NSAA Section 2 2017 - Question P1

Question P1

In this question, assume the gravitational field strength = $10\,N\,kg^{-1}$, and neglect air resistance effects.

a) State Hooke's Law, and briefly explain what is meant by elastic potential energy as applied to an elastic rope. **[2 marks]**

NSAA 2017 Section 2 - Question P1 (a) - Worked Solution

Hooke's Law: Tension is proportional to extension, or displacement. T = kx
Elastic potential energy refers to the energy stored in an elastic material as it is stretched by doing work agaisnt the bonds between the atoms. This equals the average force x extension

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b) An elastic rope of negligible mass obeys Hooke's Law perfectly, and has an unstretched length of 10 m. When Alice, whose mass is 50 kg, hangs in equilibrium from its lower end, the rope has a total length of 26 m.

Calculate the rope's elastic constant k (i.e. the ratio of the tension in the rope to its extension), and also the elastic potential energy stored in the rope. **[2 marks]**

NSAA 2017 Section 2 - Question P1 (b) - Worked Solution

X = 26 - 10 = 16 m (Displacement)
T = mg therefore kx = mg
16k = 50 x 10
k = 500/16 = 31.25 Nm^-1
Elastic potential energy:
E = kx^2/2 kx = mg therefore E = mg/2 x X, where X = 16
=mg/2 x 16 = 8mg = 4000J

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Alice now uses the same elastic rope to do a "bungee jump": one end of the rope is attached to Alice, and the other end to a bridge over a very deep valley. Alice falls off the bridge, starting from rest, and moves vertically downwards.

c) Describe in words Alice's acceleration until she reaches the lowest point of her fall.

[2 marks]

NSAA 2017 Section 2 - Question P1 (c) - Worked Solution

Let X= the distance of Alice below the bridge
Firstly, she will accelerate downwards with a constant acceleration of g = 10m/s
When X=10m (the lenght of the unstretched rope) the rope becomes taut and downwards acceleration reduces as it is opposed by the tension in the rope
When the tension equals the weight, the acceleration is zero, and the speed of fall is at its maximum
After this point the tension becomes larger than the weight and the direction of acceleration switches to upwards, until the speed falls to zero and the acceleration is maximal at the bottom of the fall

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d) Calculate Alice's vertical downward speed when she has fallen a vertical distance of 15 metres from the bridge. **[2 marks]**

NSAA 2017 Section 2 - Question P1 (d) - Worked Solution

Energy stored in rope = $1/2\ kx^2$. Extension = X-10
Energy conservation implies:
$1/2mv^2 = mgx - 1/2\ k\ (x-10)^2$. Solve for V:
$1/2k\ (x-10)^2 + 1/2mv^2 = mgx$
1/2mv^" = mgx - 1/2k $(x-10)^2$
$mv^2 = m2gx - k\ (x-10)^2$
$v^2 = 20x - k/m\ (x-10)^2$
speed = $\sqrt{20x - 5/8(x-10)^2}$
at 15m below the bridge: $V = \sqrt{300 - 5/8\ (5)^2} = \sqrt{2278/8}$
her speed is 16.9m/s

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e) Calculate the distance below the bridge where Alice is instantaneously at rest. **[3 marks]**

NSAA 2017 Section 2 - Question P1 (e) - Worked Solution

Using the equation from part 6: where V = 0
0 = 20x-5/8 (x-10)^2
5/8 (x-10)^2 = 20x
5/8 (x^2 - 20x +100) = 20
(5x^2/8) - (25/2)x + 125/2 = 20x
5x^2 - 260 x +500 = 0
(5x - 10)(x-50) = 0
Therefore X = 10/5 = 2 OR X = 50m
because the equation only applies when X>10m (i.e when the string is in extension_, 50m is the correct answer

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f) Calculate Alice's maximum speed during her fall, and state where this occurs. **[3 marks]**

NSAA 2017 Section 2 - Question P1 (f) - Worked Solution

Maximum speed will occur at the point of equilibruim when tension balances weight, where acceleration is zero (T = mg)

