



Chloroplasts and Mitochondria

This Factsheet summarises:

- The structural similarities and differences between chloroplasts and mitochondria.
- The functional similarities and differences between chloroplasts and mitochondria.

There is not room in this factsheet to deal with the complete processes of photosynthesis and cellular respiration. These are dealt with in Factsheet No 2, The essential guide to photosynthesis, September 1997, and in Factsheet No 12, Respiration, January 1998.

Chloroplasts and mitochondria are both membrane bound organelles of eukaryotic cells. They do not occur in prokaryotic cells, for example, bacteria. Mitochondria occur in the cells of animals and plants but chloroplasts only occur in the photosynthesising tissues of plants.

The structural similarities and differences between chloroplasts and mitochondria

The highest power of a light microscope can only see mitochondria as small granules, or chloroplasts as minute green discs, in the cytoplasm of cells. To see the ultrastructure (internal detail) in these structures an electron microscope is required.

Fig 1. shows the ultrastructure of a mitochondrion and Fig 2. shows the ultrastructure of a chloroplast.

Fig 1. The structure of a mitochondrion

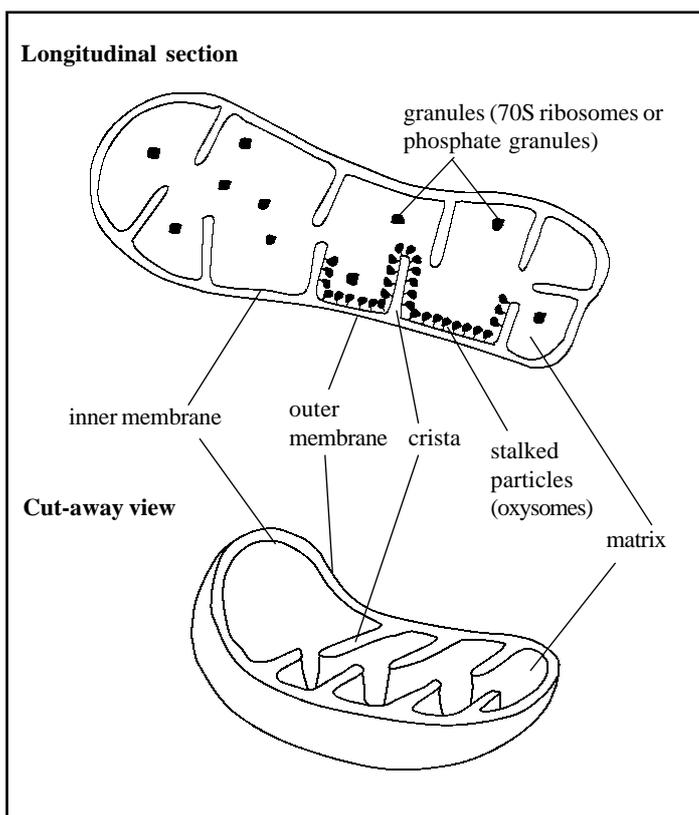
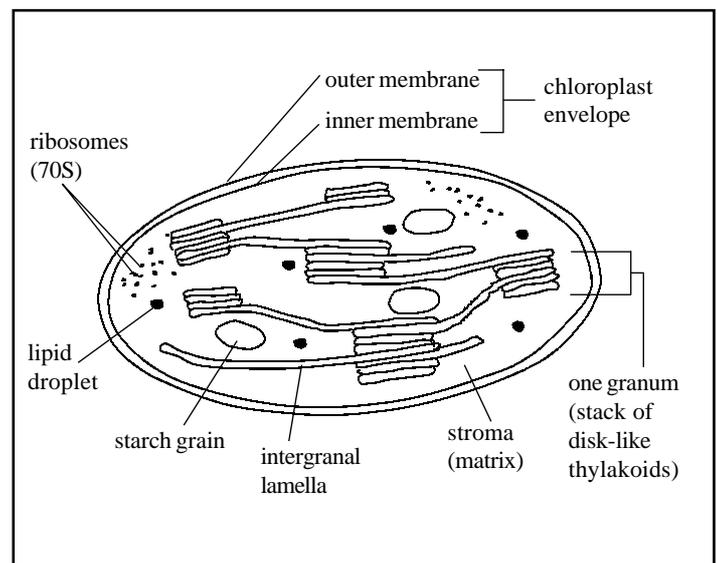


