ATP and Respiration

Wednesday, January 24, 2018

5.2.2 Respiration

Respiration is the process whereby energy stored in complex organic molecules is transferred to ATP. ATP provides the immediate source of energy for biological processes.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the need for cellular respiration	To include examples of why plants, animals and microorganisms need to respire (suitable examples could include active transport and an outline of named metabolic reactions).
(b)	the structure of the mitochondrion	The components of a mitochondrion including inner and outer michondrial membranes, cristae, matrix and mitochondrial DNA.

Energy "the ability to do work" is needed for:

1. **Metabolism** — All reactions that take place in living organisms involve energy
2. **Movement** — Within (circulation) and whole organism (locomotion)
3. **Active Transport** — Movement of ions and molecules across a plasma membrane against a concentration gradient
4. **Maintenance, repair and division** — Of organelles and cells
5. **Production of substances** — Eg. Hormones and enzymes
6. **Maintenance of body temperature** — For Endothermic organisms

Where does this energy come from?

Ultimately, all energy comes from the **SUN** as light energy (energy can never be lost or created, only converted)

Green plants and algae convert light energy into chemical energy, in the form of organic molecules such as glucose, via **PHOTOSYNTHESIS**

Consumers then ingest these organic molecules as food and use them for **RESPIRATION**. Producers use their 'own' organic molecules for respiration.

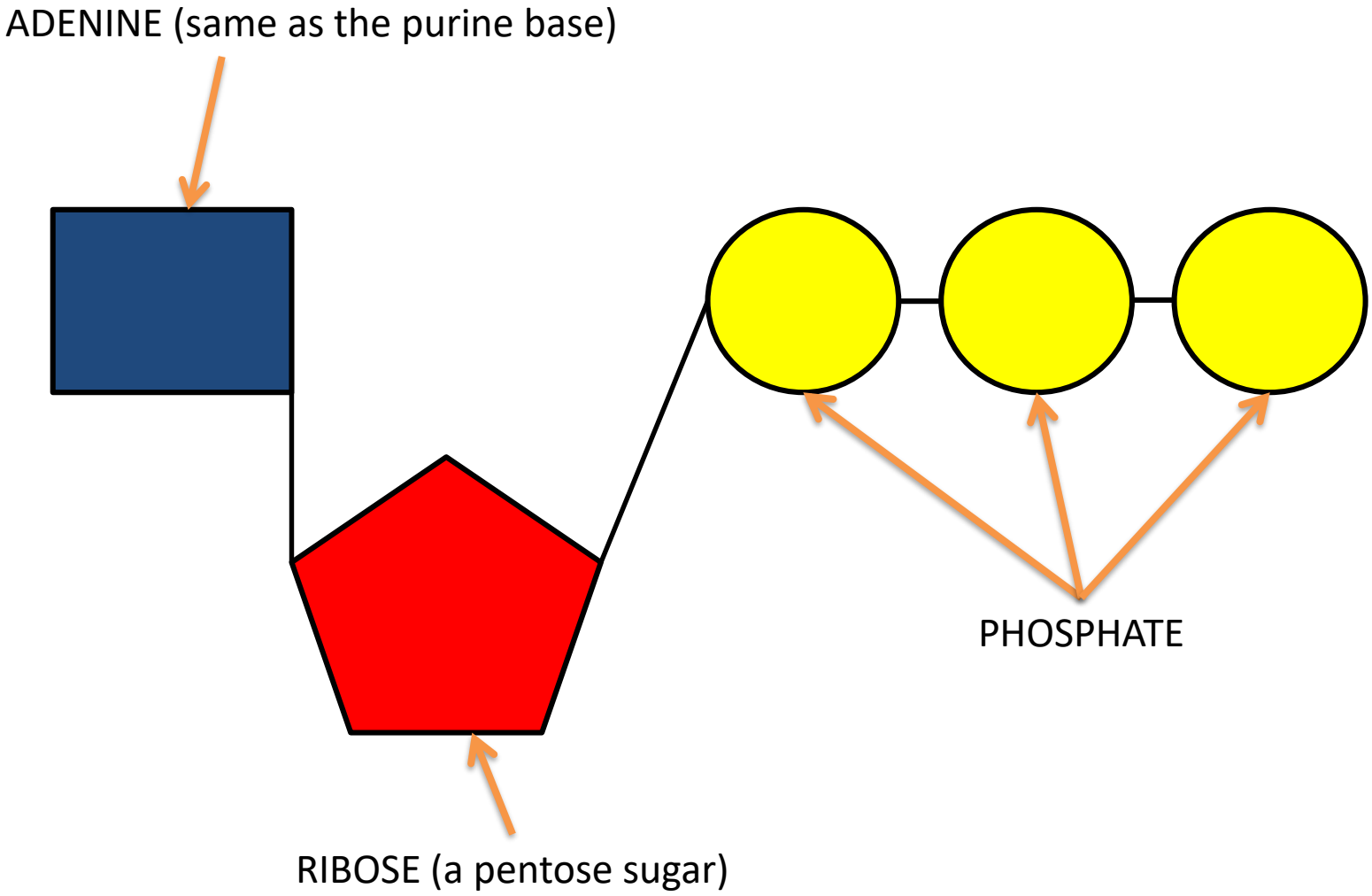
HOWEVER…

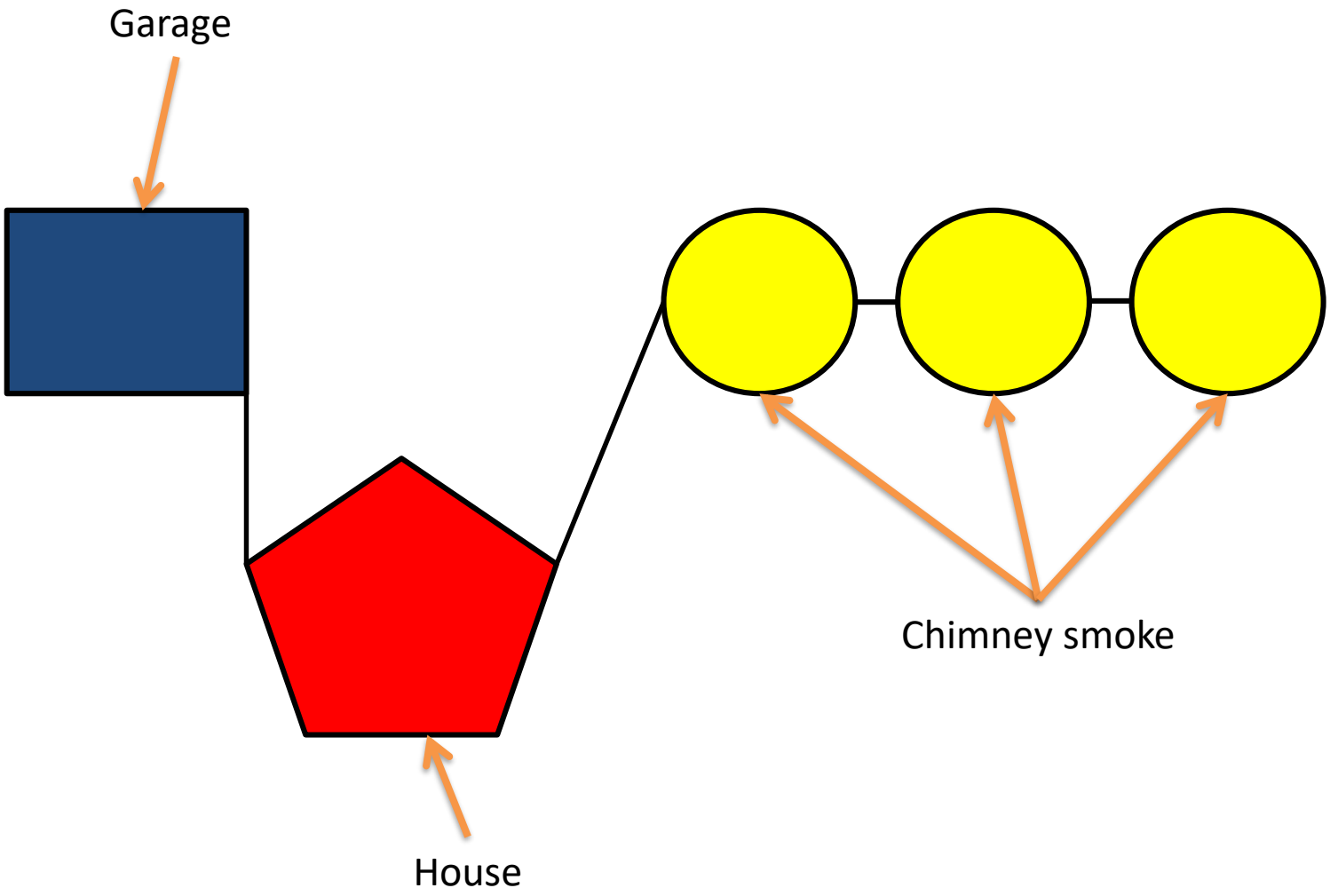
Cellular Respiration in mitochondria is NOT the energy source.

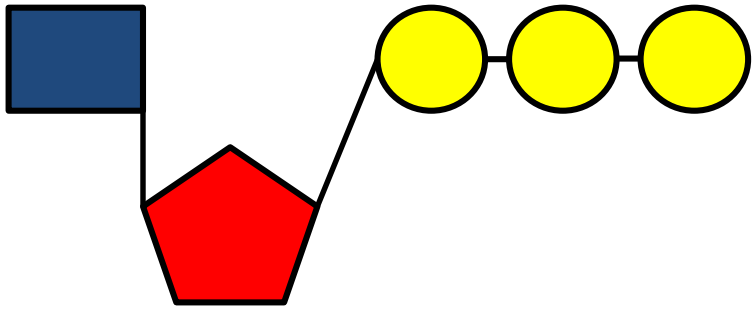
Respiration instead converts organic molecules into ATP which IS the source of energy in organisms.

Hence we have always told you that mitochondria are the site of aerobic respiration or site of production of ATP, not the source of energy in cells.