K (x-10) = mg

kx = mg + 10k

X = mg/k + 10 = 26m. 26m is therefore the point of equilibrum. We now need to calculate the speed at this point using the equation from part d

√520 - 5/8 (16)^2 = √360

= 18.97 m/s

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g) What is the magnitude and direction of the maximum acceleration that Alice experiences during her fall, and where does this occur? **[3 marks]**

NSAA 2017 Section 2 - Question P1 (g) - Worked Solution

Maximum acceleration will occur at the bottom of the fall (x = 50m), when changing direction to move upwards

T-mg = ma

k(x-10) - mg = ma

a = 31.25 x 40 - 10 x 10/50

= 15ms^-2

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h) Sketch a graph of Alice's vertical acceleration against distance fallen until she reaches the lowest point of her fall. Take the downwards direction as positive. **[3 marks]**

NSAA 2017 Section 2 - Question P1 (h) - Worked Solution

Graph should show acceleration in the y axis and displacement in the x axis. Acceleration is constant and at its highest (10ms^-2) before the rope becomes taught at 10m, therefore this section of the graph should have a horizontal line at an acceleration of 10. After this point acceleration constantly decreases until 50m. From our answer to part f we know that acceleration = 0 at 26 m

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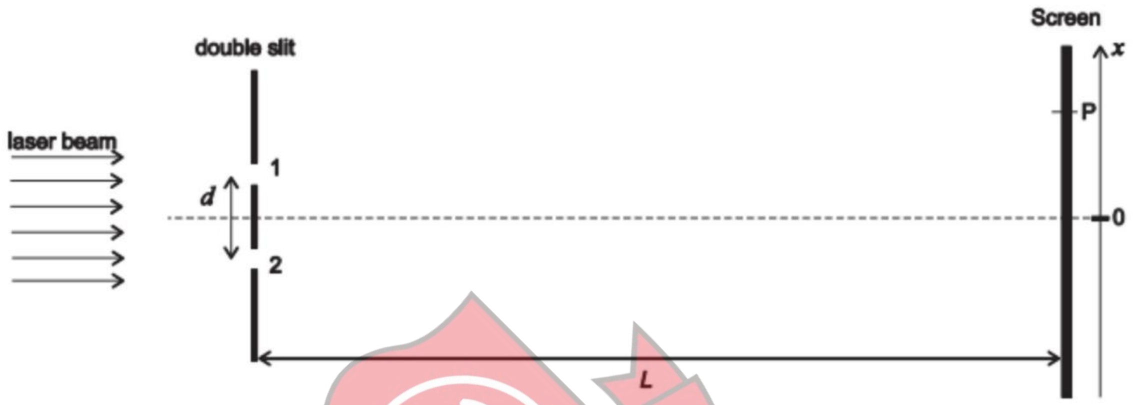
NSAA Section 2 2017 - Question P2

Question P2

In a double slit experiment, a laser beam of wavelength λ illuminates two **narrow** slits at normal incidence, as shown in the diagram. The two narrow slits are separated by a distance d and an interference pattern is seen on a screen a distance L away from the slits, where $L >> d$.



a) Explain how this experiment is used to provide evidence for the wave nature of light. **[2 marks]**

NSAA 2017 Section 2 - Question P2 (a) - Worked Solution

This experiment is used to prove the wave nature of light.
When waves meet at the screen they interfere.
If the waves meet in phase, the constructively interfere, forming the brighter spots.
When the waves are in antiphase, a phase difference of Pi radians, they destructively interfere resulting in the darker spots.

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b) The interference pattern that is seen on the screen can be sketched as a graph of light **intensity** against distance x measured from the central axis.