Fig 2. The structure of a chloroplast



The structural similarities of chloroplasts and mitochondria are:

- both are made of unit membranes.
- both have an outer envelope of two unit membranes.
- both contain an aqueous matrix containing enzymes and DNA.
- both contain 70S type ribosomes (RNA) which may be free in the matrix or attached to membranes.

Remember – unit membranes contain a core of phospholipid about 3.5 nm thick, bordered on each side by a protein layer about 2nm thick. These membranes are thus about 7.5 nm thick and have a simpler structure than the cell surface membrane.

The structural differences between mitochondria and chloroplasts are:

- chloroplasts are shaped like minute biconvex lenses, 4-10 μm in diameter and 2-3 μm thick. Mitochondria are usually rod-shaped, about 1-2 μm long and 0.3-0.7 μm wide. (A few species may have spherical or spiral shaped mitochondria).
- chloroplasts contain many double membranes called **lamellae**. These form disc like structures called **thylakoids** which are piled on top of each other, making the structures known as **grana**. Grana are joined to each other by **intergranal lamellae**. The thylakoids contain many small and large particles which can only be seen under the highest powers of the electron microscope. These are the **quantosomes** and house the photosystem systems of pigments.

The innermost membranes of mitochondria are called **christae** and are extensions of the inner membrane of the mitochondrial envelope. The christae and inner membrane are covered with thousands of small spherical bodies called **oxysomes** which are attached to the membranes by short stalks (oxysome + stalk = stalked particle).

- chloroplasts may contain temporary stores of starch and lipids but mitochondria do not.
- chloroplasts contain the photosynthetic pigments, chlorophyll a, chlorophyll b, β -carotene and sometimes xanthophyll. These are situated in the quantosomes of the thylakoids and make up the photosystems. Mitochondria do not contain photosynthetic pigments.

The functional similarities and differences between chloroplasts and mitochondria

Fig 3. and Fig 4. indicate where the reactions of photosynthesis and respiration occur in chloroplasts and mitochondria respectively.