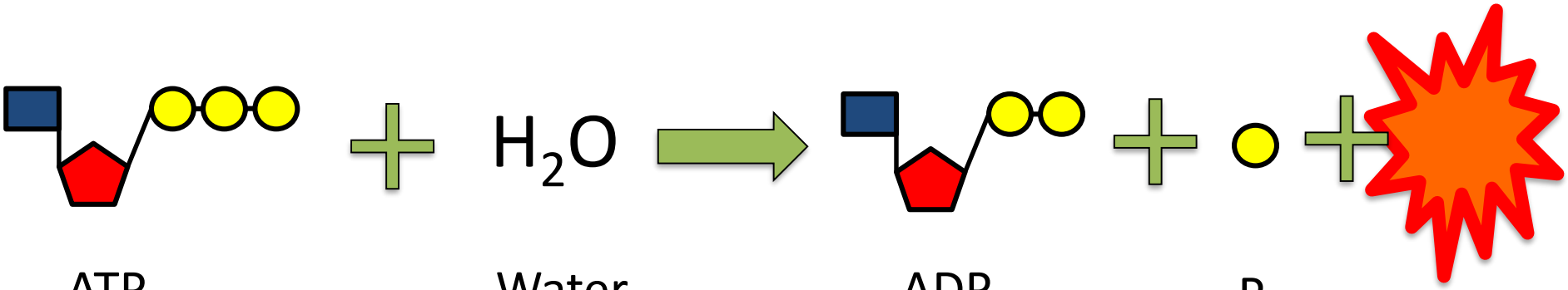
Adenosine **T**ri**P**hosphate




Garage
House
Chimney smoke



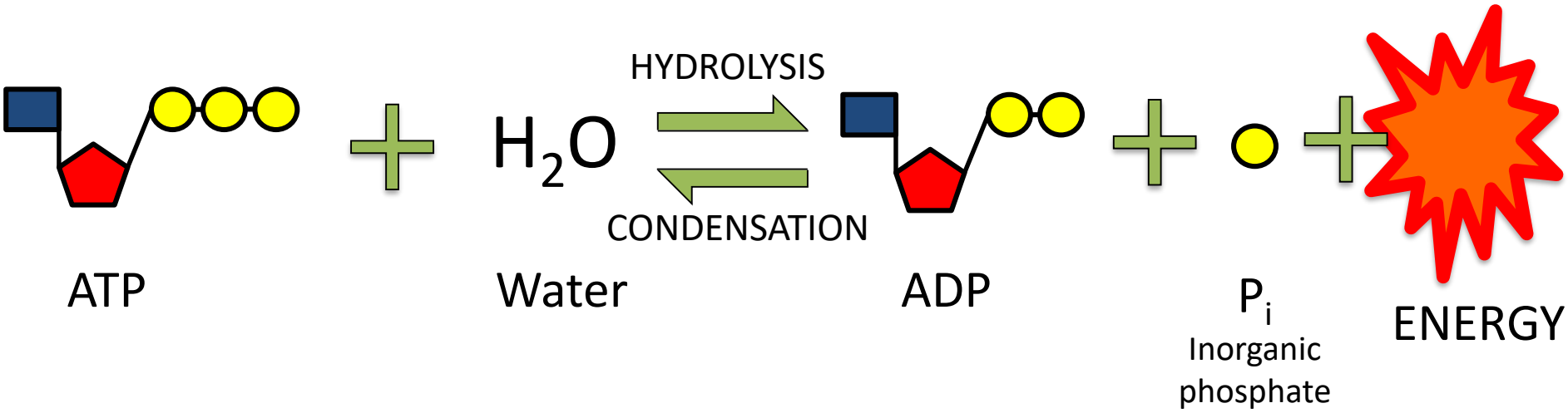
The three phosphate groups are the key to how ATP stores energy – they are only connected by weak, unstable bonds which are easily broken, releasing a large amount of energy.



What type of reaction is this? HYDROLYSIS – addition of water

This reaction is actually reversible…

ATP is hydrolysed to provide energy for reactions that require it…



ATP is reformed from ADP + P_i via a condensation reaction during reactions that generate energy.

ATP is synthesised from one of three reactions:

1. **PHOTOPHOSPHORYLATION**. The addition of an inorganic phosphate molecule to ADP in CHLOROPLASTS during PHOTOSYNTHESIS.

2. **OXIDATIVE PHOSPHORYLATION**. The addition of an inorganic phosphate molecule to ADP in MITOCHONDRIA of plant and animal cells during ELECTRON TRANSPORT.

3. **SUBSTRATE-LEVEL PHOSPHORYLATION**. The addition of an inorganic phosphate molecule to ADP from DONOR MOLECULES, such as the formation of pyruvate in glycolysis.

ATP is an IMMEDIATE ENERGY SOURCE

Because ATP is rapidly broken down to release energy and rapidly reformed from ADP and P_i, cells do not use it as an energy STORE, rather using it when it is immediately required.

Fats and carbohydrates serve as much better energy stores in the body as these can be broken down to release ATP when required.

Cells which require a lot of ATP, such as muscle cells, contain lots of mitochondia to break down glucose, releasing ATP which is then hydrolysed to release energy.

1. Make notes from pages 80 – 81 (Heinemann) to address the roles and synthesis of ATP. Include a definition of Anabolic and Catabolic metabolism

2. Answer the Questions 2, 3 & 4 on p.81. Answers on p.257

RESPIRATION

5.2.2 Respiration

Respiration is the process whereby energy stored in complex organic molecules is transferred to ATP. ATP provides the immediate source of energy for biological processes.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(c)	the process and site of glycolysis	To include the phosphorylation of glucose to hexose bisphosphate, the splitting of hexose bisphosphate into two triose phosphate molecules and further oxidation to pyruvate **AND** the production of a small yield of ATP and reduced NAD.

Glucose produced via photosynthesis in plants or consumed in animals is not a cells energy source – ATP is. Glucose is converted into ATP via cellular respiration in mitochondria.

AEROBIC RESPIRATION requires oxygen and produces carbon dioxide, water and a lot of ATP

ANAEROBIC RESPIRATION takes place in the absence of oxygen and produces lactate in animals and carbon dioxide and ethanol in plants/yeast, but only a little ATP.

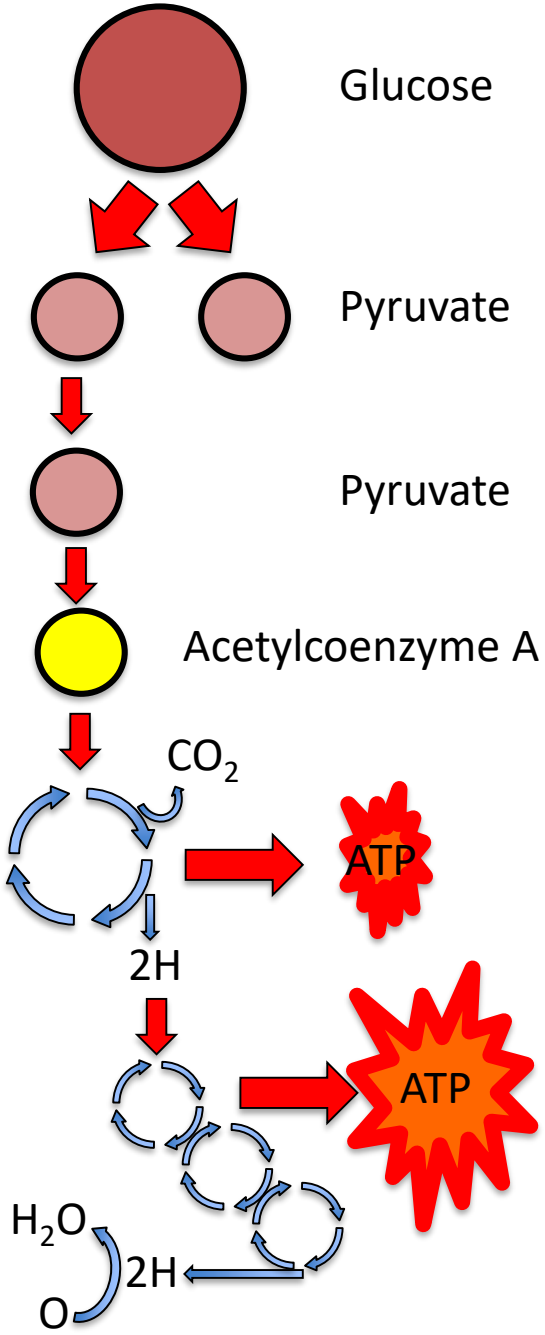
AEROBIC RESPIRATION

Stage 1. **GLYCOLYSIS**.
6-carbon glucose molecules are broken down into 2x 3-carbon **PYRUVATE** molecules. Occurs in the Cytoplasm.

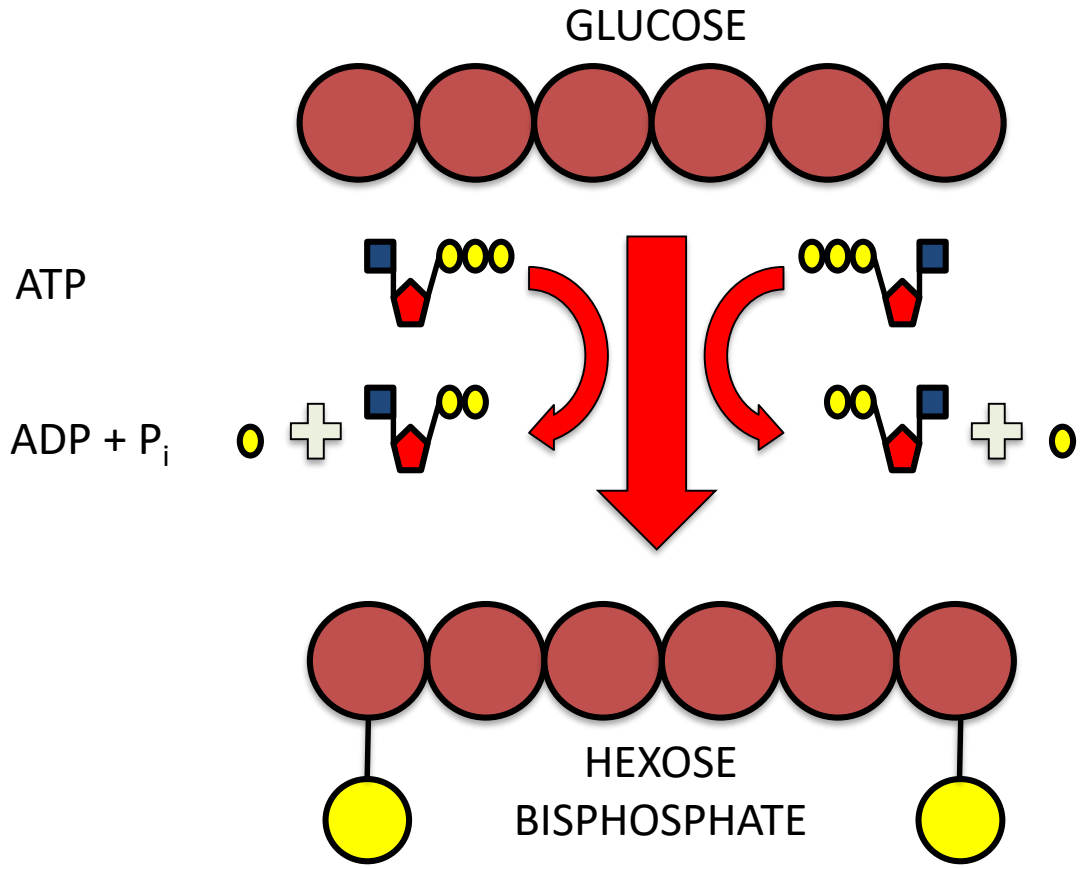
Stage 2. **LINK REACTION**.
3-carbon **PYRUVATE** molecules are converted into CO_2 and a 2-carbon **ACETYLCOENZYME A** molecule. Occurs in the Mitochondria.

