NSAA 2017
Section 2

Model Solutions

Physics:

1.

a) Hooke's law Says that a rope or Spring extends with the tension in the rope or Spring proportional to its extension by $T = kx$. The energy Stored is caused by the work done against the bonds between atoms.

It is equal to the average force times extension $= \frac{F}{2} \times x$

$$= \frac{kx}{2} x$$

$$= \frac{1}{2} kx^2.$$

b)

$x = 26 - 10 = 16\ m.$

$T = mg$

$kx = mg$

$16k = 50 \times 10$

$k = \frac{500}{16} = 31.25\ Nm^{-1}.$

$E = \frac{kx^2}{2} = \frac{mg}{2} \times 16 = 8mg = 4000J.$

c)

If x is distance of Alice below the bridge, she initially accelerates downwards at $g = 10\ ms^{-2}$. Then when $x = 10m$, the rope becomes taught and the downwards acceleration reduces due to the tension in the rope. when the tension equals the weight, the acceleration is zero. Then, the tension becomes larger than the weight and the acceleration is now upwards. At the bottom, acceleration $= 0$.

d) extension of rope $= (x-10)\,m.$

energy Stored in rope $= \frac{1}{2}k(x-10)^2 = \cancel{\frac{1}{2}k}$

by the work energy principle:

$$\frac{1}{2}mv^2 = mgx - \frac{1}{2}k(x-10)^2$$

$$\Rightarrow \frac{1}{2}k(x-10)^2 + \frac{1}{2}mv^2 = mgx.$$

$$\Rightarrow \frac{1}{2}mv^2 = mgx - \frac{1}{2}k(x-10)^2$$

$$mv^2 = m2gx - k(x-10)^2$$

$$v^2 = 20x - \frac{k}{m}(x-10)^2$$

$$V = \sqrt{20x - \frac{5}{8}(x-10)^2}.$$

when 15m from the bridge, $x = 15m$,

$$V = \sqrt{300 - \frac{5}{8}(5)^2} = \sqrt{\frac{2275}{8}} = 16.86342195$$

$$= 16.9\ m/s\ \ (3.s.f).$$

e.

$V=0$:

$$0 = 20x - \frac{5}{8}(x-10)^2$$

$$\frac{5}{8}(x-10)^2 = 20x$$

$$\frac{5}{8}(x^2-20x+100) = 20x$$

$$\frac{5x^2}{8} - \frac{25}{2}x + \frac{125}{2} = 20x$$

$5x^2 - 100x + 500 = 160x$

$5x^2 - 260x + 500 = 0$

$(5x - 10)(x - 50) = 0$

$x = \frac{10}{5} = 2m$ or $x = 50m$.

×

the equation only applies for when $x > 10m$.

$\Rightarrow$ She falls 50m below the bridge when she is at rest.

f) Maximum Speed is when passing through equilibrium when the acceleration is zero i.e $T = mg$

$$k(x - 10) = mg$$

$$kx = mg + 10k$$

$$x = \frac{mg}{k} + 10 = 26m.$$

Then using $v = \sqrt{20x - \frac{5}{8}(x-10)^2} = \sqrt{520 - \frac{5}{8}(16)^2}$

$$= \sqrt{520 - 160}$$

$$= \sqrt{360}$$

$$= 18.97\ldots \text{ m/s}$$

$$\approx \underline{\underline{19.0 \text{ m/s}}}$$

g) Maximum acceleration is when $x = 50m$ at the bottom of the fall. It is upwards. $T - mg = ma$

