{-14} \text{ J}) (1)$$

$$E = hf = hc/\lambda \Rightarrow \lambda = hc/E (1)$$

$$= 6.63 \times 10^{-34} \times 3 \times 10^8 / 8.199 \times 10^{-14} \text{ m}$$

$$= 2.4 (2.426 \text{ or } 2.42 \text{ or } 2.43) \times 10^{-12} \text{ m} \text{ [ignore omission of both factors of 2]} (1)$$

[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 circles/circular
 path/spirals

(1)2

$$Bqv = mv^2/r$$

(1)3

$$\text{cyclotron: } T = 2\pi m/Bq$$

(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 \Rightarrow (detectable) curved 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)
 \Rightarrow final momentum zero **(1)**
 [opposite charges repel \Rightarrow xx] 2

- (b) 0.140 GeV/c² **(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 10⁹] **(1)**
 Minimum energy = 1.4 × 10⁸ (eV) **or** 0.14 × 10⁹ (eV) **(1)**
 [0.14 G is **(1)**x] 2

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

[11]

35. β – decay equations

- (i) n = udd and p = uud (1)
 β^- and $\bar{\nu}$ have no quarks / are leptons / are fundamental (1) 2
- (ii) $p \rightarrow n$ (1)
 β^+ and ν [on RHS, allow e^+] (1) 2

[4]

36. Antihydrogen

- (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
- Antimatter storage
- (iv) Annihilates (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)
 $[5.36/5.38/5.4 \times 10^{-11} \text{ (J)}]$ [no ue]
 $\Delta m = \text{energy} \div (9.0 \times 10^{16} \text{ m}^2 \text{ s}^{-2})$ (1)
 $[\text{ecf their energy or } 5 \times 10^{-11}]$ (1)
 $\Delta m \div 1.01 \times 1.66 \times 10^{-27} \text{ kg}$ [ecf their Δm] (1)
 Correct answer (1)
 $[0.36 \text{ or } 36\%]$ [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)
 $\therefore \text{time down linac} = 420 \div 3.9 \times 10^8 \text{ s}^{-1}$
 or $210 \div 3.9 \times 10^8 \text{ s}^{-1}$ (1)
 $[t = 1.07/1.08/1.1 \times 10^{-6} \text{ (s) or } 0.54 \times 10^{-6} \text{ (s)}]$ 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. “The standard model”

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. Calculation of voltage

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

Use of eV (1)

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

Example of calculation:

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

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

$$= 4.1 \times 10^9 \text{ V}$$

3

Role of magnets

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

Calculation of field strength:

$$r = p / Bq \text{ rearranged to } B = p/rq \text{ (1)}$$

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

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

Example of calculation:

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

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

$$= 0.124 \text{ T}$$

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

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

[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 $\frac{1}{2}mv^2$ (1)
 $[E = (1.07 \times 10^{-19})^2 / (2 \times 4 \times 1.67 \times 10^{-27})]$ J]
7. 8.6×10^{-13} J (1)

(5.4 MeV/5.4 × 10⁶ eV)

7

[7]

43. Base units of eV

- (i) Reference to joule (1)

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

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

${}^1_1\text{p}$ and ${}^1_0\text{n}$ (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)

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

2

Unit of mass

$$\Delta E = c^2 \Delta m \text{ so } \Delta m = \Delta E / c^2 \text{ (1)}$$

GeV is energy \Rightarrow GeV/ c^2 is mass (1)

2

Mass of Higgs boson

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

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

2

Antiparticle

Same mass and opposite charge (1)

