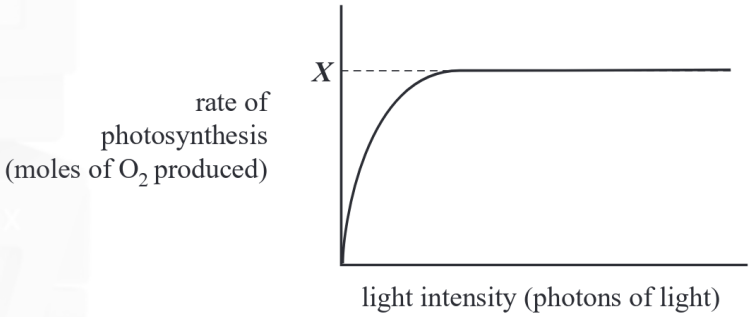
A student shone a light on a green leaf and measured the rate of photosynthesis. The student varied the intensity of the light and graphed the findings as shown below. *X* was the maximum rate of photosynthesis detected by the student.



Which one of the following conditions will increase the value of *X*?

A. adding a filter to the light used

B. using a leaf that contains more chloroplasts

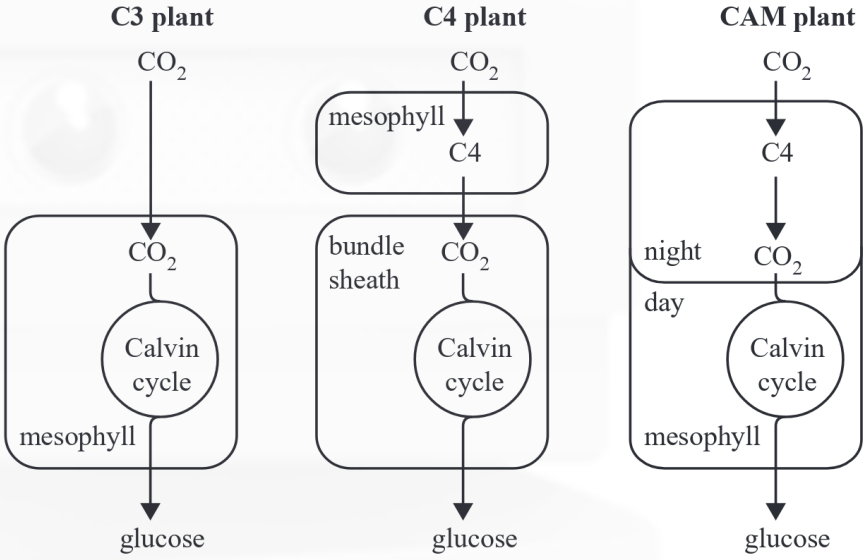
C. moving the light further away from the leaf

D. decreasing the temperature of the leaf's environment

Marking Scheme

Question	Correct answer	% A	% B	% C	% D	Comments
11	B	16	**74**	3	7	

Plants have the unique ability to photosynthesise and utilise sunlight. They are able to produce high-energy-containing molecules that fix carbon dioxide (CO_2) into forms of carbohydrates that can be stored or used by plant cells. Most plants use the C3 pathway to fix CO_2 and some use the C4 pathway. A small group of plants use a combination of both pathways. This smaller number of plants are called the CAM plants.



Source: adapted from H Kheyrodin and S Kheyrodin, 'CO_2 gas exchange in Crassulacean acid metabolism and C3 and C4 plants', *International Journal of Advanced Research in Biological Sciences*, vol. 4, issue 10, 2017, <http://dx.doi.org/10.22192/ijarbs.2017.04.10.007>

As part of their VCE Biology practical investigation, a group of students collected plant samples from their school grounds. While the students were able to identify most of the plants they collected, there was one they had not seen before. They performed a series of experiments with this plant in the laboratory. The observations they made, as well as documented information for C3, C4 and CAM plants, are shown in the table below.

Comparison of the characteristics of the unknown plant with C3, C4 and CAM plants

Plant characteristic	Unknown plant	C3 plant	C4 plant	CAM plant
ideal temperature for photosynthesis	25–35 °C	15–25 °C	30–40 °C	> 40 °C
pathway to fix CO_2	C4 pathway and Calvin cycle	only Calvin cycle	C4 pathway and Calvin cycle	C4 pathway and Calvin cycle
stomata open during the day	yes	yes	yes	no
photorespiration occurring	moderate to low	high	low	only observed in the middle of the day
water loss during the day	moderate	high	moderate	low
plant growth rate	moderate	moderate	fast	very slow

DO NOT WRITE IN THIS AREA

a. Based on the information provided, state whether the unknown plant is a C3, C4 or CAM plant. Justify your response. 5 marks

b. Outline **three** additional steps that could be carried out to extend the investigation and assist with identifying the unknown plant. 3 marks

Marking Scheme

Question 3a.

Mark	0	1	2	3	4	5	Average
%	2	1	1	2	24	70	4.6

It's a C4 plant because:

- the temperature falls in the same range
- the pathway to fix CO_2 is the same
- stomata are open during the day unlike CAM plants
- low photorespiration rate unlike C3 plants
- moderate amount of water loss.

Question 3b.

Mark	0	1	2	3	Average
%	37	41	19	3	0.9

- Determine if Calvin cycle or Rubisco is present in bundle sheath or if any specific substrates or enzymes for this cycle are present.
- The unknown plant could have physical or genetic comparisons made to other known plants.
- The sample size could be increased, reducing effect of outliers.
- Other originally controlled variables could be altered then measure the effect of growth, photosynthetic or photorespiration rate.

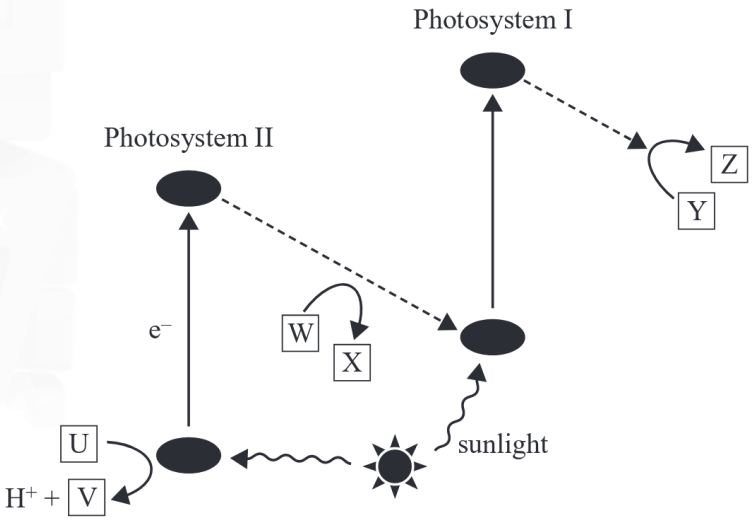
Many students were not able to provide extensions beyond what was already tested and included in the data within the stem of the question.

2022

DO NOT WRITE IN THIS AREA

Use the following information to answer Questions 9 and 10.

Photosynthesis is an important process that occurs in plants and in some bacteria. The diagram below represents one of the stages that occurs in the photosynthetic process.



Source: adapted from Arif Majid, SlideShare, <https://pt.slideshare.net/ArifMajid/light-reaction-of-photosynthesis/17>

Where in a plant cell would the stage of the photosynthetic process shown above be located?

A. mitochondria
B. thylakoid membrane
C. chloroplast inner membrane
D. chloroplast outer membrane

In the diagram shown above, what do V, W and Z represent respectively?

A. water, ATP and $NADP^+$
B. oxygen, ATP and NADPH
C. oxygen, ADP and NADPH
D. carbon dioxide, ADP and $NADP^+$

Marking Scheme

Question	Correct answer	% A	% B	% C	% D	Comments

9	B	5	**75**	12	8	
10	C	12	26	**52**	10	

2022

During photosynthesis in C_3 plants, which molecules would be produced within the thylakoid membrane?

A. NADPH and carbon dioxide

B. $NADP^+$ and water

C. oxygen and ATP

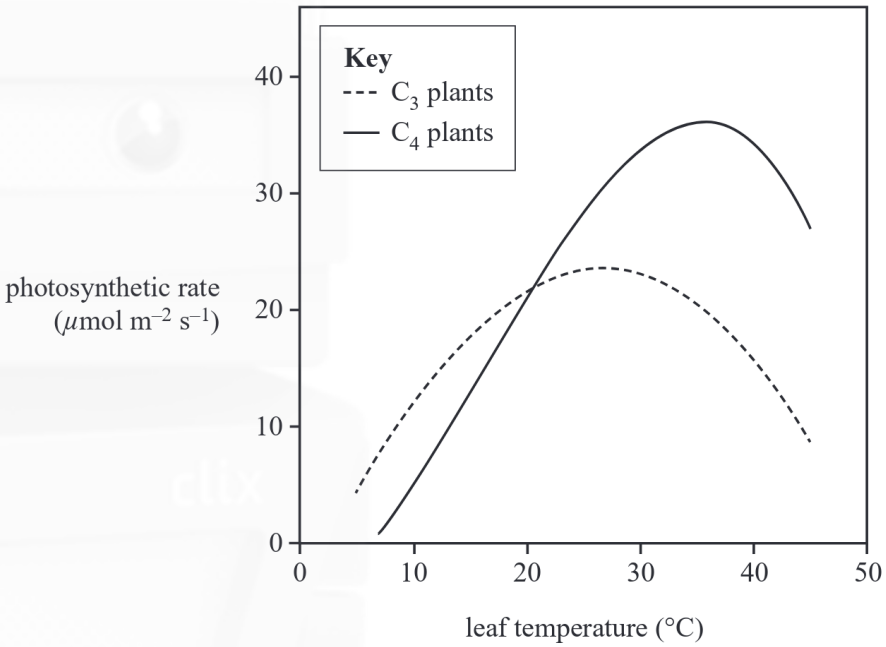
D. ADP and oxygen

Marking Scheme

Question 16	Answer = C

2022

The graph below shows the effect of leaf temperature on the rate of photosynthesis in C_3 and C_4 plants.



