# 3.11 Physics: Nuclear and Particle Physics: 1-hour Pack

AQA 7408 · Calculator allowed · about 60 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

**Answer ALL questions. Show all your working.**

**1** Iodine-131 is used to treat an overactive thyroid gland, with a half-life of 8.02 days. Use $A = \lambda \times N$ and $A = A0 \times e^{-\lambda \times t}$, where $\lambda = \ln 2 / (\text{half-life})$. Take $1\ u = 1.66 \times 10^{-27}$ kg.

**(a)** Show that the decay constant of iodine-131 is about $1.00 \times 10^{-6}$ per second. **(2)**

**(b)** A hospital pharmacy prepares a dose of iodine-131 with an initial activity of $4.00 \times 10^{8}$ Bq (400 MBq). Calculate the number of iodine-131 nuclei present in this dose. **(2)**

**(c)** Calculate the mass of iodine-131 in this dose, given that the mass of one iodine-131 atom is approximately 131 u. **(2)**

**(d)** Calculate the activity of the dose 5.00 days after preparation. **(3)**

**(e)** Technetium-99m, used only for short diagnostic imaging scans, has a half-life of about 6 hours, far shorter than iodine-131's 8.02 days. Explain why a longer half-life, such as iodine-131's, is more appropriate for a therapeutic (treatment) dose, and suggest why a half-life of days, rather than an extremely long-lived alternative of many years, is still preferred. **(3)**

**(Total for Question 1 is 12 marks)**


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**2** In a particle detector, a charged particle moving perpendicular to a uniform magnetic flux density B follows a circular arc of radius r, since the magnetic force provides the centripetal force: $B \times Q \times v = m \times v^2 / r$, where Q is the magnitude of the particle's charge.

**(a)** Show that the particle's momentum $p = m \times v$ can be written $p = B \times Q \times r$. **(2)**

**(b)** A particle track in a detector, with B = 0.850 T, has a measured radius of curvature r = 0.320 m, and the particle is known to carry a charge of magnitude $e = 1.60 \times 10^{-19}$ C. Calculate its momentum. **(2)**

**(c)** Two particle tracks are produced from the same point, curving in opposite directions in the magnetic field. State what this indicates about the two particles, and explain how the direction of curvature, combined with the known direction of B, can be used to determine the sign of a particle's charge. **(3)**

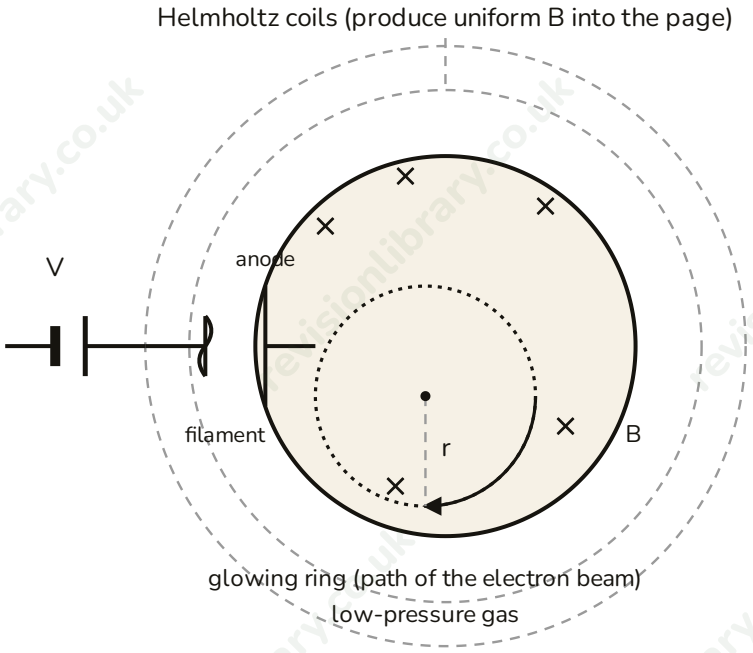
**(d)** Explain why particles with greater momentum produce tracks of larger radius of curvature, for a fixed magnetic flux density and charge. **(2)**