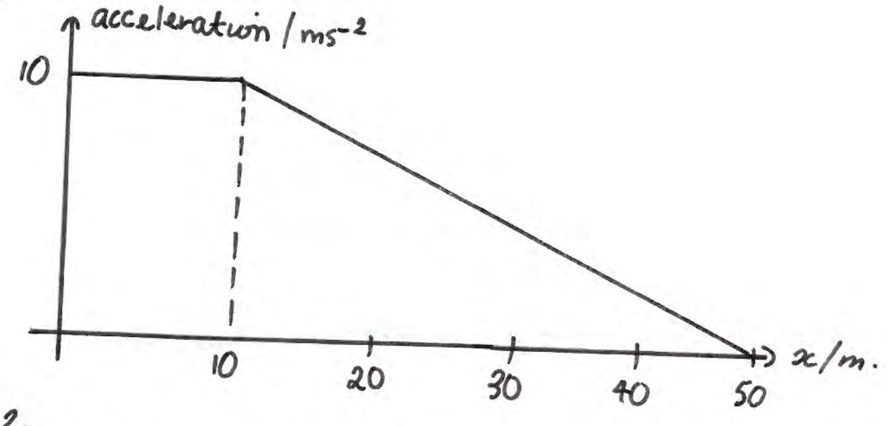
$k(x-10) - mg = ma$

$ma = 31.25(40) - 50(10)$

$= 750$

$a = \frac{750}{50} = 15.0\,ms^{-1}$

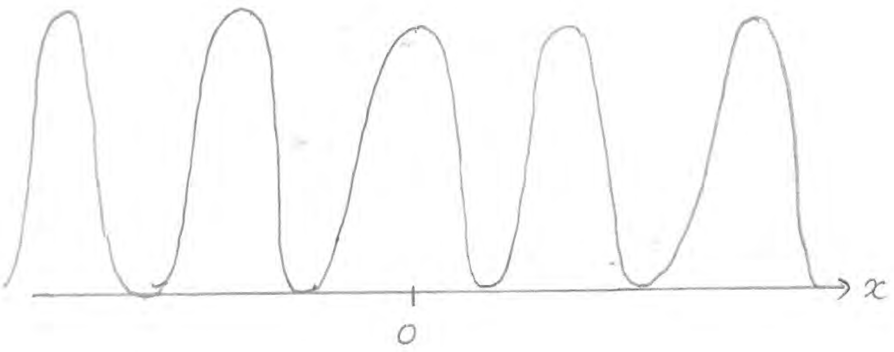
h)



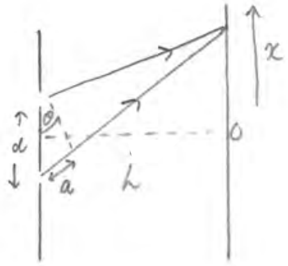
2.

a. When the waves meet at the Screen they interfere. If they meet in phase, they constructively interfere and this is where the bright spots come from. If they meet in anti-phase (a phase difference of π radians) they cancel out causing the dark spots. This is the pattern we see and So this provides evidence for a wave-like nature of light.

b.



c.



a = path difference

d. By Similar triangles:

$$\sin\theta = \frac{a}{d} \quad \text{and} \quad \frac{x}{L} = \sin\theta$$

$$\Rightarrow \frac{a}{d} = \frac{x}{L}$$

$$a = \frac{dx}{L}$$

for minima.

$$\frac{n\lambda}{2} = \frac{dx}{L} \quad \text{for } n \text{ is odd integer.}$$

$$\frac{\lambda}{2} = \frac{dx}{L} \Rightarrow x = \frac{L\lambda}{2d}.$$

e. $$A = A_1 + A_2 = A_0\left(\cos\left(\omega t - \frac{2\pi}{\lambda}(L - \Delta L)\right) + \cos\left(\omega t - \frac{2\pi}{\lambda}(L + \Delta L)\right)\right)$$

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

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

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

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

$$\Rightarrow \text{for } A = 0, \quad \cos\left(\frac{2\pi\Delta L}{\lambda}\right) = 0$$

$$\frac{2\pi\Delta L}{\lambda} = \frac{\pi}{2}, \frac{3\pi}{2}$$

$$\Delta L = \lambda \cdot \frac{\pi}{4\pi} = \frac{\lambda}{4} \text{ or } \frac{3\lambda}{4}.$$

9.

$$\Delta L = \frac{dx}{2L} = \frac{(0.10 \times 10^{-3})(1.5 \times 10^{-2})}{2 \times 5} = 150\text{nm} \quad (\text{from part d}).$$

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

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

Chemistry

Question 1

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]

Answer: …………… $2Li(m) + H_2(g) \rightarrow 2LiH(s)$ (**A**) ……………………………………………

………

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

[2 marks]

Answer: ………… **ionic** because (1) high melting point and (2) conducts on melting …………

………

………

………

(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]

Answer: ……… anode = oxidation: H_2 appears ……………

………………… cathode = reduction: Li appears ……………………………………………………

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]

Answer: ………………………………………………………………………………………………………

………………… $4LiH(s) + AlCl_3(s) \rightarrow LiAlH_4(s) + 3LiCl(s)$ ……………………

…………………… **A** ……………………………………………………………………………

………

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]

Answer: 2.4 dm^3 of gas at rtp corresponds to 2.4/24.0 = 0.10 mol of the gas …………….