Stage 3. **KREBS CYCLE**.
ACETYLCOENZYME A undergoes a series of oxidation-reduction reactions to produce some ATP and lots of reduced NAD. Occurs in the Mitochondria.

Stage 4. **ELECTRON TRANSPORT CHAIN**.
The electrons produced in the Krebs Cycle are used to synthesise ATP with water produced as a by-product. Occurs in the Mitochondria.

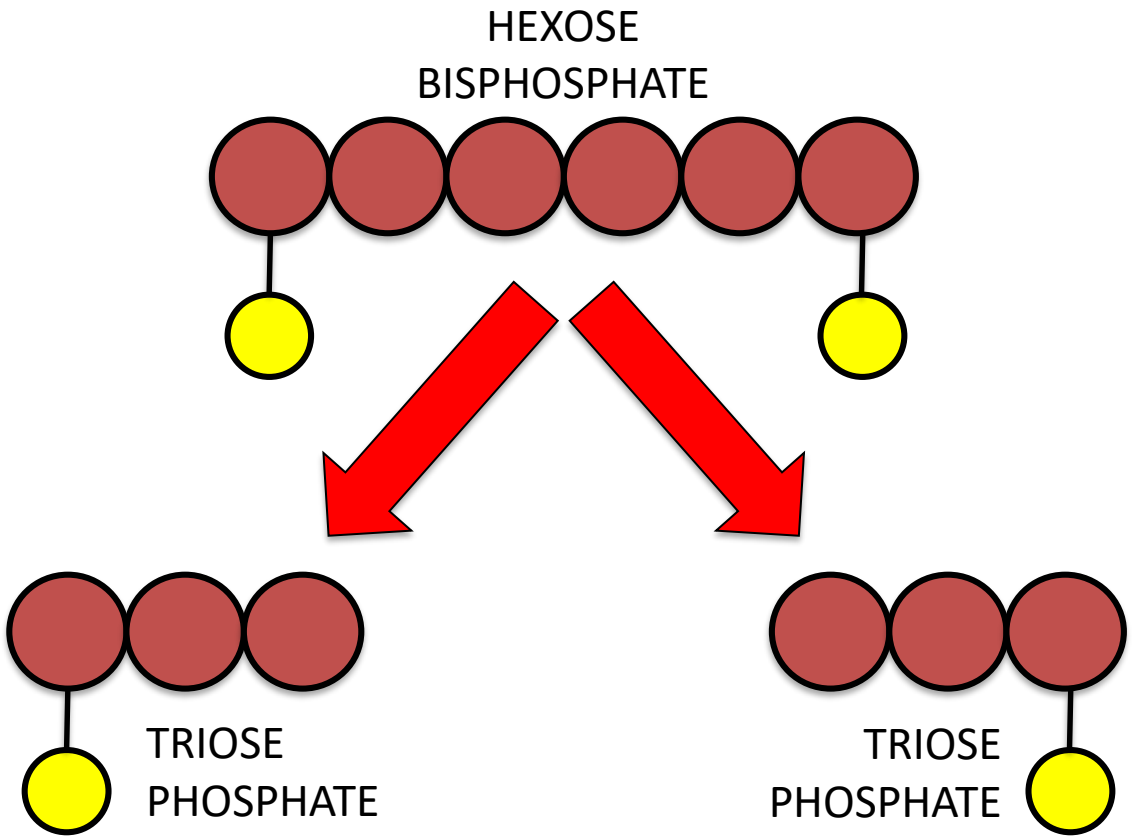


GLYCOLYSIS



STEP 1 – Glucose is made more reactive by the addition of two inorganic phosphate molecules (phosphorylation) from the hydrolysis of ATP. This lowers the activation energy of subsequent enzyme-controlled reaction.

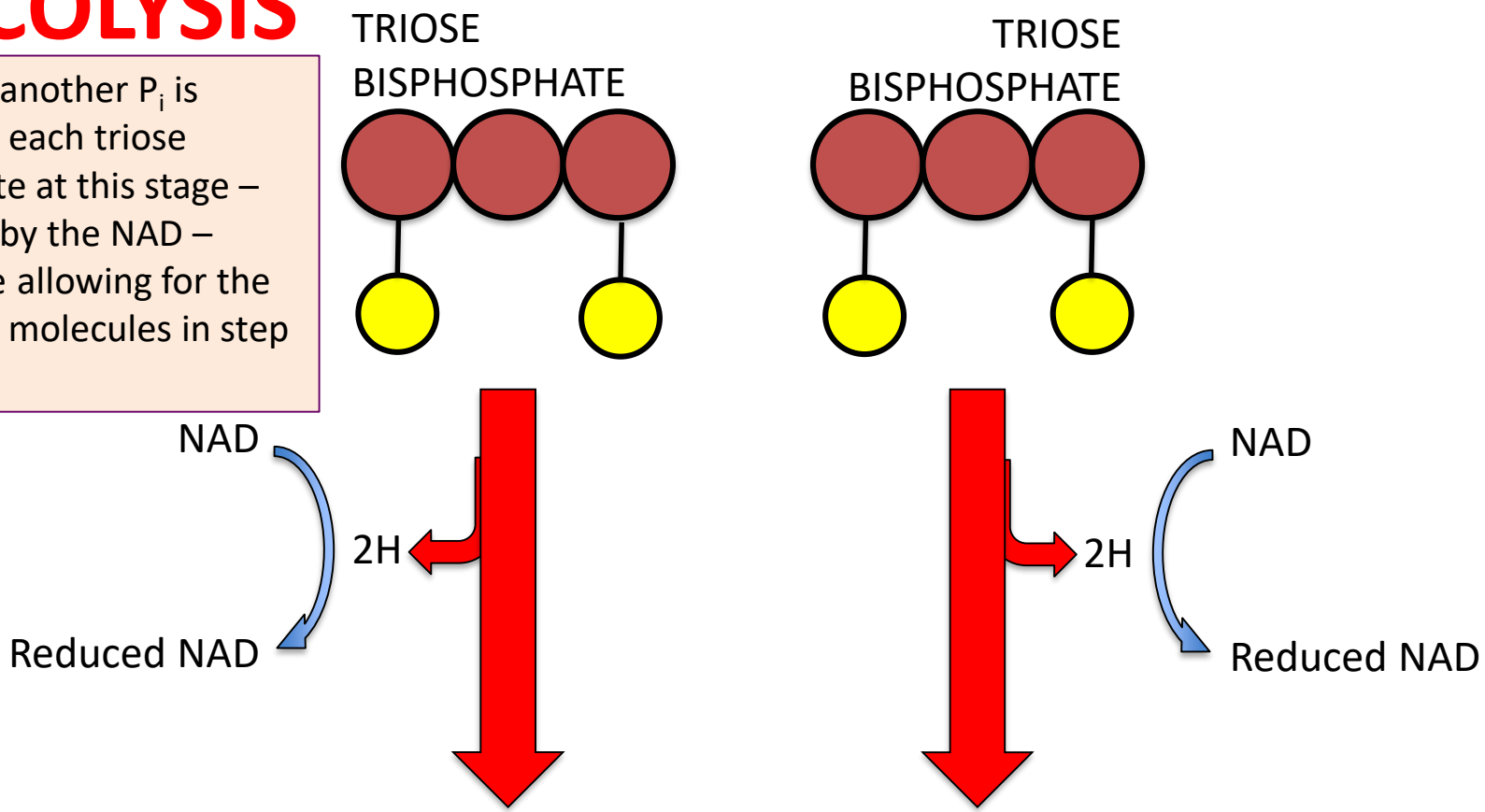
GLYCOLYSIS



STEP 2 – Each hexose bisphosphate molecule is split into two 3-carbon molecules known as **TRIOSE PHOSPHATE** (lysis)