Sketch this graph for both positive and negative values of x. **[3 marks]**

NSAA 2017 Section 2 - Question P2 (b) - Worked Solution

Graph will show regular waves that reach 0 light intensity at the trough and peak intensity at the central axis

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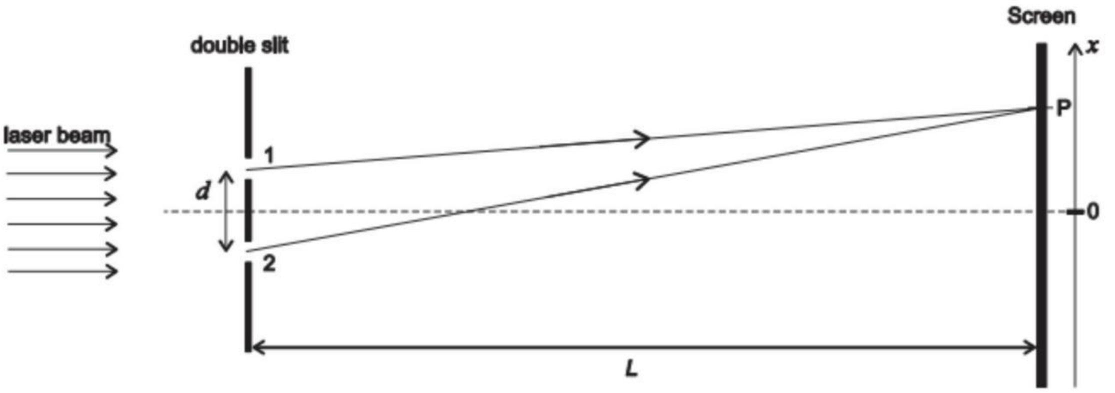
c) Illustrate on the diagram below the path difference between two rays of light from the two slits arriving at point P on the screen. **[1 mark]**

Answer:



NSAA 2017 Section 2 - Question P2 (c) - Worked Solution

Path difference is the difference in the distance between two light sources and the point on the screen they are travelling to

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d) By referring to the diagram in part **c)**, derive an expression for the x position of the first minimum (the minimum closest to $x = 0$) in terms of λ, d and L. **[3 marks]**

NSAA 2017 Section 2 - Question P2 (d) - Worked Solution

The first minimum will be where the path difference = 1/2 lambda and the waves are in antiphase

Using the similar triangles:
sin theta = a/d and x/L = sin theta
a/d = x/L
a = dx/L

nlambda/2 = dx/L
lambda/2 = dx/L
x = Llambda/2d

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The amplitude of the light wave from slit 1, arriving at point P, can be described mathematically by the function

$$A_1 = A_0 \cos\left(\omega t - \frac{2\pi(L - \Delta L)}{\lambda}\right)$$

Similarly, the amplitude of the light wave from slit 2 that arrives at point P can be described as

$$A_2 = A_0 \cos\left(\omega t - \frac{2\pi(L + \Delta L)}{\lambda}\right)$$

where A_0, λ, t and ω are constants.

e) Using the trigonometric identity $\cos B + \cos C = 2\cos\left(\frac{B-C}{2}\right)\cos\left(\frac{B+C}{2}\right)$, derive an expression for the total amplitude of the light wave, $A = A_1 + A_2$ at point P.

Give your answer in the form $A = F\cos(G)\cos(H)$ where F, G and H are expressions in terms of A_0, λ, t, ω, L and ΔL. **[3 marks]**

NSAA 2017 Section 2 - Question P2 (e) - Worked Solution

$A = 2A_0 \cos cos\left(\frac{2\pi AL}{\lambda}\right) \cos cos\left(wt - \frac{2\pi L}{\lambda}\right)$

OR

$F = 2A_0 = \left(\frac{2\pi AL}{\lambda}\right) \quad H = \left(wt - \frac{2\pi L}{\lambda}\right)$

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f) Let $t = 0$ while L and λ remain constant. What are the two smallest positive values of ΔL for which $A = 0$? **[4 marks]**

NSAA 2017 Section 2 - Question P2 (f) - Worked Solution

If t = 0

$$A = 2A_0 \cos cos \left(\frac{2\pi AL}{\lambda}\right) \cos cos \left(\frac{2\pi L}{\lambda}\right)$$

$$\cos cos \left(\frac{2\pi AL}{\lambda}\right) = 0$$

Therefore

$$\frac{2\pi AL}{\lambda} = \frac{\pi}{2} \ , \ \frac{3\pi}{2}$$

So,

$$\Delta L = \frac{\lambda}{4} , \ \frac{3\lambda}{4}$$

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g) If the first minimum at point P is at $x = 1.5$ cm when $d = 0.10$ mm and $L = 5.0$ m, what is the value of ΔL and what is the wavelength of the laser light? **[4 marks]**

