| Qn | Expected Answers | Marks | Additional guidance |
|---|---|---|---|
| 1 (a) | A ✓ | 1 | |
| 1(b) | B ✓ | 1 | |
| 2 | Unit of $f^2$ is $s^{-2}$ ✓or f is $s^{-1}$ (unit of x is m therefore) combined unit is m $s^{-2}$ (which is the unit of acceleration.) ✓ | 2 | |
| 3 (a) | M= Q/C.Δθ = 1.6 x $10^8$/4 200 x 37✓ = 1030 kg✓ (1000 kg to 2 sf acceptable) | 2 | One mark if 310 used giving 123 kg |
| 3(b) | e.g. lower body temperature, you just can't do it(approx twenty times body mass), too much fluid absorbed ✓ | 1 | Any sensible comment |
| 4 (a) | 70 m $s^{-1}$✓ | 1 | |
| 4(b) | 70 x 0.11 = 7.7 ✓ kg m $s^{-1}$✓ Ns e.c.f. from (a) | 2 | |
| 5(a) | Area under graph (equiv to ½ QV) = ½ x 3.5 x $10^{-3}$ x 8 ✓ = 0.014 J ✓ | 2 | |
| 5(b) | Grad = 3 x $10^{-3}$/6.8 (for example) ✓ = 4.4 x $10^{-4}$ F✓ | 2 | Answers in range 4.3 to 4.6 (x $10^{-4}$). Penalise 4 or more sf |
| 6(a) | E ~ kT = 1.38 x $10^{-23}$ x 10, 000✓ = 1.38 x $10^{-19}$ J✓ If3/2 kT used accept 2.1 x $10^{-19}$ J | 2 | Need to give own value of answer |
| 6(b) | Collision between atoms ✓ distribution or transfer of energy (speed) ✓ or more sophisticated answers linked to statistical arguments. | 2 | |
| 7 | First line of table:2.4 x $10^{-3}$, 4.8 x $10^{-3}$ ✓ Second line of table:2.2 x $10^{-3}$, 4.4 x $10^{-3}$, ✓ 4.7 x $10^{-2}$ ✓ | 3 | Look carefully at the table. Ecf for third marking point only. |

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|---|---|---|---|
| 8(a) | Time for one (complete) oscillation OWTTE ✓ | 1 | |
| 8(b) | 1.0 m✓ or 1 m | 1 | |
| (c)(i) | Either: $T^2$ vs L, T vs$L^{1/2}$ or Lg T vs Lg L ✓ | 1 | |
| (c)(ii) | Consistent: straight line✓ through origin ✓or, for lg graph, gradient of straight line✓= 2 (or ½ ✓) | 2 | |
| (d) | Energy lost per oscillation= mgh ✓/43 000 = 9 x 9.8 x1.2 /43 000✓ = 2.46 mJ ✓ | 3 | Need to give own value of answer if method not clear. |
| (e) (i) | runs for longer✓ as more stored energy✓ | 2 | Can argue that smaller mass gives same stored energy . |
| (e) (ii) | Any two from: * longer L gives larger T<br>*longer L allows smaller changes in time period (i.e. to make clock run a little slower/quicker)<br>*large mass bob has more energy in system<br>*(fractional) energy loss per oscillation smaller<br>*air resistance has less effect on a massive bob | 2 | Don't award 'runs for longer' as a conclusion twice. |
| 9 (a) | Time = $2\pi$ r/1.7 x $10^4$ ✓ = 155230 s ✓ = 43.1 hours | 2 | |
| (b) (i) | $-GMm/r^2$ ✓ = $-mv^2/r$<br>So: $GM/r^2$ = $v^2/r$✓<br>Therefore M = $v^2r/G$ | 2 | |
| (ii) | M = (1.7 x $10^4)^2$ x 4.2 x $10^8$/ 6.67 x $10^{-11}$ ✓<br>= 1.82 x $10^{27}$ kg ✓ | 2 | Need to give own value of answer if method not clear |
| (c) | Vg = -GM/r = - 6.67 x $10^{-11}$ x 1.9 x $10^{27}$/7.1 x $10^7$ ✓<br>= -1.79 x $10^9$ J $kg^{-1}$ ✓ | 2 | |
| (d) (i) | ½ $mv^2$ =½ x 4 x $10^{12}$ x $10000^2$ = 2 x $10^{20}$ J ✓ | 1 | |
| d(ii) | the fragment will have gained k.e. ✓ as it lost gpe during the approach to the planet. ✓<br>(Or force argument: Attracted by gravity✓ causes it to accelerate✓ | 2 | Penalise inconsistent argument. Do not allow 'increasing gravity' arguments. |
| 10 (a)(i) | -E/kT is very large ✓ (or $e^{-\text{large number}}$ is small, or $1/e^{\text{large number}}$ is small) OWTTE | 1 | |
| (a)(ii) | E/kT approaches zero, ✓ so BF approaches one | 1 | Or $e^{-x}$ where x is a positive number must be less than one. |
| (a) (iii) | $e^{-1}$ ✓ = 0.37 OWTTE | 1 | |
| (b) (i) | F = $e^{-1.3 \times 10^{-19}/1.38 \times 10^{-23} \times 310}$✓ = $e^{-30}$ = 9.4 x $10^{-14}$✓<br>($e^{-30.2}$ = 6.3 x $10^{-14}$)✓ | 2 | Need to give own value of answer |
| (b)(ii) | F = $e^{-6.0 \times 10^{-20}/1.38 \times 10^{-23} \times 310}$✓ = 8.1 x $10^{-7}$ ✓<br>8.1 x $10^{-7}$/6.3 x $10^{-14}$ = 1.2 x $10^7$ ✓ | 3 | 6 x $10^{-14}$ gives 1.35 x $10^7$ |