………$M_r(LiAlH_4) = 6.94 + 26.98 + 4 \times 1.008 = 37.952$ g mol^{-1} ………

…… 3.8 g of $LiAlH_4$ corresponds to 3.8/37.952 = 0.10 mol ……………………………

………1.8 g of Al corresponds to 1.8/26.98 = 0.067 mol …………………………………

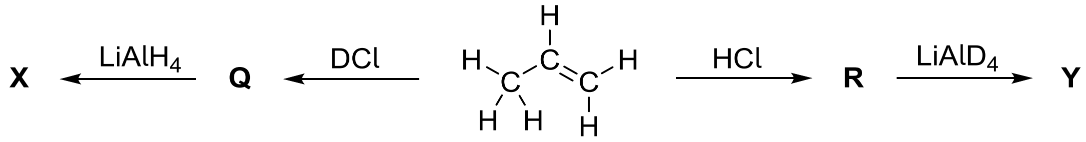
……… flammable gas likely to be H_2 ………………………………………

……… $3LiAlH_4(s) \rightarrow 2Al(m) + 3H_2 +$ **Li_3AlH_6** ………………………………

…………1 mol …… 2/3 mol ..1 mol…**B** ……………………………………………………………

d) Lithium aluminium deuteride can be prepared if deuterium gas is used in place of normal hydrogen. Deuterium, often give the symbol D, is the non-radioactive isotope of hydrogen, *i.e.* D = ^2H. 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.

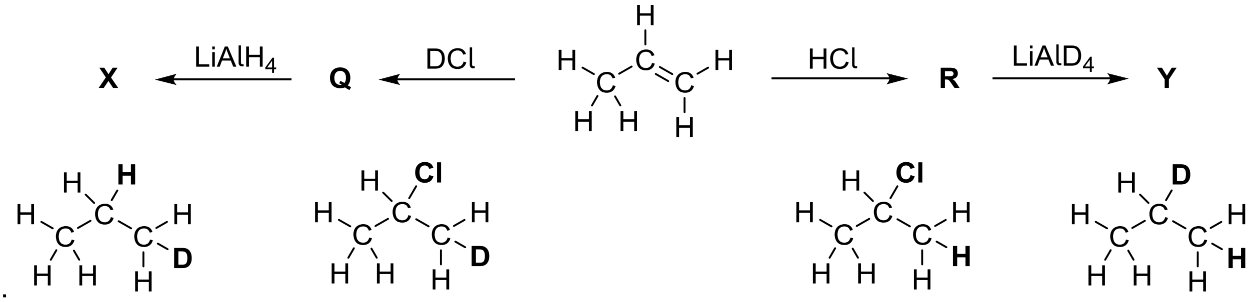
Isomers of mono-deuterated propane, **X** and **Y**, may be prepared from propene according to the following scheme which also uses hydrogen chloride, HCl, and deuterium chloride, DCl. In the scheme, only the carbon-containing compounds are shown; other by-products are not.



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

[4 marks]

Answer: ……………….



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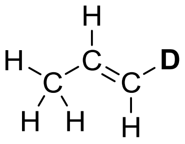
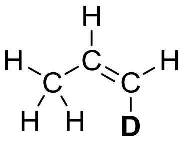
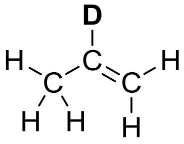
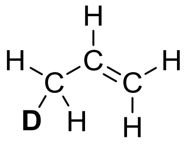
e) 2,2-dideuterated propane may be prepared easily in two steps, from a mono-deuterated propene, **Z**. (The formula for **Z** is C_3H_5D.)

(i) Draw the structures of all the alkenes with formula C_3H_5D.

[2 marks]

Answer: ……

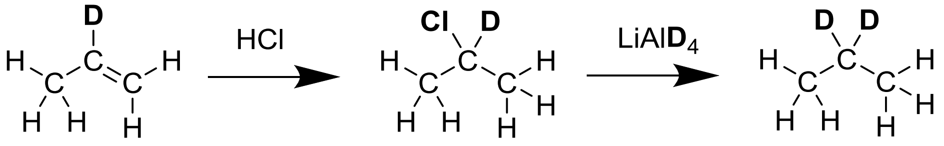





……….

(ii) Give a synthesis of 2,2-dideuterated propane starting from **Z** showing reagents and intermediates in each step.

[3 marks]

Answer: ………………………………………………………………………………………………………



……… **Z** ………….

……

Question 2

Read the preamble 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

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

and for MgF_2 the process is

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

The lattice enthalpy is invariably large and negative.

