RECOGNISING ACHIEVEMENT

NUCLEAR AND PARTICLE PHYSICS

Mark Scheme 2825/04

January 2003

Question	Expected Answers	Marks
1 (a) (i)	$F_E \propto 1/r^2$ or $F_E = Q^2/(4\pi\varepsilon_0 r^2)$ or in words	1
(ii)	$F_G \propto (-)1/r^2$ or $F_G = (-)m^2G/r^2$ or in words	1 [2]
(b)	electrostatic forces (between protons) always repulsive gravitational forces always attractive	1 [1]
(c)	(at equal separations) magnitude of F_E >> magnitude of F_G so F_E scale has bigger range of values than F_G	1 1 [2]
(d)(i)	d_0 is equilibrium separation	1
(ii)	PQ: repulsive; QR: attractive	1
(iii)	if neutrons get closer/further apart than Q, they repel/attract ; idea that force acts to restore/return particle to same point/separation	2 [4]
(e)	$\rho = m/V = m_n/[(4/3)\pi r^3]$ $= 1.67\times10^{-27}/[(4/3)\pi(1.4 \times 10^{-15}/2)^3]$ $= 1.16\times10^{18}$ kg m^{-3} ans. + unit uses $r = 1.4\times10^{-15}$ gives 1.45×10^{17} kg m^{-3} allow ecf so 1, 0, 1 = 2/3 $\rho = m/r^3$ ie assumes a cube of side r giving 4.9×10^{18} gets 0 0 1 = 1/3 $\rho = m/(2r^3)$ ie cube of side $2r$ gives 6.1×10^{17} and gets 0 1 1 = 2/3	1 1 + 1 [3]

Question	Expected Answers	Marks
2(a)	fission means splitting nucleus into parts caused by absorption/capture of a neutron idea reaction cannot start without neutrons neutrons having ke's comparable with ke of thermal molecular ke /slow moving/low energy	1 1 1 1 [4]
(b)	BE of products = 1210 + 760 = 1970MeV BE of reactant = 1770 MeV so energy released = 1970 - 1770 = 200 MeV energy in joule = $200\times10^{6}\times1.6\times10^{-19}$ ($= 3.2\times10^{-11}$ J)	1 1 1 [3]
(c)(i)	mass of U-235 = 0.03x4.2 = 0.126 (kg) mass of 1 atom = $0.235/(6.02\times10^{23})$ $= 3.9\times10^{-25}$ (kg) (so number of atoms = $0.126/(3.9\times10^{-25}) = 3.23\times10^{23}$)	1 1
(ii)	total energy = $3 \times 10^{23} \times 3.2 \times 10^{-11}$ $= 9.6 \times 10^{12}$ J (3.23×10^{23} gives $1.0(3)\times10^{13}$ for1/1)	 1
(iii)	power = E/t $= 9.6\times10^{12}/(2 \times 3.16 \times 10^{7} \times 3) = 5.06\times10^{4}$ W (=50.6 kW) (1.03×10^{13} gives 5.43×10^{4} (W) (= 54.3 kW) for 2/2)	1 1 [5]

Question	Expected Answers	Marks
3(a)	nuclei repel each other (1) high temperature means nuclei have high speeds (1) high speeds/large ke needed to overcome repulsion/Coulomb barrier/ to get nuclei to come close enough together (for fusion) (1) any 2	2
	(electrons have separated from nuclei) so plasma consists of free electrons and positive ions / is completely ionised	1
	A use 'magnetic bottle' / magnetic field	1
	detail: ions rotate around/follow magnetic field lines, so cannot escape	1
	B strong gravitational field/gravitational field of star	1
	nucleons and electrons pushed together by pressure of material	1
	C inertial confinement laser beams directed inwards/converging and compress a fuel pellet	[7]
(b)(i)	${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{1}\beta\ (+\nu)$	1
(ii)	${}^{2}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{2}He$	1
(iii)	${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2\,{}^{1}_{1}H$	1
(c)	${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2\,{}^{1}_{1}H$ $2\,{}^{2}_{1}H + 2\,{}^{1}_{1}H \rightarrow 2\,{}^{3}_{2}He$ $2\,{}^{1}_{1}H + 2\,{}^{1}_{1}H \rightarrow 2\,{}^{2}_{1}H + 2\,{}^{0}_{1}\beta\ (+2\nu)$ allow β^{+} <u>or</u> ${}^{0}_{1}e$ add:	
	$6\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\,{}^{0}_{1}\beta + 2\,{}^{1}_{1}H$ process	1
	cancel two ${}^{1}_{1}H$'s: $4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\,{}^{0}_{1}\beta\ (+2\nu)$ final equation	1 [5]

Question	Expected Answers	Marks	
4(a)	*either* two oppositely charged electrodes/with pd between them (1) *or* states use electric field charged particle experiences force/attraction/repulsion due to field (1) force causes acceleration (1) any 2	2	[2]
(b)	particle moves inside magnetic field field is uniform (1) force is perpendicular to direction of motion/acts as centripetal force (1) must be in a vacuum (1) any 2	1 2	[3]
(c)(i)	speed of light/relativistic limiting speed	1	
(ii)	$T = 2\pi r/v$ $= 2\pi \times 4.25\times1000/(3\times10^8) = 8.9\times10^{-5}$ s	1 1	[3]
(d)	*B* in same direction, force towards centre for both ; +ve charges moving in one direction is same (direction of) current as -ve charges moving in opposite direction can be made to collide (1) energy of collision is greater if both are moving (1) initial mtm is zero so final mtm zero so avoids/reduces waste of energy (in high-mtm products) *or* wtte (1) any 2	1 1 2	[4]