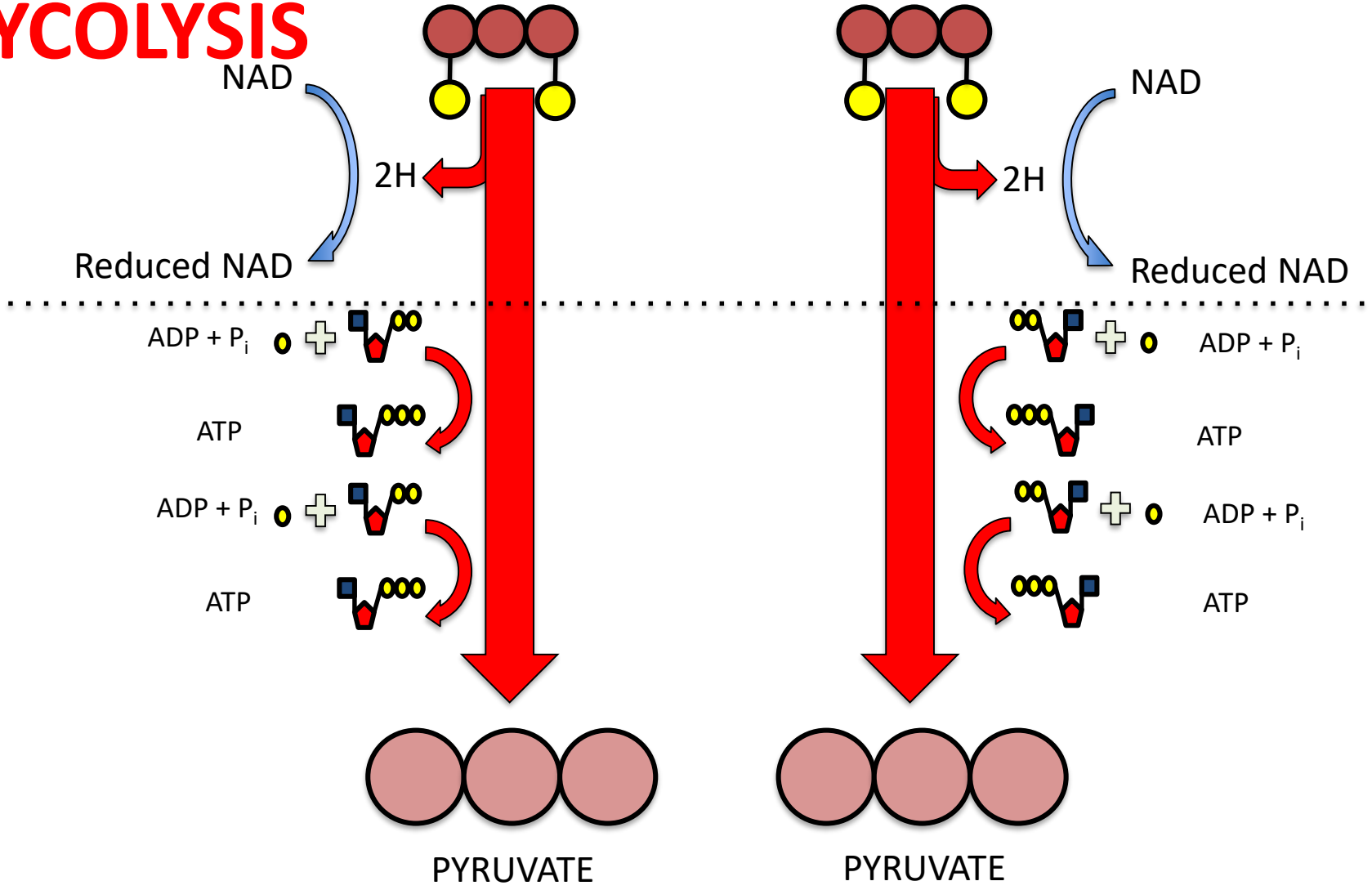
GLYCOLYSIS

Secretly, another P_i is added to each triose phosphate at this stage – donated by the NAD – therefore allowing for the four ADP molecules in step 4.



STEP 3 – Hydrogen is removed (oxidised/dehydrogenation) from each of the Triose Phosphate molecules and transferred to a hydrogen-carrier molecule known as **NAD** to form **reduced NAD** (remember OIL RIG)

GLYCOLYSIS



STEP 4 – Enzyme-controlled reactions convert each triose phosphate into PYRUVATE (also 3-carbon). This process regenerates two molecules of ATP from ADP (ADP formed in step 1, phosphorylation of glucose)

GLYCOLYSIS

Energy Yields

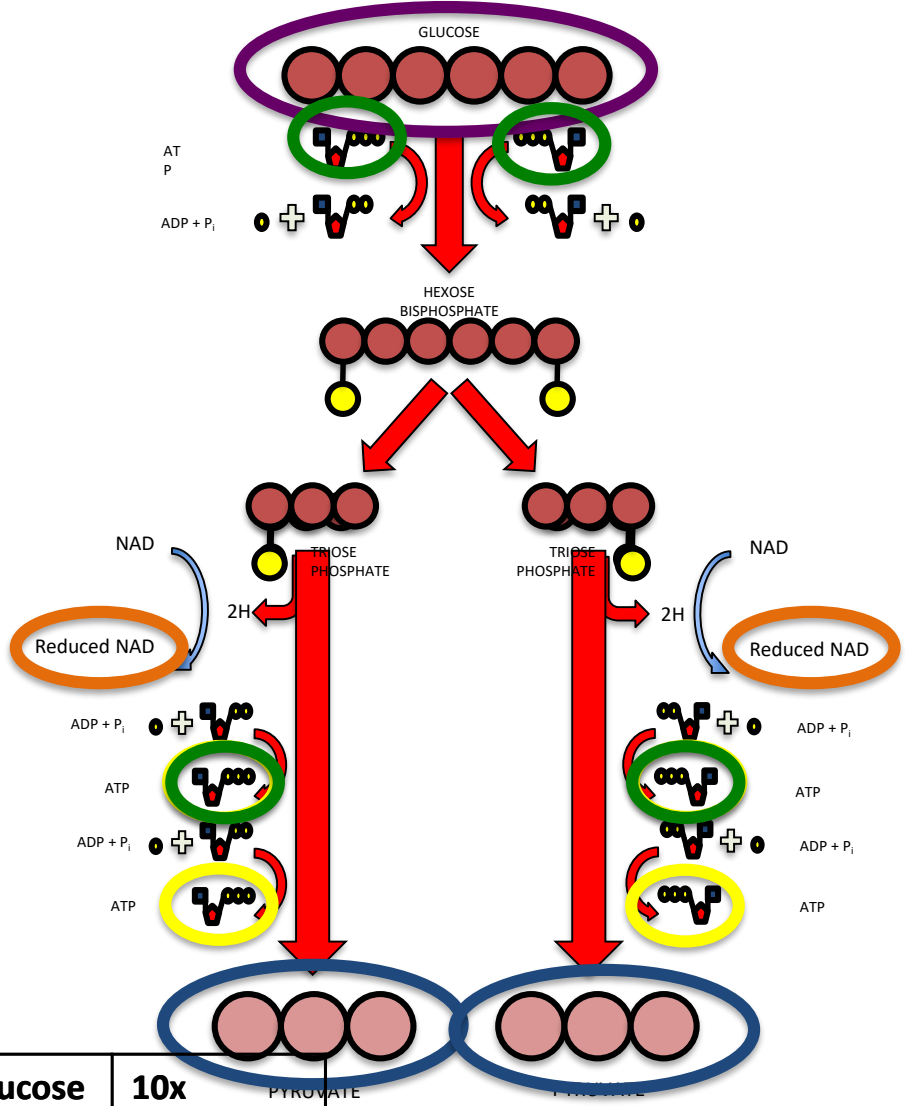
One molecule of Glucose produces:

2 molecules of ATP

4 molecules of ATP are produced, but
2 are used to phosphorylate glucose.

2 molecules of reduced NAD

2 molecules of Pyruvate



Molecule Produced	2x Glucose	4x Glucose	6x Glucose	8x Glucose	10x Glucose
ATP	4	8	12	16	20
Reduced NAD	4	8	12	16	20
Pyruvate	4	8	12	16	20

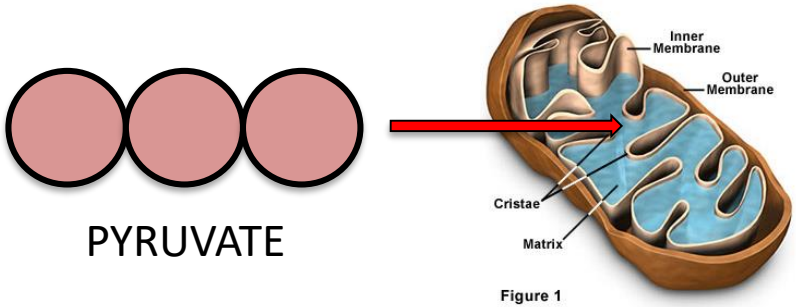
5.2.2 Respiration

Respiration is the process whereby energy stored in complex organic molecules is transferred to ATP. ATP provides the immediate source of energy for biological processes.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(d)	the link reaction and its site in the cell	To include the decarboxylation of pyruvate to acetate, the reduction of NAD, and the combination of acetate with coenzyme A.

LINK REACTION

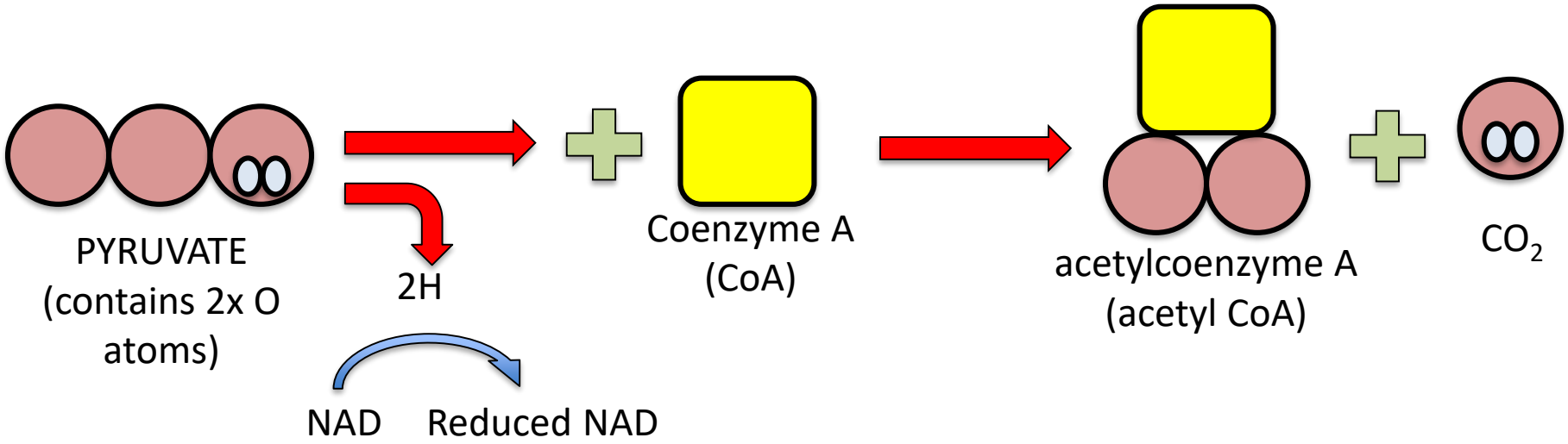
The LINK REACTION serves to **OXIDISE** pyruvate molecules prior to the Krebs Cycle.



PYRUVATE

Figure 1

Pyruvate molecules are actively transported into the MATRIX of mitochondria.



Pyruvate is oxidised by donating a Hydrogen to NAD to form reduced NAD.

Oxidised pyruvate binds with CoA to produce acetyl CoA. This binding releases one carbon atom (**decarboxylation**) and two oxygen atoms from the pyruvate, which form CO_2. It does NOT involve molecular O_2.

