Oxford Cambridge and RSA

A Level Biology B (Advancing Biology)

H422/02 Scientific literacy in biology

Insert

Tuesday 20 June 2017 – Morning

Time allowed: 2 hours 15 minutes

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INSTRUCTIONS

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INFORMATION

- This Insert contains the Advance Notice.
- This document consists of **4** pages.

TURBOCHARGED PHOTOSYNTHESIS?

As the world's population increases, the spectre of severe food shortages is growing, with the United Nations predicting that food production will need to double by 2050. Researchers have taken an important step towards enhancing photosynthesis. They have engineered plants using enzymes from cyanobacteria, which speeds up the process of converting carbon dioxide into sugars.

Researchers have long wanted to increase yields by targeting D-ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco), the key enzyme responsible for carbon dioxide fixation. Rubisco can account for up to half of the soluble protein found in a leaf. The reason for its abundance is to compensate for its slow catalysis. The enzyme is inefficient because it cannot discriminate between oxygen and carbon dioxide and so wastes energy by fixing oxygen.

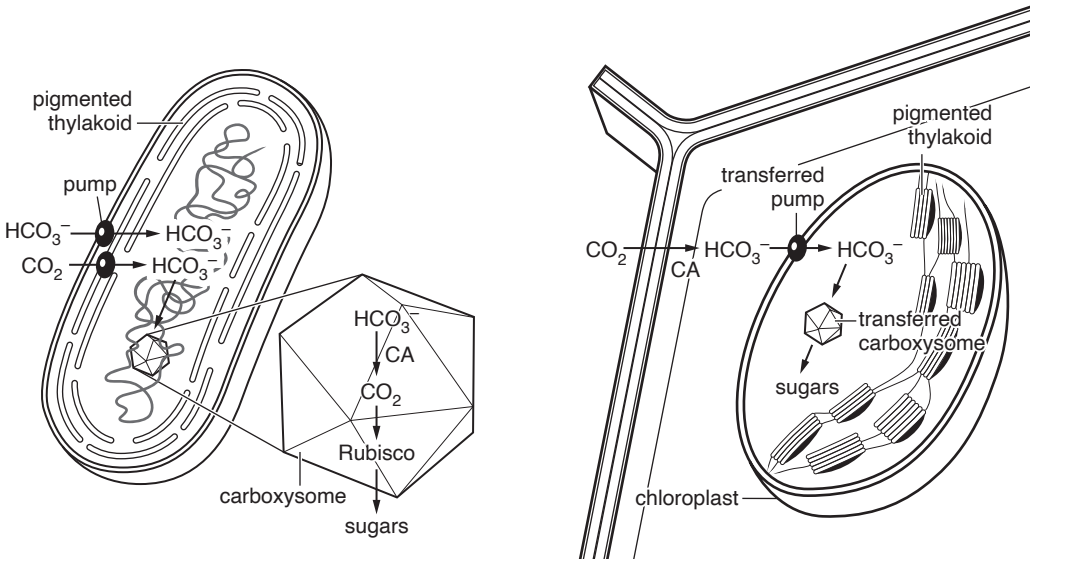
The enzyme evolved at a time when oxygen levels in the atmosphere were much lower than they are today. There was little evolutionary pressure to select for an ability to discriminate between oxygen and carbon dioxide molecules. Photosynthetic organisms have evolved two solutions to cope with the problems of rising oxygen levels:

- a slower acting version of Rubisco with an improved ability to discriminate between carbon dioxide and oxygen
- carbon dioxide concentrating mechanisms (CCMs).

Researchers have estimated that tinkering with Rubisco and boosting the concentration of carbon dioxide around it could generate up to a 60% increase in the yields of rice and wheat. They are focused on introducing CCMs into crops to increase photosynthetic carbon dioxide fixation.

CCMs have evolved independently in cyanobacteria. One example involves a series of membrane-bound pumps for carbon dioxide and hydrogencarbonate ions (HCO_3^-) and special compartments called carboxysomes, which contain Rubisco. HCO_3^- ions are pumped into the cell and then converted to CO_2 in the carboxysomes by the enzyme carbonic anhydrase (CA). This increases the local CO_2 concentration and increases Rubisco efficiency. Furthermore, cyanobacteria have retained an ancient form of Rubisco that is almost three times as efficient as that found in many crops.