Source: adapted from W Yamori, K Hikosaka and DA Way, 'Temperature response of photosynthesis in C_3, C_4 and CAM plants: temperature acclimation and temperature adaptation', *Photosynthesis Research*, (2014) 119: 101–117, <https://doi.org/10.1007/s11120-013-9874-6 >; licensed by CCC-Rightslink (USA) with permission from Springer-Nature

This graph shows that

A. C_4 plants have a higher photosynthetic rate than C_3 plants across all temperatures.

B. maximum enzyme efficiency occurs at the same temperature in C_3 and C_4 plants.

C. the optimum temperature for photosynthesis in C_3 plants is 35 °C.

D. the photosynthetic rate of C_3 and C_4 plants is the same at 20 °C.

Marking Scheme

Question 17	Answer = D

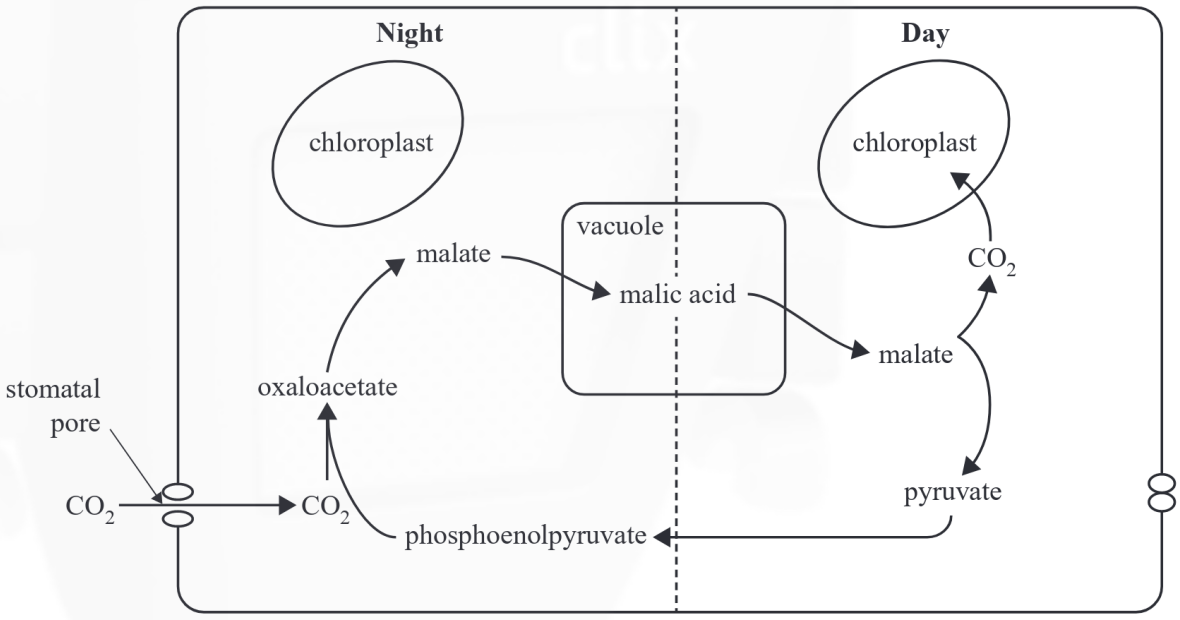
DO NOT WRITE IN THIS AREA

Agave is a genus of about 200 plant species that are adapted to dry environments. The photograph below shows some of these plants.

Source: Jesus Cervantes/Shutterstock.com

Agave plants use the CAM pathway to carry out photosynthesis. Several of the key steps in this pathway are outlined in the diagram below.

A simplified overview of the CAM pathway in an agave leaf cell



Source: adapted from IN Forseth, 'The ecology of photosynthetic pathways', *Nature Education Knowledge*, 3(10):4, Figure 6

a. What primary advantage does an agave plant have in using the CAM pathway compared to C_3 plants? 1 mark

DO NOT WRITE IN THIS AREA

2022

The first response when chloroplasts are exposed to red and violet wavelengths of light is the

A. conversion of CO2 into glucose.
B. splitting of water.
C. formation of ATP.
D. production of oxygen gas.

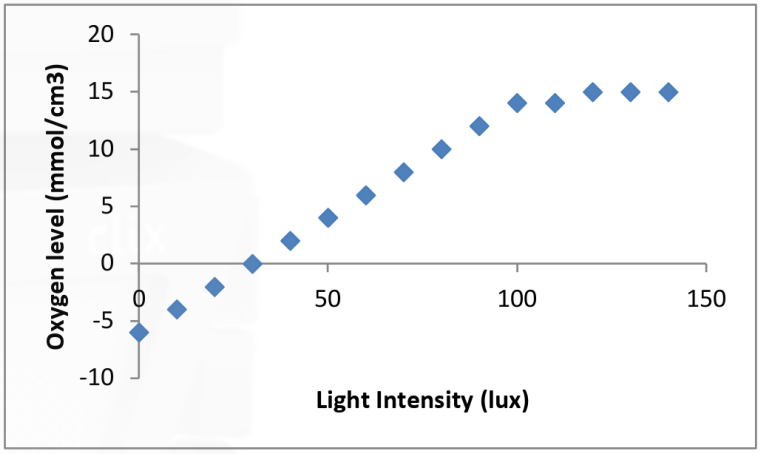
Marking Scheme

Solution: B

Red and violet wavelengths of light carry the energy for the light independent reaction. Once the energy is absorbed the first step is to split water to release oxygen and hydrogen ions. These hydrogen ions move through ATPase to form ATP

2022

The following graph was produced as the results of an experiment on a group of tomato plants, each placed in a Perspex container and exposed to differing light intensities. The change oxygen gas around the plant was measured after 60 minutes and the difference (compared to the original level of oxygen gas) graphed against the light intensity



The following conclusion could be made based on the presented data.

A. There is no photosynthesis occurring at a light intensity of 10 lux.
B. Photosynthesis never produces more than 15 mmol/cm^3 of oxygen.
C. At light intensity of 25 lux the rate of respiration is equal to the rate of photosynthesis.
D. At as light intensity of 150 lux, the tomato plants are no longer respiring.

Marking Scheme

Solution: C

Oxygen usage is due to cellular respiration exceeding photosynthetic rate up to a light intensity of about 25 lux. With an increase in light intensity above 25 lux the production of oxygen increases due to photosynthesis being greater than respiration. The rate of photosynthesis levels as other factors such as carbon dioxide is limiting the reaction from increasing further. The rate of oxygen production is also explained with respiration

2022

Plants can be categorised as C3, C4 or CAM plants. A plant has a thick cuticle, reduced leaves with a low surface-area-to-volume ratio and stomata sunken into pits. The stomata are open at night to permit entry of CO_2 to be fixed and stored. Then, during the day the CO_2 is released for use in the Calvin cycle. In this way, the rubisco is provided with high concentration of CO_2 while the stomata are closed during the hottest and driest part of the day to prevent the excessive loss of water.
The type of plant described is

A. a C3 plant.
B. a CAM plant.
C. a C4 plant.
D. either a C3 or C4 plant.

Marking Scheme

Solution: C

C3 plants are the typical temperate climate plant where CO2 is converted to G3P during the day. This is inefficient usage of CO2 compared to a C4 plant that converts the CO2 into a 4 carbon compound and then converts that 4 carbon compound back into CO2 during the day. C4 plant are better adapted for drier conditions. CAM plants separate the LDR (day) from the LIR (night), which suits desert plants.

2022

The following diagram is of a chloroplast. Structures X, Y and Z are all associated with the process of photosynthesis.

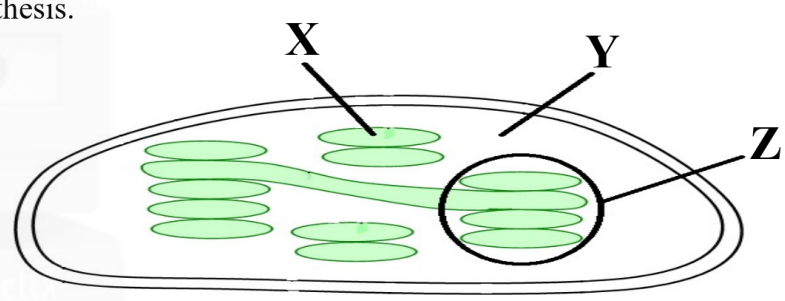


Diagram from http://cronodon.com/BioTech/Plant_Bodies_Cells.html

The following comment that is **correctly** associated with structures X, Y and Z is

A. The light dependent reaction occurs in structures X and Z.
B. The light independent reaction occurs in structure X and Y.
C. Carbon fixation occurs within structure X and Z.
D. Structures X and Z absorb green light wavelengths to drive photolysis of water.

Marking Scheme

Solution: A

Understanding the structure of a chloroplast is a good way towards understanding the biochemical nature of photosynthesis. X is the lumen of the grana and Z form stacks of grana (or thylakoid membranes) where the light independent reaction occurs. Y is the stroma and the location of the light independent reaction (carbon fixation) of photosynthesis. Light wavelengths other than green are absorbed in the light dependent reaction.

2022

The first response when chloroplasts are exposed to red and violet wavelengths of light is the

A. Conversion of CO2 into glucose
B. Splitting of water
C. Formation of ATP
D. Production of oxygen gas

Marking Scheme

Solution: B

Red and violet light wavelengths of light carry the energy used for the light dependent reaction. Once the light is absorbed the reaction begins with the splitting of water which produces oxygen gas as well as hydrogen ions used to generate ATP.

2022

When comparing CAM, C3 and C4 plants

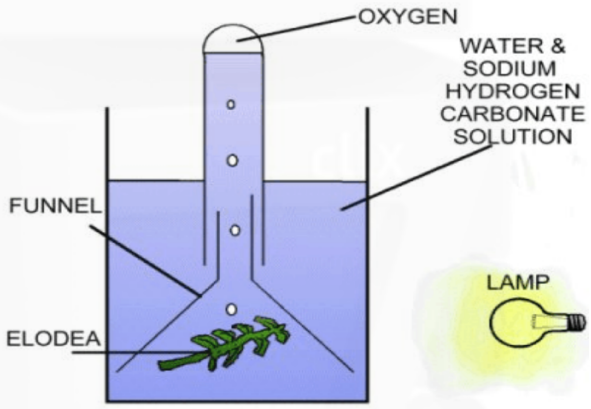
A. All plant types are able to photosynthesise 24 hours a day
B. CAM plants fix carbon dioxide at night
C. C3 plants produce an intermediate 4 carbon compound
D. C4 plants produce a 3 carbon compound in the Calvin cycle

Marking Scheme

Solution: B

C3 plants are the typical plants that convert carbon dioxide during the day into a 3 carbon compound which is subsequently converted to glucose. C4 plants the efficiency of usage of carbon dioxide is increased with the separation of LR and LIR from each other but occur at the same time. CAM plants fix the carbon dioxide at night.

An investigation on the effect light intensity had on the rate of photosynthesis was carried out using *Elodea canadensis* as a model plant. *Elodea* is an aquatic plant that is regularly used in experiments as outlined in the diagram below. The number of bubbles of oxygen was counted and then converted into a rate of oxygen production. 10 identical sets of apparatus were placed at different distances from an incandescent light source. A diagram of the apparatus as well as the results for this experiment are outlined below.



Distance from light source (m)	Number of oxygen bubbles (per minute)
0.05	24
0.1	25
0.25	25
0.5	22
1	15
2	10
4	5
6	2
8	1
10	1

Link: https://moodle.beverleyhigh.net/mod/resource/view.php?id=6094&forceview=1

a) Apart from the average number of bubbles of oxygen, what other method could be used as a measure of the rate of photosynthesis?

_____(1 mark)

b) (i) Complete the graph below of rate of photosynthesis V light intensity

(2 marks)

(ii) Explain the relationship between light intensity and photosynthetic rate.

_____

_____

_____(2 marks)

c) State 3 conditions that would need to be controlled in this experiment

_____

_____

_____(2 marks)

d) Describe the reaction occurring in the chloroplast that produces oxygen.