NSAA 2017 Section 2 - Question P2 (g) - Worked Solution

$$\Delta L = \frac{dx}{2L} = \frac{(0.10\times10^{-3})(1.5\times10^{-2})}{2\times5} = 150nm$$

$$\Delta L = \frac{\lambda}{4}$$

$$\lambda = 4\Delta L = 600\text{nm}$$

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NSAA Section 2 2017 - Question C1

Question C1

Data: Assume that the molar gas volume = 24.0 $dm^3 mol^{-1}$ at room temperature and pressure (rtp).

a) When lithium metal and hydrogen gas are heated together, a single substance, **A**, is formed as colourless crystals with a melting point of 688 °C. Molten **A** conducts electricity, and electrolysis of the molten substance re-forms the elements.

(i) Give an equation for the formation of **A**. **[1 mark]**

NSAA 2017 Section 2 - Question C1 a(i) - Worked Solution

2Li(m) + H2(g) → 2LiH(s)

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(ii) Classify the structure of **A** as either molecular covalent, giant covalent, or ionic. Briefly justify your answer. **[2 marks]**

NSAA 2017 Section 2 - Question C1 a(ii) - Worked Solution

Ionic becuase it has a high melting point (due to the strong ionic bonds) and conducts when melted (In the solid state the ions are unable to move about to conduct electricity)

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(iii) During the electrolysis of molten **A**, which element appears at the positive electrode (the anode) and which appears at the negative electrode (the cathode)? **[1 mark]**

NSAA 2017 Section 2 - Question C1 a(iii) - Worked Solution

At the anode negative ions lose electrons (oxidation), H2 appeares. At the cathode positive ions gain electrons (reduction), Li appears

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b) Substance **A** reacts with aluminium chloride to form lithium aluminium hydride ($LiAlH_4$) and one other by-product.

Give a balanced chemical equation for the formation of lithium aluminium hydride from **A** and aluminium chloride. **[2 marks]**

NSAA 2017 Section 2 - Question C1 (b) - Worked Solution

4LiH(s) + AlCl3(s) → LiAlH4(s) + 3LiCl(s

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c) When 3.8 g of lithium aluminium hydride is heated to 125 °C, it decomposes to give three substances: 1.8 g of aluminium metal, 2.4 dm^3 of a flammable gas (measured at rtp), and substance **B**.

Determine the formula for substance **B**. **[5 marks]**

NSAA 2017 Section 2 - Question C1 (c) - Worked Solution

2.4 dm3 of gas at rtp corresponds to 2.4/24.0 = 0.10 mol of the gas
Mr(LiALH4) = 6.94 +26.98 + 4 x 1.008 = 37.952 g/mol
3.8g of LiALH4 corresponds to 3.8/37.952 = 0.1 mol
1.8g Al corresponds to 1.8/26.98 = 0.067 mol
The flammable gas is likely to be H2
3LiAlH4 → 2Al + 3H2 + Li3AlH6

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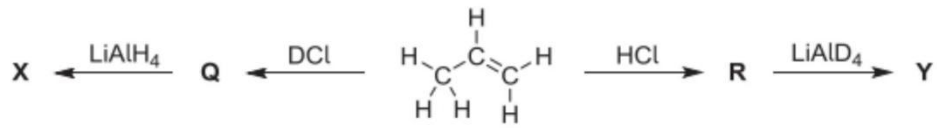
d) Lithium aluminium deuteride can be prepared if deuterium gas is used in place of normal hydrogen. Deuterium, often given the symbol D, is the non-radioactive isotope of hydrogen, i.e. D = ^{2}H. The formula for lithium aluminium deuteride can be written $LiAlD_4$. Both $LiAlH_4$ and $LiAlD_4$ are common reducing agents and the latter is useful for preparing deuterium-containing compounds.