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

$$\frac{-1.07\times10^5\times n_{\mathrm{ions}}\times z_+\times z_-}{r_+ + r_-} \qquad \textbf{Equation 1}$$

In this expression, r_+ is the radius of the positive ion, in pm ($1\,\mathrm{pm} = 10^{-12}\,\mathrm{m}$), 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 $n_{\mathrm{ions}} = 2$, but for MgF_2 $n_{\mathrm{ions}} = 3$.

z_+ is the charge number on the positive ion; for example for Na^+ it is 1, but for Mg^{2+} it is 2. z_- is likewise 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:

$$r_+ = 73\,\mathrm{pm},\quad r_- = 133\,\mathrm{pm}$$

[3 marks]

Answer: ……………………………………………………………………………………………………

…………… $\frac{-1.07\times10^5\times3\times2\times1}{73+133} = -3120\,\mathrm{kJ\ mol^{-1}}$ …………………………

………

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

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

[3 marks]

Answer: ……………………………………………………………………………………………………

………………… $\dfrac{-1.07\times10^5\times4\times3\times1}{54+133}=-6870\,\text{kJ mol}^{-1}$ ………………………………

………

………

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

$$CuF_2(s) + \tfrac{1}{2}F_2(g) \rightarrow CuF_3(s)$$ **Equation 2**

Determine the oxidation state of copper in each of the species and hence classify what kind of reaction this is.

[3 marks]

Answer: ……………………………………………………………………………………………………

……………CuF_2: assume F = −1, so Cu is +2 (as species neutral) …………………………

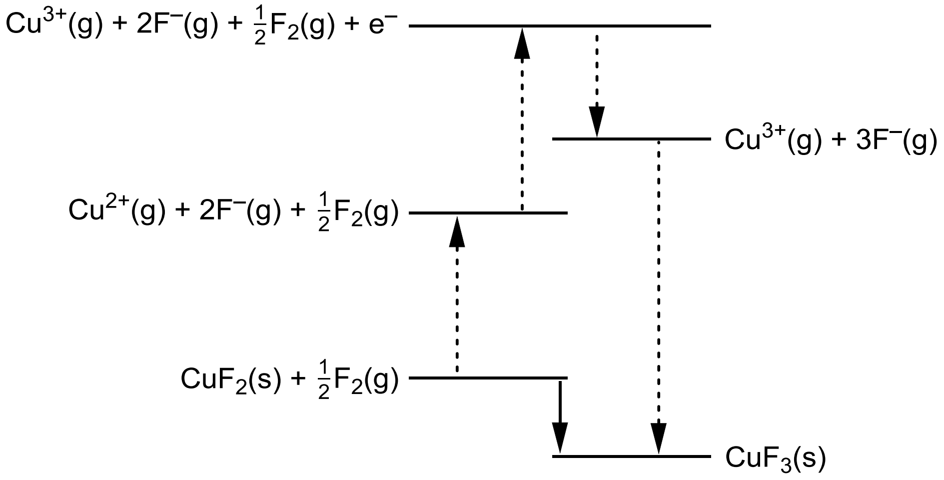
………… CuF_3: assume F = −1, so Cu is +3 (as species neutral)………………………………………

…………This is a redox reaction…………………………….

………

………

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



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

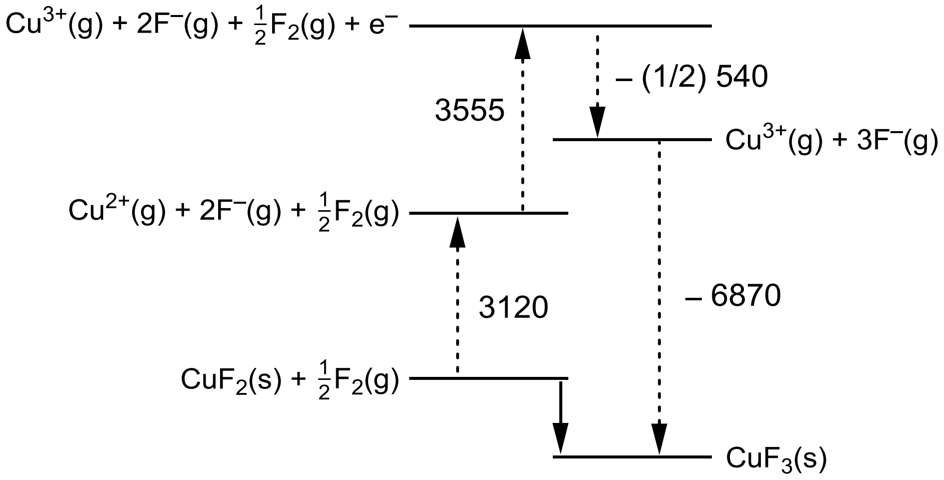
$F_2(g) + 2e^- \rightarrow 2F^-(g)$ $\Delta H = -540\,\text{kJ mol}^{-1}$
$Cu^{2+}(g) \rightarrow Cu^{3+}(g) + e^-$ $\Delta H = 3555\,\text{kJ mol}^{-1}$