To Do:

Answer questions on p. 481 & 483

18.1

Summary questions

1 *Dehydrogenation* – removal of hydrogen from triose phosphate molecules to form pyruvate **and** reduction of NAD / formation of reduced NAD (1); *phosphorylation* – addition of phosphate group to a glucose molecule forming hexose bisphosphate (1); (both) catalysed by enzymes (1).

2 NAD accepts hydrogen (atom) **and** is reduced (1) during the formation of pyruvate (1); supplies hydrogen to enzyme involved in later stage of respiration (1).

3 Addition of phosphate group (1); to ADP (1); or formation of ATP (using phosphate) from another molecule (1).

4 *Dehydrogenation* – hydrogen removed in breakdown of glucose (1); hydrogen required at a later stage (1). *Phosphorylation* – addition of phosphate groups destabilises (large) molecules/glucose (1); leads to breakdown of glucose (1); and synthesis of ATP (1).

18.2

Summary questions

1 Hydrogen is also removed (1); removal of hydrogen oxidises pyruvate (1).

2 Acetyl group (1); carbon dioxide (1)

3 Pyruvate (1); acetyl CoA (1); reduced NAD (1);

4 Enzymes required are in cytoplasm/ORA (1); glucose molecule too large to move into mitochondrion (1); no transport proteins for pyruvate (1); mitochondria not originally present in (eukaryotic) cells (1).

5.2.2 Respiration

Respiration is the process whereby energy stored in complex organic molecules is transferred to ATP. ATP provides the immediate source of energy for biological processes.

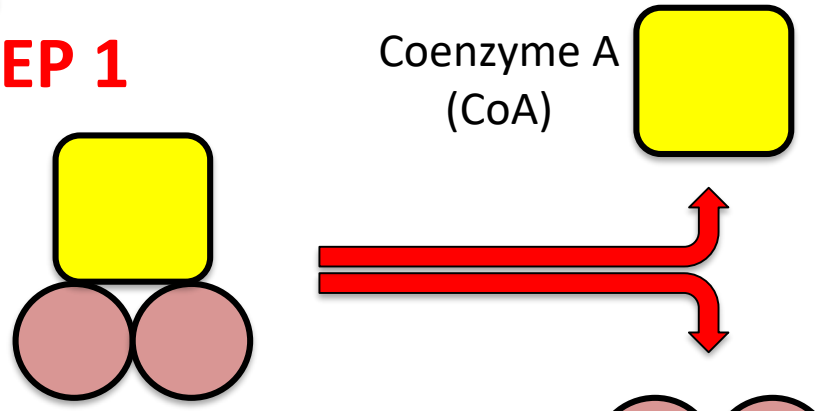
	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(e)	the process and site of the Krebs cycle	To include the formation of citrate from acetate and oxaloacetate and the reconversion of citrate to oxaloacetate (names of intermediate compounds are not required) **AND** the importance of decarboxylation, dehydrogenation, the reduction of NAD and FAD, and substrate level phosphorylation.

KREBS CYCLE

A series of oxidation-reduction reactions that produce a small amount of ATP and lots of reduced **COENZYMES**, such as NAD and FAD.

(COENZYMES: Molecules that are required by some enzymes in order to function. They carry hydrogen atoms from one molecules to another)

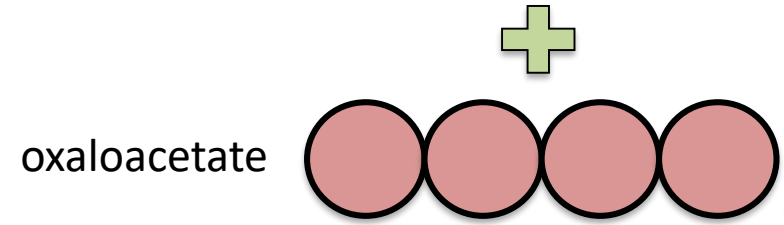
STEP 1

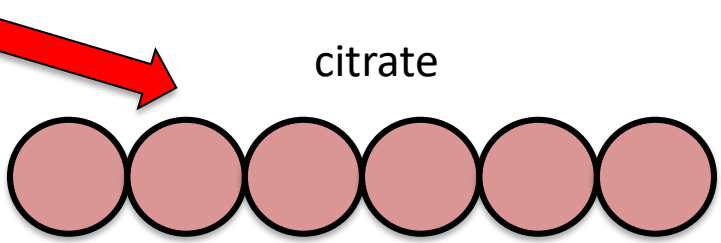


The 2-carbon acetyl coenzyme A separates into the coenzyme A and a 2-carbon molecule (called an acetyl group). CoA is reused in the Link Reaction.

acetylcoenzyme A
(acetyl CoA)

acetyl group





The acetyl group binds with a 4-carbon molecule (**OXALOACETATE**)to form a 6-carbon molecule (**CITRATE**).

KREBS CYCLE

STEP 2

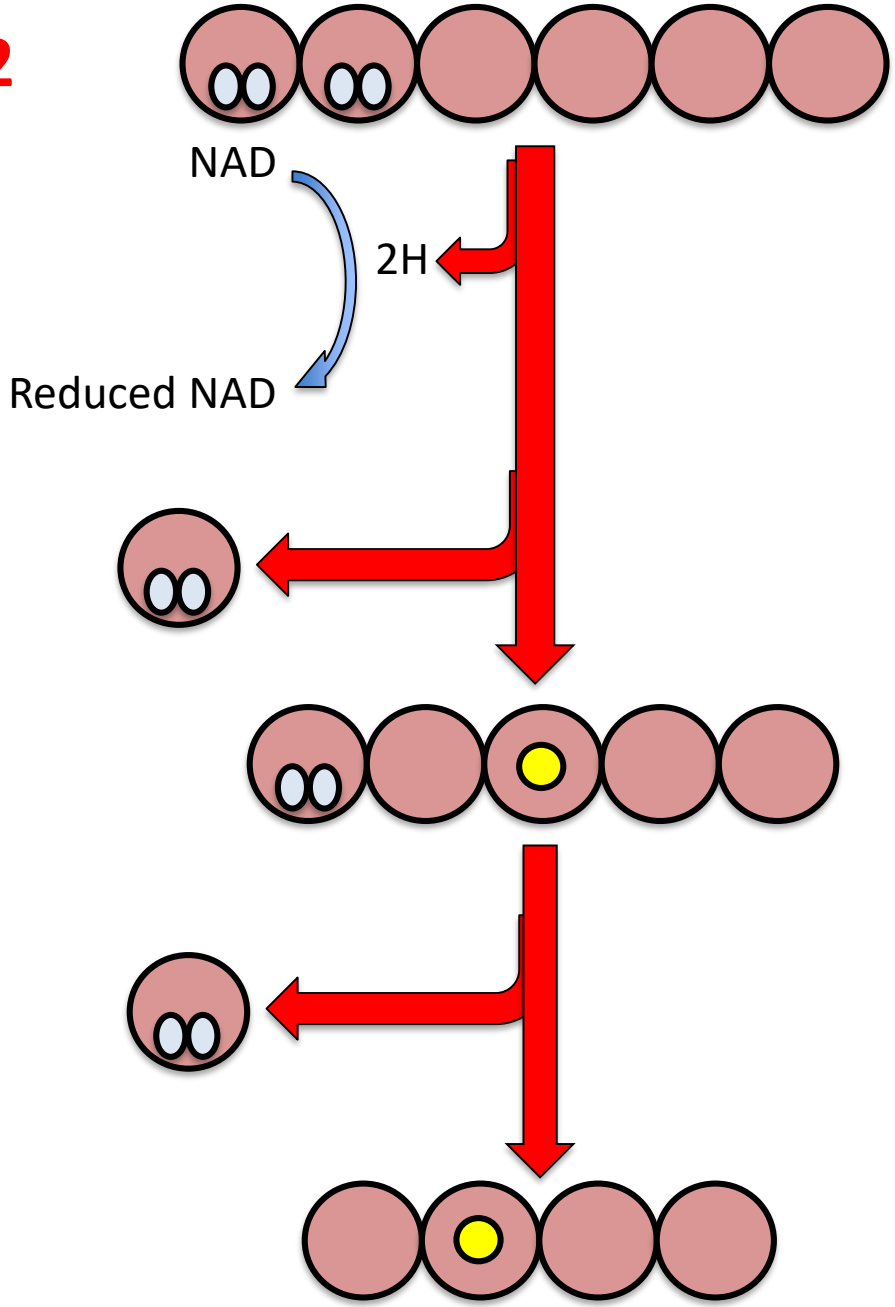
The Citrate contains oxygen atoms.
It is oxidised by passing H atoms to NAD, forming reduced NAD.

The NAD contributes a 'secret' phosphate to Citrate.

One carbon atom and two oxygen atoms are lost from the 6-carbon Citrate in the form of CO_2, leaving a 5-carbon molecule.

The 5-carbon molecule then loses a molecule of CO_2 to leave a 4-carbon oxaloacetate molecule.