_____

_____

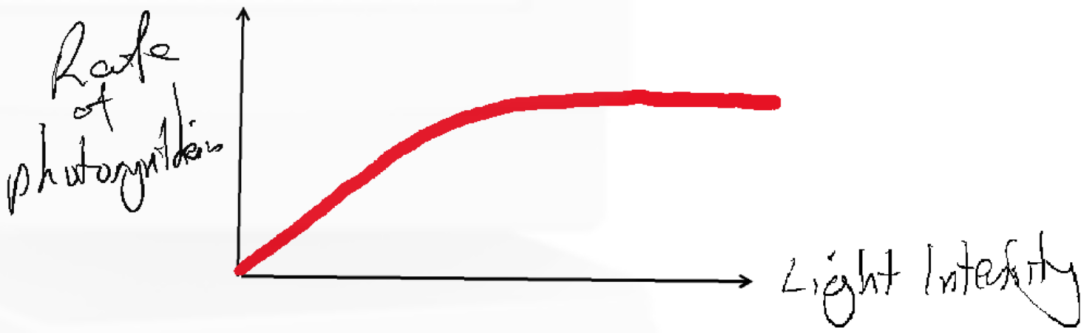
_____(2 marks)

a) Various factors could be used to measure the rate of photosynthesis such as

- Carbon dioxide absorption per unit time
- Change in biomass per unit time

NOTE: per unit time should be included to determine rate (1 mark)

b) (i)



NOTE: Correct axis labelled (1 mark) and labelled axis (1 mark) (2 marks)

(ii) As light energy increases the rate of photosynthesis increases because more energy is available to split water

(1 mark)

Once a certain light intensity is reached the rate of photosynthesis plateaus as factors such as carbon dioxide availability and chlorophyll availability are not increasing and so limit the rate the process can occur at.

(1 mark)

c) Factors needing to be controlled are

- Temperature
- pH
- Carbon dioxide availability
- Water availability
- Size of plant material

NOTE: 3 factors needed for 2 marks, 1 mark penalty if incorrect or less than 3 (2 marks)

d) Light dependent reaction at the grana (1 mark)
Water is split in the presence of light energy to produce oxygen (1 mark)

2021

Consider the process of photosynthesis.
Which of the following shows correct information about each of the two stages of photosynthesis?

	Light-dependent stage	Light-independent stage
A.	produces oxygen	produces carbon dioxide
B.	requires water	requires NADH
C.	occurs in the stroma	occurs in the grana
D.	energy is provided by light	energy is provided by ATP molecules

Marking Scheme

Question	Correct answer	% A	% B	% C	% D	Comments
5	D	6	17	8	69	

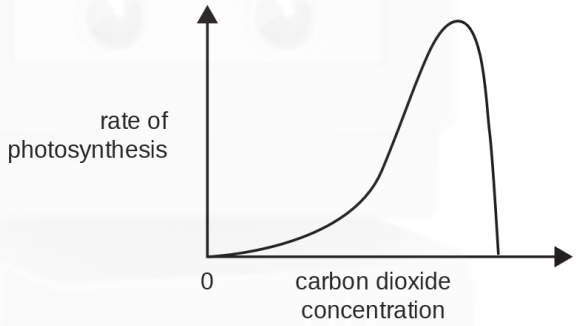
2021

DO NOT WRITE IN THIS A

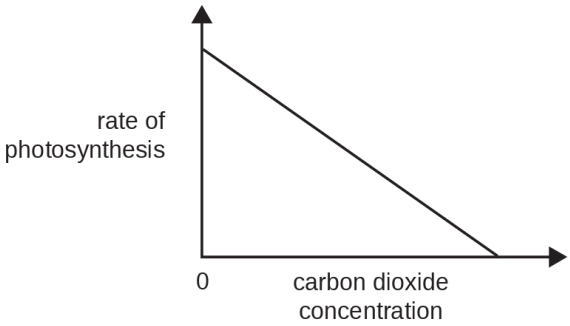
In a series of experiments, the rate of photosynthesis in plant cells was measured in environments with different concentrations of carbon dioxide. All other variables were kept constant.

Which one of the following graphs reflects the trend that would be shown by the results of these experiments?

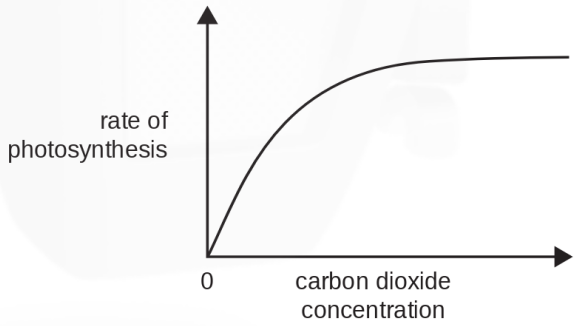
A.



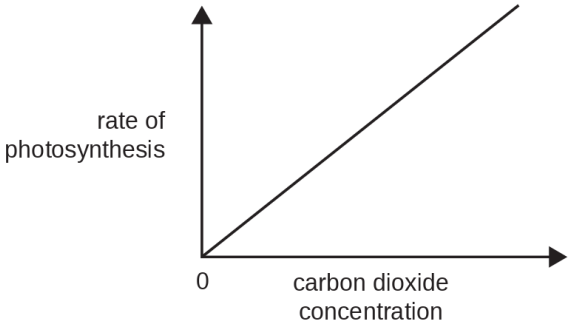
B.



C.



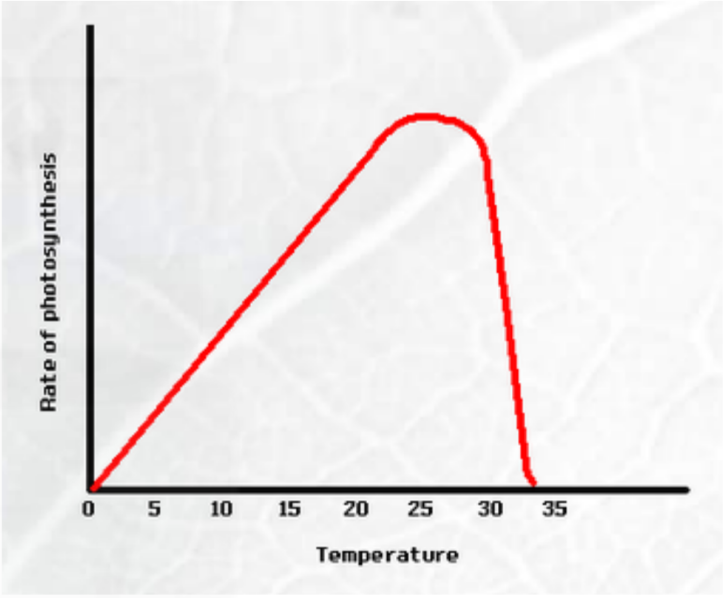
D.



Marking Scheme

Question	Correct answer	% A	% B	% C	% D	Comments
6	C	6	3	86	6	

The following graph shows the effect of changing temperature on the process of photosynthesis



Link: https://biology-igcse.weebly.com/effect-of-temperature-on-the-rate-of-photosynthesis.html

A reasonable conclusion to make would be

A. Photosynthesis enzymes denature at temperatures lower than 10°C.
B. Enzyme collisions with substrates are never higher than at 25°C.
C. Raising the carbon dioxide concentration would make the optimal temperature higher.
D. Photosynthesis enzymes 3D shape and collisions with substrates are at an optimal level at temperatures of 25°C.

Marking Scheme

Solution: D
Photosynthetic enzymes like most others denature at high temperatures and move more slowly at low temperatures. The optimum is a balance of movement and shape. As the temperature increases the movement of the enzymes increases but it also puts pressure on the bonds holding the molecules 3D shape.

Study Design Reference
- the factors that affect the rate of photosynthesis: light availability, water availability, temperature and carbon dioxide concentration

Web Link
https://www.bbc.co.uk/bitesize/guides/zx8vw6f/revision/2

The mitochondria and chloroplast are very different organelles; however, in a plant cell they are important for the processes of photosynthesis and respiration.

a) State and explain 2 specific differences between mitochondria and chloroplasts with reference to photosynthesis and respiration

(4 marks)

Glucose, oxygen, carbon dioxide and water are critical for photosynthesis and respiration within plant cells.

b) In terms of the chemicals listed above, explain how a plant can survive indefinitely when exposed to a low light intensity

(3 marks)

Cyanide is a toxic chemical that can affect both respiration and photosynthesis. This is because cytochrome oxidase has an active role in the electron transport chains of both processes and cyanide is a non-competitive inhibitor of the enzyme. The graph below shows the effect of changing substrate concentration while cyanide is present on these metabolic pathways

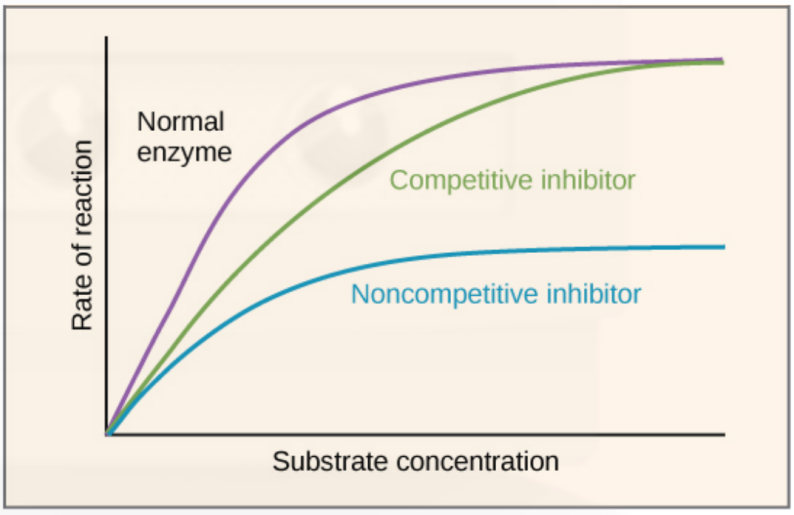


Diagram from: https://teachmephysiology.com/biochemistry/molecules-and-signalling/enzyme-inhibition/

c) Why do competitive and non-competitive inhibitors effect the rate of reaction differently when substrate concentration increases/

(2 marks)

d) How would the addition of cyanide specifically effect the reaction of photosynthesis?