calculate the enthalpy change for:

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

[5 marks]

Answer: …



…

…Required value is 3120 + 3555 – (1/2) 540 – 6870 = **– 465 kJ mol^{-1}**….

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

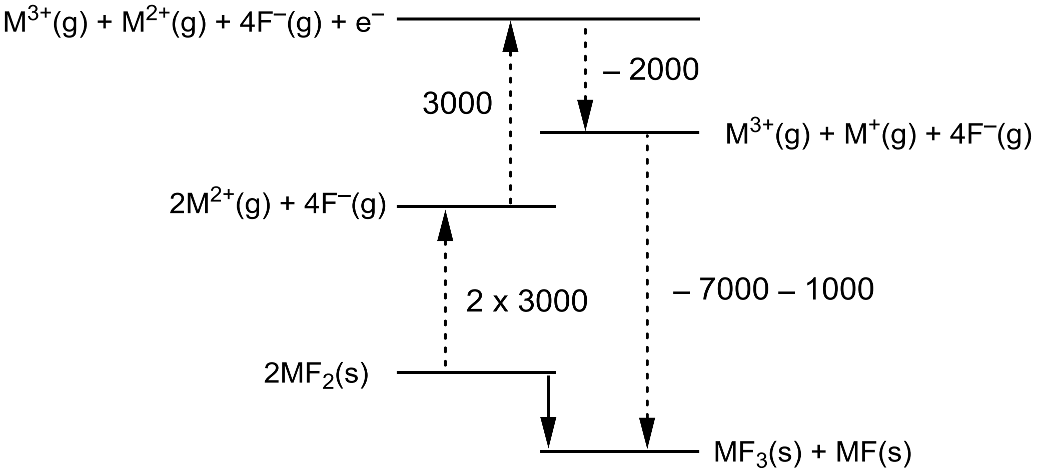
$$2MF_2(s) \rightarrow MF_3(s) + MF(s)$$

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

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

[6 marks]

Answer: ………



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……………….

Required value is 2 × 3000 + 3000 – 2000 – 7000 – 1000 = **– 1000 kJ mol^{-1}**………………………

Biology

Question B1

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

Fig. (i)

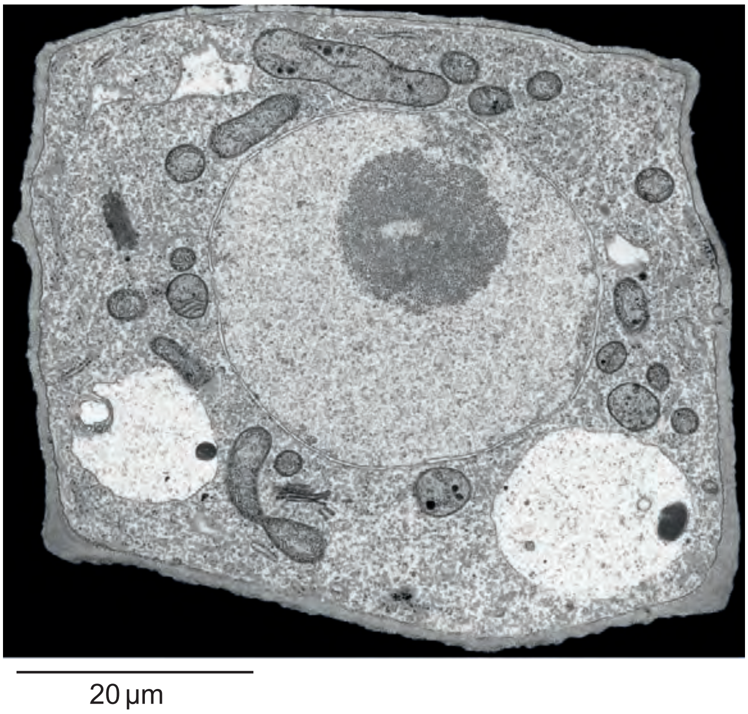

Fig. (ii)

Answer:

(i) Eukaryote (1/2 mark), Plant cell (1 mark)

(ii) Prokaryote (1/2 mark), Bacterium (1 mar..