Question	Expected Answers	Marks	
5(a)	strange, charm, top, bottom (any order) 2 quarks per mark: 2/4 or 3/4 gets 1/2	2	[2]
(b)(i)	ddu	1	
(ii)	duu	1	[2]
(c)(i)	emission of electrons and positrons accept β^+ and β^-	1	
(ii) 1	${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$ (+ ν-bar)	1	
2	${}^{14}_{8}O \rightarrow {}^{14}_{7}N + {}^{0}_{1}e$ (+ ν)	1	
(iii) 1	(electron) anti-neutrino	1	
2	(electron) neutrino	1	
(iv)	neutrons: decrease of 1 (8 to 7) protons: increase of 1 (6 to 7) protons, neutrons correct electrons: increase of 1 (emitted electron) electrons correct	1 1	
(v)	$d^{(-1/3)} \rightarrow u^{(2/3)} + e^{(-1)}$ *or* down quark decays to up quark and electron	1	[8]

Question	Expected Answers	Marks
6(a)	${}^{105}_{45}Rh \rightarrow {}^{105}_{46}Pd + {}^{0}_{-1}e$ (+ ${}^{0}_{0}\nu$–bar)	1 [1]
(b)	mass difference = 104.905 44 - (104.904 83 + 0.000 55) = 0.000 06 u (ignores electron gives 0.00061u gets 0 1 =1/2)	1 1 [2]
(c)	0.000 06 u = 0.000 06x1.66x10^{-27} <u>or</u> E = 0.000 06x931 (= 9.96x10^{-32} kg) $E = \Delta m c^2$ = (0.055 9) MeV = 9.96x10^{-32}x (3x10^{8})^{2} = 0.055 9 x10^{6}x 1.6 x 10^{-19} = 9.0x10^{-15} J = 9.0x10^{-15} J (omits u → kg step gives 5.4 x 10^{12} J for 0 1 1 = 2/3 ecf from (b): 0.00061 gives 9.1 x 10^{-14} J for 3/3)	1 1 1 [3]
(d)	9.0x10^{-15} = ½ x 9.11x10$^{-31}v^2$ so v = 1.4 x10^{8}m s^{-1} (9.1 x 10^{-14} gives 4.47 x 10^{8} for 2/2, m_e = 0.00055kg gives 5.7 x 10^{-6} for 1/2)	1 1 [2]
(e)	(recoiling) nucleus has some energy/ke (1) neutrino takes some energy (1) accept relativistic mass increase means lower speed (for same ke)(1) any 2	2 [2]

Question	Expected Answers	Marks
7(a)(i) (ii)	1015 N (accept 1010-1020) 130 N (accept 125-135) both correct, no unit penalty	1 [1]
(b)	$F = ma$ written or implicit (1015-130) = 1100a so a = 0.80 ms^{-2} (accept 0.80-0.81, accept 0.8 in place of 0.80) (1015 + 130) can get only 1 0 0 = 1/3 max)	1 1 1 [3]
(c)	18 ms^{-1} (accept 15-21) find largest difference/distance between force graphs (and note speed) *or* clear from graph 'where lines cross' gets 0/1 'it is the terminal velocity' gets 0/1	1 1 [2]
(d)	49.7 ms^{-1} (accept 49.5 - 50.0) speed is max. when driving force equals/balanced by drag force accept 'speed where forces are equal' if speed has been stated correctly	1 1 [2]
(e)	220 N (accept 220 - 225) work done = force x distance = 220x1000 (= 2.2x10^5 J) allow ecf from incorrect graph reading 220 x 1000 only gets 1 0 1 = 2/3 22 x (anything) loses last mark	1 1 1 [3]
(f)	work done = 35(2)x1000 = 3.5(2)x10^5 J accept (3.5 - 3.6)x10^5	1 [1]
(g)	distance travelled on 1 litre at 31 ms^{-1} = 2.2x16/3.5(2) = 10.0 km (9.8 - 10.1) allow (total) energy (in 1 litre of fuel) = 16 x 2.2 x 10^5 for 1/2 reference to 22(ms^{-1}) or 31(m s^{-1}) gets 0/2	1 1 [2]
(h)	ke = $\frac{1}{2}mv^2$ = ½ x 1100x31^2 (= 5.29x10^5 J) subs.	1 [1]
(i)	(ke lost =) heat gained = $mc(\theta_2 - \theta_1)$ 5.3x10^5 = 8x460 Δθ either of first two lines correct (1) $\Delta\theta$ = 144K so θ_2 = 144 + 15 = 159 °C calculation of 144 (1) addition of 15 (1) assumption: brakes initially at 15 °C all heat is dissipated in brakes no heat lost from brakes no air resistance/drag any assumption (1) not Law of Energy assumption without calculation can score 1/3 any 3	3 [3]
(j)	$W = Fd$ *or* $F = ma$ and $v^2 - u^2 = 2as$ (1) 5.3x10^5 = 9300d 9300 = 1100 a so a = 8.45(m s^{-1}) so d = 57 m 31^2 (- 0^2) = 2 x 8.45 s so s = 57m (1) assumption: no work done against (other) drag forces car is on horizontal road air resistance negligible any valid assumption (1) 'constant braking force' and 'constant deceleration' get 0/1 any 2	2 [2]