(2 marks)

a) Mitochondria and chloroplasts have several different features

- Chloroplast have grana for the light dependent reaction (1) and mitochondria have cristae for the electron transport chain (1) **(2 marks)**
- Chloroplast has stroma for the light independent reaction (1) and the mitochondria have matrix for the Krebs cycle (1) **(2 marks)**

b) At low light intensity the rate of photosynthesis may be equal to the rate of respiration **(1 mark)**

The carbon dioxide and water are reactants for photosynthesis that are gained as the products of respiration and the reactants of cellular respiration (glucose and oxygen) are gained as the products of photosynthesis **(1 mark)**

Enough energy (ATP) is provided from respiration to sustain the metabolic demands indefinitely **(1 mark)**

c) Non-competitive: the same number of enzymes are always inhibited so when substrate is in excess the rate of reaction is lower than when no inhibitor is present **(1 mark)**

Competitive: as the substrate concentration increases the proportion of inhibitors to substrate decreases meaning the effect of the inhibitor is minimized **(1 mark)**

d) Cyanide binds to a site on cytochrome oxidase away from the active site that leads to a change in the shape of the active site. **(1 mark)**

This prevents the electrons from binding with hydrogen and NADP to form NADPH, which is one of the products of the light dependent reaction **(1 mark)**

Study Design Reference

- inputs, outputs and locations of the light dependent and light independent stages of photosynthesis in C_3 plants (details of biochemical pathway mechanisms are not required)
- the main inputs, outputs and locations of glycolysis, Krebs Cycle and electron transport chain including ATP yield (details of biochemical pathway mechanisms are not required)
- the general factors that impact on enzyme function in relation to photosynthesis and cellular respiration: changes in temperature, pH, concentration, competitive and non-competitive enzyme inhibitors

Web Link
Photosynthesis and respiration: https://craven.instructure.com/courses/12394/pages/online-interactives-photosynthesis-and-cellular-respiration
Enzyme inhibition: https://sciencemusicvideos.com/ap-biology/module-9-energy-and-enzymes/enzyme-inhibition-and-regulation-interactive-tutorial/

2021

Photosynthesis includes

A. The light reaction in the stroma and the light independent reaction in the grana
B. The light reaction in the matrix and the light independent reaction in the stroma
C. The light reaction in the grana and the light independent reaction in the cytosol
D. The light reaction in the grana and the light independent reaction in the stroma

Marking Scheme

Solution: D
Students should know the inputs, outputs and location for each of the 2 stages of photosynthesis. The light dependent reaction occurs in the grana (along the thylakoid membrane) and the light independent reaction occurs in the stroma of the chloroplast.

2020

During photosynthesis

A. ATP and NADH created in the light-independent stage are transported to the chloroplasts' thylakoid membranes.

B. ADP and NADH are used in the electron transport chain after being created in the light-dependent stage.

C. ATP and NADPH are created in the grana of the chloroplasts and are used in the light-independent stage.

D. ADP and NADPH are created during the Krebs cycle and carried to the stroma of the chloroplasts.

Marking Scheme

Question	% A	% B	% C	% D	Comments
12	8	8	76	8	

Greenhouses have been used to generate higher crop yields than open-field agriculture. To encourage plant growth in greenhouses, the conditions required for photosynthesis are controlled. Commercial greenhouses, like the ones shown below, often use a lot of energy for heating, ventilation, lighting and water.

Source: SUPEE PURATO/Shutterstock.com

a. Consider the reactions of photosynthesis. Why would it be important to maintain the temperature within narrow limits in a commercial greenhouse? Justify your answer. 2 marks

b. Scientists are developing a new material to cover greenhouses, which can split incoming light and convert the rays from green wavelengths into red wavelengths.

Explain how this new material increases crop yields. 2 marks

c. In plants and algae, photosynthesis is carried out in chloroplasts. It is thought that chloroplasts originated from bacteria.

Describe **two** features of chloroplasts that support the theory that chloroplasts originated from bacteria. 2 marks

Marking Scheme

Question 3a.

Marks	0	1	2	Average
%	53	18	28	0.7

Any two of:

- Photosynthesis is regulated by enzymes.
- Enzymes have an optimum temperature.
- Enzymes may denature at high temperatures or activity is decreased at lower temperatures.
- The greater the rate of reaction the more growth will occur.

Many students were unable to make the link that enzymes were involved in photosynthesis and therefore the importance of temperature.

Question 3b.

Marks	0	1	2	Average
%	25	27	48	1.2

Any two of:

- Green plants reflect green light OR do not use it for photosynthesis.
- Red light is used in photosynthesis OR increased availability of light for photosynthesis.
- More glucose is produced due to greater rate of photosynthesis.

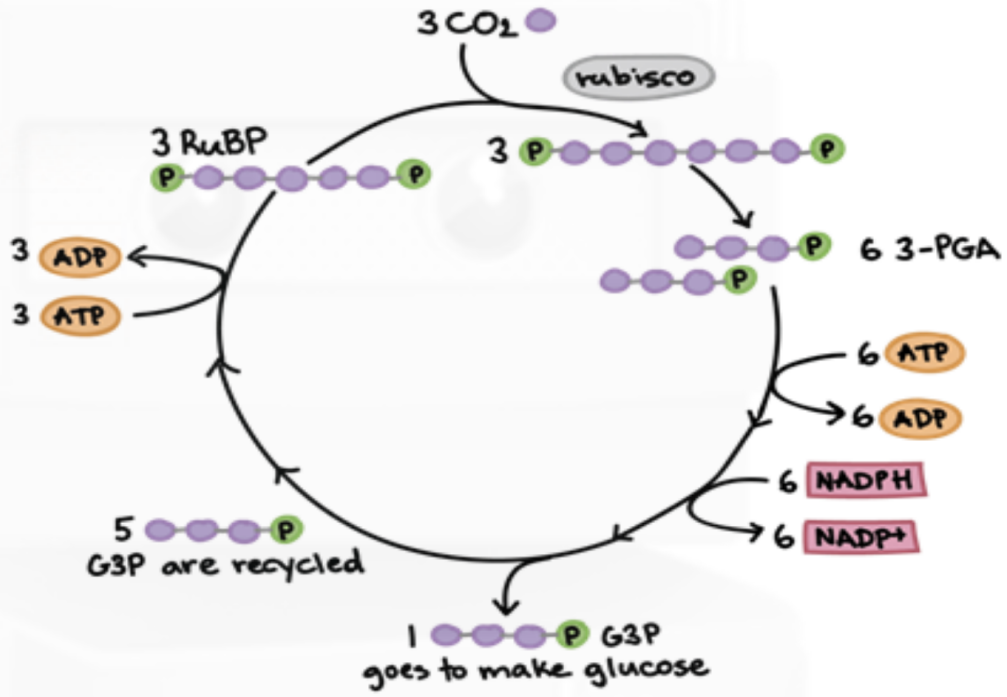
Question 3c.

Marks	0	1	2	Average
%	22	21	57	1.3

Any two of:

- Chloroplasts have their own circular DNA like the DNA found in bacteria.
- Chloroplasts have their own ribosomes.
- New chloroplasts are made by existing chloroplasts dividing in a similar way to how bacterial cells reproduce.
- Chloroplasts have a double membrane, one eukaryotic and one prokaryotic.
- They have a similar size and appearance.

The biochemical diagram below represents the light independent reaction (Calvin Cycle) occurring inside a photosynthesising eukaryotic cell.



Modified from: https://www.biologyjunction.com/calvin-cycle-definition

a) State the specific cellular location of this reaction within a eukaryotic cell.

_____ **(1 mark)**

b) Explain the importance of both ATP and NADPH in the conversion of 3-PGA into G3P.

_____

_____

_____

_____ **(2 marks)**

c) Why is the light independent reaction above also called a cycle (Calvin Cycle)?

_____

_____

_____

_____ **(2 marks)**

Marking Scheme

a) Stroma **(1 mark)**

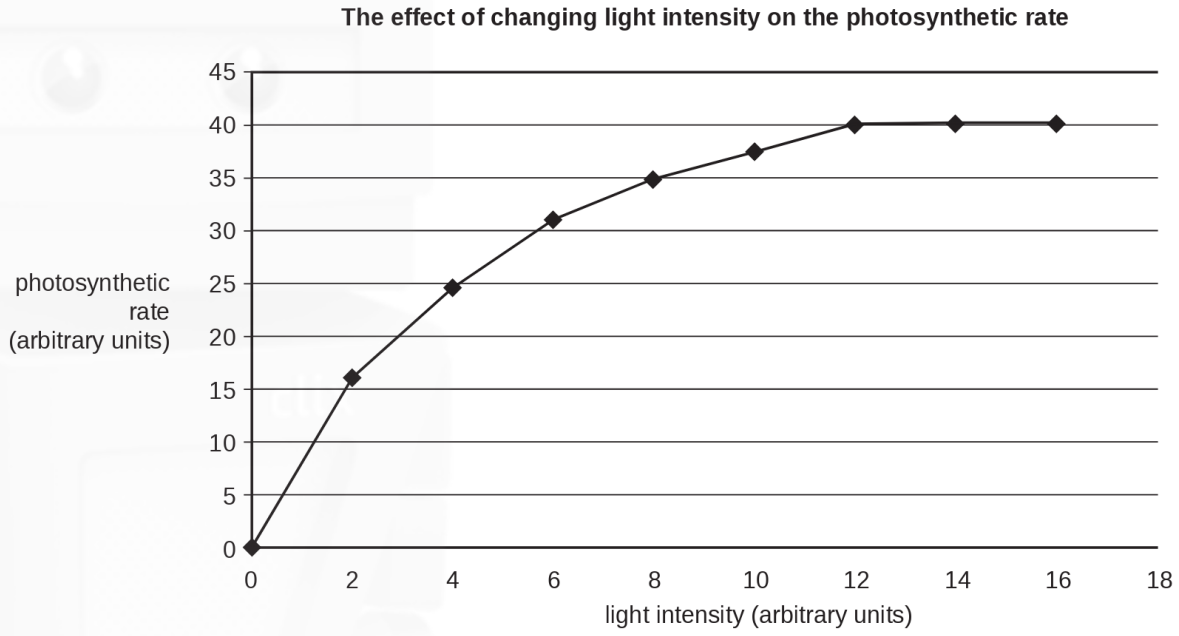
b) Both ATP and NADPH are coenzymes involved in Carbon fixation **(1 mark)**
ATP transfers energy and NADPH transfers hydrogen into G3P **(1 mark)**

c) RuBP is a 5-carbon molecule which combines with carbon dioxide (a 1 carbon molecule). 3 RuBP combine with 3 carbon dioxide to make 6 3-PGA **(1 mark)**
The 6 3-PGA are converted into 6 G3P and 1 of these is used to become part of glucose. The remaining G3P are converted into 3RuBp which is the same number that was originally used. This makes it a cycle **(1 mark)**

Study Design Reference
The cycling of coenzymes (ATP, NADH, and NADPH) as loaded and unloaded forms to move energy, protons and electrons between reactions in the cell.
Inputs and outputs of the light dependent and light independent (Calvin cycle) stages of photosynthesis in C3 plants (details of the biochemical pathway mechanisms are not required)

2019

An experiment was carried out at a constant temperature and with a constant carbon dioxide concentration in order to determine the effect of changing light intensity on the photosynthetic rate. The following is a graph of the results.



Based on your knowledge and the information in the graph, which one of the following conclusions can be reached?

A. Photosynthesis ceases to occur at a light intensity of 14 arbitrary units.
B. Plants do not undergo photosynthesis at a light intensity of 1 arbitrary unit.
C. Light intensity is a limiting factor when the photosynthetic rate is less than 40 arbitrary units.
D. Increasing the amount of carbon dioxide at a light intensity of 16 arbitrary units would lead to a decrease in the photosynthetic rate.