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| b) iii) | Higher factor means more molecules are able ✓ to react because they enough (sufficient) energy. ✓ | 2 | Don't allow 'more energy' |
| 11(a) i) | $12/2.5 \times 10^{18}$✓ = $4.8 \times 10^{-18}$✓ | 2 | Need to give own value of answer |
| a) ii) | $0.693/ 5 \times 10^{-18} = 1.39 \times 10^{17}$ s ✓ = $4.3 \times 10^{9}$ years. ✓ (or using $4.8 \times 10^{-18}$ gives $4.5 \times 10^{9}$ years ) | 2 | |
| a) iii) | radioactive decay is a random process ✓so all that is known is that in a given sample a given number will decay, but not which nuclei. | 1 | |
| 11(b) | 3 half lives✓ = $3 \times 4.3 \times 10^{9}$□ = $1.3 \times 10^{10}$ years✓ | 2 | ecf a(ii) |
| 11(b) ii) | Because the stars were not formed before the universe ✓ (but some time after) | 1 | |
| c)(i) | Minimum age = $9.8 \times 10^{9}$ yr ✓maximum = $1.9 \times 10^{10}$ yr✓ ($3.1 \times 10^{17}$ and $6.3 \times 10^{17}$ in seconds) | 2 | One mark if both correct but in s. |
| c) ii) | It shows that the younger age of the universe can't be correct ✓ hence larger value of Ho incorrect ✓ | 2 | Must be focused on values given (c) |
| | Quality of written communication | 4 max | |

