H2P3 2014
Section A

1. **(a)** The gradient of the momentum-time graph represents the resultant force that acts on the object. [1]

(b) According to Newton's third law, the resultant forces that acts on them are in opposite directions, therefore the gradients have opposite signs. [1]

(c)

$$Force,\ F_B = gradient = \frac{(28-22)\times 10^3}{1.5} = 4.0\ kN \quad [1]$$

$$By\ N3L,\ F_A = F_B = 4.0\ kN \quad [1]$$

(d)

According to Newton's second law, $Force,\ F_A = \frac{dp}{dt} = \frac{m_A v_A - m_A u_A}{dt}$ [1]

Similarly, $Force,\ F_B = \frac{dp}{dt} = \frac{m_B v_B - m_B u_B}{dt}$

According to Newton's third law, $F_A = -F_B$ [1]

$$\Rightarrow \frac{m_A v_A - m_A u_A}{dt} = -\frac{(m_B v_B - m_B u_B)}{dt} \Rightarrow m_A u_A + m_B u_B = m_A v_A + m_B v_B$$

Therefore, momentum is conserved since total *initial* momentum = total *final* momentum. [1]

(e)

Kinetic energy, $KE = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

Total initial KE, $= \frac{18000^2}{2(2000)} + \frac{22000^2}{2(4000)} = 1.42\times 10^5\ J$ [1]

Total final KE, $= \frac{12000^2}{2(2000)} + \frac{28000^2}{2(4000)} = 1.34\times 10^5\ J$ [1]

Change in KE, $KE_f - KE_i = (1.34-1.42)\times 10^5 = -8.0\ kJ$

Therefore, collision is inelastic since KE is *not* conserved. [1]

2(a) Resistance is the ratio of the potential difference across an electrical component to the current flowing through it. [1]

Resistivity ρ is given by RA/L, where R is the resistance of the component, A is its cross-sectional area, and L is its length. [1]
(Do not accept A = area)

Resistivity is a property of the material that the component is made of, [1]
whereas the resistance is a property of the component (depending on ρ, L and A).[1]

(b)(i) Resistance, $R = \dfrac{\rho L}{A} = \dfrac{(0.13)(0.20)}{1.0\times10^{-4}} = 260\ \Omega$ [1]

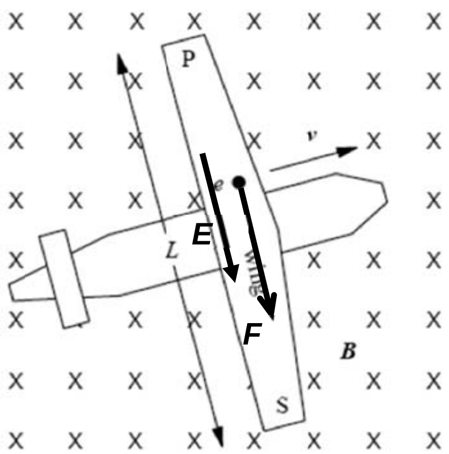
(ii) Current, $I = V/R = 3.0/260 = \mathbf{1.15 \times 10^{-2}\ A}$ [1]

(iii) Resistance of the object, $r = \dfrac{\rho L}{A} = \dfrac{\left(\dfrac{0.13}{2}\right)(0.10)}{1.0\times10^{-4}} = 65\ \Omega$ [1]

The object and half of the original water-tube are connected in series.
Total resistance of the combined tube = $R/2 + r$ = 130 + 65
= 195 Ω [1]

New current, $I_2 = 3.0/195 = \mathbf{1.54 \times 10^{-2}\ A}$ [1]

3(a)(i)



[1]

[1]

(ii) F = Bev [1]

(iii) As the plane moves, the electrons will experience a force F in the direction shown in (i). Electrons will accumulate at side S, leaving behind positive charge at P. A potential difference is now set up with side P being higher potential than S. [1]
Hence an electric field is set up in the direction P to S.

(b) (i) Because of the electric field E in a(iii), the electron will now experience an electric force F_E directed from S to P. [1]

When the electric force F_E equals in magnitude to the magnetic force F in a(ii), then the electron does not move along the wing. [1]

(ii) $F_E = F_B$

$eE = Bev$

$E = Bv$

$= 5.0 \times 10^{-5}(720 \times 10^3/3600)$

$= 1.0 \times 10^{-2}$ V m^{-1}

4(a)

(i) When intensity of the incoming light is decreased, less photons are incident upon the surface of the metal per unit time. [1] Hence, the number of photoelectrons that are produced are decreased proportionally [1]

(ii) When the potential difference is made negative, photoelectrons lose kinetic energy and gain electric potential energy as they approach the gauze. [1] When the potential difference is sufficiently large, even the fastest photoelectron will have zero kinetic energy before it reaches the gauze, causing no current be observed. [1]