DO NOT WRITE IN THIS AREA

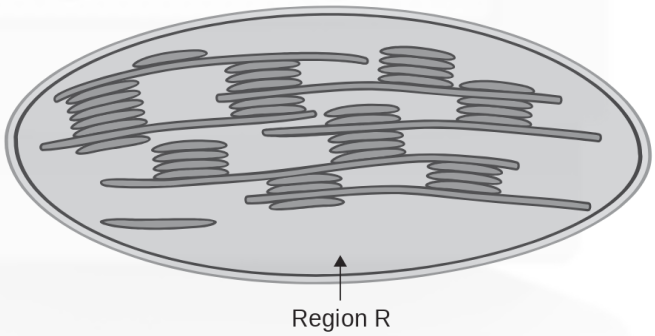
Marking Scheme

Question	% A	% B	% C	% D	Comments
15	12	5	71	11	

a. A chloroplast is surrounded by a double membrane.

i. Name **two** molecules, as inputs for photosynthesis, that would need to diffuse from the cytosol of the plant cell across the chloroplast membranes and into the chloroplast. 1 mark

ii. Under high magnification, the internal structure of a chloroplast is visible. The diagram below shows part of this structure.



Source: Kazakova Maryia/Shutterstock.com

A higher concentration of oxygen is found in Region R when a plant is photosynthesising compared to when it is not photosynthesising.

Account for the differences in oxygen concentrations found in this region. 2 marks

b. Describe the role played by each of the coenzymes NADPH and ATP in photosynthesis. 2 marks

DO NOT WRITE IN THIS AREA

Question 2ai.

Marks	0	1	Average
%	31	69	**0.7**

Water and carbon dioxide (chemical symbols equally acceptable).

Question 2aii.

Marks	0	1	2	Average
%	45	31	24	**0.8**

- Water is split in the light-dependent reaction to produce oxygen gas.
- Oxygen produced diffuses into the stroma (region R) **or** When light is not available, oxygen is not produced.

Question 2b.

Marks	0	1	2	Average
%	16	40	44	**1.3**

- NADPH transfers hydrogen ions. Protons and electrons was also an acceptable answer.
- ATP transfers energy.

To gain full marks students were required to give the role of each coenzyme.

Carbon dioxide levels have been steadily increasing in the atmosphere since the industrial revolution. This is causing a large number of changes in weather patterns that has significantly affected biodiversity.

a) Explain how plant growth may have been effected over time with increased levels of atmospheric carbon dioxide.

_____

_____ **(1 mark)**

The biochemical reactions within plants that are affected by increased levels of carbon dioxide also require other factors for them to proceed. For example, temperature, pH, water and chlorophyll levels need to be optimal.

b) What coloured light is reflected by chlorophyll?

_____ **(1 mark)**

Atmospheric carbon dioxide levels are currently at about 0.4%

c) On the axis below, draw a line graph that would show how temperature effects the biochemical reactions that are affected by this increased level of carbon dioxide.

(2 marks)

There are 2 main reactions that are affected by increased levels of atmospheric carbon dioxide. This is because the reactants of one are the products of the other.

d) Complete the following table stating the reactants, products and cellular location of each reaction.

Reaction	Specific Location	Reactant(s)	Product(s)
Light dependent		1. 2. 3.	1. 2. 3.
Light independent		1. 2. 3.	1. 2. 3.

(4 marks)

a) Plant growth has increased because carbon dioxide is an input for photosynthesis, which will provide more chemical energy (glucose) for growth. **(1 mark)**

b) Green light is reflected and the other wavelengths are absorbed **(1 mark)**

c)

Correct axis included **(1 mark)**
Correct shape of line graph **(1 mark)**

d)

Reaction	Specific Location	Reactant(s)	Product(s)
Light dependent	**Grana (thylakoid)**	**1. Water** **2. NADP** **3. ADP/Pi**	**1. Oxygen** **2. NADPH** **3. ATP**
Light independent	**Stroma**	**1. Carbon dioxide** **2. NADPH** **3. ATP**	**1. Glucose** **2. NADP** **3. ADP/Pi**

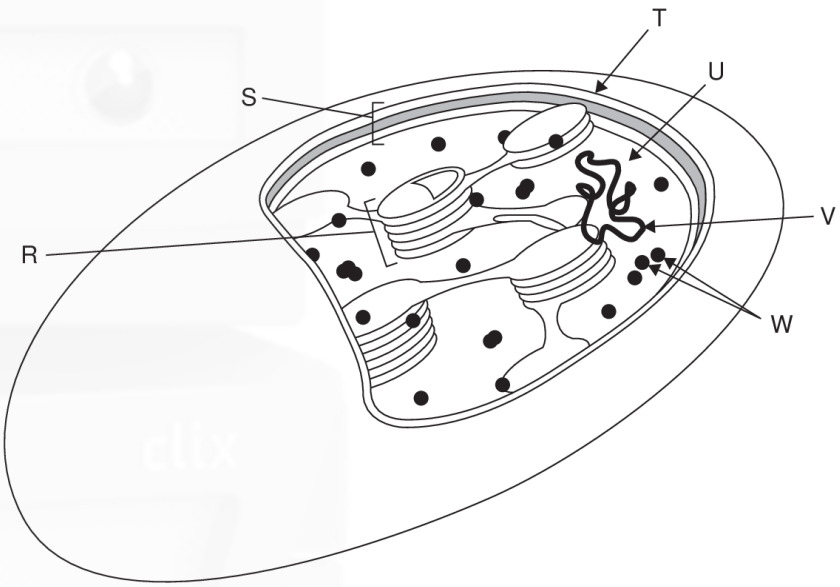
NOTE: Subtract 1 mark for any error up to 4 marks
4 marks

Study Design Reference

Inputs and outputs of the light dependent and light independent (Calvin cycle) stages of photosynthesis in C3 plants (details of the biochemical pathway mechanisms are not required) factors that affect the rate of photosynthesis, including light, temperature and carbon dioxide concentration

Use the following information to answer Questions 13 and 14.

The diagram below shows the structures of a chloroplast, labelled R–W.



Source: adapted from Kelvinsong (own work)/Wikimedia Commons/CC-BY-3.0

Question 13

Which combination of two structures could be used as evidence for the bacterial origin of chloroplasts?

A. U and R
B. S and V
C. U and W
D. W and T

Marking Scheme

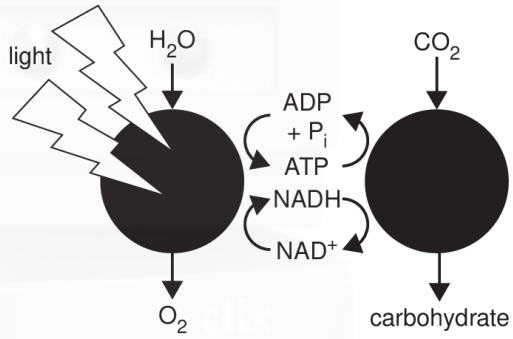
Question	% A	% B	% C	% D	Comments
13	9	65	12	14	
14	9	79	5	7	

N THIS AREA

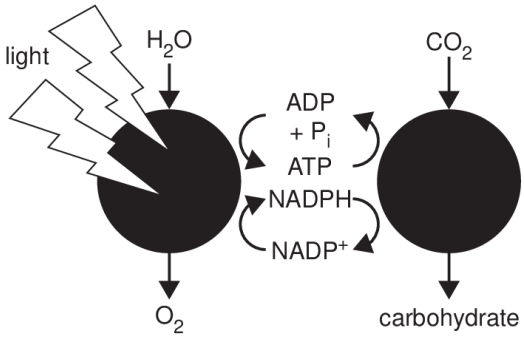
Question 15

Which one of the following diagrams correctly represents the inputs and outputs of photosynthesis?

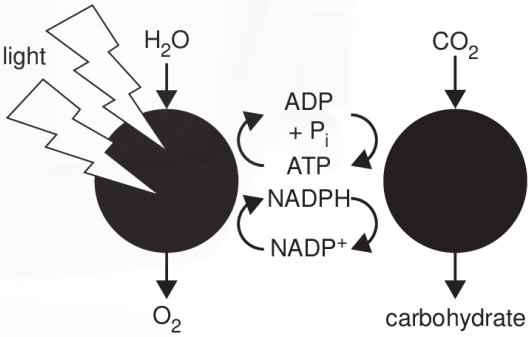
A.



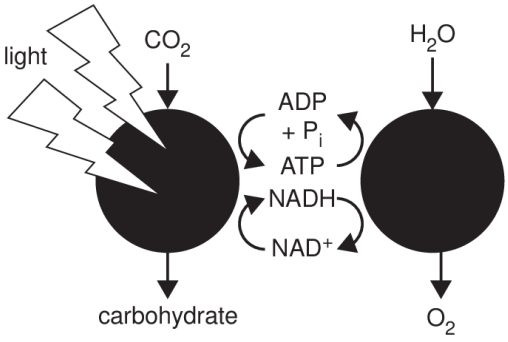
B.



C.



D.



Marking Scheme

Question	% A	% B	% C	% D	Comments
15	12	53	27	8	The arrows in the middle of each diagram indicated the direction of the reaction, relative to the left or right reaction. Option C has one of the reactions reversed and hence was incorrect.
15	12	53	27	8	The arrows in the middle of each diagram indicated the direction of the reaction, relative to the left or right reaction. Option C has one of the reactions reversed and hence was incorrect.

Two students noticed bubbles forming on the submerged leaves of an *Elodea* plant growing in an aquarium. The bubbles seen on the leaves were the result of a gas formed within the cells of the leaves. The photograph below shows the appearance of these bubbles.

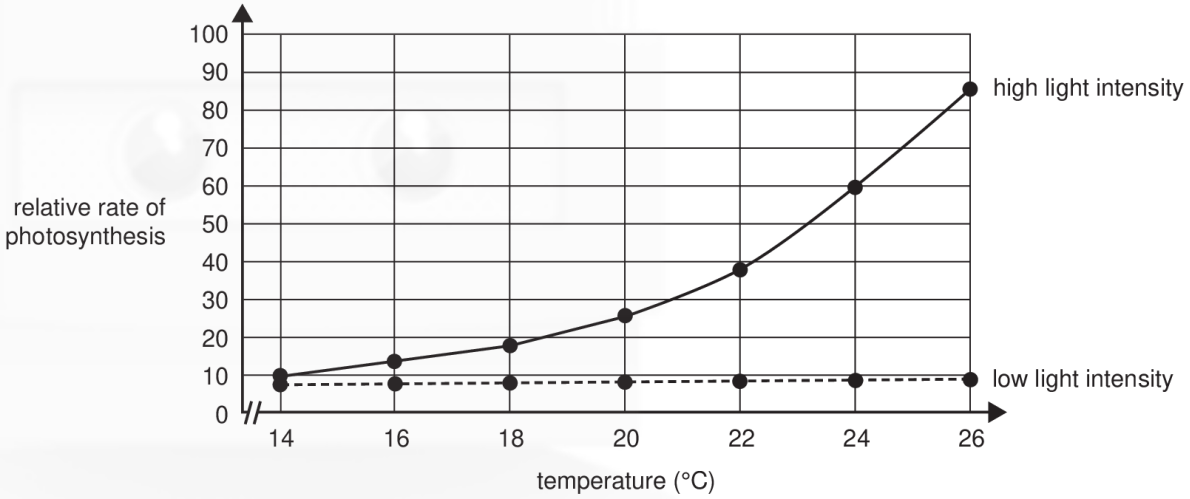
Source: PH Raven, RF Evert and SE Eichhorn, *Biology of Plants*, 4th edition, Worth Publishers, Inc., New York, p. 97

There was a bright light shining on the aquarium. The bright light was not affecting the temperature of the water.

a. Describe what occurs within the cells of the leaves to result in the formation of these bubbles. 3 marks

DO NOT WRITE IN THIS AREA

b. The students investigated the rate of photosynthesis in the leaves of the *Elodea* plant. The graph of their results is shown below.



i. Name the two stages of photosynthesis. 2 marks

ii. Consider the relative rates of photosynthesis at a temperature of 20 °C. Explain the difference observed in the relative rates of photosynthesis when the *Elodea* plant was exposed to light of low intensity compared to when it was exposed to light of high intensity. Refer to both stages of photosynthesis in your answer. 2 marks

Marking Scheme

Question 1a.

