

**SECTION A**

- A1.** (a) correct placing of both error bars; [1]  
*Total error bar length 3 to 5 squares.*  
*Be generous as the error bars are a bit difficult to place.*
- (b) (i) a straight line can be drawn; [2]  
 that passes through the error bars;  
*Notice that first point may be implicit, for example, if they have drawn a straight-line of best fit.*
- (ii) slope =  $-1.0$ ; (*accept answers in the range  $-0.95$  to  $-1.1$  and ignore any units*)  
 intercept =  $1.85$ ; (*accept answers in the range of  $1.75$  to  $1.90$* )  
 correct statement of equation e.g.  $\frac{R}{R_s} = 1.85 - 1.0 \times \frac{M}{M_s}$ ;  $\left\{ \begin{array}{l} \text{accept e.g.} \\ R = 1.85 - 1.0 \times M \end{array} \right.$  [3]
- (iii)  $1.85 M_s$ ;  $\left\{ \begin{array}{l} M_s \text{ unit needed. Accept answers in the range } 1.6 M_s \text{ to } 2.0 M_s, \\ \text{i.e. consistent with a line of best-fit} \end{array} \right.$  [1]
- (c) the maximum mass corresponds to a star of zero radius/ $R=0$ , so it is unphysical /  
 radius is zero/too small; [1]
- (d) (i) smooth curve through data points; [1]
- (ii)  $1.4 M_s$  / consistent with any line of best-fit even if straight; [1]  
*Do not penalize absence of unit  $M_s$  if already penalized earlier.*
- (iii) answers based on an extrapolation from a curve which is imprecise; [1]  
*The idea is to see a comment about extrapolation outside the data range so plain references to uncertainties in general should not be accepted.*
- (e) (i) since  $\ln R = \ln k + n \ln M$  ;  
 a plot of  $\ln R$  against  $\ln M$  would produce a straight line; [2]  
*Accept log in place of ln.*
- (ii) with  $n$  being the gradient/slope of the graph; [1]

- A2.** (a) (i) the rocket exerts a force on the gases and so the gases exert a force on the rocket / there is a reaction force on rocket from gases / *OWTTE*;  
force on the rocket causes the rocket to accelerate; [2]
- (ii) the net external force on the rocket and gases/system is zero / system is closed/isolated, therefore the total momentum of the system stays the same;  
change in momentum of the gases = (–) change in momentum of the rocket; [2]
- (iii) force on gases is rate of change of gas momentum =  $Rv$ ;  
so force on rocket is also  $Rv$ ;  
$$a = \frac{F}{M};$$
  
$$a = \frac{Rv}{M}$$
 [3]
- (b) the two-stage rocket will have a larger final speed;  
because after the fuel in the first stage is used up the acceleration will be  $a = \frac{Rv}{M}$   
and  $M$  will be less than the corresponding single stage rocket mass; [2]

- A3.** (a) satisfies  $pV = nRT$  (at all  $p$ ,  $V$  and  $T$ ) / point molecules / no intermolecular forces; [1]  
 Allow any other kinetic theory assumption.
- (b) (i) the (total random) kinetic energy of the molecules (of the gas); [1]
- (ii) the (absolute kelvin) temperature is proportional to/is a measure of the average kinetic energy of the molecules of the gas; and hence the internal energy is proportional to the temperature (and the total number of molecules in the gas) /  $U \propto NT$ ; [2]  
 Do not accept  $T$  increases  $U$  increases. Award [0] for any reference to potential energy.
- (c) (i) correct substitution to get  

$$T = \frac{pV}{nR} = \frac{2.0 \times 10^5 \times 8.0 \times 10^{-3}}{0.64 \times 8.31};$$

$$\approx 300 \text{ K}$$
 [1]
- (ii) use of  $\frac{V}{T} = \text{constant/ratio idea}$ ;  
 to calculate new volume at  $24 \times 10^{-3} \text{ m}^3$ ; [2]
- (iii)  $W = p\Delta V$   
 $\Delta V = 16 \times 10^{-3} \text{ m}^3$ ;  
 so  $W = 2.0 \times 10^5 \times 16 \times 10^{-3} = 3200 \text{ J}$ ; [2]
- (iv)  $\Delta U = Q - W$ ;  
 $W = 0$  therefore increase in  $U$  greater (for constant volume);  
 therefore  $T$  is greater; ( $T$  greater must be justified by correct arguments) [3]