(iii) According to Einstein's photoelectric equation, the maximum kinetic energy of the photoelectrons depends only on the frequency of incident light used and the work function of the metal. [1] Hence, even if the intensity is increased, the maximum kinetic energy of each photoelectron remains the same and the stopping potential remains constant. [1]

(iv)

Using the modified Einstein's photoelectric equation:

$$\frac{hc}{\lambda} = \phi + eV \qquad [1]$$

$$\frac{6.63\times10^{-34}\times3\times10^{8}}{1\times10^{-8}} = 4.3\times1.6\times10^{-19} + 1.6\times10^{-19}\times V$$

$$V = 120\text{ V} \qquad [1]$$

(b)

(i) KE is gain is due to lost in EPE:

$$KE = eV = 1.6\times10^{-19}\times2500 = 4.0\times10^{-16}\text{ J}$$

(ii)

$$p = mv$$

$$\frac{1}{2}p^2 = \frac{1}{2}m^2v^2 = KE\times m$$

$$\therefore\ p = \sqrt{2KEm} \qquad [1]$$

Using deBroglie's relation:

$$\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{\sqrt{2\times4.0\times10^{-16}\times9.1\times10^{-31}}} = 2.46\times10^{-11}\ \text{m} \qquad [1]$$

(iii) Slit width given, $d = \frac{1}{300}\times10^{-3} = 3.33\times10^{-6}\ \text{m}$ [1]

Since the slit width is very much larger than the deBroglie wavelength, an appreciable interference pattern will not be easily observed.[1] (The pattern will look classical)

Extra Info: Calculation of angle of first order bright fringe:

$$d\sin(\theta) = n\lambda$$

$$\sin(\theta) = \frac{\lambda}{d} = \frac{2.46\times10^{-11}}{3.33\times10^{-6}}$$

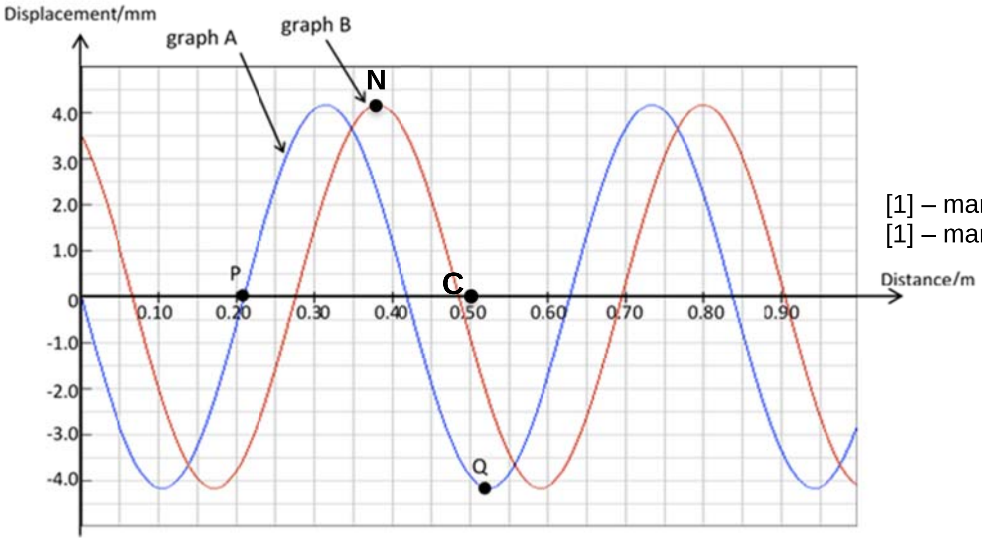
$$\theta = 4.23\times10^{-4}\ ^\circ$$

Section B

5(a) (i) Longitudinal wave is a wave where the vibration of the particles is parallel to the direction of wave propagation. [1]

Progressive wave means that energy will be transmitted in the direction of wave propagation. [1]

(ii)



[1] – marking point C
[1] – marking point N

(iii) 1. From the graph, wavelength λ = 0.42 m. [1]

2. From graph A to graph B, the wave has moved a distance of 0.070 m in 0.20 ms.

v = dist/time

= $0.070/(0.20 \times 10^{-3})$

= $350\ \text{m s}^{-1}$ [2]