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

Answer: The structural features are to small to see with the naked eye, but electron microscopes give greater resolution of smaller objects (only 1/2 mark given if resolution is not mentioned)

....

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

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

Answer:

(i) ………. = 1,500x

………………………………………………………………………………………………………

(ii) = 30,000/0.5 = 60,000x

………………………………………………………………………………………………………

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

Answer: Ribosome, Mitochondrion, Chloroplast (1 mark)

The order can be inferred by which organisms have them: All cellular organisms have ribosomes, only Eukaryotes have Mitochondria, and only plants have chloroplasts.

(2 marks)

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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]**

Answer: Students should show appropriate working, but do not actually need to convert values into the real measurements (1 mark)

………………………………………………………………………………………………………

Answer can be between 6% and 20% (1 mark)

………………………………………………………………………………………………………

………………………………………………………………………………………………………

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]**

Answer:

Students should state that in eukaryotes:

Aerobic respiration occurs in Mitochondria (1 mark)

Photosynthesis occurs in Chloroplasts (1 mark)

DNA replication occurs in the Nucleus (1 mark)

They should state that in bacteria:

Respiration and photosynthesis take place on the external membrane (1 mark)

DNA replication occurs in the cytoplasm (1 mark)

Further marks (up to 5) are available for more advanced arguments, such as:

- Knowing that glycolysis occurs in the cytoplasm of both cells
- Identifying that eukaryotes have more membranes/SA for reactions
- Identifying that compartmentalisation allows physical boundaries for reactions
- Identifying that compartmentalisation creates micro-environments
- Particularly advanced accounts of where cellular processes occur (e.g meiosis)
- Details of other cellular compartments (e.g peroxisomes, lysosomes, the ER, Golgi)
- Particularly direct comparisons between the two cells

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[Turn over!

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]

Answer:

(i) *E. coli* (1 mark)
(ii) *F. ananassa* (1 mark)

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]**

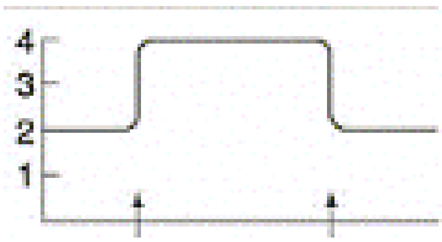
Answer:

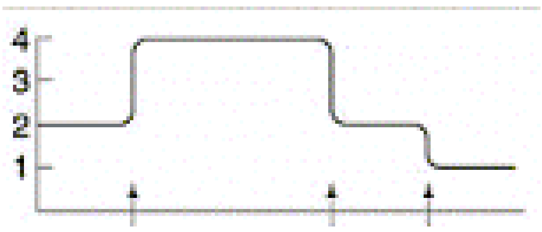
Figures can vary slightly, but should have:

Axes with time and relative amount of DNA (1 mark)

A clear doubling and halving of the amount of DNA in Mitosis (1 mark)

A clear second round of halving in Meiosis (1 mark)





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

Answer: 2^{23} = 8388608 (either will do)

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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]**

Answer: 1/4 (1 mark)

……………………………………………………………………………………………………

……………………………………………………………………………………………………

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

Answer: 3/8 (2 marks)

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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]

Answer:

Students should:

1. State that Asexual organisms produce clones with little variation (1 mark)
2. State that Sexual organisms have increased variation in offspring (1 mark)
3. Explain one way in which variation is generated by sex (e.g independent assortment, recombination, random fertilisation etc) (1 mark)
4. State a factor that influences variation in both reproductive types (environment, mutation) (1 mark)
5. State that variation leads to differential survival and those best adapted survive (1 mark)

Further marks (up to 5) are available for more advanced arguments, such as:

- Outlining more than one way in which variation is generated in sexual organisms
- Explaining how variation can be generated in an asexual organism (e.g environment, conjugation)
- Giving specific examples of either type of reproduction.
- Referring to the genetics of variation (e.g. mendelian genetics, polygenic systems)
- Explaining that sexual organisms may be more prone to extinction because they cannot adapt quickly enough.
- Giving a particularly detailed account of natural selection
- Giving a specific example of where selection acts upon variation