**SECTION B**

**B1. Part 1** Wave motion

(a) (i) 1.5 mm; [1]

(ii) 8.0 cm; [1]

(iii) distance travelled in 0.20 s is 3.2 cm;  
so speed is  $\left(\frac{3.2 \times 10^{-2}}{0.20}\right) = 0.16 \text{ m s}^{-1}$ ; [2]

(iv)  $f = \frac{0.16}{8.0 \times 10^{-2}} = 2.0 \text{ Hz}$ ; [1]

(b) travelling waves transfer energy (standing waves do not);  
travelling waves have a constant amplitude (standing waves do not);  
standing waves have points that always have zero displacement (travelling waves do not);  
the phase of a travelling wave constantly changes (but in standing waves points in between consecutive nodes have constant phase); [2 max]

(c) (i) it is the speed of energy transfer/rate/speed at which wavefronts move forward; [1]

(ii) a standing wave is formed from the superposition of two travelling waves;  
wave speed refers to the speed of the travelling waves; [2]

(d) (i) the oscillating string collides with the air molecules surrounding it;  
creating a pressure/longitudinal wave; [2]

(ii) wavelength of wave on string is  $2 \times 0.80 = 1.6 \text{ m}$ ;  
frequency is then  $\left(\frac{240}{1.6}\right) = 150 \text{ Hz}$ ;  
sound has the same frequency and so wavelength is  $\left(\frac{340}{150}\right) = 2.3 \text{ m}$ ; [3]

*Award [1 max] for those using a wavelength of 0.80m obtaining a wavelength of 1.1m in air. Accept alternative derivations that use a ratio and do not calculate the frequency explicitly.*

**Part 2** Electromagnetic induction

- (a) the induced e.m.f. is equal/proportional to the (negative time) rate of change of the magnetic flux (linkage through the loop); [1]
- (b) (i) the flux is changing and therefore an (e.m.f.) and a clockwise current are induced (in the loop);  
 a magnetic force on the loop develops that opposes the motion;  
 the force decreases the speed; [3]
- (ii) when a length  $\Delta x$  of the loop has entered the region of magnetic field the flux changes by  $\Delta\Phi = BL\Delta x$ ;  
 the rate of change of flux *i.e.* the e.m.f. is then  

$$V = \left( \frac{\Delta\Phi}{\Delta t} \right) = \frac{BL\Delta x}{\Delta t};$$

$$= BLv$$
 [2]  
*or*  
 equating electric to magnetic force on electrons to get  $eE = evB \Rightarrow E = vB$ ;  
 use of  $E = \frac{V}{L}$  to get answer;
- (iii) at  $t = 0$ ,  $V = BLv = 0.30 \times 0.54 \times 5.0$ ;  
 $V = 0.81 \text{ V}$ ;  
 at  $t = 0.18 \text{ s}$ ,  $V = 0$  because the flux is not changing and there is no induced e.m.f.; [3]
- (c) (i) kinetic energy lost is  $\frac{1}{2} \times 0.060 \times (5.0^2 - 3.0^2) = 0.48 \text{ J}$ ;  
 so power =  $\left( \frac{0.48}{0.14} \right) = 3.4 \text{ W}$ ; [2]
- (ii) maximum current is at  $t = 0$ ;  

$$I_{\text{max}} = \left( \frac{0.81}{0.12} \right) = 6.8 \text{ A};$$
 [2]
- (d) speed shown decreasing (along a curve);  
 and then remaining constant; [2]