Fig. 1a shows the arrangement of CCMs in cyanobacteria. Fig. 1b shows a plant cell after transfer of HCO_3^- pumps and carboxysomes.



a cyanobacteria **b plant cell**

Fig. 1

Scientists from Cornell University in New York and Rothamsted Research in the UK have collaborated on work with tobacco plants (*Nicotiana tabacum*), a common model organism for genetic engineering research. They have taken the faster Rubisco genes from the cyanobacterium *Synechococcus elongatus* and inserted them into the genome of chloroplasts in the tobacco plants.

The ability of two strains of modified plants to carry out photosynthesis was assessed by measuring their rate of CO_2 fixation. Table 1 shows the results of these experiments with two modified strains of tobacco plant (Rbcx and M35) and the unmodified (wild-type, WT) tobacco.

CO_2 concentration (μmol dm^{-3})	**Rate of CO_2 fixation in tobacco plants (mol CO_2 fixed per mol active sites s^{-1})**					
	Rbcx		**M35**		**WT**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
125	2.91	0.18	3.29	0.38	1.85	0.16
250	4.25	0.30	4.67	0.55	1.88	0.17
640	5.71	0.30	6.38	0.77	1.53	0.15

Table 1

Researchers now agree that two improvements are needed: a faster version of Rubisco as well as bacterial carboxysome membrane-bound pumps for CO_2 and HCO_3^-. Scientists are working on the transfer of cyanobacterial carboxysomes or CCM pumps into the chloroplasts of tobacco plant cells. However, extending this to crop plants is still a long way off.

It now seems certain that supercrops with “turbocharged photosynthesis” will be growing in fields in a few decades. This seems like great news in a world where demand for food, biofuels and plant materials like cotton continues to increase, and where global warming will have an ever greater impact on crop production. However, critics of genetic modification have long argued that GM crops will have disastrous effects on ecosystems. So far these fears seem exaggerated. There are monster plants running rampant through many countries, but they are not GM creations – they are invasive species.

This is not surprising; most GM traits are not useful to wild plants. A trait such as herbicide resistance is only useful to plants growing in areas where herbicides are used, such as in fields and road verges. However, if biologists succeed in boosting CO_2 fixation by 25 per cent or more, the upgraded plants will have a selective advantage over wild types. This may add fuel to the anti-GM campaign, with protests against the introduction of turbocharged crops and the debate of growing superplants in open fields.

The arguments in favour are also powerful. An ecosystem based on superplants would support more life overall.

If society decides to go ahead with this technology, further choices arise. Humans could just stand by and let boosted grains, vegetables and trees run wild. An alternative to this could be to upgrade many wild plants too. For many, this may seem like a shocking idea. However, the reality is that the areas we think of as wild and untouched are nothing like they were before our ancestors arrived.

Adapted text from:

‘Should we upgrade photosynthesis and grow supercrops?’ Michael Le Page; *New Scientist* Magazine issue 2989 published 4 October 2014

‘A faster Rubisco with potential to increase photosynthesis in crops’. Linn et al; *Nature* **513**,547–550 (Published online 17 September 2014)

‘Hacked photosynthesis could boost crop yields’; Heidi Ledford; *Nature* doi:10.1038/nature.2014.15949

‘Towards turbocharged photosynthesis’ G.Dean Price; S.M Howitt; Nature Volume 513; Nature 497. Pub Macmillan Publishers Ltd. 2014

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You must have:
- the Insert (inserted)

You may use:
- a scientific or graphical calculator
- a ruler

H422/02

First name									
Last name									
Centre number						Candidate number				

INSTRUCTIONS
- The Insert will be found inside this document.
- Use black ink. You may use an HB pencil for graphs and diagrams.
- Complete the boxes above with your name, centre number and candidate number.
- Answer **all** the questions.
- Write your answer to each question in the space provided. If additional space is required, use the lined page(s) at the end of this booklet. The question number(s) must be clearly shown.
- Do **not** write in the barcodes.

INFORMATION
- The total mark for this paper is **100**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended responses will be assessed in questions marked with an asterisk (*).
- This document consists of **24** pages.