Chlorophyll absorbs light energy, water is split to form hydrogen ions or oxygen gas, and oxygen will diffuse out through the plasma membrane.

Question 1bi.

Both of:

- light-dependent stage
- light-independent stage/Calvin cycle/carbon fixation.

Question 1bii.

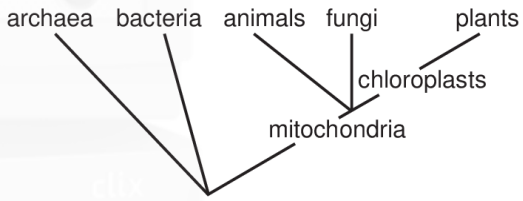
- At low light intensities the amount of ATP and NADPH produced is smaller OR there is less energy to produce H^+ as fewer chlorophyll molecules are excited.
- In the carbon fixation/light-independent stage, less glucose is produced at lower light intensities.

2018

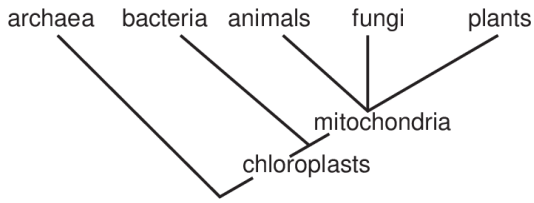
Consider the theory of the evolution of mitochondria and chloroplasts.

Which one of the following diagrams correctly represents this theory?

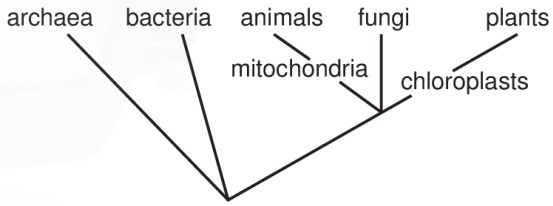
A.



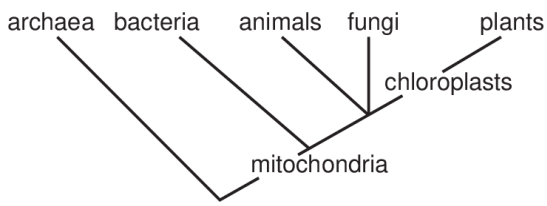
B.



C.



D.



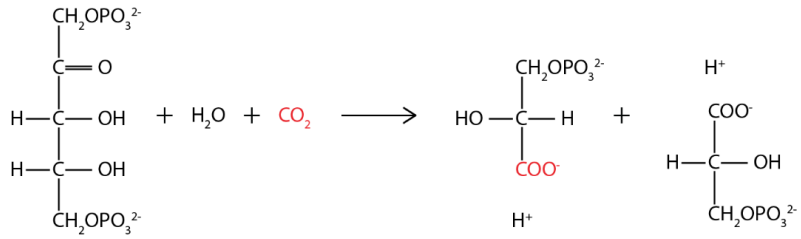
Marking Scheme

Question	Answer
23	A

2018

The next 3 questions refer to the following information

Ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) is Earth's most abundant enzyme, used by autotrophic organisms to convert CO_2 into organic compounds. A diagram showing this reaction is illustrated below



Ribulose 1,5-bisphosphate (RuBP)

2 molecules of 3-phosphoglycerate (3PG)

The substrate(s) in this reaction

A. RUBISCO
B. 3PG and H+
C. RuBP
D. RuBP, H2O and CO2

RUBISCO can be isolated and analyzed for its rate of reaction. The most suitable way of measuring the rate of this reaction would be

A. Time taken for the carbon dioxide produced to displace 100ml of water from a measuring cylinder
B. The volume of carbon dioxide formed
C. The time taken for the available carbon dioxide to be removed from the environment
D. The time taken for the RUBISCO to be used up

If the temperature of the environment is increased from 20°C to 30°C a reasonable conclusion to make would be

A. The 3D shape of the RUBISCO would change so that the active site is no longer complementary to carbon dioxide
B. The number of collisions between the RUBISCO and carbon dioxide would decrease
C. The number of collisions between the RUBISCO, carbon dioxide, water and RuBP would increase
D. The time taken for RUBISCO to catalyze one reaction would increase

Marking Scheme

Question 12
Solution: D

A substrate is the chemical that combines with the enzyme to form a product. In this case study the substrates are ribulose 1,5 biphosphate (RuBP), carbon dioxide and water.

Question 13
Solution: C

This reaction has 3 substrates and the easiest one to measure would be carbon dioxide. Rate measurements involve the formation (or usage) of a particular chemical in a certain time frame. In this instance the only logical measurement of rate would be removal of carbon dioxide over time.

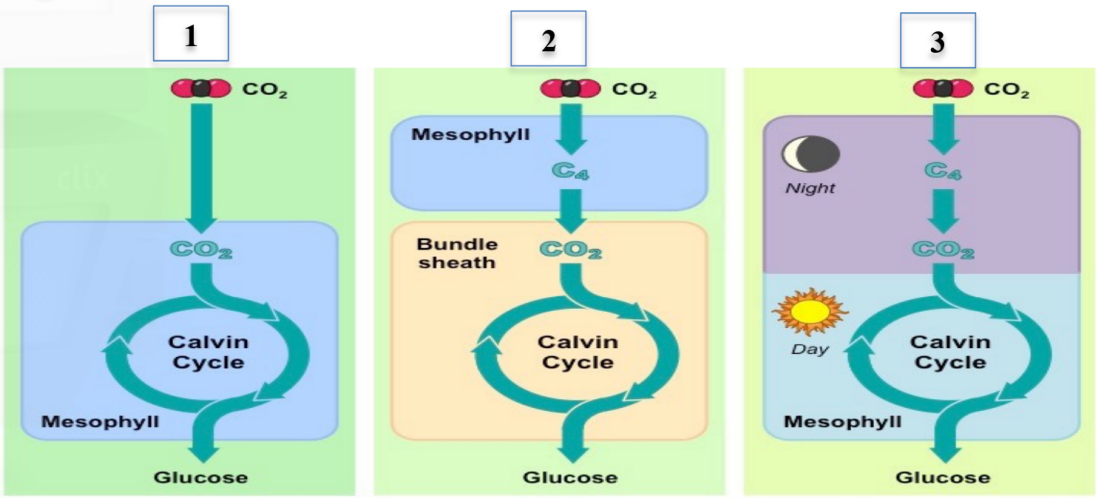
Question 14
Solution: C

Increasing the temperature around a plant from 20 to 30 degrees would be leading towards its optimum and so the kinetic energy would be increasing the number of collisions between Rubisco and the substrates would increase. This would lead to a greater reaction rate.

2018

The next 3 questions refer to the following information

The diagrams below (1, 2 and 3) show three different types of plants



It is appropriate to say that the type of plant that diagrams 1, 2 and 3 could represent are

	Plant 1	Plant 2	Plant 3
A.	C4	CAM	C3
B.	C3	C4	CAM
C.	CAM	C3	C4
D.	C3	CAM	C4

Based on the information for each type of plant it would be reasonable to state that

A. Plants that fix carbon dioxide directly from the air are called C_3 plants
B. In the C_3 pathway, carbon dioxide is physically separated from oxygen in order to improve CO_2 binding to Rubisco
C. In the C_4 pathway, carbon dioxide reserves are decreased in order to improve CO_2 binding to Rubisco
D. CAM plants respire at night and photosynthesises during the day

An example of plant 1, 2 and 3 could be

	Plant 1	Plant 2	Plant 3
A.	daffodil	corn	cactus
B.	corn	cactus	daffodil
C.	cactus	daffodil	corn
D.	corn	daffodil	cactus

Marking Scheme

Question 15
Solution: B

Question 16
Solution: A

Question 17
Solution: A

C3 plants make direct use of carbon dioxide by converting it into a 3 carbon compound that is part of carbon fixation. These are plants that grow in a temperate environment like daffodils. C4 plants convert the carbon dioxide into a 4 carbon compound to make better use of the available carbon dioxide. Then the 4 carbon compound is converted back to carbon dioxide to then be integrated into the Calvin cycle. These plants are often crop plants like corn. CAM plants separate carbon dioxide conversion into the C4 compound (night) and the integration of the carbon dioxide into the Calvin cycle (day). This is typical of cactus plants.

2017

Question 12

Evidence for the bacterial origin of chloroplasts is supported by observations that both chloroplasts and bacteria

A. do not contain ribosomes.
B. reproduce and divide by mitosis.
C. have a single circular chromosome.
D. store chlorophyll in their outer membrane.

AREA

Marking Scheme

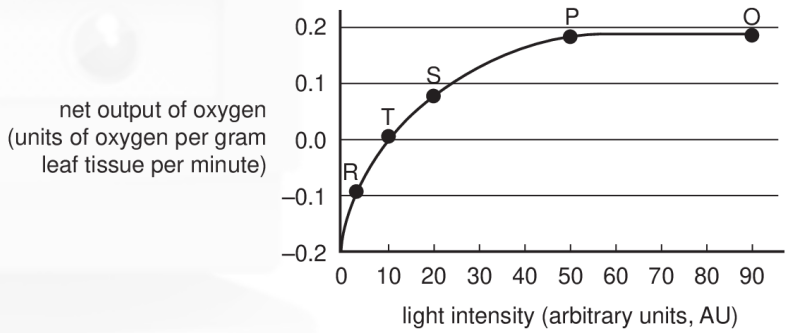
Question	% A	% B	% C	% D	% No answer	Comments

12	11	17	66	6	0	

2017

Use the following information to answer Questions 13 and 14.

The graph below shows the net output of oxygen in spinach leaves as light intensity is increased. Temperature is kept constant during the experiment.



Question 13

Which one of the following conclusions can be made based on the graph?

A. At point T photosynthesis is no longer occurring.

B. The optimal level of light intensity for photosynthesis is 40 AU.

C. At point S the amount of oxygen output is a third of that at point P.

D. Below 10 AU of light intensity the aerobic respiration rate is greater than the photosynthesis rate.

Question 14

The rate of oxygen output remains constant between points P and O because

A. heat has denatured the enzymes involved in the photosynthesis reactions.

B. the concentration of available carbon dioxide limits the rate of photosynthesis.

C. the light intensity has damaged the chlorophyll molecules present in the spinach chloroplasts.

D. high levels of oxygen produced at point P have accumulated around the spinach leaves, resulting in no more oxygen being produced.