**(e)** A neutral particle leaves no track of its own, but its presence and momentum can sometimes still be inferred. Suggest how physicists identify the existence of a short-lived, electrically neutral particle that itself decays into charged particles, using track data alone. **(2)**

**(Total for Question 2 is 11 marks)**


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**3** Required practical: in a fine beam tube experiment, electrons are accelerated from rest through a potential difference V, then enter a region of low-pressure gas where a uniform magnetic flux density B, produced by a pair of Helmholtz coils, acts perpendicular to their velocity. The electrons then travel in a circular path of radius r, visible as a glowing ring due to ionisation of the gas. Use $v = \sqrt{2 \times e \times V / m}$ and $r = m \times v / (e \times B)$, where e/m is the electron's specific charge.




**(a)** Show that the speed v of an electron leaving the electron gun, having been accelerated from rest through potential difference V, is given by $v = \sqrt{2 \times e \times V / m}$. **(2)**

**(b)** By combining $v = \sqrt{2eV/m}$ with $r = mv/(eB)$, show that the specific charge of the electron can be found using $e/m = 2V / (B^2 \times r^2)$. **(3)**

**(c)** In one trial, V = 200 V and B = $4.00 \times 10^{-4}$ T, giving a measured path radius r = 11.9 cm. Calculate a value for e/m from this data. **(3)**

**(d)** The accepted value of e/m for the electron is $1.76 \times 10^{11}$ C/kg. Calculate the percentage difference between the value found in (c) and this accepted value. **(2)**

**(e)** State two adjustments a student could make to reduce the percentage uncertainty in their measurement of r. **(2)**

**(f)** Explain why this method could not be used with useful precision to determine the specific charge of a proton, using the same apparatus and typical laboratory values of V and B. **(2)**

**(Total for Question 3 is 14 marks)**


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**4** The up (u), down (d) and strange (s) quarks have charges of +2/3 e, -1/3 e and -1/3 e respectively; only the strange quark (or antiquark) carries non-zero strangeness, with the s quark having strangeness -1 and the s-bar antiquark having strangeness +1.

**(a)** The Sigma-plus baryon, Sigma+, has strangeness S = -1 and overall charge +1 e, and (like the proton) is made of three quarks chosen from up, down and strange. Deduce its quark composition, explaining your reasoning. **(3)**

**(b)** The K- meson has quark composition: one strange quark (s) and one up antiquark (u-bar). Calculate its overall charge and state its strangeness, explaining your reasoning for each. **(3)**

**(c)** State one property that is always identical between a particle and its corresponding antiparticle, and one property that is equal in magnitude but always opposite in sign. **(2)**

**(d)** The muon (μ-) and the tau (tau-), like the electron, are classified as leptons. State two similarities and one difference between the electron, the muon and the tau. **(3)**

**(Total for Question 4 is 11 marks)**


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# Mark scheme · 3.11 Physics: Nuclear and Particle Physics: 1-hour Pack

## Question 1

(a) half-life converted to seconds: 8.02 x 24 x 3600 = 6.93 x $10^5$ s **M1**

(a) $\lambda = \ln 2 / 6.93 \times 10^5 = 1.00 \times 10^{-6}$ $s^{-1}$ shown (cso, answer given) **A1**

**(a) Answer: $\lambda = 1.00 \times 10^{-6}$ $s^{-1}$**

(b) N0 = A0 / λ correctly substituted, ft from (a) **M1**

(b) N0 = 4.00 x $10^{14}$ (awrt) **A1**

**(b) Answer: N0 = 4.00 x $10^{14}$ nuclei**

(c) mass = N0 x 131 x 1.66 x $10^{-27}$ correctly substituted, ft from (b) **M1**