Fig 3. Photosynthesis in the chloroplast

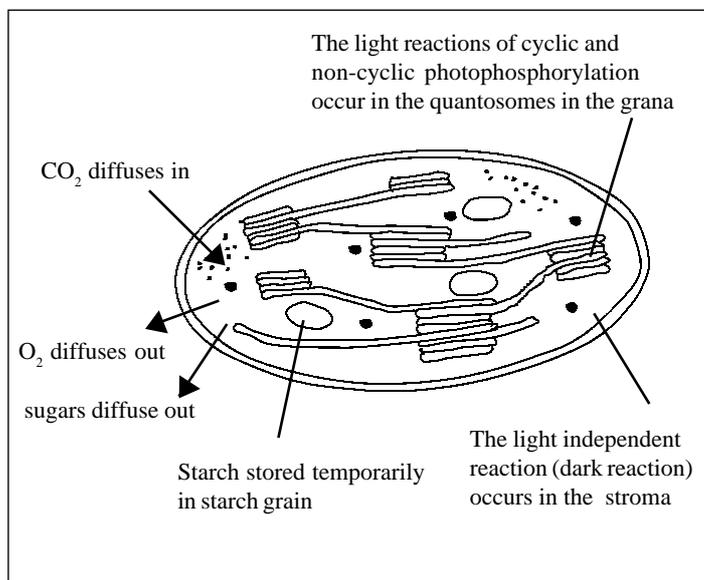
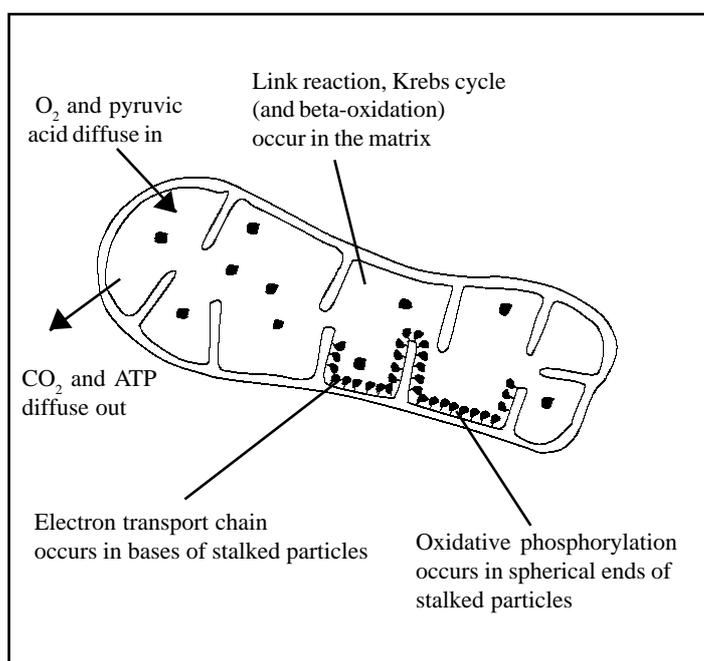


Fig 4. Photosynthesis in the mitochondria



The functional similarities between chloroplasts and mitochondria are:

- Both organelles contain DNA and RNA, which are involved with the synthesis of the membrane and enzyme proteins, when the organelles replicate during cell division.
- Both organelles contain similar enzymes and coenzymes, concerned with dehydrogenations, electron transport and ATP exchange, but these enzymes and coenzymes are used in different ways in chloroplasts and mitochondria.

Point of special interest

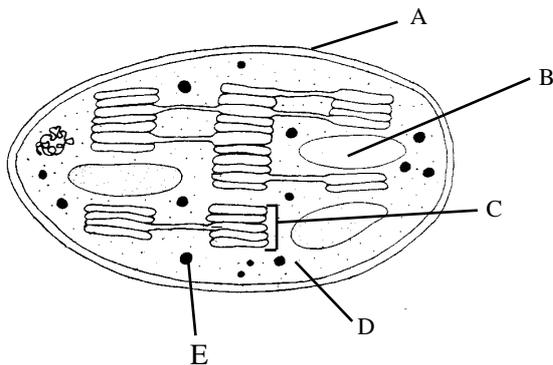
Mitochondrial DNA carries genes for inheritance but they can only be transmitted from mother to offspring via the egg. In mammals only the male nucleus of the sperm penetrates the egg and thus the sperm makes no other contribution. Therefore all the mitochondrial DNA in a male has come from the mother and cannot be passed on to the next generation. The mitochondrial DNA is also subject to mutations. Only those that occur in the female will be passed on to the next generation.

The functional differences between chloroplasts and mitochondria are:

- chloroplasts are concerned with the process of photosynthesis whereas mitochondria are concerned with aerobic respiration. Thus photosynthesis only operates in light but mitochondria operate all the time, whether in light or dark.
- chloroplasts absorb carbon dioxide, for use in photosynthesis during light periods, and release oxygen, whereas mitochondria continually absorb oxygen for respiration and release carbon dioxide. Mitochondria also absorb pyruvic acid, the final product of glycolysis, which occurs in the cytoplasm of cells.
- the light dependent stage of photosynthesis (light reaction) occurs in the quantosomes of the thylakoids. The small and large quantosomes are thought to house the pigment systems of photosystem I and photosystem II respectively. Cyclic photophosphorylation involves only photosystem I but non-cyclic photophosphorylation involves both photosystems I and II. The light independent stage of photosynthesis (dark reaction or Calvin pathway) occurs in the stroma of the chloroplast and uses ATP and NADPH, generated by the light reaction, to fix carbon dioxide onto the acceptor, ribulose biphosphate. This results in the synthesis of sugars. The enzymes of the Link Reaction and Krebs cycle, for metabolising pyruvic acid, (and the enzymes for the β -oxidation of fatty acids), are present in the matrix of the mitochondria. The bases of the stalked particles house the coenzymes of the respiratory chain, including the electron transport chain. The spherical heads of the stalked particles contain the enzymes, such as ATPase, which link the respiratory chain to oxidative phosphorylation which occurs in the spherical heads. ATP is thus generated in the spherical heads.
- the coenzyme used for hydrogen transfer in the process of photosynthesis, in the chloroplasts, is NADP (nicotinamide adenine dinucleotide phosphate). The initial coenzyme used for hydrogen transfer in the process of respiration, in the mitochondria, is NAD (nicotinamide adenine dinucleotide).
- chloroplasts store starch and oil (lipid) droplets, mitochondria do not.

Practice questions

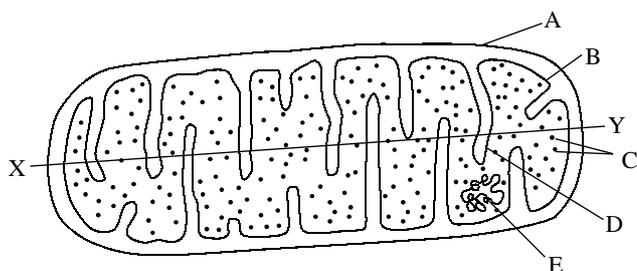
1. The diagram shows the structure of a chloroplast.



- (a) Name structures labelled A to E on the diagram. 5
- (b) State where in the chloroplast:
 - (i) the light dependent reaction takes place. 1
 - (ii) the light independent reaction takes place. 1
- (c) State three similarities in the structure of chloroplast and mitochondria. 3
- (d) Suggest why each of the following are present in both chloroplasts and mitochondria:
 - (i) ATPase. 2
 - (ii) ribosomes. 1

Total 13

2. The diagram shows the structure of a mitochondrion.



- (a) Name structures A to E. 5
- (b) State where the following are situated in the mitochondrion:
 - (i) The enzymes involved with oxidative phosphorylation and electron transport. 1
 - (ii) The enzymes involved with the Krebs cycle. 1
- (c) Why does the mitochondrion contain RNA? 1
- (d) The magnification of the diagram is 240,000 times. Calculate the actual length of the mitochondrion. Express your answer in μm . Make your measurements along the axis XY. Show your working. 2

Total 10

3. ATP is produced in both chloroplasts and mitochondria. The table below compares the process of ATP production in these organelles. Complete the table with a tick in the appropriate box if the statement is true for ATP production in each organelle and a cross if the statement is incorrect.

Statement	Chloroplast	Mitochondrion
Electrons are excited by photons		
Electrons pass through carriers		
Involves oxidative photophosphorylation		
ATP produced from ADP and phosphate		
Occurs in day and night		

Total 5

- 4. Suggest reasons why:
 - (a) liver cells contain many more mitochondria than adipose (fat storage) cells. 3
 - (b) palisade mesophyll cells in the leaves at the top of beech trees, growing in a beechwood, contain more chloroplasts than palisade mesophyll cells in the leaves at the bottom of the tree. 2
 - (c) mitochondria that have become filamentous (elongated) have the same diameter as the more usual rod-shaped mitochondria. 2
 - (d) both chloroplasts and mitochondria contain DNA and RNA. 2