**B2. Part 1** Nuclear fusion

- (a) the minimum energy required to (completely) separate the nucleons in a nucleus / the energy released when a nucleus is assembled from its constituent nucleons; [1]
- (b) mass defect =  $1 \times 1.007276 + 2 \times 1.008665 - 3.016049 = 8.56 \times 10^{-3} \text{ u}$  ;  
 binding energy =  $8.56 \times 10^{-3} \times 931.5 = 7.97 \text{ MeV}$  ;  
 binding energy per nucleon =  $\frac{7.97}{3} \text{ MeV}$  ;  
 $= 2.66 \text{ MeV}$  [3]
- (c) calculation of binding energies as shown below;  
 deuterium  ${}^2_1\text{H}$   $1.11 \times 2 = 2.22 \text{ MeV}$   
 tritium  ${}^3_1\text{H}$   $2.66 \times 3 = 7.97 \text{ MeV}$   
 helium  ${}^4_2\text{He}$   $7.20 \times 4 = 28.8 \text{ MeV}$   
 energy released is the difference of binding energies;  
 and so equals  $18.6 \text{ MeV}$ ; [3]  
*Award [2 max] for an answer that uses binding energy per nucleon without multiplying by the number of nucleons.*
- (d) (i) the electrostatic/Coulomb force; [1]
- (ii) total energy initially available is  $2E_K$  ;  
 at closest point potential energy is  $E_p = \frac{kq_Dq_T}{d}$  ;  
 reference to energy conservation to equate the two; [3]
- (iii) correct identification of charges involved  $q_D = q_T = 1.6 \times 10^{-19} \text{ C}$  ;  
 substitution to get  $E_K = \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{2 \times 1.2 \times 10^{-14}}$  ;  
 $E_K = 9.6 \times 10^{-15} \text{ J}$  [2]
- (e) (i)  $4.6 \times 10^8 \text{ K}$  ; [1]
- (ii) even at lower temperatures there are nuclei moving sufficiently fast for fusion to occur;  
 because the formula for energy only refers to the average energy; [2]
- (iii) the nuclei have to overcome a Coulomb barrier/the repulsive force between the nuclei;  
 and so high temperatures are required to make the nuclei come sufficiently close to each other (for the nuclear force to then make them fuse); [2]
- (iv) at short distances the dominant force is the strong nuclear force which is attractive;  
 at large separations the nuclear force is negligible because it has short range leaving the repulsive electric force as the dominant force; [2]

**Part 2** The Doppler effect

- (a) the difference between the emitted and received frequency;  
when there is relative motion between the source and the receiver; [2]

- (b) (i)  $u + v$ ; [1]

(ii)  $f \left( 1 + \frac{u}{v} \right)$ ; [1]

(c)  $\lambda' = \frac{u + v}{f \left( 1 + \frac{u}{v} \right)}$ ;  
 $= \frac{v}{f} = \lambda$ ; [2]

- (d) frequency received by moving observer is  $1200 \left( 1 + \frac{u}{340} \right)$ ;

reflected wave appears to original source to be coming from a moving source;  
and so the reflected wave back at the original source has a frequency

$$1400 = \frac{1200 \left( 1 + \frac{u}{340} \right)}{\left( 1 - \frac{u}{340} \right)}$$

$u = 26 \text{ m s}^{-1}$ ; [4]

*Award [2 max] for use of single Doppler  $57 \text{ m s}^{-1}$  or  $59 \text{ m s}^{-1}$ .*

**B3. Part 1**      Mechanics

(a) (i)  $\frac{350}{9.8} = 36 \text{ kg};$  (*accept 35 kg*) [1]

(ii) girl took 0.5 s to fall;  
so  $v = gt = (9.8 \times 0.5) = 4.9 \text{ ms}^{-1};$  (*accept 5.0 ms<sup>-1</sup>*) [2]

(iii)  $h = \frac{1}{2}gt^2$   
 $= \frac{1}{2}(9.8 \times 0.50^2);$   
 $= 1.2 \text{ m};$  (*accept 1.3 m*) [2]

**or**

use of conservation of energy to get

$$\frac{1}{2}mv^2 = mgh \Rightarrow h = \frac{v^2}{2g};$$

$$h = \frac{4.9^2}{2 \times 9.8} = 1.2 \text{ m};$$
 (*accept 1.3 m*)

(iv) maximum force on girl = 1400 N;  
so maximum acceleration =  $\frac{1400}{36} = 39 \text{ ms}^{-2};$  (*accept 40 ms<sup>-2</sup>*) [2]