(c) mass = 8.70 x $10^{-11}$ kg (or 87.0 ng), awrt, ecf **A1**

**(c) Answer: mass = 8.70 x $10^{-11}$ kg (87.0 nanograms)**

(d) t converted to seconds (5.00 x 86400 = 4.32 x $10^5$ s) and substituted into $A = A0 \times e^{-\lambda \times t}$ **M1**

(d) exponent evaluated correctly: λ x t = 0.432, giving $e^{-0.432}$ = 0.649 **M1**

(d) A = 2.60 x $10^8$ Bq (awrt, ft from a and b) **A1**

**(d) Answer: A = 2.60 x $10^8$ Bq**

(e) a longer half-life allows the isotope to remain active and continue delivering radiation to the target tissue over the several days needed for the treatment to take effect, whereas a short-lived isotope like technetium-99m would decay away almost completely within a day, delivering too little dose, oe **B1**

(e) a half-life of only days (rather than years) still means the patient's activity falls to a safe level within a reasonably short time after treatment, limiting the total radiation dose received by the patient and by other people, oe **B1**

(e) coherent balance of both points made explicit, i.e. the half-life needs to be long enough for treatment but short enough for safety, oe **B1**

**(e) Answer: A longer half-life sustains the dose over the days needed for treatment to work, unlike a short-lived isotope; but a half-life of days (not years) still allows activity to fall to a safe level soon after treatment, limiting total radiation exposure.**

## Question 2

(a) B x Q x v = m x $v^2$ / r rearranged to give B x Q = m x v / r **M1**

(a) p = m x v = B x Q x r (cso, answer given) **A1**

**(a) Answer: p = BQr**

(b) p = B x Q x r correctly substituted **M1**

(b) p = 4.35 x $10^{-20}$ kg m/s (awrt 3 s.f.) **A1**

**(b) Answer: p = 4.35 x $10^{-20}$ kg m/s**

(c) the two particles carry charge of opposite sign, since they experience the magnetic force in opposite senses (curving in opposite directions) for the same field and similar initial velocity, oe **B1**

(c) with the direction of B and the initial velocity known, the force direction expected for a positive charge (from F = qv x B) can be predicted, and compared with the observed curvature, oe **B1**

(c) a particle curving the way expected for a positive charge is positive; a particle curving the opposite way is negative, oe **B1**

**(c) Answer: Opposite curvature indicates opposite-sign charges. Comparing the observed curvature with the direction predicted by F = qv x B for a positive charge (given B and the initial velocity) identifies the sign of each particle's charge.**

(d) rearranging p = BQr gives r = p / (BQ), so for fixed B and Q, r is directly proportional to p, oe **B1**

(d) a higher-momentum particle is harder to deflect (needs a larger radius to provide the required centripetal force at that momentum), so its track curves more gently, oe **B1**

**(d) Answer: Since r = p/(BQ), radius is directly proportional to momentum for fixed B and Q; higher-momentum particles are harder to deflect and so curve more gently (larger radius).**

(e) the neutral particle's decay point appears as a 'vertex' where two or more charged tracks begin from an empty point, with no incoming charged track leading to it, oe **B1**

(e) applying conservation of momentum and energy to the visible charged decay products (working backwards from their measured momenta) allows the momentum, energy and identity of the original neutral particle to be reconstructed, oe **B1**

**(e) Answer: The decay shows up as charged tracks appearing to originate from an empty point (no incoming track). Applying conservation of momentum and energy to these visible tracks allows the neutral parent particle's properties to be reconstructed.**


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## Question 3

(a) the work done accelerating the electron equals the kinetic energy gained: e x V = (1/2) x m x $v^2$, oe **M1**

(a) correctly rearranged to v = $\sqrt{2 \text{ x e x V / m}}$ (cso, answer given) **A1**