DO NOT WRITE IN THIS

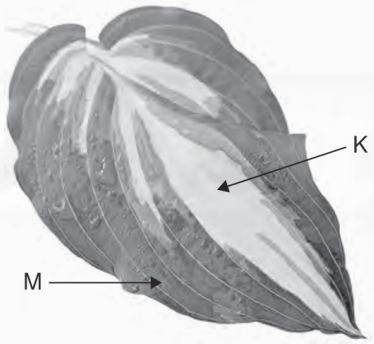
Marking Scheme

Question	% A	% B	% C	% D	% No answer	Comments
13	5	12	12	70	0	
14	6	74	4	15	0	

DO NOT WRITE IN THIS AREA

Question 15

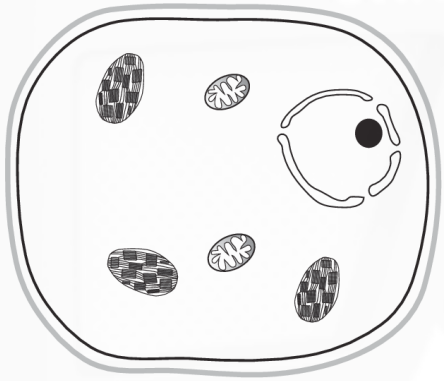
A variegated leaf from a plant is shown below.



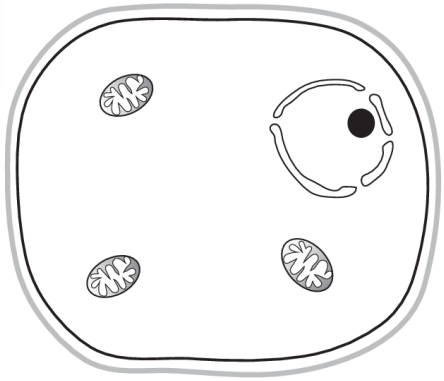
Source: Le Do/Shutterstock.com

Cells from sections M and K were examined and simple sketches were produced.

A typical cell from section M



A typical cell from section K



From this information, it can be concluded that

A. cells in section K would be unable to carry out aerobic respiration.

B. light-independent reactions of photosynthesis can occur in cells from section K.

C. there is chlorophyll present in cells from section K but not in cells from section M.

D. glucose would be manufactured from carbon dioxide and water in cells from section M but not in cells from section K.

Marking Scheme

Question	% A	% B	% C	% D	% No answer	Comments
15	9	12	3	76	0	

Question 16

A molecule that takes part in many biochemical reactions is $NADP^+$.

It is correct to state that

A. $NADP^+$ becomes NADH when it is loaded.

B. $NADP^+$ has a higher energy level when it is unloaded.

C. energy is released when $NADP^+$ is converted to NADPH.

D. $NADP^+$ carries additional energy when protons and electrons are added to it.

Marking Scheme

Question	% A	% B	% C	% D	% No answer	Comments
16	15	6	31	48	0	NADPH is the loaded form, which requires an input of energy to be produced.
16	15	6	31	48	0	NADPH is the loaded form, which requires an input of energy to be produced.

2017

The Calvin cycle uses the enzyme *Rubisco* (RuBP carboxylase) to fix CO_2 to RuBP and make a 3C compound (GP).

a) Name the cellular location of the Calvin cycle

_____(1 mark)

Plants that fix carbon dioxide directly from the air are called **C_3** plants (as the initial product is a 3C compound). C3 plants include some of the most important sources of calories all over the world: cowpea, cassava, soybean, and rice. The regions where these crops are grown in are often hot and dry, meaning they could benefit from the energy-saving mechanisms of C4 photosynthesis.

b) Describe the difference between C3 and C4 plants

_____

_____

_____

_____(2 marks)

Marking Scheme

a) Stroma (of the chloroplast) **(1 mark)**

b) C3 plants in the presence of RUBISCO, combines uses carbon dioxide to make a C3 compound **(1 mark)**
C4 plants convert the carbon dioxide into a C4 compound in a different location that maximises the availability of carbon dioxide. The C4 compound can then be transported to chloroplasts to undergo typical carbon fixation
(1 mark)

2017

At low light intensities there is a point where the rate of gas exchange around a leaf is zero. The best reason to explain this is that

A. respiration rate is greater than photosynthesis rate.
B. photosynthesis rate is greater than respiration rate.
C. photosynthesis rate is the same as respiration rate.
D. the plant is only respiring.

Marking Scheme

Question 11 Answer = C
Plants are constantly respiring and so give out carbon dioxide. At low light intensities plants will also photosynthesise which will absorb carbon dioxide. There will be a point where the rate of respiration is equal to the rate of photosynthesis and so the gas exchange will be zero.

Study Design Reference
The purpose of photosynthesis.
The purpose of cellular respiration.

2017

The most abundant protein on earth is called RUBISCO (Ribulose-1,5-bisphosphate carboxylase), which is involved in the light independent reaction of photosynthesis. It would be true to say that

A. RUBISCO is located in the matrix of the chloroplast.
B. RUBISCO is located in the stroma of the chloroplast.
C. RUBISCO is located in the grana of the chloroplast.
D. RUBISCO is embedded in the thylakoid membrane.

Marking Scheme

Question 12 Answer = B
The light independent reaction of photosynthesis occurs in the stroma of a chloroplast and so this is where RUBISCO would also be located.

Study Design Reference
chloroplasts as the site of photosynthesis, an overview of their structure and evidence of their bacterial origins.
inputs and outputs of the light dependent and light independent (Calvin cycle) stages of photosynthesis in C3 plants (details of the biochemical pathway mechanisms are not required)

2016

Question 10
Plants grown in light were supplied with water containing radioactive oxygen atoms. After four hours, an analysis of the chemicals in and around the plants was undertaken.
Which one of the following would contain the radioactive oxygen atoms after four hours?
A. protein
B. glucose
C. oxygen gas
D. carbon dioxide gas

Marking Scheme

The table below indicates the percentage of students who chose each alternative. The correct answer is indicated by shading.

Question	% A	% B	% C	% D	Comments
10	2	26	51	20	

Question 11

Which one of the following statements about photosynthesis in chloroplasts is correct?

A. The grana are the site of the light-independent stage.

B. Chlorophyll found in the stroma traps light for use during the light-dependent stage.

C. The light-dependent stage produces ATP for use during the light-independent stage.

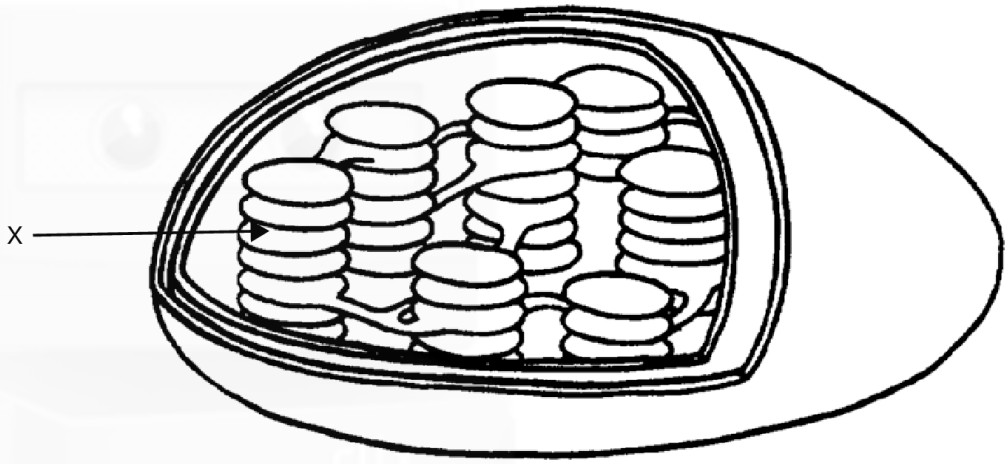
D. The light-independent stage captures carbon dioxide for use during the light-dependent stage to produce glucose.

Marking Scheme

The table below indicates the percentage of students who chose each alternative. The correct answer is indicated by shading.

Question	% A	% B	% C	% D	Comments
11	8	14	69	8	

Below is a diagram of a chloroplast.



Source: J Soucie; © BIODIDAC

a. Name the structure labelled X. 1 mark

_____

b. Complete the following table by referring to the diagram above and your knowledge of photosynthesis. 3 marks

Name of the stage of photosynthesis that occurs at X	_____	
Two input molecules that are required for reactions at X	1. _____	2. _____
Two output molecules that result from the reactions at X	1. _____	2. _____

DO NOT WRITE IN THIS AREA

Marking Scheme

Question 3a.

Grana or thylakoid (membrane)

Question 3b.

Name of the stage of photosynthesis that occurs at X	light-dependent stage	
Two input molecules that are required for reactions at X	1. water (Light was not acceptable.)	2. • ADP • Pi • NADP
Two output molecules that result from the reactions at X	1. oxygen	2. • ATP • NADPH or $H^{(+)}$ (NAD was not acceptable.)

2014

During photosynthesis in chloroplasts, energy is used to split water, forming oxygen and hydrogen ions.

The splitting of water occurs

A. in the stroma during the light-independent reaction.

B. in the grana during the light-dependent reaction.

C. on the membrane of the thylakoids during the light-independent reaction.

D. on the surface of the outer chloroplast membrane during the light-dependent reaction.

Marking Scheme

The table below indicates the percentage of students who chose each alternative. The correct answer is indicated by shading.

Question	% A	% B	% C	% D
7	11	75	7	7

2014

An increase in the atmospheric CO_2 level increases the rate of photosynthesis.

The rate of photosynthesis increases because

A. the rate of the light-independent reactions on the thylakoid membranes of the chloroplasts increases.

B. water loss from the leaf decreases, resulting in the availability of water for photosynthesis increasing.

C. the increased CO_2 level lowers the pH inside the chloroplasts and increases the rate of enzyme-catalysed reactions.

D. the rate of the light-independent reactions in the stroma increases with the increase in CO_2 level.

Marking Scheme

The table below indicates the percentage of students who chose each alternative. The correct answer is indicated by shading.

Question	% A	% B	% C	% D
8	8	4	12	76

Scientists are looking at ways to increase the efficiency of photosynthesis in plants, including the way in which carbon dioxide is captured.

c. i. Name the stage of photosynthesis in which carbon dioxide is captured. 1 mark

_____

ii. The stage of photosynthesis in which carbon dioxide is captured requires other inputs.
Name two other inputs and describe the role played by each in this stage of photosynthesis. 2 marks

Name of input	Role

Marking Scheme

Question 1ci.

Marks	0	1	Average
%	44	56	**0.6**

Light-independent stage or Calvin (Benson) cycle

Many students initially gave the light-independent stage, but changed their answer to the light-dependent stage.

