UNIVERSITY OF CAMBRIDGE

NATURAL SCIENCES ADMISSIONS ASSESSMENT

D568/12

Thursday 2 November 2017

40 minutes

SECTION 2

4342346528

Candidate number	N						Centre number					

	d d	m m	y y y y
Date of birth		–	–

First name(s)	

Surname / Family name	

INSTRUCTIONS TO CANDIDATES

Please read these instructions carefully, but do not open the question paper until you are told that you may do so. This paper is Section 2 of 2.

There are six questions in this paper, of which you should answer any **two**.

There are 20 marks for each question. In total 40 marks are available.

You should write your answers in the spaces provided in this question paper. Please complete this section in **black pen**. Pencil may be used for graphs and diagrams only.

You can use the blank pages inside this booklet for rough working or notes, but **no extra paper** is allowed. Only answers in the spaces indicated in the paper will be marked.

Calculators may be used in this section. Please record your calculator model in the box below:

Calculator model	

Write the numbers of the questions you answer in the order attempted in the boxes below:

Question number

Please wait to be told you may begin before turning this page.

This question paper consists of 28 printed pages and 4 blank pages.

PV1

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Physics

Question P1

In this question, assume the gravitational field strength $= 10\,\text{N}\,\text{kg}^{-1}$, 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]**

Answer: ……

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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]**

Answer: ……

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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]

Answer: ……

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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]**

Answer: ……

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

Answer: ……

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

Answer: ……

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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]**

Answer: ……

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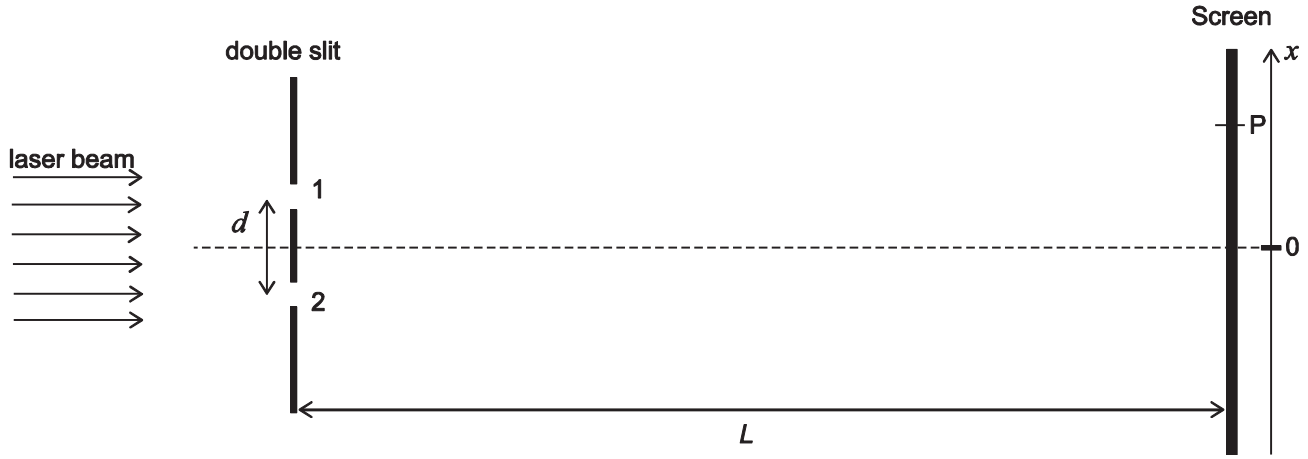
h) Sketch a graph of Alice's vertical acceleration against distance fallen until she reaches the lowest point of her fall. Take the downwards direction as positive. **[3 marks]**

Answer:

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]**

Answer: ……

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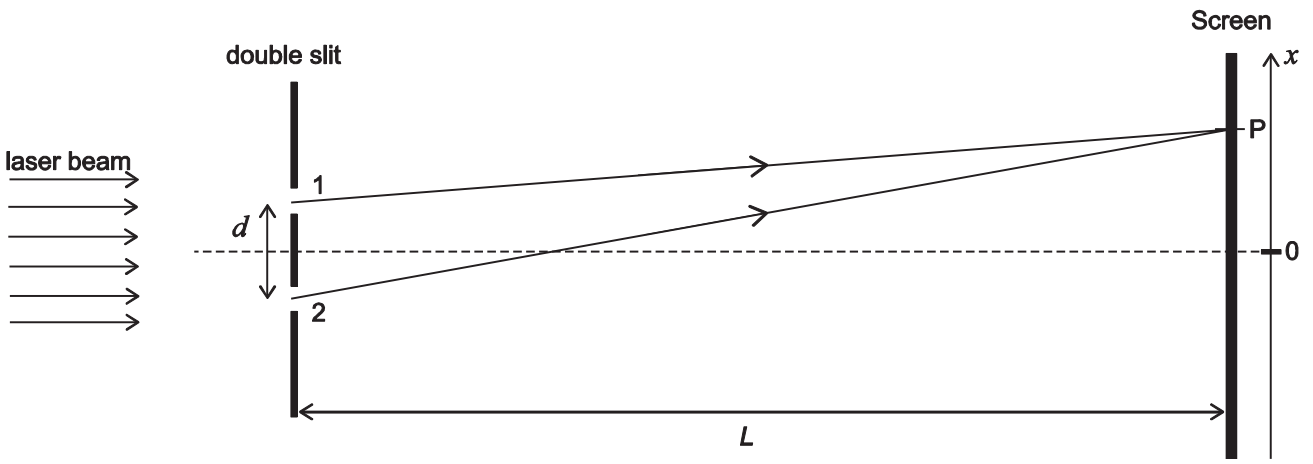
b) The interference pattern that is seen on the screen can be sketched as a graph of light **intensity** against distance x measured from the central axis.