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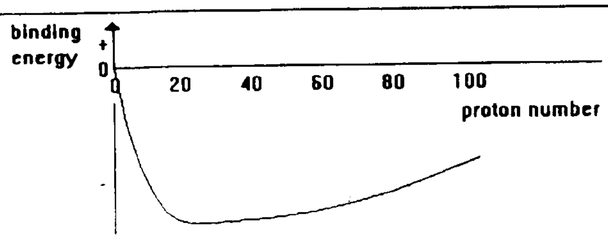
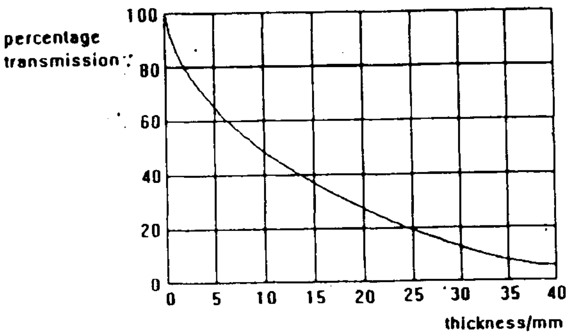
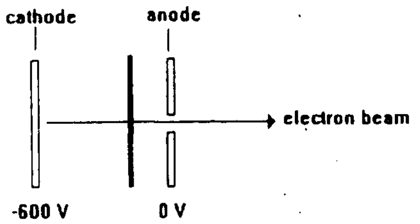
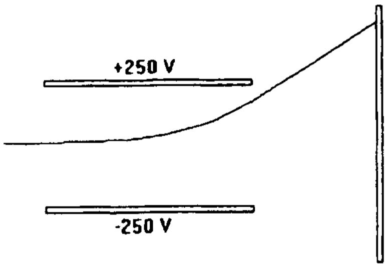
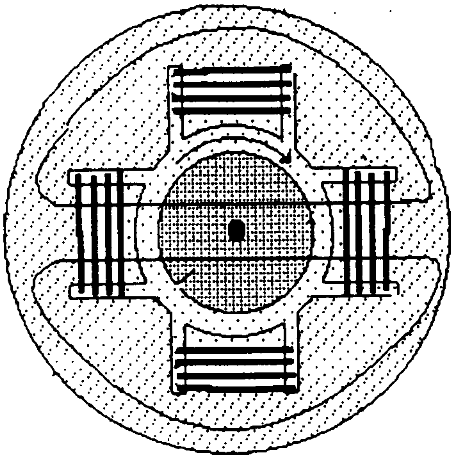
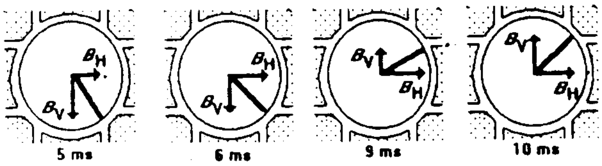
| Qn | Expected Answers | Marks | Additional guidance |
|---|---|---|---|
| 1 (a) | neutrino | 1 | |
| 1 (b) | alpha | 1 | |
| 1 (c) | proton | 1 | |
| 2 (a) | 90 mWb = $90\times10^{-3}$ Wb, 450 μs = $450\times10^{-6}$ s<br>$90\times10^{-3}/450\times10^{-6}$ (= 200 Wb $s^{-1}$) | 1<br>1 | |
| 2 (b) | 200 V | 1 | |
| 3 | gradient/slope | 1 | |
| 4 | C | 1 | |
| 5 | $F = qvB$ (eor)<br>$F = 0.25 \times 3.2\times10^{-19} \times 1.5\times10^{7} = 1.2\times10^{-12}$ N | 1<br>1 | |
| 6 (a) | 3.0 - 2.5 = 0.5 eV | 1 | |
| 6 (b) | A | 1 | |
| 7 | six | 1 | |
| 8 |  | 4 | minimum between 20 and 40 [1]<br>tends to 0 at small proton number [1]<br>slow increase above 40 [1]<br>to less than half minimum value [1] |
| 9 | $B = F/Il$<br>T ≡ N $A^{-1}$ $m^{-1}$<br>T ≡ kg m $s^{-2}$ $A^{-1}$ $m^{-1}$ | 1<br>1<br>1 | accept correct alternative demonstrations for [3] |