Answer **all** the questions.

1 This question is based on the Advance Notice article **TURBOCHARGED PHOTOSYNTHESIS?**, which is an insert.

(a) Use Fig. 1 on the insert to help you answer the following questions.

(i) State the precise location of the photosystems involved in the light-dependent reaction of photosynthesis.

..... **[1]**

(ii) Describe how the structures containing the photosystems are arranged differently in plant cells and cyanobacteria.

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..... **[2]**

(iii) State the precise location of Rubisco in:

unmodified plant cells .....

cyanobacteria .....
[2]

(iv) Explain how cyanobacteria are able to almost eliminate oxygen (O_2) fixation by Rubisco.

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..... **[3]**

(b) Table 1 on the insert shows the results of experiments to measure carboxylase activity in wild type (WT) tobacco plants and two lines of modified tobacco plant at different concentrations of carbon dioxide (CO_2).

(i) Explain why the units of carboxylase activity are 'mol CO_2 fixed per mol active sites s^{-1}' rather than just 'mol CO_2 fixed s^{-1}'.

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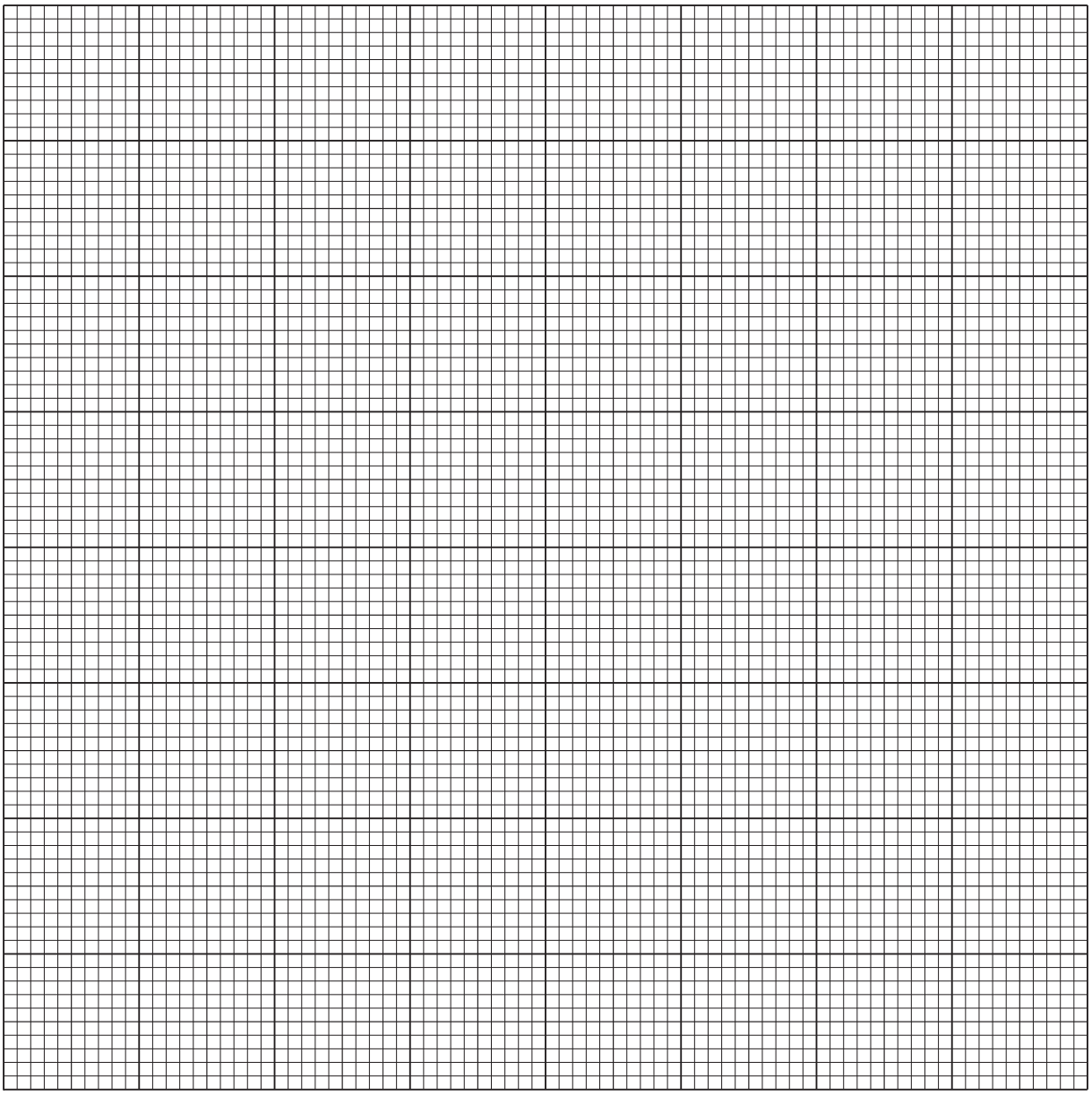
..... **[1]**