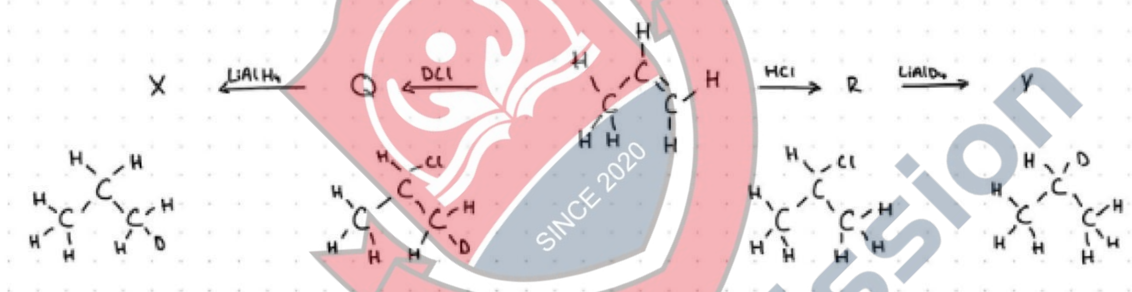
Isomers of mono-deuterated propane, **X** and **Y**, may be prepared from propene according to the following scheme which also uses hydrogen chloride, HCl, and deuterium chloride, DCl. In the scheme, only the carbon-containing compounds are shown; other by-products are not.



Give the structures of **X** and **Y** and the intermediates **Q** and **R** formed during the syntheses.

[4 marks]

NSAA 2017 Section 2 - Question C1 (d) - Worked Solution



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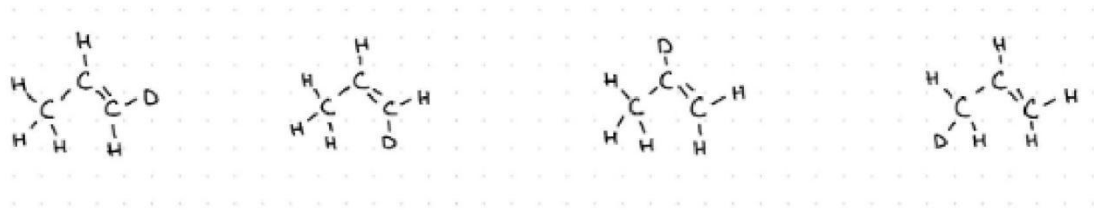
e) 2,2-dideuterated propane may be prepared easily in two steps, from a mono-deuterated propene, **Z**. (The formula for **Z** is C_3H_5D.)

(i) Draw the structures of all the alkenes with formula C_3H_5D. **[2 marks]**

NSAA 2017 Section 2 - Question C1 e(i) - Worked Solution



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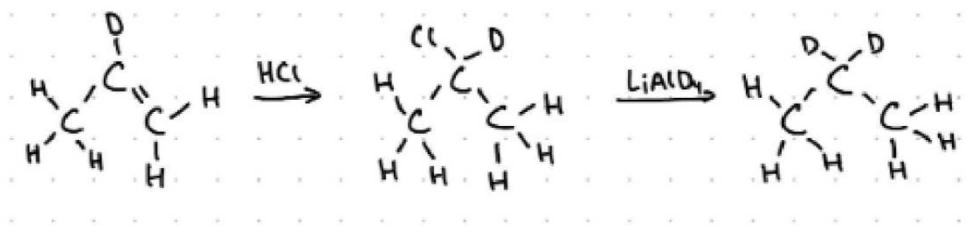
(ii) Give a synthesis of 2,2-dideuterated propane starting from **Z** showing reagents and intermediates in each step, making sure to give the displayed formula for **Z**. **[3 marks]**

NSAA 2017 Section 2 - Question C1 e(ii) - Worked Solution



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NSAA Section 2 2017 - Question C2

Question C2

Read the following carefully before proceeding to answer the question.