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

Answer:

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:



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]**

Answer: ……

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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]**

Answer: ……

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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]**

Answer: ……

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

Answer: ……

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H 1 1.008																	He 2 4.003
Li 3 6.941	Be 4 9.012					symbol atomic number mean atomic mass						B 5 10.81	C 6 12.01	N 7 14.01	O 8 16.00	F 9 19.00	Ne 10 20.18
Na 11 22.99	Mg 12 24.31											Al 13 26.98	Si 14 28.09	P 15 30.97	S 16 32.06	Cl 17 35.45	Ar 18 39.95
K 19 39.10	Ca 20 40.08	Sc 21 44.96	Ti 22 47.87	V 23 50.94	Cr 24 52.00	Mn 25 54.94	Fe 26 55.85	Co 27 58.93	Ni 28 58.69	Cu 29 63.55	Zn 30 65.38	Ga 31 69.72	Ge 32 72.63	As 33 74.92	Se 34 78.97	Br 35 79.90	Kr 36 83.80
Rb 37 85.47	Sr 38 87.62	Y 39 88.91	Zr 40 91.22	Nb 41 92.91	Mo 42 95.95	Tc 43	Ru 44 101.1	Rh 45 102.9	Pd 46 106.4	Ag 47 107.9	Cd 48 112.4	In 49 114.8	Sn 50 118.7	Sb 51 121.8	Te 52 127.6	I 53 126.9	Xe 54 131.3
Cs 55 132.9	Ba 56 137.3	La* 57 138.9	Hf 72 178.5	Ta 73 180.9	W 74 183.8	Re 75 186.2	Os 76 190.2	Ir 77 192.2	Pt 78 195.1	Au 79 197.0	Hg 80 200.6	Tl 81 204.4	Pb 82 207.2	Bi 83 209.0	Po 84	At 85	Rn 86
Fr 87	Ra 88	Ac^{+} 89															

*Lanthanides	Ce 58 140.1	Pr 59 140.9	Nd 60 144.2	Pm 61	Sm 62 150.4	Eu 63 152.0	Gd 64 157.3	Tb 65 158.9	Dy 66 162.5	Ho 67 164.9	Er 68 167.3	Tm 69 168.9	Yb 70 173.0	Lu 71 175.0
$^{+}$Actinides	Th 90 232.0	Pa 91 231.0	U 92 238.0	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103

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Chemistry

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]**

Answer: ……

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

Answer: ……

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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]**

Answer: ……

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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]**

Answer: ……

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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]**

Answer: ……

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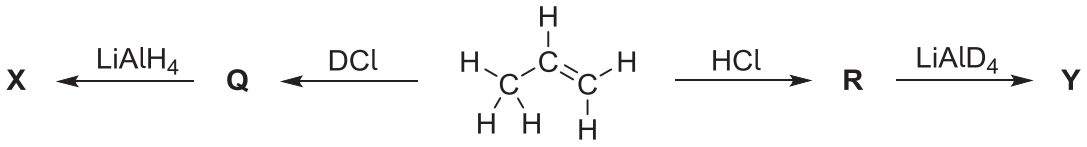
d) Lithium aluminium deuteride can be prepared if deuterium gas is used in place of normal hydrogen. Deuterium, often given the symbol D, is the non-radioactive isotope of hydrogen, i.e. $D = {}^2H$. The formula for lithium aluminium deuteride can be written $LiAlD_4$. Both $LiAlH_4$ and $LiAlD_4$ are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

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, making sure to give the displayed formula for **Z**. **[3 marks]**

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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:

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

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:

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

[3 marks]

Answer: ……

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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]