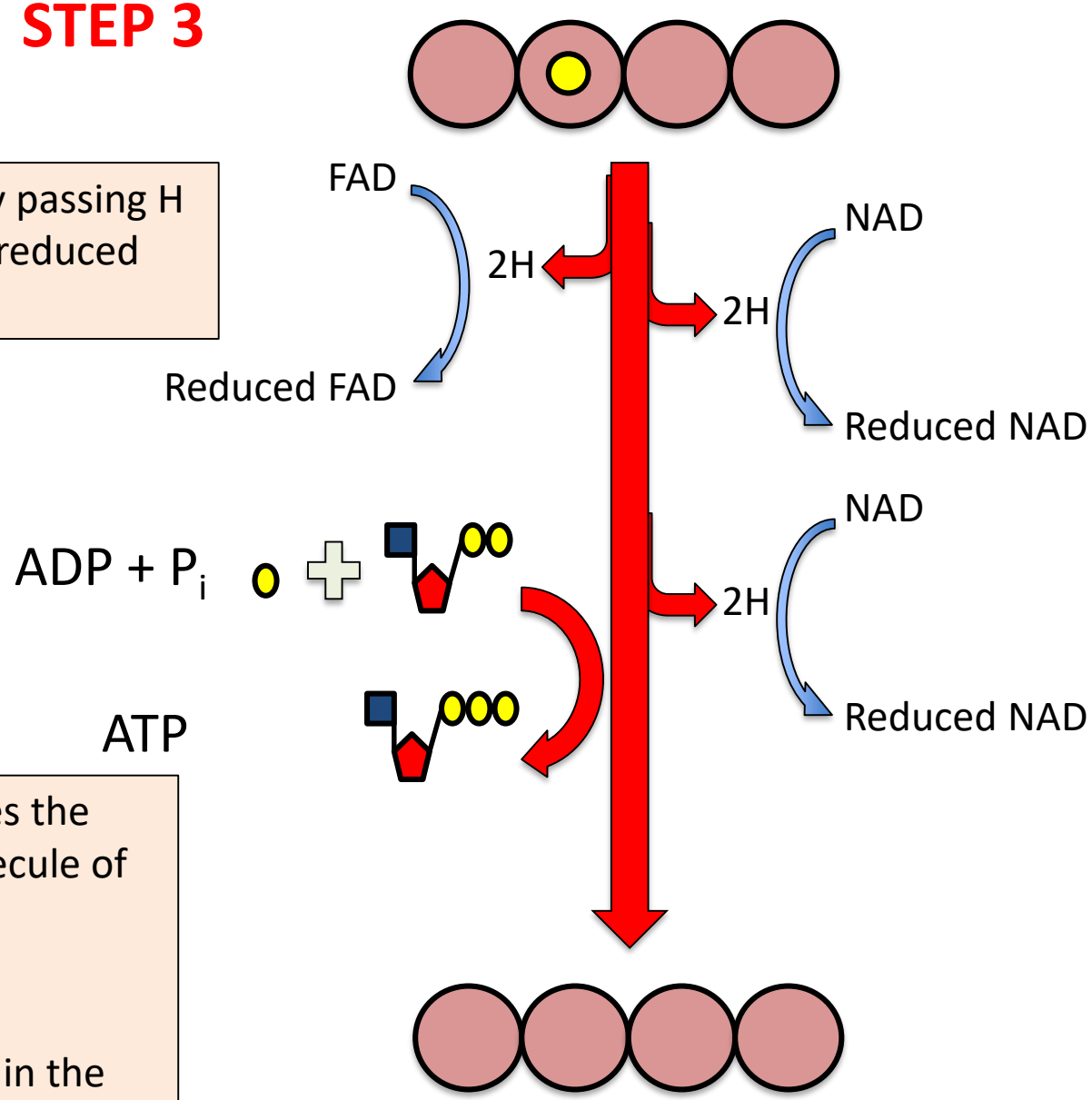
Note how no molecular oxygen has been used; the oxygen has been provided by the carbon molecule derived from acetyl CoA.



KREBS CYCLE

STEP 3

The oxaloacetate is oxidised by passing H atoms to FAD & NAD, forming reduced FAD & NAD

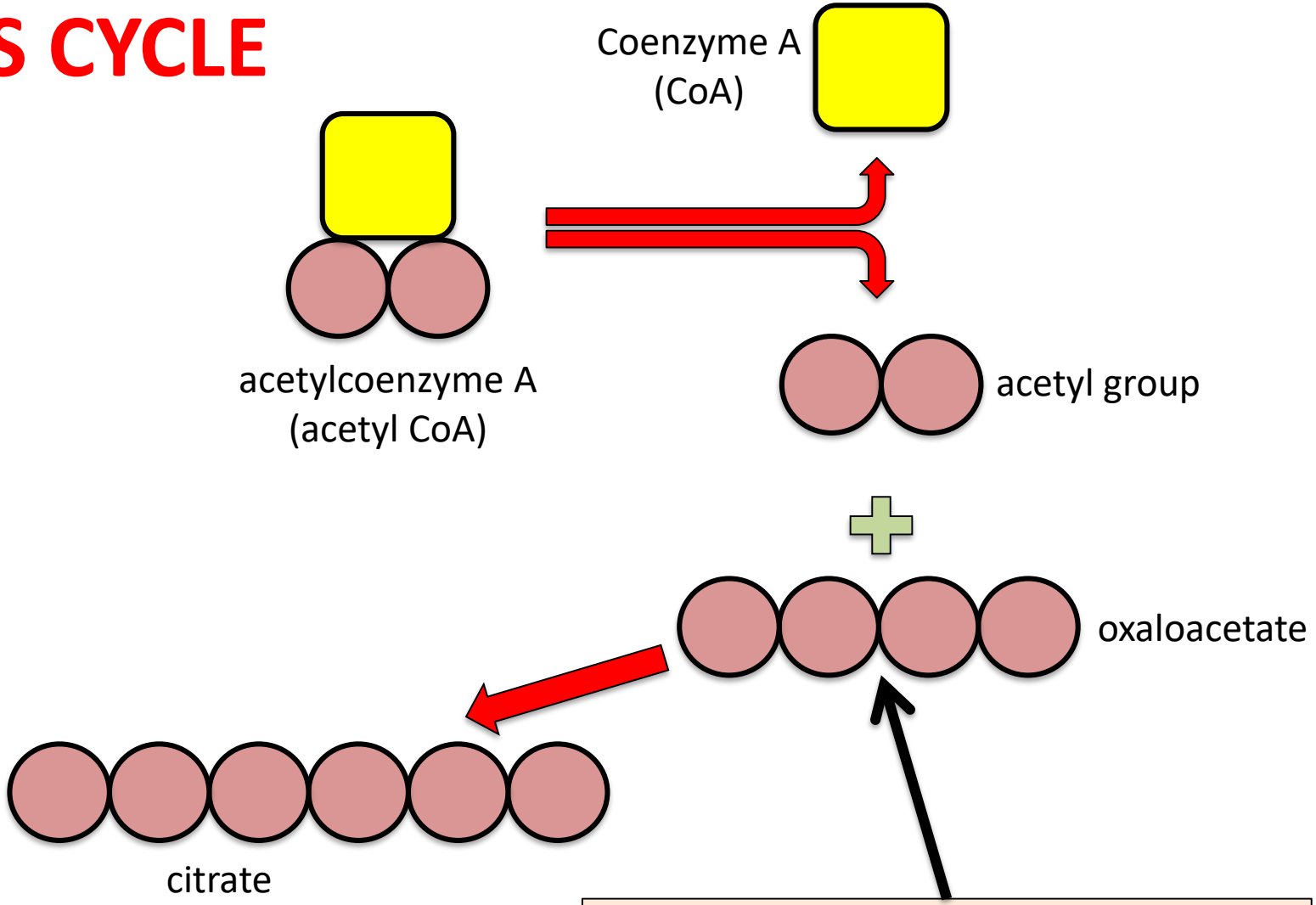


The oxaloacetate then contributes the phosphate to ADP to form a molecule of ATP.

This is **SUBSTRATE-LEVEL PHOSPHORYLATION** (mentioned in the ATP lesson), as the 4-carbon oxaloacetate is the substrate that contributes the P_i.

KREBS CYCLE

STEP 4



The 4-carbon oxaloacetate molecule is then free to bind with the 2-carbon acetyl group at the start of the Krebs Cycle and go round again.

KREBS CYCLE

Net gains from one molecule of acetyl CoA (Krebs Cycle):

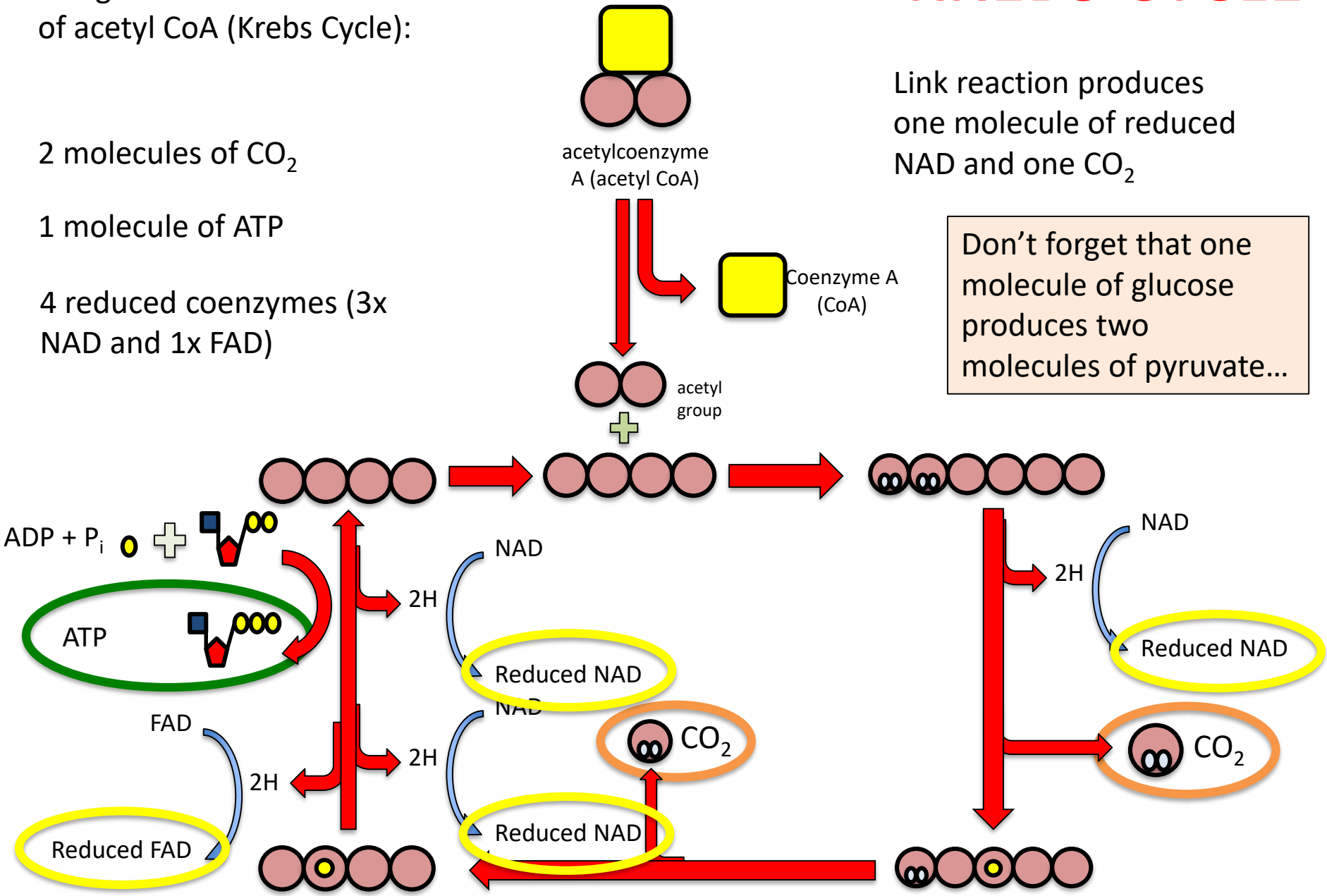
2 molecules of CO_2

1 molecule of ATP

4 reduced coenzymes (3x NAD and 1x FAD)

Link reaction produces one molecule of reduced NAD and one CO_2

Don't forget that one molecule of glucose produces two molecules of pyruvate…



IMPORTANT!!