(b) (i) the net force is still in the downward direction / the trampoline force is less than the weight / the trampoline has not yet deflected enough to give rise to a force larger than the weight;  
and so the girl keeps accelerating downwards; [2]

(ii) the change in momentum = area under graph from point C to point D;  
 $= \frac{1}{2} \times 350 \times (0.53 - 0.50);$   
 $\approx 5 \text{ N s}$  [2]

(iii)  $36 \times (v_{\text{max}} - 4.9) = 5 \text{ N s};$   
so  $v_{\text{max}} = 5 \text{ ms}^{-1};$  [2]

**Part 2** Wave-particle duality

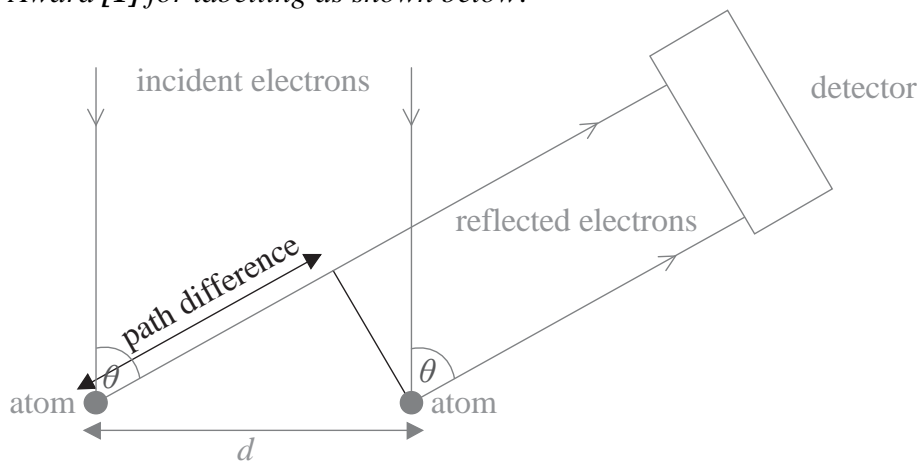
(a) there is a (probability) wave associated with all particles;  
wavelength is given by Planck's constant divided by the particle's momentum; [2]

(b) the de Broglie wavelength of the ball is  $\lambda = \frac{6.63 \times 10^{-34}}{0.06 \times 20} \approx 6 \times 10^{-34} \text{ m}$ ;  
and this is much smaller than the 1 m gap;  
wave properties will not be observed; [3]

(c)  $\frac{p^2}{2m} = eV$  or  $\frac{1}{2}mv^2 = eV$ ;  
 $p = \sqrt{2meV}$ ;  
shown substitution into  $\lambda = \frac{h}{p}$ ; [3]

(d)  $1.7 \times 10^{-10} \text{ m}$ ; [1]

(e) (i) Award [1] for labelling as shown below.



(ii) the path difference is an integral number of wavelengths;  
so the waves will interfere constructively; [2]

(f) use of  $d \sin \theta = \lambda$  to find the electron wavelength;  
 $\lambda = d \sin \theta = 2.15 \times 10^{-10} \times \sin 51^\circ = 1.7 \times 10^{-10} \text{ m}$ ;  
comment that this is the same as the de Broglie wavelength for electrons of this energy which is what is expected if de Broglie were correct; [3]

(g) atoms are regularly arranged in a crystal;  
with a small separation between them; [2]

**B4. Part 1** Gravitation

(a) (i)  $F = \frac{GM^2}{4R^2}$ ; (**n.b.** the factor of 4 is crucial here)  
 $= \frac{Mv^2}{R}$ ;

to give  $v = \sqrt{\frac{GM}{4R}}$  [2]

*Need to see clear setting of gravitational force equal to centripetal force.*

(ii)  $v = \frac{2\pi R}{T}$ ;

substitution into formula for  $v$ ;

[2]

*Do not accept use of Kepler's third law  $T^2 = kR^3$  as a starting point.*

(b) correct substitution to get  $T = \sqrt{\frac{16\pi^2 \times (6.5 \times 10^8)^3}{6.67 \times 10^{-11} \times 3.0 \times 10^{30}}}$ ;

$T = 1.47 \times 10^4$  s (= 4.1 hrs);

[2]