(ii) Plot a graph of these results on the grid below. Include error bars showing two standard deviations.



[4]

(iii) Using Table 1 and your graph in **(b)(ii)**, analyse whether the researchers successfully demonstrated that replacing Rubisco in tobacco plants with the cyanobacterial enzyme increased the effectiveness of photosynthesis.

Explain your conclusions.

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..... **[3]**

(iv) A student made the following statement:

"Photosynthesis is more effective in the M35 strain than the Rbcx strain."

Use Table 1 and your graph in **(b)(ii)** to evaluate the validity of the student's statement.

Explain your conclusions.

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..... **[2]**

(c)* Evaluate the risks and benefits of growing supercrops.

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..... **[6]**

2 **(a)** Oogenesis occurs in the ovaries of female mammals, resulting in the production of gametes.

(i) Name the type of nuclear division that results in the production of **secondary** oocytes from **primary** oocytes during oogenesis.

..... **[1]**

(ii) Complete the table below to indicate the stage and type of nuclear division in which the events being described occur.

Event	Type of nuclear division	Stage in nuclear division
Chromosomes line up on the equator; there is no association between homologous chromosomes.		
Homologous chromosomes form bivalents.		
Homologous chromosomes separate and are pulled to opposite poles.		
Crossing over occurs.		

[4]

(b) Fig. 2.1 shows how oestrogen production varies throughout life in human females.

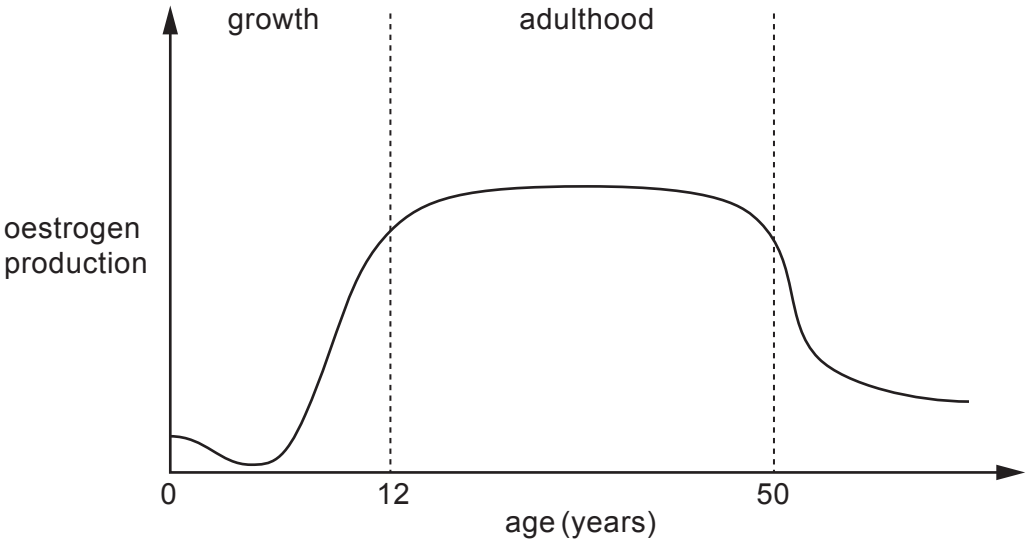

Fig. 2.1

(i) Explain how the rapid increase in oestrogen production towards the end of the growth phase results in the release of secondary oocytes.