Answer: ……

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

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

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

Answer: ……

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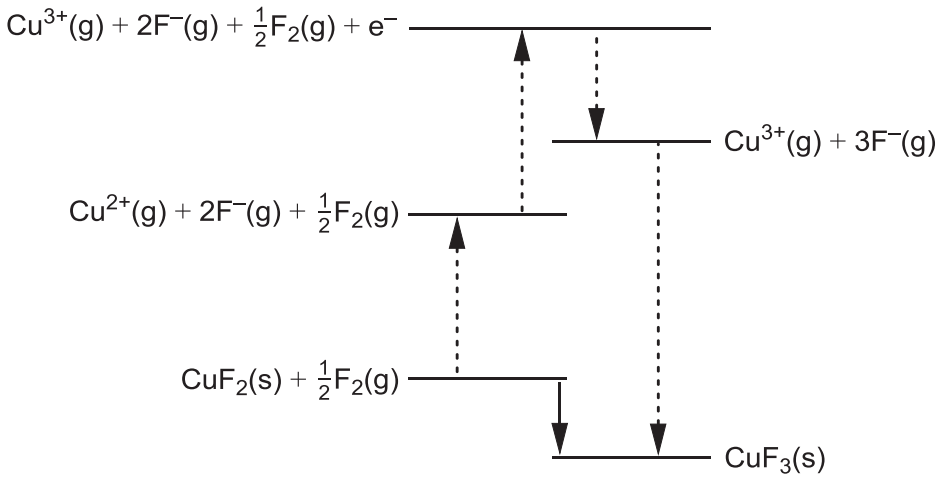
d) The enthalpy change for the reaction in Equation 2 can be calculated using the following Hess's Law cycle.



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]

Answer: ……

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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]

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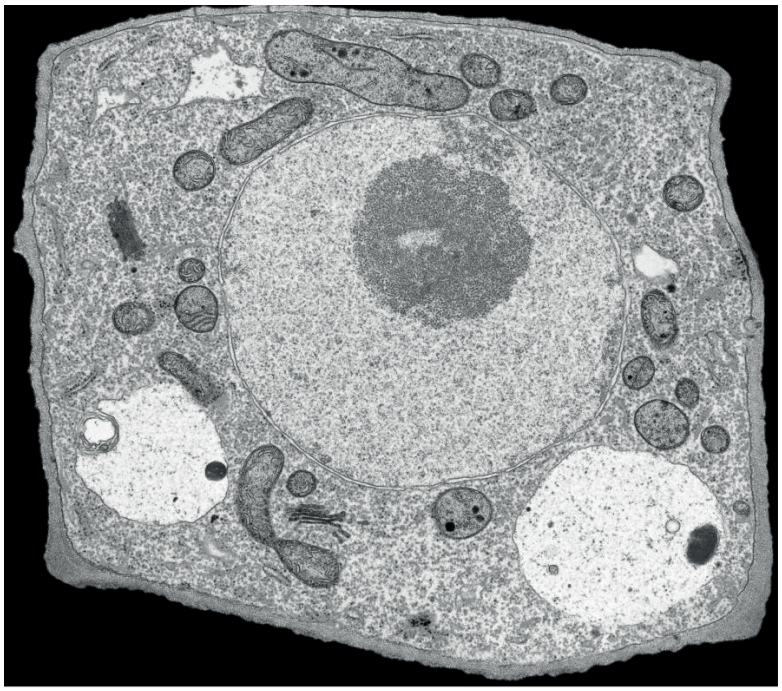
Biology

Question B1

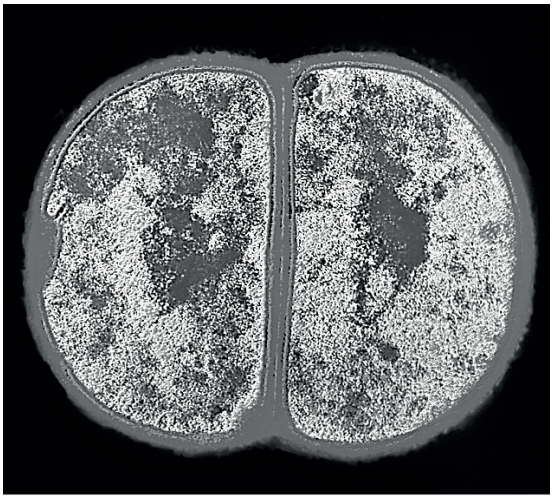
a) Identify the types of cells that can be seen in Fig. **(i)** and **(ii)**. **[2 marks]**

Fig. (i)



20 µm

Fig. (ii)



0.5 µm

Answer:

(i) ……

(ii) ……..

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

Answer: ……....

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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]**

Answer:

(i) ……

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(ii) ……..

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

Answer: ……....

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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: ……....

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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]**

Answer: ....

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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) ……

(ii) ……..

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:

Mitosis Meiosis

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: ……

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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: ……

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

Answer: ……

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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]

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