| Qn | Expected Answers | Marks | Additional guidance |
|---|---|---|---|
| 10(a) | $A = \lambda N$ (owtte)<br>large $T_{1/2}$ means small decay constant $\lambda$ | 1<br>1 | |
| 10(b)(i) |  | 3 | starts at 100% [1]<br>exponential shape [1]<br>going through correct points (by eye) [1] |
| 10(b)(ii) | 18% transmission<br>(accept between 15% and 20%)<br>ecf: activity = $0.18 \times 4.0\times10^4 = 7.2\times10^3$ s$^{-1}$ | 1<br><br>1 | ecf from graph<br><br>(accept between $6.0\times10^3$ and $8.0\times10^3$) |
| 10(c)(i) | particles emitted in all directions, body only on one side (AW) | 1 | |
| 10(c)(ii) | energy absorbed = activity × time × energy<br>$= 0.5 \times 4\times10^4 \times 8.8\times10^{-14} \times 3600 = 6.3\times10^{-6}$ J | 1<br>1 | |
| 10(c)(iii) | any of the following, maximum [2]<br>• beta has short range so dose is **not** shared over whole body<br>• dose equivalent to tissue around source will be between 1 and 100 μSv<br>• still much smaller than annual background dose of 2 mSv, so risk is small<br>• calculation of relative risk | 2 | |

| Qn | Expected Answers | Marks | Additional guidance |
|---|---|---|---|
| 11(a)(i) |  | 2 | line parallel to cathode (can curve at edges) [1]<br><br>1/3rd way across from anode to cathode (by eye) [1] |
| 11(a)(ii) | $E_K = eV$<br>$E_K = 1.6\times10^{-19} \times 600 = 9.6\times10^{-17}$ J | 1<br>1 | |
| 11(b)(i) | five lines at right angles where touch plates (by eye)<br>evenly spaced with downwards arrows | 1<br><br>1 | accept increased spacing/outward curved lines at edges |
| 11(b)(ii) | 500 V | 1 | |
| 11(b)(iii) | $E = V/d$<br>$E = 500 / 40\times10^{-3} = 1.25\times10^{4}$<br>N $C^{-1}$ or V $m^{-1}$ or correct equivalent | 1<br>1<br>1 | ecf 12(b)(ii) |
| 11(d)(i) |  | 3 | parabolic inside deflection plates [1]<br><br>straight outside (both ends) [1]<br><br>upwards deflection [1] |
| 11(d)(ii) | any of the following, maximum [2]<br>• constant horizontal speed/no horizontal force<br>• vertical acceleration/force between plates<br>• due to electric field/attraction to upper plate/repulsion from lower plate<br>• no forces outside field region (owtte) | 2 | |

| Qn | Expected Answers | Marks | Additional guidance |
|---|---|---|---|
| 12(a)(i) | $V = kQ/r$<br>$V = 9.0\times10^{9} \times 1.6\times10^{-19}/5.3\times10^{-11} = 27.2$ V | 1<br>1 | |
| 12(a)(ii) | $E_p = QV$<br>$E_p = -1.6\times10^{-19} \times 27.2 = -4.35\times10^{-18}$ J | 1<br>1 | |
| 12(b)(i) | $p = mv$<br>$v = 2.0\times10^{-24} / 9.1\times10^{-31} = 2.2\times10^{6}$ m s$^{-1}$<br>$E_k = 0.5mv^2 = 0.5 \times 9.1\times10^{-31} \times (2.2\times10^{6})^2$<br>( $= 2.2\times10^{-18}$ J) | 1<br>1<br>1 | accept $E_k = p^2/2m$<br>accept reverse calculation |
| 12(b)(ii) | $\lambda = h/p$<br>$\lambda = 6.6\times10^{-34} / 2.0\times10^{-24} = 3.3\times10^{-10}$ m | 1<br>1 | |
| 12(c) | electron is bound/in orbit around proton (wtte)<br>so forms a standing wave<br>with nodes at limits of atom (accept a diagram) or diameter/circumference = integral number of half wavelengths | 1<br>1<br>1 | |

| Qn | Expected Answers | Marks | Additional guidance |
|---|---|---|---|
| 13(a) |  | 1 | any sensible complete loop which threads both H coils and stays in iron as much as possible |
| 13(b)(i) | 90° / $\pi/2$ | 1 | |
| 13(b)(ii) |   | 1 | all four resultants same correct length by eye |
| 13(b)(iii) | rotates round anticlockwise | 1 | |
| 13(b)(iv) | changing flux induces emf in rotor<br>which results in currents in rotor<br>which interact with field to create rotating force | 1<br>1<br>1 | accept argument in terms of Lenz's law for full marks |
| | Quality of written communication | 4 max | |