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..... **[2]**

(ii) Changes occur to the cells within ovaries over the course of a woman's lifetime.

Use the data in Fig. 2.1 to explain the role of oestrogen production in the changes to ovarian cells that occur during adulthood.

In your answer you should refer to the stages of nuclear division that occur.

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..... **[3]**

(c) Fig. 2.2 shows how the number of ovarian follicles changes from birth to 50 years of age.

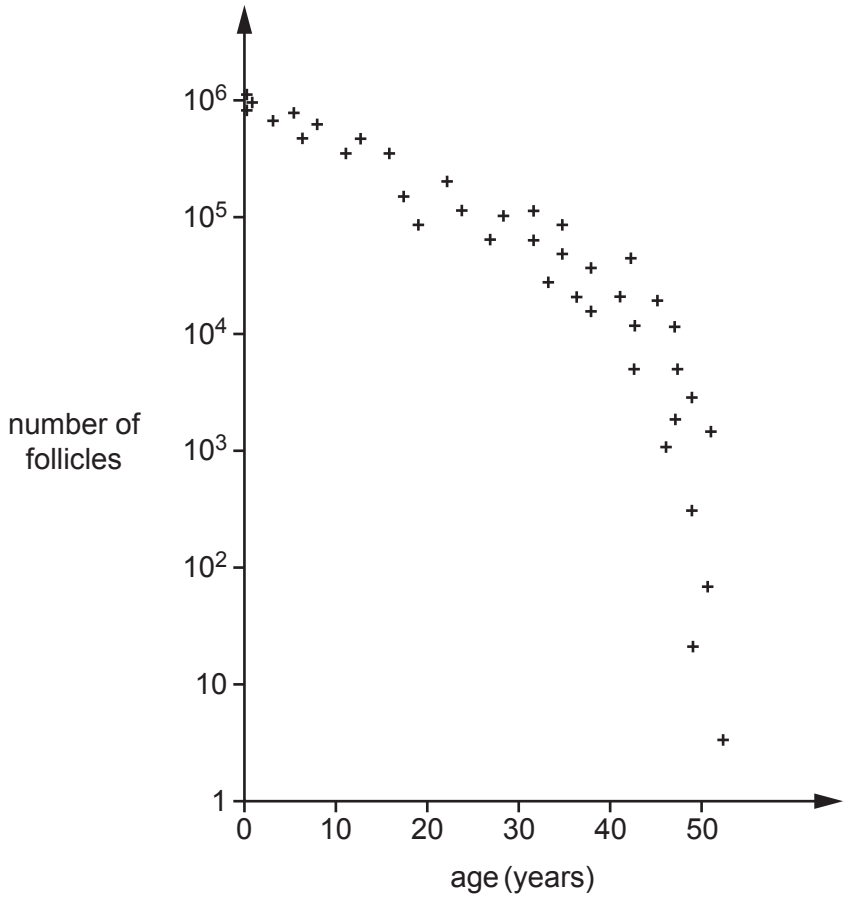

Fig. 2.2

(i) Using the data in Fig. 2.2, describe **and** explain the relationship between the number of follicles and age.

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..... **[4]**

(ii) Name the biological process that occurs as a result of changes in the number of follicles between 45 and 50 years of age.

..... **[1]**

(iii) Describe **two** symptoms that women may experience during this process.

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..... **[1]**

Turn over for the next question

3 **(a)** There is evidence that heart rate increases when people experience pain. Heart rate is one physiological factor that is regulated tightly and kept within narrow limits.

(i) Name the process by which the internal environment of an organism is kept within narrow limits.

..... **[1]**

(ii) A student made the following revision notes about the control of heart rate.

Complete the student's notes using the most appropriate word(s).

'The resting heart rate of an adult human is about 70 beats per minute. This is known as the set point. There are two types of receptor that control heart rate: …… in the walls of the carotid artery that detect changes in blood pH and pressure receptors in the carotid artery and the aorta. When blood pressure rises, pressure receptors transmit nervous impulses to the …… which decreases heart rate via the …… nervous system. This is an example of …… .' **[4]**

(iii) Some doctors who study pain ask patients to give an estimate of the level of their pain by using a scale of 1 to 10.