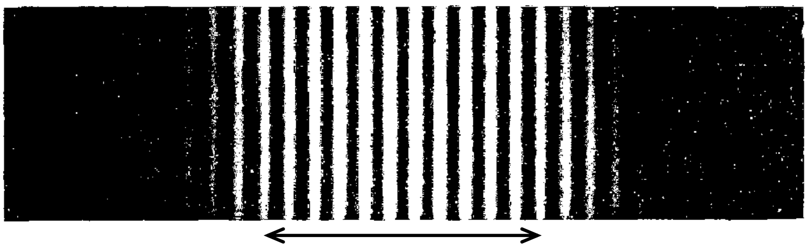
3. $v = f\lambda$
   $f = v/\lambda$
   $= 350/0.42 = 830$ Hz [1]

4. distance between P and Q, x = 0.31 m
   phase diff, $\phi = (x/\lambda) \times 2\pi$ [1]
   $= (0.31/0.42) \times 2\pi$
   $= 4.6$ rad. [1]

   Or: P and Q is ¾ of a wavelength apart, hence
   $\phi = (x/\lambda) \times 2\pi$
   $= (3/4) \times 2\pi = 3\pi/2$.

(b)(i) Principle of superposition states that when 2 or more waves meet at a point the resultant displacement is the vector sum of the individual displacements. [1]
When monochromatic light passes through the two closely spaced slits, the light waves from the two slits will superpose. Bright fringes are formed at points where the two waves meet in phase and interfere constructively. [1]
Dark fringes are formed at points where the two waves meet out of phase and interfere destructively. [1]

(ii)



Since photograph is full-scale, by measuring using a ruler as shown:
13 fringe spacings = 4.5 cm [1]
Hence fringe spacing $\Delta x = 4.5/13 = 0.35$ cm $= 3.5 \times 10^{-3}$ m [1]

(iii)
$$\Delta x = \frac{\lambda D}{d}$$
$$\lambda = \frac{\Delta x \times d}{D}$$
$$= \frac{3.5 \times 10^{-3} \times 0.30 \times 10^{-3}}{1.5}$$
$$= 7.0 \times 10^{-7} \text{ m} = 700 \text{ nm}$$

(iv) When light passes through each of the small slit, the light waves will spread or diffract. [1] The fringes appear brighter at the centre compared to the edges because of diffraction of light from each of the slit. [1] This causes the central fringes to be brighter than those at the edges.

(v) Any sketch of a bright patch of light without fringes. [1]

6(a)(i) X is a **neutron**.

(ii) Energy released = (144 + 90)(8.5 MeV) – 235(7.5 MeV) [1]
= 226.5 MeV
= **227 MeV** or **3.62 × 10^{-11} J** [1]

(b)(i) 235 g of U-235 contains 6.02 × 10^{23} nuclei. [1]

1.0 kg contains $\frac{1000}{235} \times (6.02 \times 10^{23})$ = **2.56 × 10^{24} nuclei** [1]

(ii) Total energy released from the fission of 1.0 kg of U-235
= (2.56 × 10^{24}) × 230 MeV
= 5.888 × 10^{26} MeV [1]

Total electrical energy generated
= 25% × 5.888 × 10^{26} MeV
= **1.47 × 10^{26} MeV** or **2.32 × 10^{13} J** [1]

(iii) Average power output = $\frac{energy\ generated}{time}$ [1]

= $\frac{2.35 \times 10^{13}}{24 \times 60 \times 60}$ = **272 MW** [1]

(iv) Energy can also be released as **gamma radiation**. [1]

(c)(i) For Mo, the half-life, $t_{1/2}$ = 67 hrs
Apply $A = A_0 \exp(-\lambda t)$, where A_0 is the activity today.

30 days later, the activity A is

$A = A_0 \exp\left[-\frac{0.693}{67\text{ hrs}}(30 \times 24\text{ hrs})\right] = (5.831 \times 10^{-4})A_0$ [1]

Today: We have A_0 decays in 1 s
30 days later: We have $(5.831 \times 10^{-4})A_0$ decays in 1 s.

To get A_0 decays, we need a time of $\frac{A_0}{(5.831 \times 10^{-4})A_0}$ [1]
= **1700 s** [1]

(ii) The first series produces Tc which has a very long half-life, so the waste will stay radioactive for an extremely long time. [1]
To store this waste safely, it has to be secured in specially-designed containers that can endure for many thousands of years. [1]

Most of the products in the second series have much shorter half-lives, so they have greater levels of activity. [1]
Containers with extra thick walls are needed to contain the greater levels of beta-radiation and gamma radiation. [1]

(d) Mass of a deuterium nucleus ≈ 2*m*, so $F_D \approx \frac{4m}{2m}\left(1+\frac{m}{2m}\right)^{-2} = 0.889$

Mass of a carbon nucleus ≈ 12*m*, so $F_C \approx \frac{4m}{12m}\left(1+\frac{m}{12m}\right)^{-2} = 0.284$

[1 for both calculations]