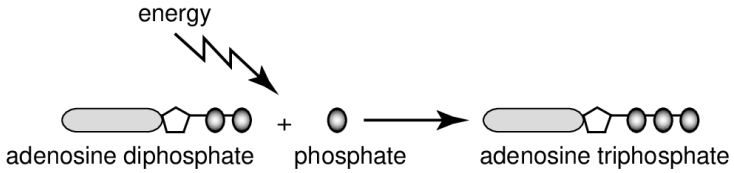
Question 1cii.

Marks	0	1	2	Average
%	56	20	24	**0.7**

Name of input	Role
ATP	provides energy to form glucose
NADPH	carries hydrogen ions

NAD was incorrect as it is a carrier molecule in cellular respiration and not in photosynthesis.

Adenosine diphosphate (ADP) is an organic molecule found in large quantities in most cells. ADP is converted to adenosine triphosphate (ATP) by phosphorylation, as shown in the diagram below.



The original source of energy for this reaction is

A. ADP.

B. glucose.

C. sunlight.

D. phosphate.

Marking Scheme

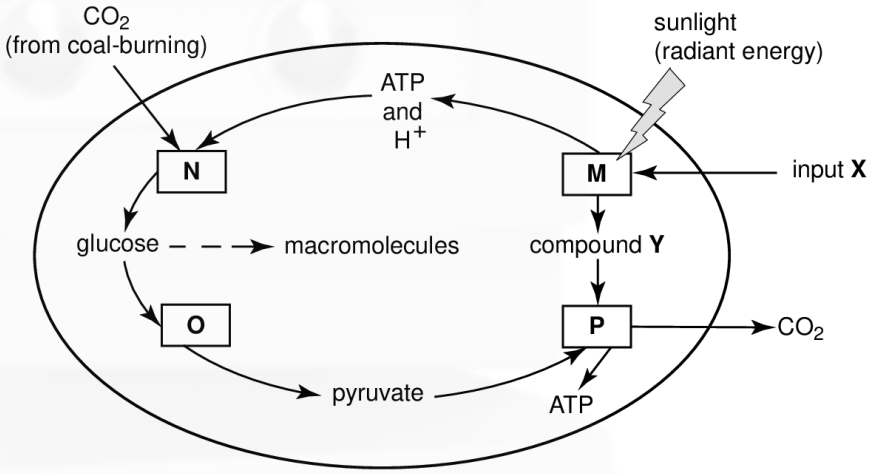
Question	% A	% B	% C	% D
21	12	51	30	7

2012

Climate change has been linked to an excess of carbon dioxide in the atmosphere. The burning of coal is a major contributor to this excess of carbon dioxide.

Microalgae such as *Chlorella* can use greater amounts of carbon dioxide than land plants and they do not require prime soil, reliable rainfall and a particular climate. *Chlorella* can be grown cheaply in existing or engineered ponds which are supplied with carbon dioxide from a coal-burning power station nearby.

The following diagram represents a summary of the processes (labelled M, N, O, P) occurring in a *Chlorella* cell.



a. Name

i. input X _____

ii. compound Y _____

2 marks

b. With reference to the diagram above, complete the following table.

Process	Name of process	Site of process
M		grana of chloroplast
O	glycolysis	
P	stages of cellular respiration	

3 marks

Chlorella pond farms could reduce 50% of the carbon dioxide that is produced by coal-burning power stations. Consider the summary of processes occurring in a *Chlorella* cell.

c. Given that carbon dioxide is an output of process P, explain how *Chlorella* farming could prevent 50% of the carbon dioxide emitted by coal-burning power stations from entering the atmosphere.

2 marks

d. What are **two** conditions, other than carbon dioxide supply, that an engineer or biologist maintaining a *Chlorella* pond farm would need to control to keep the growing conditions at an optimum level?

1 mark

Marking Scheme

Question 8ai.–ii.

Marks	0	1	2	Average
%	35	28	37	**1**

i. Input X: water or inorganic phosphate
ii. Compound Y: oxygen

Question 8b.

Marks	0	1	2	3	Average
%	17	15	23	45	**2**

Process	Name of process	Site of process
M	light-dependent reaction	grana of chloroplast
O	glycolysis	cytoplasm/cytosol
P	stages of cellular respiration	mitochondria

Question 8c.

Marks	0	1	2	Average
%	54	33	12	**0.6**

Both of:

- carbon dioxide used in photosynthesis
- more than is produced (in cellular respiration).

Question 8d.

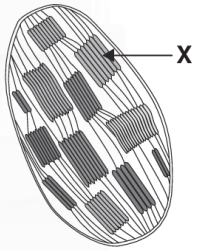
Marks	0	1	Average
%	28	72	**0.7**

Two of:

- suitable temperature
- light
- water/space
- lack of competition.

A wide variety of sensible and suitable answers were provided by students. Oxygen was not accepted.

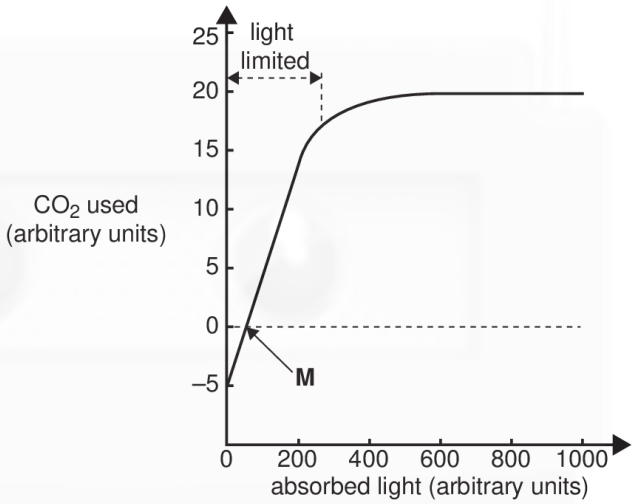
The diagram below shows a chloroplast.



c. Describe the chemical changes that occur at location X when light is present.

2 marks

The graph below shows the rate of carbon dioxide exchange between a leaf and its external environment as light intensity is altered. All other variables are kept constant throughout the experiment.



d. **i.** Outline what is occurring at point M in terms of chemical reactions.

ii. Explain why the graph line becomes nearly horizontal from about 600 units of absorbed light.

1 + 1 = 2 marks

RuBisCo is an enzyme found in chloroplasts. Its normal function is to catalyse the reaction in which carbon dioxide is a substrate. In certain plants, when the level of carbon dioxide is low in the leaf, RuBisCo uses oxygen as the substrate and releases hydrogen peroxide and ammonia.

e. Explain why it is beneficial for a plant to have a high level of carbon dioxide in its leaves.

2 marks

Marking Scheme

Question 7c.

Two of:

- water is split to form oxygen gas
- water is split to form H^+ or NADPH is formed
- ATP is formed (from ADP and P_i).

Question 7d.

Question 7di.
The amount of carbon dioxide being released in cellular respiration equals the amount of carbon dioxide used in photosynthesis.

The question asked 'in terms of chemical reactions', therefore students were required to make statements about photosynthesis, cellular respiration and there being no CO_2 used as indicated by the graph. While the term 'compensation point' suitably described Point M, it did not answer the question.

Question 7dii.
There is a limiting factor (other than light) such as:

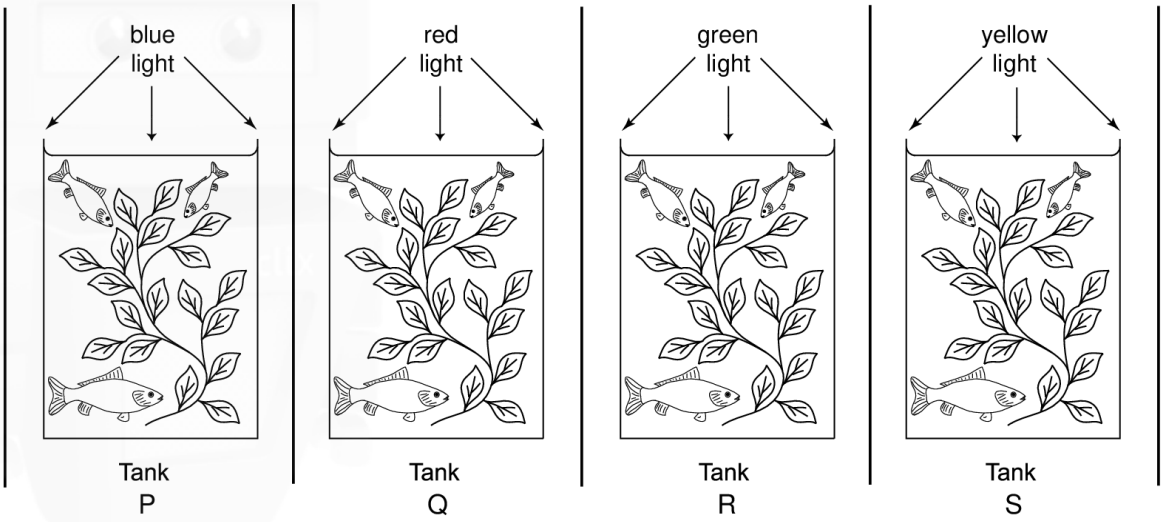
- lack of CO_2
- lack of water
- lack of enzymes
- inability of chlorophyll to absorb any more light.

Question 7e.
Either of:

- Increase the rate of photosynthesis and therefore greater production of glucose/growth
- Reduce the production of hydrogen peroxide and ammonia and these are toxic and could harm the plant.

2010

Samples of a particular water plant and fish were placed in four identical glass tanks. The fish were provided with food pellets. The tanks were isolated from each other, and each was illuminated by a different coloured light source.



Question 17

The plant that is expected to produce the most oxygen is the plant in tank

A. P.

B. Q.

C. R.

D. S.

Marking Scheme

The table below indicates the percentage of students who chose each alternative. The correct answer is indicated by shading.

Question	% A	% B	% C	% D	% No Answer	Comments
17	23	44	18	14	0	Plants absorb different wavelengths of light. Light which is not absorbed is reflected. Oxygen is a by-product of photosynthesis and is dependent on the light energy absorbed. The greatest amount of oxygen production occurs in red light, followed by blue, then yellow, while the green light is reflected.

Question 3

Elysia chlorotica is a bright green sea slug, with a soft leaf-shaped body. It has a life span of 9 to 10 months. This sea slug is unique among sea slugs as it is able to survive on solar power.

E. chlorotica acquires chloroplasts from the algae it eats, and stores them in the cells that line its digestive tract.

Young *E. chlorotica* fed with algae for two weeks can survive for the rest of their lives without eating.

a. What is the product of photosynthesis that provides the energy that enables *E. chlorotica* to survive for so long without eating?

_____

1 mark

A watery environment can have a low concentration of dissolved gases.

c. Explain how having chloroplasts allows *E. chlorotica* to overcome this disadvantage.

_____

_____

1 mark

Total 5 marks

Marking Scheme

Question 3a.

Marks	**0**	**1**	**Average**
%	26	74	**0.8**

Glucose or $C_6H_{12}O_6$

Question 3c.

Marks	**0**	**1**	**Average**
%	88	12	**0.1**

The oxygen produced in photosynthesis can be used in cellular respiration.