Total 9

- 5. (a) Chloroplasts and mitochondria both have features which are characteristic of prokaryotic cells. State two such features and for each feature say how the eukaryotic cell differs. 4
- (b) Why are mutations in mitochondrial DNA in the male of no evolutionary significance? 3

Total 7

- 6. Distinguish each of the following pairs:
 - (a) oxidase phosphorylation and oxidative photophosphorylation 2
 - (b) oxysomes and quantosomes 2
 - (c) mitochondrial matrix and chloroplast stroma 2

Total 6

Answers

1. (a) A = outer membrane/envelope;
B = starch grain;
C = grana/stack of thylakoids;
D = stroma;
E = lipid droplet;
- (b) (i) in quantosomes/thylakoids/grana;
(ii) in the stroma;
- (c) both are made of unit membranes;
their outer envelopes are double/have two membranes;
both contain ribosomes;
both contain DNA;
both contain a matrix; max 3
- (d) (i) ATPase links phosphorylation of ADP to the respiratory chain/
electron transport;
thus important in respiration and photosynthesis;
- (ii) important in replication/synthesis of new membrane proteins
(during cell division);
2. (a) A = outer membrane;
B = inner membrane;
C = ribosomes;
D = christa;
E = DNA;
- (b) (i) in stalked bodies/spherical heads (oxidative phosphorylation)/
stalked base (electron transfer.);
- (ii) in the matrix;
- (c) to enable synthesis of new membrane/mitochondrial proteins during
cell division;
- (d) length of XY = 7.1 cm/710 mm/710,000 mm; (this may alter due to
printing/copying – so adjust mark scheme if necessary)
 $\frac{710,000}{240,000} = 2.96$ mm;

3.

Statement	Chloroplast	Mitochondrion
Electrons are excited by photons	✓	✗ ;
Electrons pass through carriers	✓	✓ ;
Involves oxidative photophosphorylation	✓	✗ ;
ATP produced from ADP and phosphate	✓	✓ ;
Occurs in day and night	✗	✓ ;

4. (a) liver cells metabolically very active due to secretion/protein
synthesis/glycogen synthesis;
thus require a large supply of ATP;
adipose cells are metabolically inert/not usually active and so need
less ATP;
- (b) higher light intensity at top of tree/more available light means more/
higher density of chloroplasts are required to trap it /make use of
it;
less available light at bottom (due to shading) so fewer/lower density
of chloroplasts are required to trap it;
(although leaves may be larger in shade to accommodate more
palisade cells)
- (c) diameter is kept small to reduce length of diffusion gradients;
for oxygen/pyruvic acid in/carbon dioxide/ATP out;
- (d) DNA transfers genetic code of mitochondria/chloroplasts from
cell to cell/organelle to organelle during replication;
RNA involved in synthesis of new membranes/enzymes in the
organelles during replication;
5. (a) chloroplasts/mitochondria have circular DNA/not on chromosomes/
not in a nucleus;
eukaryotic cells have linear DNA/on chromosomes/in nucleus;
chloroplasts/mitochondria have small/70S ribosomes; eukaryotes
have large/80S ribosomes;
chloroplasts/mitochondria similar size to prokaryotic cells/small/
0.5-3.0 μm ; eukaryotic cells are much larger/20 μm ;
- (b) Sperm mitochondria do not enter the egg at fertilisation;
offspring therefore only receive maternal mitochondrial DNA via
the egg;
if mutations are not passed on they cannot have selective advantages
or disadvantages;
6. (a) energy input to oxidative phosphorylation is from
dehydrogenations / chemical energy;
energy input to oxidative photophosphorylation is from light
energy excited electrons;
- (b) oxysomes contain the enzymes of oxidative phosphorylation/
electron transport chain;
quantosomes contain the photosynthetic pigments and
photosystems I and II;
- (c) the matrix houses the enzyme of the dark reaction of
photosynthesis;

Acknowledgements;

This Factsheet was researched and written by Martin Griffin

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