Explain why some researchers think that measuring heart rate is a more accurate way of determining the level of pain.

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..... **[1]**

(b) Neuropathic pain is a type of pain caused by neurones malfunctioning following nerve damage. When this happens, some voltage-gated sodium ion channels (VGSCs) in pain receptors open spontaneously.

(i) Explain how the spontaneous opening of a VGSC in a pain receptor leads to the generation of a nerve impulse in the sensory neurone attached to the pain receptor.

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..... **[3]**

(ii) Three different types of VGSC in different parts of the nervous system have been linked to neuropathic pain. Drugs to treat neuropathic pain are now being developed that specifically block these types of VGSC.

Suggest why it is important to develop drugs that only block these three types of VGSC.

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..... **[2]**

(c) (i) Single nucleotide polymorphisms (SNPs) have been detected in the genes coding for several types of VGSC. It is thought that these SNPs might alter the response of different patients to drugs that block VGSCs.

Describe the steps involved in identifying the SNPs present in a DNA sample from a patient.

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..... **[2]**

(ii) Screening for other SNPs is used in the study, diagnosis, and treatment of cancer.

A mutation in either the *BRCA1* or *BRCA2* gene increases the risk of breast cancer.

Explain why screening for these mutations is only offered to individuals with a strong family history of breast cancer and a living relative with breast cancer.

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..... **[2]**

4 **(a)** Fig. 4 shows a simplified diagram of part of a DNA molecule.

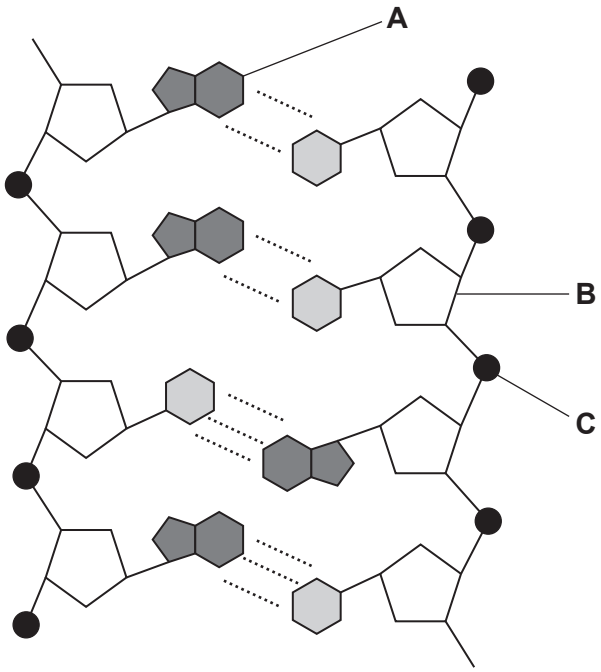

Fig. 4

(i) Identify the parts of the DNA molecule labelled **A** to **C** in Fig. 4.

A .....

B .....

C .....

[3]

(ii) The table below shows the results of an analysis of the base composition for each strand of a DNA molecule.

Complete the table by adding the missing values for strands 1 and 2.

DNA strand	Percentage of each base			
	A	C	G	T
strand 1		35	22	
strand 2	18			

[2]

(b) Hydrogen bonding is central to the function of nucleic acids.

Explain how hydrogen bonding contributes to the process of semi-conservative replication of DNA.

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..... **[2]**

(c) Hereditary non-polyposis colorectal cancer (HNPCC) is a type of bowel cancer caused by a mutation in genes that normally repair DNA.

Explain why mutations in DNA repair genes lead to development of cancer in the bowel and other organs.

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..... **[3]**

5 The MenB vaccine was developed to protect against disease caused by the bacterium *Neisseria meningitidis*. Infection with this bacterium (meningococcal infection) is a major cause of meningitis and blood poisoning, particularly in babies and young children.

The MenB vaccine was introduced into the routine UK vaccination schedule on 1st September 2015. It is available to all new babies born on or after 1st July 2015.

(a) (i) The MenB vaccine is a subunit vaccine.

Explain what is meant by a subunit vaccine.

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..... **[1]**

(ii) Parents have been reassured that the MenB vaccine cannot cause meningitis in their children.