Since a greater fraction of a neutron's energy is transferred to a deuterium nucleus, a neutron will slow down more when it collides with a deuterium nucleus (than with a carbon nucleus). [1]
Hence, deuterium is a more efficient moderator. [1]

7(a)

(i) 10 lines can be produced. [1]

(ii) Kinetic Energy of electrons,

$K = \frac{1}{2}mv^2 = \frac{1}{2}\times 9.1\times 10^{-31}\times(1.09\times 10^6)^2 = 5.41\times 10^{-19}$ J [1]

Hence the possible frequencies of light visible are from

$$E_3 \to E_1 = \Delta E_{31} = 5.12\times 10^{-19} \text{ J}$$
$$f_{31} = \frac{\Delta E_{31}}{h} = \frac{5.12\times 10^{-19}}{6.63\times 10^{-34}} = 7.72\times 10^{14} \text{ Hz}$$
$$E_2 \to E_1 = \Delta E_{21} = 3.38\times 10^{-19} \text{ J}$$
$$f_{21} = \frac{\Delta E_{21}}{h} = \frac{3.38\times 10^{-19}}{6.63\times 10^{-34}} = 5.10\times 10^{14} \text{ Hz}$$
$$E_3 \to E_2 = \Delta E_{32} = (5.12 - 3.38)\times 10^{-19} = 1.74\times 10^{-19} \text{ J}$$
$$f_{32} = \frac{\Delta E_{32}}{h} = \frac{1.74\times 10^{-19}}{6.63\times 10^{-34}} = 2.62\times 10^{14} \text{ Hz}$$

[1] for correct equations, [1] for all 3 answers.

(iii) The energy difference,

$$\Delta E = \frac{hc}{\lambda_1} - \frac{hc}{\lambda_2} = (6.63\times 10^{-34}\times 3\times 10^8)\left(\frac{1}{589.0\times 10^{-9}} - \frac{1}{589.6\times 10^{-9}}\right)$$
$$= 3.44\times 10^{-22} \text{ J}$$ [1]

The energy transition is to the ground state. [1]

(iv) Using an aperture, isolate a small ray of sunlight in a dark room. Allow the ray to pass through a diffraction grating and observe the resultant dark lines using a spectrometer. [1] If the dark lines contains the same wavelengths as the bright fringes of sodium given in part (a), then the sun contains sodium vapour. [1]

(b) A pulse of gamma radiation lasts for 1.0×10^{-4} s. A photon of gamma radiation may be assumed to be at any point within the pulse, although the location is unknown.

(i) The length of the pulse, $s = ut = 3\times10^{8}\times1.0\times10^{-4} = 30000\text{ m}$ [1]
Since the photon may be anywhere within the pulse,its uncertainty is also 30000 m

(ii)

$$\Delta x\Delta p \geq \frac{h}{4\pi} \quad [1]$$

$$\Delta p \geq \frac{6.63\times10^{-34}}{4\pi\times30000} \quad [1]$$

$$=1.76\times10^{-39}\text{ kg m s}^{-1}\ [1]$$

(c) (i) The region between the sample's surface and the tip constitutes a potential barrier to the electrons that are bound to the surface by electrostatic forces. [1]
According to quantum theory, the electrons can still tunnel through this potential barrier despite not having enough kinetic energy to do so. [1]
The probability is higher the closer the tip is to the material, thus the current produced by the tunneling electrons depends on the height of the tip to the material surface. [1]
By keeping the height of the tip constant, moving the tip across the surface and measuring the current produced as the tip travels, the height of the surface can be imaged. [1] (also allow for constant current method)

(ii) In a particular case study, the ability of an electron to tunnel across a 4.0 eV potential barrier of width *d* is being investigated. When electrons of energy 1.0 eV approach the gap (barrier), the probability of successful tunnelling is *T*. If the width *d* of the gap is increased by 10 %, determine the new value of the energy E' of the electrons such that the probability of successful tunnelling remains at the same value *T*. [3]

$$T \propto e^{-2dk},\ k \propto \sqrt{U-E} \qquad \text{[1] for tunneling equation}$$

Where *d* is the barrier gap, *U* is the potential barrier height and *E* is the energy of the electrons.

After the gap is increased,

$$T' \propto e^{-2d'k'},\ k' \propto \sqrt{U-E'}$$

If *T*=*T'*,

$$e^{-2d\sqrt{4.0-E}} = e^{-2d'\sqrt{4.0-E'}}$$

$$-2d\sqrt{4.0-E} = -2d'\sqrt{4.0-E'}$$

$$d\sqrt{4.0-E} = 1.1d\sqrt{4.0-E'}$$ [1] for correct relation ship between E and E'

$$E' = 4 - \frac{4-E}{1.1^2} = 4 - \frac{4-1.0}{1.1^2} = 1.52 \text{ eV}$$ [1]