[Accept Particle and its antiparticle annihilate (\rightarrow 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. | <u>Particle X</u> | |
| | Positive (1) | 1 |
| | Is a baryon (1) | 1 |
| | <u>Quark compositions</u> | |
| | Proton uud; neutron udd BOTH (1) | 1 |
| | <u>Explanation and deduction of identity of X</u> | |
| | 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. | <u>Results of experiments and conclusions</u> | |
| | <u>Most pass straight through/undeflected (1)</u> | |
| | A few deflect/reflect (at large angles) (1) | |
| | Small nucleus/mostly empty space (1) | |
| | Concentrated mass and/or positive charge (1) | 4 |
| | <u>How to determine x graphically</u> | |
| | Plot $\log N$ v. $\log (\sin \theta/2)$ [OR \ln on both sides] [Any base] (1) | |
| | Gradient = x (1) | 2 |
| | <u>Meaning of numbers in the symbol for the gold nucleus</u> | |
| | Bottom number: 79 protons (1) | |
| | Top number: $197 = n_s + p_s$) | |
| | OR) | |
| | $197 = \text{nucleons}$) (1) | |
| | OR) | |
| | $197 - 79 = 118 = n_s$) | 2 |

Mass of alpha particle

Mass of alpha particle $\approx 4 \times m_p$

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

Calculation of electric force

$F = kq_1q_2/r^2$ OR $q_1q_2/4\pi\epsilon_0 r^2$ (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 × d ⇒ -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. | <u>Comparison between antiparticle and its particle pair</u> | | |
| | Similarity: same mass as its particle pair (magnitude of charge) (1) | | |
| | Difference: opposite charge/baryon number/(lepton number / spin) (1) | 2 | |
| | <u>Quark composition</u> | | |
| | $\bar{u} \bar{u} \bar{d}$ [OR anti-down etc] (1) | 1 | |
| | <u>Baryon number</u> | | |
| | -1 (1) | 1 | |
| | <u>Why difficult to store antiprotons</u> | | |
| | As soon as they <u>contact</u> protons/matter (1) | | |
| | they <u>annihilate</u> (1) | 2 | |
| | <u>Maximum possible mass</u> | | |
| | $\times 2$ (1) | | |
| | $\div 0.93$ 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)] | | |
| | <u>Two reasons why interaction cannot take place</u> | | |
| | Q/charge not conserved (1) | | |
| | B/baryon number not conserved (1) | 2 | |
| | | | [11] |
| 51. | <u>Explanation</u> | | |
| | Diffraction (1) | | |
| | Molecular/atomic separation \cong 1nm/de Broglie wavelength (1) | 2 | |
| | <u>Kinetic energy</u> | | |
| | Use of $\lambda = h/mv$ (1) | | |
| | Use of k.e. = $1/2mv^2$ OR $p^2/2m$ (1) | | |
| | k.e. = $9.1-9.2 \times 10^{-23}$ 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)

$$= 2 \times 9.11 \times 10^{-31} \times (3 \times 10^8)^2 \text{ J}$$

$$= 1.6398 \times 10^{-13} \text{ J (1)}$$

[Factor 2 omitted: lose second tick]

$$= 1.6398 \times 10^{-13} / 1.6 \times 10^{-19} (\times 10^6) \text{ MeV}$$

$$= 1.02 \text{ MeV (1)}$$

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 / $> 90^\circ$ (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{p} | uud | (2) |
| π^- | d \bar{u} | π^+ | u\bar{d} | (1) |
| K^0 | d \bar{s} | \bar{K}^0 | s\bar{d} | (2) |

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

Proton is **uud** 1

antiproton or \bar{p} is **uud** [allow \bar{p} or p-bar] 1

π^+ 1

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

Quark composition is **ud and sd** 1

[5]

57. Outline of evidence from Geiger's and Marsden's scattering experiment
 Most alpha particles went (almost) straight through (1)
 Some or a few deflected at larger angles/ $>90^\circ$ /rebounded (1)
 A tiny minority [e.g. 1 in 8000] were deflected at angles $> 90^\circ$ OR rebounded (1) 3

Suggestion

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

Explanation

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

[5]

58. Fundamental particle

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"]

Circled fundamental particles in list (2)

Positron and muon

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

Explanation

Any three from:

Quality of written communication (1)

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

These have charges $\pm 2/3$ and $\pm 1/3$ (1)

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

[6]

59. Cathode Ray Tube

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

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

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

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

Number of electrons per second

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

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

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)
 $= 15 \text{ Js}^{-1} \text{ (W)} / 14.4 \text{ Js}^{-1}$ (1) 2

[ecf their energy]

[9]