Explain why the MenB vaccine cannot cause the disease.

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..... **[1]**

(iii) The MenB vaccine has also been shown to be effective against other types of meningococcal infection.

Suggest why.

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..... **[2]**

(b)* Evaluate the importance of herd immunity in the prevention of epidemics.

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..... **[6]**

6 Patients with chronic anaemia have reduced levels of haemoglobin in their blood. When anaemia develops over a long period of time, the concentration of the compound 2,3-bisphosphoglycerate (2,3-BPG) in the blood increases.

Fig. 6 shows the oxygen dissociation curves of haemoglobin from two individuals, one suffering from chronic anaemia and the other a normal control.

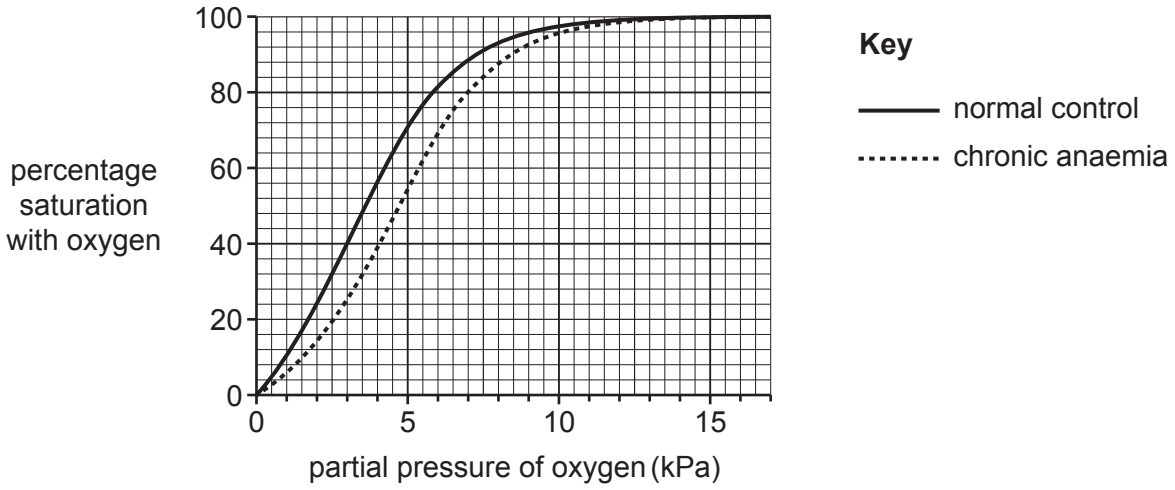

Fig. 6

(a) (i) P_{50} is the partial pressure of oxygen at which haemoglobin is 50% saturated.

Using Fig. 6, calculate the percentage increase in P_{50} in the anaemic patient compared with the normal control.

Show your working. Give your answer to **three** significant figures.

Answer = ... % **[2]**

(ii) Using the data in **Fig. 6**, describe the effect of 2,3-BPG on the oxygen affinity of haemoglobin.

Explain how this effect might partially compensate for the reduction in levels of haemoglobin that occur in anaemic patients.

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..... **[3]**

(b) Haemoglobin is contained in erythrocytes. While studying oxygen transport, a student investigated the water potential of erythrocytes. They wrote the following description in their laboratory notebook:

I placed a drop of blood on a microscope slide and covered it with a coverslip, then added a drop of distilled water on one side of the coverslip. I immediately observed the slide under high power. I repeated the procedure with sodium chloride solutions of two different concentrations to find the one that caused plasmolysis to occur.

(i) Explain why the term 'plasmolysis' is used incorrectly in this student's description.

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..... **[1]**

(ii) State **two** ways in which the experimental procedure described by the student could be improved.

improvement 1 .....

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improvement 2 .....

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[2]

7 **(a)** Fig. 7.1 shows the structures visible in a light micrograph of a generalised animal cell.