In their solid (crystalline) form many inorganic salts (such as NaCl or MgF_2) can be thought of as consisting of a giant lattice in which positive ions (e.g. Na^+, Mg^{2+}) and negative ions (e.g. Cl^-, F^-) are arranged in a regular pattern, called a *lattice*. The ions are held together by electrostatic forces arising from the favourable interactions between ions of opposite charge.

The lattice enthalpy is the enthalpy change for a process in which the **solid** material is formed from ions in the gas phase. For NaCl(s) this is the process

$$Na^+(g) + Cl^-(g) \rightarrow NaCl(s)$$

and for MgF_2 the process is

$$Mg^{2+}(g) + 2F^-(g) \rightarrow MgF_2(s)$$

The lattice enthalpy is invariably large and negative.

The lattice enthalpy in $kJ\,mol^{-1}$ can be estimated using the following expression:

$$\frac{-1.07 \times 10^5 \times n_{ions} \times z_+ \times z_-}{r_+ + r_-} \qquad \textbf{Equation 1}$$

In this expression, r_+ is the radius of the positive ion, in pm ($1\,pm = 10^{-12}\,m$), and r_- is the radius of the negative ion, also given in pm.

n_{ions} is the number of ions in the formula unit; for example, for NaCl $n_{ions} = 2$, but for MgF_2 $n_{ions} = 3$.

z_+ is the charge number on the positive ion; for example for Na^+ it is 1, but for Mg^{2+} it is 2. Likewise z_- is the **absolute value** of the charge number on the negative ion: for Cl^- it is 1 (**not** -1).

a) Use Equation 1 to calculate the lattice enthalpy for CuF_2 given the following data:

$$r_+ = 73\,pm, \quad r_- = 133\,pm$$

[3 marks]

NSAA 2017 Section 2 - Question C2 (a) - Worked Solution

(-1.07 x 10^5 x 3 x 2 x 1) / (73+133) = 3120kJ / mol

b) Use Equation 1 to calculate the lattice enthalpy for CuF_3 given the following data:

$$r_+ = 54\,\text{pm},\ \ r_- = 133\,\text{pm}$$

[3 marks]

NSAA 2017 Section 2 - Question C2 (b) - Worked Solution

(-1.07 x 10^5 x 4 x 3 x 1) / (54 +133) = -6870kJ/mol

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c) Calculated values of the lattice enthalpy can be used to estimate the enthalpy change of hypothetical reactions, such as

$$CuF_2(s) + \frac{1}{2}F_2(g) \rightarrow CuF_3(s) \quad \textbf{Equation 2}$$

Determine the oxidation state of copper in each of the species and hence classify what kind of reaction this is. **[3 marks]**

NSAA 2017 Section 2 - Question C2 (c) - Worked Solution

CuF2: assume F=-1, so Cu is +2 (as species neutral)
CuF3: assume F = -1, so Cu is +3 (As species neutral)
therefore this is a redox reaction

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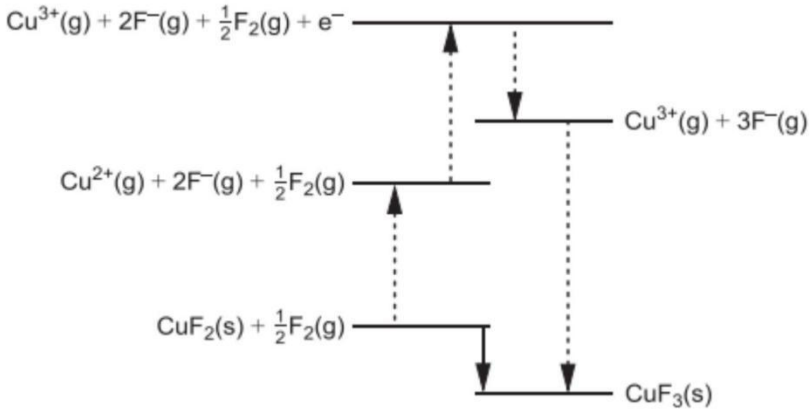
d) The enthalpy change for the reaction in Equation 2 can be calculated using the following Hess's Law cycle.