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

(ii) $\text{H/p} + \text{Li} \rightarrow 2\alpha/2\text{He}$ (1)

${}^1_1\text{p}$ and ${}^4_2\text{He}$ correctly labelled (1)

${}^7_3\text{Li}$ (1) 4

(iii) Mass defect = 0.01865u (1)

Either

Use of $\times 1.66 \times 10^{-27}$

Use of $\times 9.0 \times 10^{16}$

$\Rightarrow 2.79 \times 10^{-12}$ J

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

Or

Use of $\times 930$ (1)

Use of $\times 1.6 \times 10^{-13}$ (1)

$\Rightarrow 2.78 \times 10^{-12}$ J (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 $l_{\text{pr}} > l_{\text{pi}}$ (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 $\rightarrow \overline{u\bar{u}\bar{d}}$ (1)

2

Any two lepton pairs from the following:

$e^- e^+$ (

$\mu^- \mu^+$ (NOT e.g. muon and antimuon/ $\mu \bar{\mu}$

$\tau^- \tau^+$)

$\nu_e \bar{\nu}_e$)

$\nu_\mu \bar{\nu}_\mu$ } OR just $\nu \bar{\nu}$ (2)

2

$\nu_\tau \bar{\nu}_\tau$)

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 $p = m v$ (1)

$m = 9.11 \times 10^{-31}$ (1)

$7.2 - 7.3 \times 10^6 \text{ m s}^{-1}$ (1)

Kinetic energy

Use of $E_k = 1/2 m v^2$ (1)

147 – 152 [ecf] (1)

5

High energy electron

Nucleus tiny/a lot smaller so λ very small (1)

v 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

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

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

$/ 9 \times 10^{16}$

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

2

Charge and mass of anti-particle to the charmed quark

Charge: $-\frac{2}{3} \text{ (1)}$

Mass: $1.3 \text{ GeV}/c^2$ [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 $m_t v_t = m_b v_b$ OR in words

$m_t \gg m_b \rightarrow v_t \ll v_b$ / greater mass (\rightarrow lower velocity)

3

[11]

65. Atom is neutral (1)

Quark composition is $\bar{u}\bar{u}\bar{d}$ (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. Conservation laws:

- (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)
[So possible, no mark]

4

[4]

67. Isotope of lead:



1

Other particles:

(82)
ons

electr
1

How appropriate number of quarks can combine:

3 quarks involved (1)

$$2 \times +2/3 + 1 \times -1/3 = +1 \text{ (1)}$$

2

Explanation:

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

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

2

Description:

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 $\Sigma q - \bar{q} = 3$

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:

$$p = Bqr \quad \Rightarrow \quad v = \frac{Bqr}{m} \text{ (1)}$$

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

[must have 2.9]

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

Time for last semi-circle of orbit:

$$t = \frac{d}{v} = \frac{\pi \times 1.5}{2.87 \times 10^7} \text{ (1)}$$

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

2

Frequency of accelerating p.d.

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

1

[6]

70. Wavelength of photon:

$$2E \text{ (1)}$$

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

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

$$E = hf = \frac{hc}{\lambda} \text{ (1)}$$

$$\Rightarrow \lambda = \frac{hc}{E}$$

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

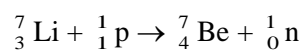
5

[5]

71. Completion of nuclear equation:

One mark for top line all correct (1)

One mark for bottom line all correct



2

Calculation of energy transfer

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

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:

$$\frac{\text{Power}}{\text{Volume}} = \frac{5.6 \times 10^3 \text{ W}}{280 \times 10^{-6} \text{ m} \times 1.2 \times 10^{-3} \text{ m}^2} = 1.66 \times 10^{10} \text{ W m}^{-3}$$
$$= 17 \text{ GW m}^{-3}$$

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

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

1

Calculation of momentum:

$$p = BQr = 5.4 \times 10^{-3} \text{ T} \times 1.6 \times 10^{-19} \text{ C} \times 0.048 \text{ m} \text{ (1)}$$
$$= 4.1 \times 10^{-23} \text{ N s} \text{ (1)}$$

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]