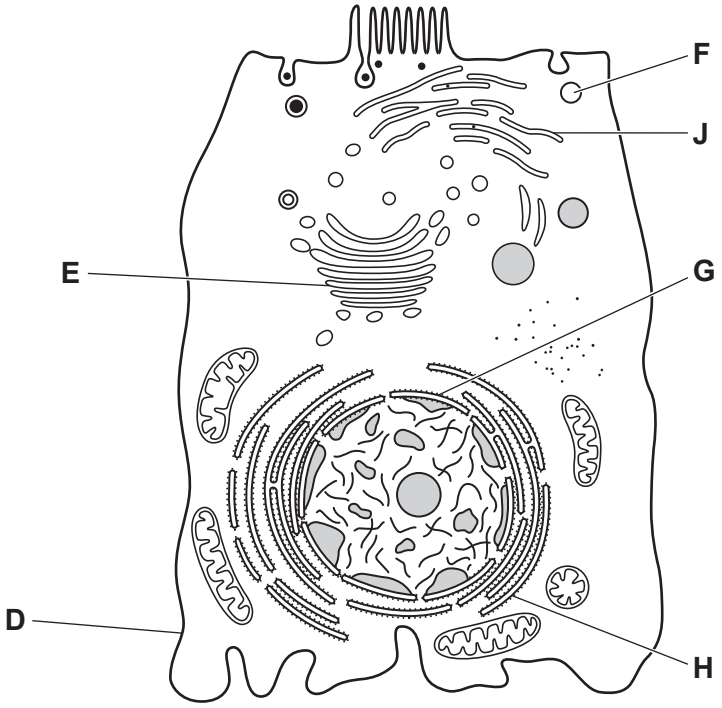

Fig. 7.1

(i) Identify the structures labelled **D** to **H** in Fig. 7.1.

D .....

E .....

F .....

G .....

H .....

[5]

(ii) Describe **two** functions of structure **H** and **one** function of structure **J**.

H .....

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H .....

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J .....

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[3]

(b) The route taken by proteins that are secreted from the cell has been worked out by many different experiments. One series of experiments involved the following steps:

- A virus was modified so that one of its proteins (VSVG) was tagged with green fluorescent protein (GFP).
- Cells were infected with the modified virus.
- The virus produced the tagged protein, VSVG-GFP, using the cells' organelles, but only when the temperature was reduced from 40 °C to 32 °C.
- This allowed the path through the cell taken by the VSVG-GFP to be followed by fluorescence microscopy from the time the temperature was reduced.

Fig. 7.2 shows the results of one experiment where the distribution of fluorescence within individual cells was followed for up to 600 minutes.

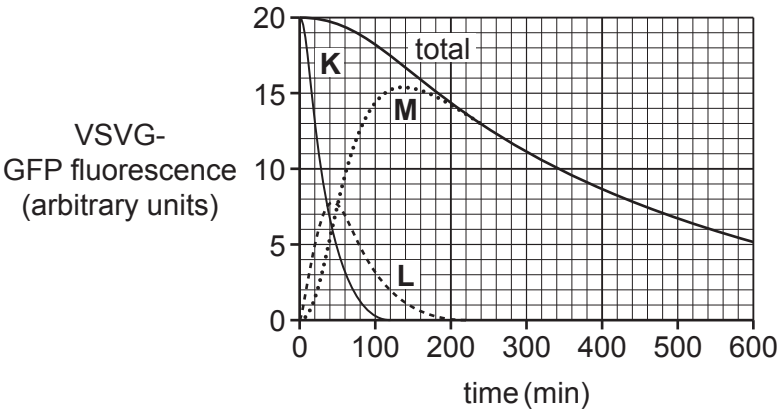

Fig. 7.2

(i) Using Fig. 7.2 and your knowledge of the synthesis and secretion of proteins, identify the organelles corresponding to curves **K**, **L** and **M** on Fig. 7.2.

Give reasons for your answers.

K .....

reason .....

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L .....

reason .....

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M .....

reason .....

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[6]

(ii) Using Fig. 7.2, estimate the time taken for secretion of VSVG-GFP to reach a maximum.

..... **[1]**

(c) Vinblastine is a drug used in the treatment of cancer. It inhibits the assembly of microtubules.

Another experiment similar to that described in part **(b)** was carried out, but the cells were treated with vinblastine before the temperature was reduced from 40° C to 32° C.

When VSVG-GFP fluorescence was followed through the treated cells, only curve **M** disappeared.

Suggest why.

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..... **[2]**

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).