Using your results from **a)** and **b)**, and given the following enthalpy changes

$F_2(g) + 2e^{-} \rightarrow 2F^{-}(g) \qquad \Delta H = -540\ kJ\ mol^{-1}$

$Cu^{2+}(g) \rightarrow Cu^{3+}(g) + e^{-} \qquad \Delta H = 3555\ kJ\ mol^{-1}$

calculate the enthalpy change for:

$$CuF_2(s) + \frac{1}{2}F_2(g) \rightarrow CuF_3(s)$$

[5 marks]

NSAA 2017 Section 2 - Question C2 (d) - Worked Solution

3120 + 3555 - (1/2) 540 - 6870 = -465 kJ/mol

e) Use the data given below to calculate the enthalpy change for the following reaction (M is an unspecified metallic element).

$$2MF_2(s) \rightarrow MF_3(s) + MF(s)$$

You may find it helpful to start by constructing an appropriate Hess's Law cycle.

$$MF_2(s) \rightarrow M^{2+}(g) + 2F^-(g) \qquad \Delta H = 3000\,kJ\,mol^{-1}$$
$$MF_3(s) \rightarrow M^{3+}(g) + 3F^-(g) \qquad \Delta H = 7000\,kJ\,mol^{-1}$$
$$MF(s) \rightarrow M^{+}(g) + F^-(g) \qquad \Delta H = 1000\,kJ\,mol^{-1}$$
$$M^{+}(g) \rightarrow M^{2+}(g) + e^- \qquad \Delta H = 2000\,kJ\,mol^{-1}$$
$$M^{2+}(g) \rightarrow M^{3+}(g) + e^- \qquad \Delta H = 3000\,kJ\,mol^{-1}$$

[6 marks]

NSAA 2017 Section 2 - Question C2 (e) - Worked Solution

2 x 3000 + 3000 - 2000 - 7000 - 1000 = 1000 kJ mol-1

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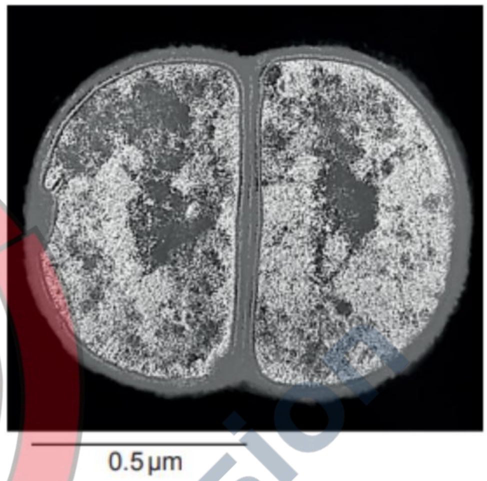
NSAA Section 2 2017 - Question B1

Question B1

a) Identify the types of cells that can be seen in Fig. **(i)** and **(ii)**. **[2 marks]**

Fig. (i)

Fig. (ii)



NSAA 2017 Section 2 - Question B1 (a) - Worked Solution

(i) Plant cell
(ii) Bacterial cell

b) Why was an electron microscope used to create these images? **[1 mark]**

NSAA 2017 Section 2 - Question B1 (b) - Worked Solution

(1) You cannot observe cells via the naked eye, and hence an electron microscope is used
(2) An electron microscope has a greater resolution, and allows us to observe small structures that would not be visible from a light microscope.

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c) Assume that the scale bar below each image is 3 cm long.

Estimate the magnification of each image. **[2 marks]**

NSAA 2017 Section 2 - Question B1 (c) - Worked Solution

Magnification = actual size of bar / size of bar mentioned

3 cm = 30000 μm

(i) 30000 / 20 = x1500
(ii) 30000 / 0.5 = x60000

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d) Discuss the evolutionary order of appearance of the mitochondrion, chloroplast and ribosome, explaining your reasoning. **[3 marks]**

NSAA 2017 Section 2 - Question B1 (d) - Worked Solution

All cells have ribosomes, so ribosomes must have been first. All eukaryotes have mitochondria, so mitochondria must have come afterwards. Only plant cells have chlorplasts, so chloroplasts will be last in the evolutionary hierarcy.