You may sometimes see reduced NAD/FAD written as NADH or $FADH_2$.

THEY ARE THE SAME THING!!

The Link Reaction and Krebs Cycle do not produce much ATP.

What they do produce is lots of reduced coenzymes, which carry H atoms which are used to produce lots of ATP molecules in the **ELECTRON TRANSPORT CHAIN**.

5.2.2 Respiration

Respiration is the process whereby energy stored in complex organic molecules is transferred to ATP. ATP provides the immediate source of energy for biological processes.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(f)	the importance of coenzymes in cellular respiration	With reference to NAD, FAD and coenzyme A.
(g)	the process and site of oxidative phosphorylation	To include the roles of electron carriers, oxygen and the mitochondrial cristae.
(h)	the chemiosmotic theory	To include the electron transport chain, proton gradients and ATP synthase in oxidative phosphorylation and photophosphorylation.

ELECTRON TRANSPORT CHAIN.

The mechanism by which the energy in the hydrogen atoms, carried by coenzymes, is converted into ATP. This process occurs on the folded inner membrane of the mitochondria – the CRISTAE.

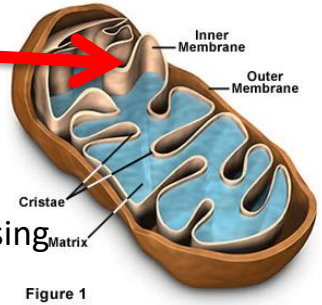
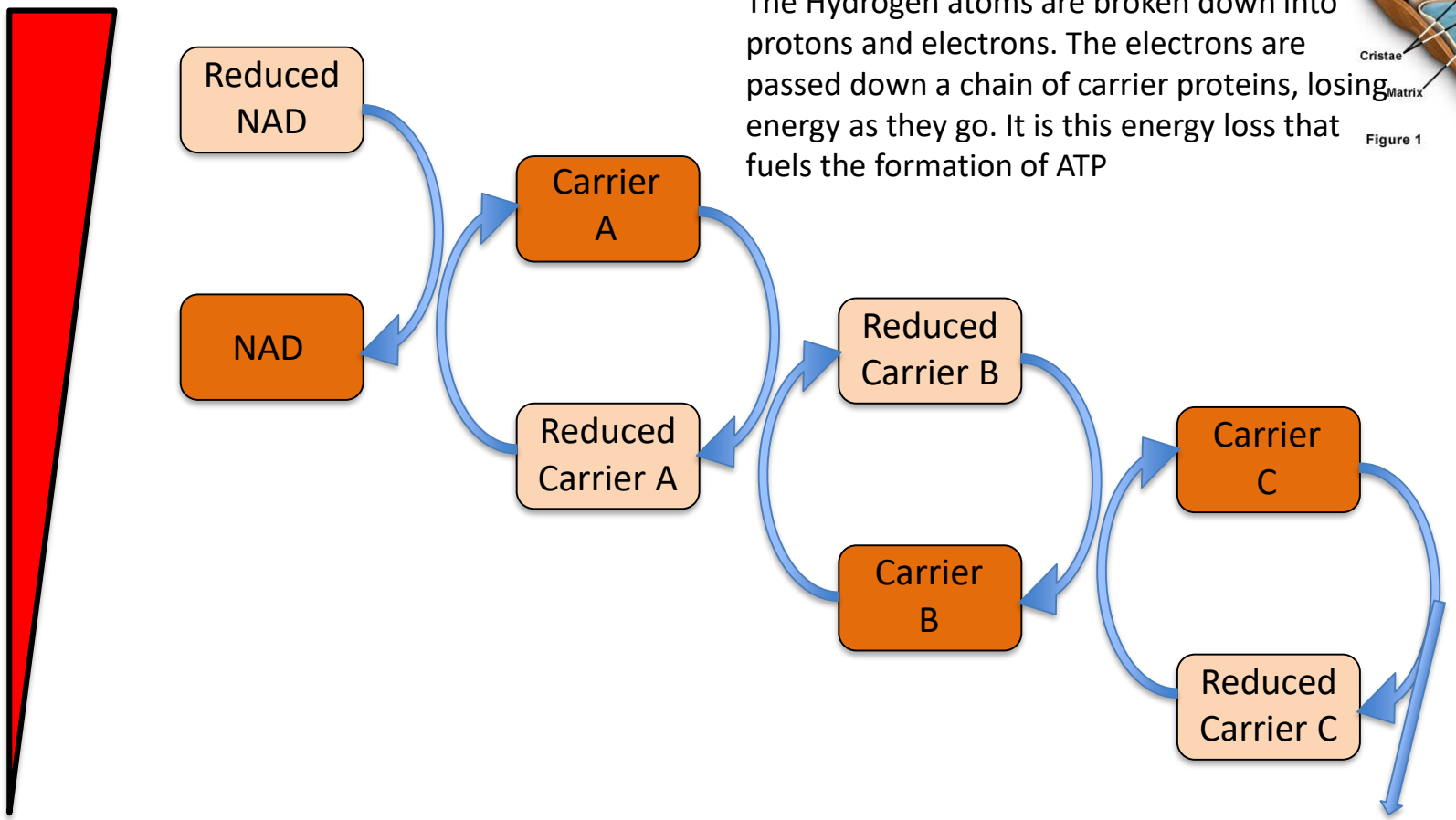


Figure 1

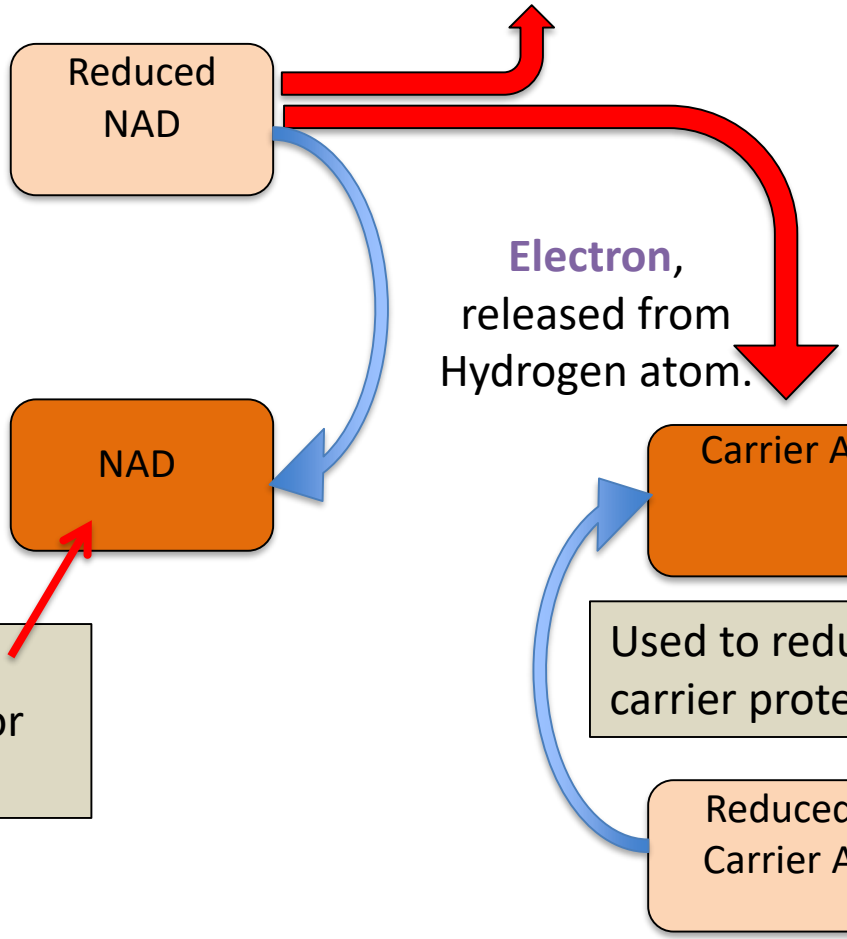
The Hydrogen atoms are broken down into protons and electrons. The electrons are passed down a chain of carrier proteins, losing energy as they go. It is this energy loss that fuels the formation of ATP



ELECTRON TRANSPORT CHAIN. Step 1

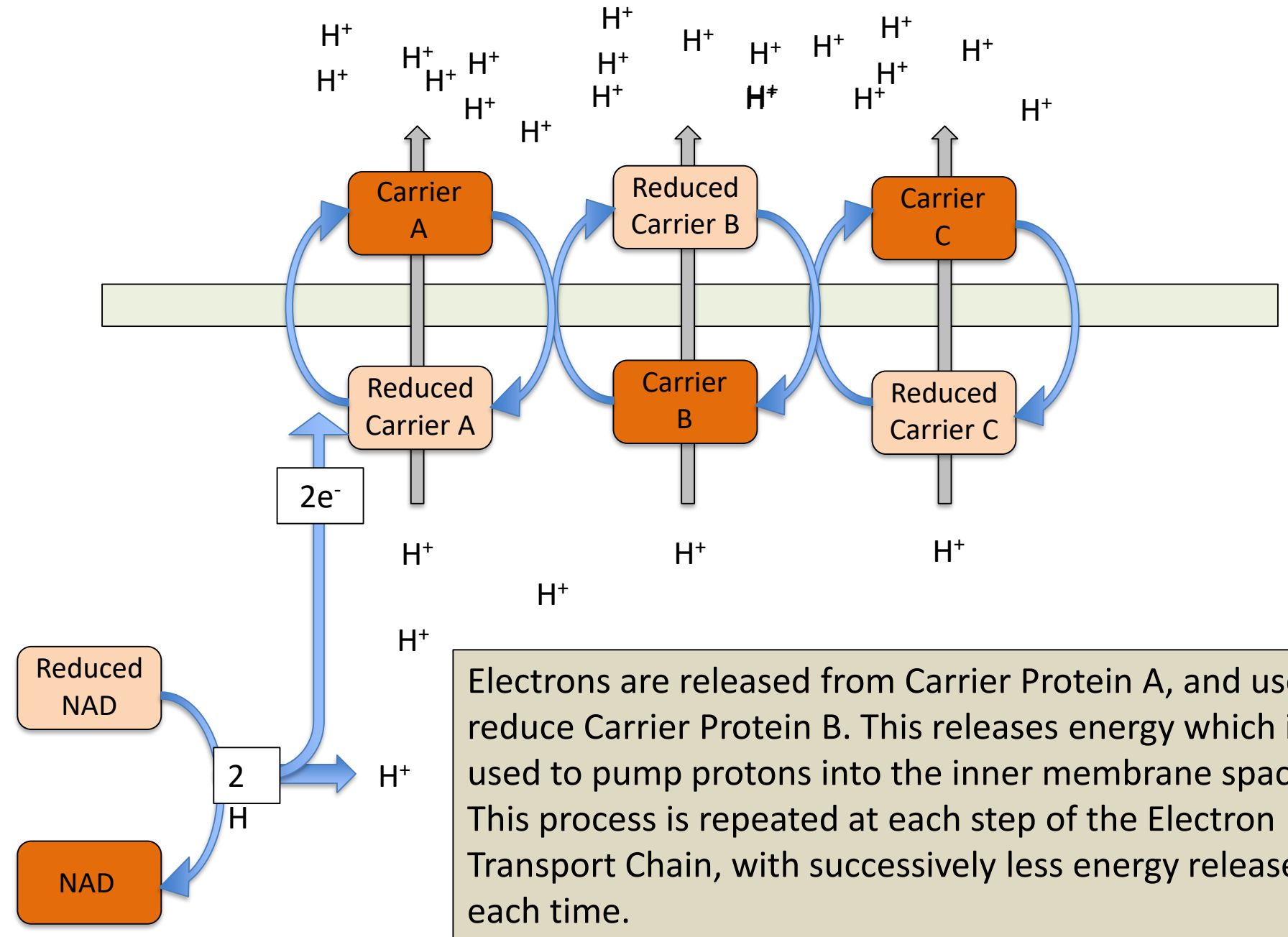
Actively Transported across the inner membrane of the mitochondria by the carrier proteins