**(a) Answer: e x V = (1/2) x m x $v^2$, rearranged to give v = $\sqrt{2eV/m}$.**

(b) r = mv/(eB) rearranged to give v = eBr/m **M1**

(b) correct substitution of v = eBr/m into eV = (1/2)$mv^2$ to eliminate v **M1**

(b) correctly rearranged to e/m = 2V / ($B^2$ x $r^2$) (cso, answer given) **A1**

**(b) Answer: e/m = 2V / ($B^2$ $r^2$)**

(c) r converted to metres (0.119 m) and correctly substituted into e/m = 2V/($B^2$ $r^2$) **M1**

(c) $B^2$ $r^2$ correctly evaluated (2.27 x $10^{-9}$, awrt) **M1**

(c) e/m = 1.77 x $10^{11}$ C/kg (awrt 3 s.f., allow 1.76 to 1.77 x $10^{11}$) **A1**

**(c) Answer: e/m = 1.77 x $10^{11}$ C/kg**

(d) percentage difference = |experimental - accepted| / accepted x 100, correctly substituted (ft from c) **M1**

(d) 0.3% (awrt, allow 0.3 to 0.4%) **A1**

**(d) Answer: approximately 0.3%**

(e) use a lower B or higher V so that the path radius r is larger, making the (fixed) absolute uncertainty in reading r a smaller percentage of the measurement, oe **B1**

(e) use a method that reduces parallax/reading error, e.g. a mirror behind the scale, or measure the diameter across the ring at several points and average, oe **B1**

**(e) Answer: Increase r (by lowering B or raising V) so the fixed reading uncertainty is a smaller percentage; use a mirror scale or average several diameter readings to reduce parallax error.**

(f) a proton has a much larger mass than an electron, so for the same B and V, its radius of curvature r = mv/(eB) (or equivalently derived from e/m = 2V/($B^2r^2$)) would be far larger, oe **B1**

(f) within a laboratory-sized fine beam tube, the resulting radius would be too large to measure accurately (the path would appear almost straight), so useful precision could not be achieved, oe **B1**

**(f) Answer: A proton's much greater mass means, for the same V and B, its path radius would be far larger than an electron's - too large to curve appreciably or be measured accurately within a laboratory-sized tube.**

## Question 4

(a) since Sigma+ has strangeness -1 and only a strange quark carries strangeness -1, it must contain exactly one strange (s) quark **B1**

(a) the remaining two quarks must together contribute a charge of +1 - (-1/3) = +4/3 e **B1**

(a) this is only achieved by two up quarks (+2/3 + 2/3 = +4/3), giving a composition of uus **B1**

**(a) Answer: Sigma+ = uus (two up quarks and one strange quark).**

(b) charge of u-bar = -2/3 e (opposite of the up quark's +2/3 e), so total charge = -1/3 + (-2/3) = -1 e **B1**

(b) strangeness = -1, since the s quark contributes strangeness -1 and the u-bar (containing no strange quark) contributes 0 **B1**

(b) correct overall reasoning shown linking quark charges/strangeness to the totals (cso for both final values) **B1**

**(b) Answer: Charge = -1 e; strangeness = -1.**

(c) identical property: rest mass (or spin) **B1**

(c) opposite-sign property: charge (or baryon number, lepton number, or strangeness) **B1**

**(c) Answer: Rest mass is identical for a particle and its antiparticle; charge (and quantum numbers such as baryon number, lepton number and strangeness) are equal in magnitude but opposite in sign.**

(d) first valid similarity, e.g. all three carry charge -1 e **B1**

(d) second valid similarity, e.g. each is a fundamental (point-like) lepton, not made of quarks, and each has its own associated neutrino **B1**

(d) valid difference, e.g. they have very different (increasing) rest masses, electron less than muon less than tau, and only the electron is stable (the muon and tau are unstable and decay) **B1**

**(d) Answer: Similarities: all carry charge -1e and are fundamental leptons (not made of quarks), each with its own neutrino. Difference: their rest masses differ greatly (electron < muon < tau), and only the electron is stable.**


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