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e) Estimate the percentage of the volume of the cell that the nucleus takes up in Fig. **(i)**, assuming that the cell can be approximated as a cube and the nucleus as a sphere.

(The volume of a sphere is $\frac{4}{3}\pi r^3$ where r is the radius of the sphere.) **[2 marks]**

NSAA 2017 Section 2 - Question B1 (e) - Worked Solution

Answer = 6 to 20%

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f) Discuss how differences in the structure of the cells shown in Fig. **(i)** and **(ii)** affect the locations of different processes within these cells. **[10 marks]**

NSAA 2017 Section 2 - Question B1 (f) - Worked Solution

Within cells different compartments can be formed, allowing physical barriers. This can allow certain areas of a cell to form a microenvironment that contains the right reagents and enzymes for a particular reaction to occur there
The main difference between a plant and bacterial cell is that plant cells contain membrane-bound organelles, wereas bacterial cells don't. including a nucleus, mitochondria and chloroplasts

In eukaryotes:
aerobic respiration occurs in mitochondria
photosynthesis occurs in chloroplasts
DNA replication occurs in the nucleus

In bacteria:
Respiration and photosynthesis take place on the external membrane
DNA replicaation occurs in the cytoplasm, due to the lack of a nucleus the genetic material is find as a nucleoid in the cytoplasm.

Glycolysis occurs in the cytoplasm of both types of cell

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NSAA Section 2 2017 - Question B2

Question B2

a) From the following list of organisms identify one that can reproduce itself **(i)** without using mitosis or meiosis, and **(ii)** using *either* mitosis alone or meiosis.

1 *Homo sapiens*

2 *Fragaria ananassa* (strawberry)

3 *Escherichia coli*

[2 marks]

NSAA 2017 Section 2 - Question B2 (a) - Worked Solution

B2 (a) (i)
Escherichia coli

Bacteria can reproduce by binary fission

B2 (a) (ii)

Fragria ananassa (strawberry)

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b) For the processes of mitosis and meiosis, draw separate line graphs to show how the relative amount of DNA in a single healthy dividing cell changes with time.

You should label the axes on the graphs.

(Assume that no mutations occur.) **[3 marks]**

NSAA 2017 Section 2 - Question B2 (b) - Worked Solution

There are 23 chromosomes

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c) Calculate how many possible combinations of chromosomes could be produced in each gamete during sexual reproduction in humans (assuming no recombination). **[2 marks]**

NSAA 2017 Section 2 - Question B2 (c) - Worked Solution

The possible number of gametes = 2^n, where 'n' is the haploid number. A gamete contains 23 chromosome, therefore 2^23, or 8388608 is the number of possible combinations of chromosomes

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d) A female has a recessive disease-causing allele on one of her non-sex-determining chromosomes. She mates with a male with the same disease-causing allele on one of his chromosomes. They have one child. Assuming that no mutations occur, what is the probability that:

(i) this child will have the disease? **[1 mark]**

(ii) this child is male and does not have the disease? **[2 marks]**

NSAA 2017 Section 2 - Question B2 (d) - Worked Solution

B2 (d) (i)
Recessive trait, so requires 2 copies to have the disease. Since both parents are carriers, there is a 1 in 4 chance that a child will have the disease

B2 (d) (ii)
Probablity that the child is male 1/2. Probablitiy that the child does not have the disease 3/4.
Therefore 1/2 x 3/4 = 3/8 is the probablilty that the clikd is male and does not have the disease

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e) Discuss:

(i) how different mechanisms of reproduction affect the levels of variation in the next generation;

(ii) how variation affects the likelihood of survival in a changing environment.

[10 marks]

NSAA 2017 Section 2 - Question B2 (e) - Worked Solution

B2 (e) (i)
asexual reproduction produces a clone with little variation. Sexual reproduction produces more variation via independent assortment, recombination and random fertalisation. In all reproduction variation is introduced via random mutation

B2 (e) (ii)
Variation leads to differential survival and those best adapted survive, this is known as natural selection

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