(c) (i) decreasing energy means that  $R$  has to decrease;  
 and hence the period decreases as well by reference to the formula relating period to separation;

[2]

(ii)  $\frac{1.47 \times 10^4}{\Delta t} = 7 \times 10^{-5}$ ;

$\Delta t \approx 2 \times 10^8$  (years);

[2]

**Part 2** Electricity

- (a) greater;  
 negative charges at top (and an equal amount of positive at the bottom);  
 (the negative charges are closer to the particle) and so there is an attractive force  
 between the particle and the sphere; [3]
- (b) (i) *diagram A*: excess negative charge at top;  
*diagram B*: same as diagram A;  
*diagram C*: negative charge uniformly distributed on sphere; [3]
- (ii) there is an attractive force between the positive particle and the (negative  
 charged) sphere;  
 therefore work has to be done on the charged particle; [2]
- or*
- the positively charged particle has negative potential energy because the  
 sphere is negatively charged;  
 hence positive work must be done to remove the particle far away;
- (c) work done per unit charge in moving charge completely around the circuit / power  
 supplied per unit current; [1]
- (d) (i) two sets of series resistors at  $90\ \Omega$  each;  
 and these are in parallel for a total of  $45\ \Omega$ ;  
 plus the internal resistance in series for a grand total of  $50\ \Omega$ ; [3]
- (ii) total current is  $I = \left(\frac{12}{50}\right) = 0.24\ \text{A}$ ; [1]
- Watch for ECF if answer for resistance is wrong.*
- (iii)  $P_{\text{total}} = EI$ ;  
 $= (12 \times 0.24) = 2.9\ \text{W}$ ; [2]
- Watch for ECF if answer for current is wrong.*
- (iv) across  $30\ \Omega$  voltage drops by  $3.60\ \text{V}$  (so potential at X is  $3.60\ \text{V}$ );  
 across  $60\ \Omega$  voltage drops by  $7.20\ \text{V}$  (so potential at Y is  $7.20\ \text{V}$ );  
 so potential difference between X and Y is (negative)  $3.6\ \text{V}$ ; [3]
- (e) in the original circuit there is no current between X and Y / the resistance between  
 X and Y is infinite;  
 introducing a real voltmeter changes the total resistance of the circuit / allows  
 current between X and Y / the resistance between X and Y is no longer infinite; [2]
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(b) white light;  
with red and blue fringe/border; [2]

**H2.** (a) the ratio of the speed of light in a vacuum to the speed of light in a substance; [1]  
*Accept ratio of  $\sin(i)$  to  $\sin(r)$  provided that the angles  $i$  and  $r$  are unambiguously defined.*

(b) (i) line (R) bent away from normal and line (L) obeying law of reflection; [1]  
*Judge by eye.*

(ii)  $\sin(\text{critical angle}) = 0.67$  / critical angle =  $42^\circ$  ;  
the refracted ray eventually disappears;  
when the critical angle has been passed for angles greater than the critical angle;  
the light undergoes total internal reflection / all the light is internally/totally reflected; [4]

- H4.** (a) (i) realization that missing fringes are related to the diffraction pattern of individual slits;  
 at the expected angle for constructive interference from the double slit, the individual slits have a minimum / *OWTTE*; [2]
- (ii) missing fringe corresponds to fourth fringe so path difference corresponds to  $4\lambda$  (at  $\theta = 0.01857$  rad);  
 first slit minimum at  $\theta = \frac{\lambda}{b} \therefore b = \frac{\lambda}{\theta} = \frac{650 \text{ nm}}{0.01857} = 3.5 \times 10^{-5} \text{ m}$ ; [2]  
*Accept substitution which avoids calculating angle e.g.*  
 $\theta = \frac{4\lambda}{d} = \frac{\lambda}{b} \therefore b = \frac{d}{4} = 3.5 \times 10^{-5} \text{ m}.$
- (b) fringes will be brighter;  
 more slits therefore more light getting through;  
 sharper;  
 slightly away from constructive interference, each subsequent slit further out of phase, so net result will be zero amplitude / *OWTTE*;  
 not have missing fringes; [3 max]  
*To award [3] answers must include two changes and one corresponding explanation.*
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