Proton, released from Hydrogen atom.



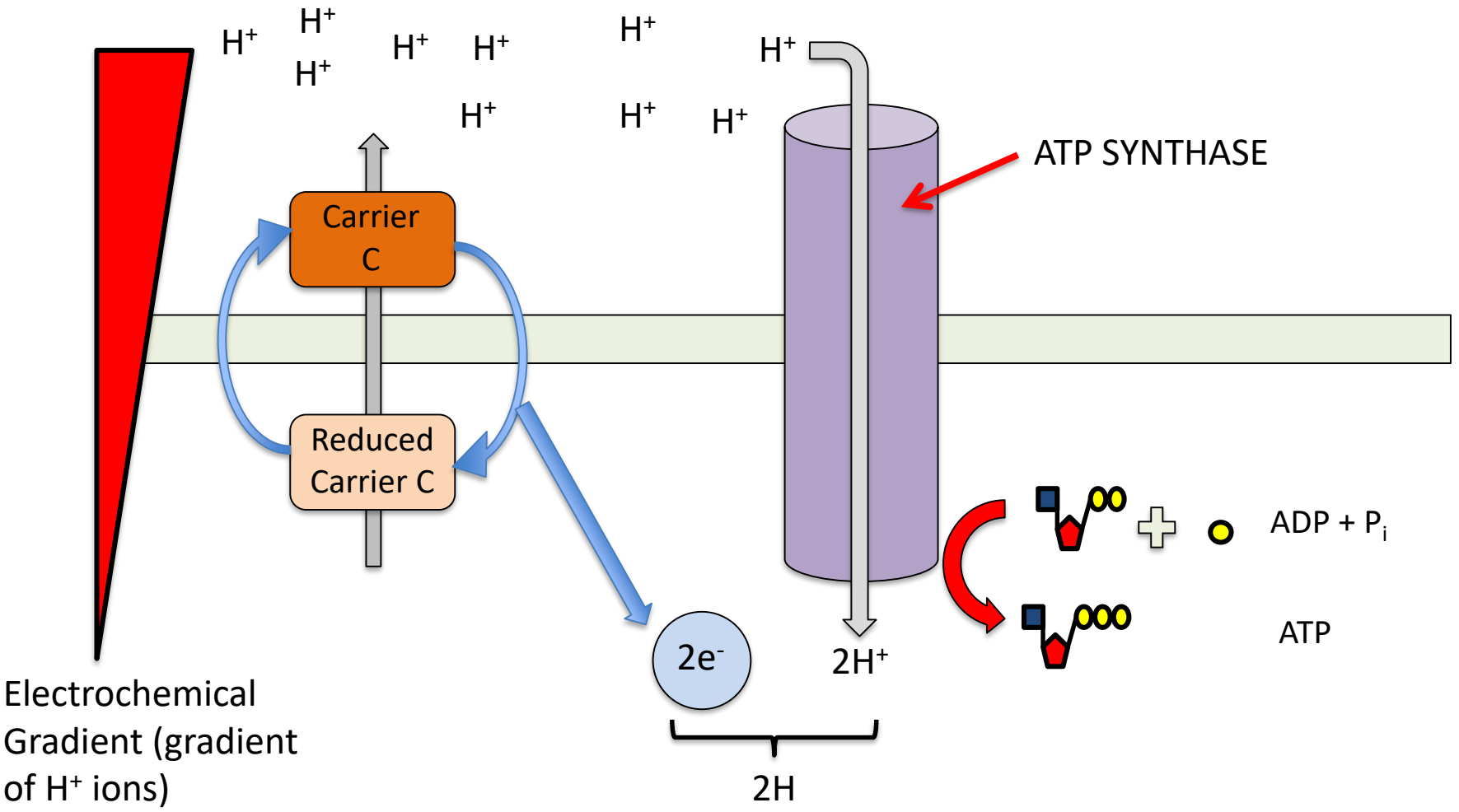
Energy is lost each time the electron is moved from one carrier protein to the next.
This energy is used to pump the protons into the inner membrane space.

ELECTRON TRANSPORT CHAIN. Step 2.



Electrons are released from Carrier Protein A, and used to reduce Carrier Protein B. This releases energy which is used to pump protons into the inner membrane space This process is repeated at each step of the Electron Transport Chain, with successively less energy released each time.

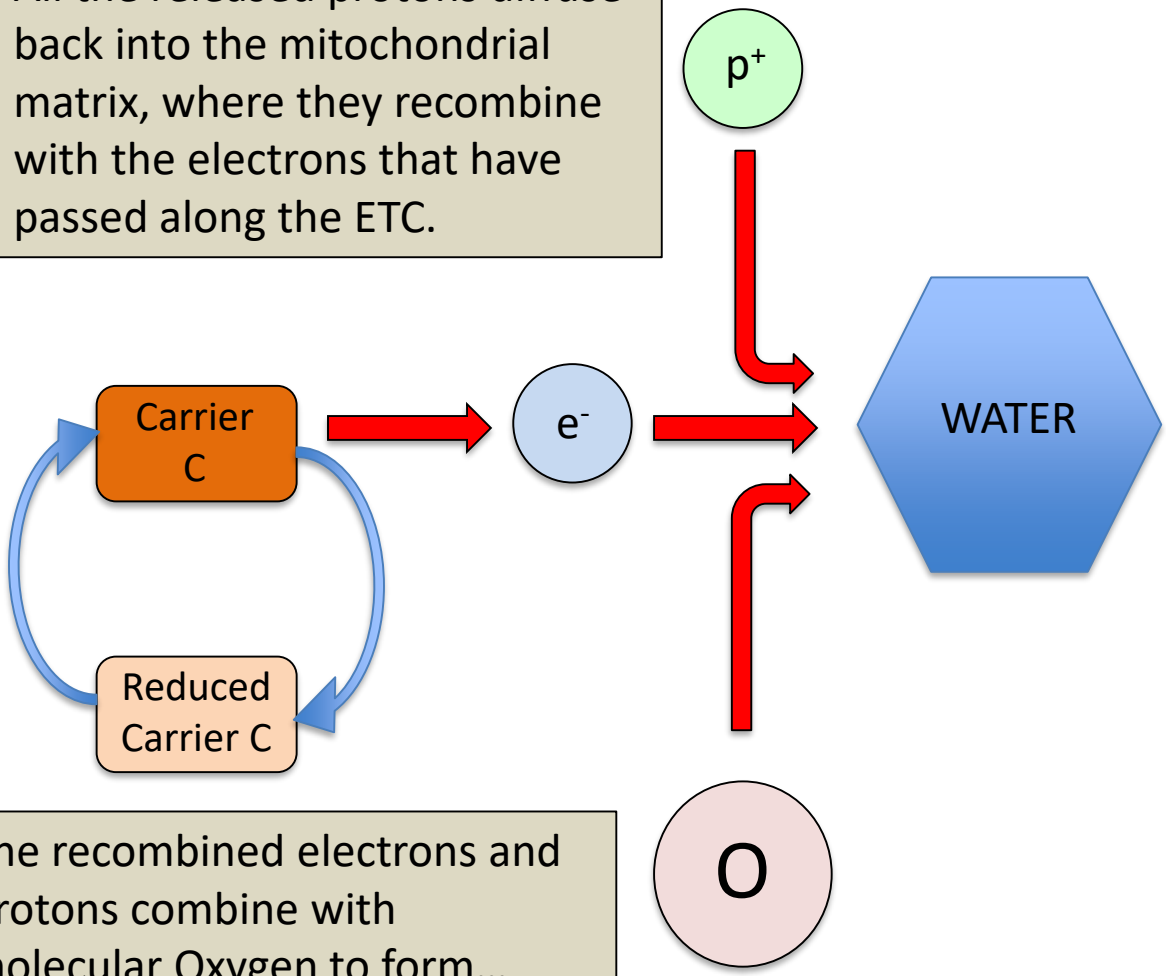
ELECTRON TRANSPORT CHAIN. Step 3.



Pumping the hydrogen protons into the inner membrane space creates an electrochemical gradient. These protons return to the matrix via the ATP Synthase, which drives the synthesis of ATP. The returned protons recombine with the electrons released from the ETC to make hydrogen.

ELECTRON TRANSPORT CHAIN. Step 4.

All the released protons diffuse back into the mitochondrial matrix, where they recombine with the electrons that have passed along the ETC.



The recombined electrons and protons combine with molecular Oxygen to form…

Oxygen is the final acceptor of electrons in the electron transport chain.

Because oxygen accepts the hydrogen atoms at the end of respiration, it prevents a 'back-up' of electrons and protons earlier in the chain.

The cell is able to detect the presence of oxygen and allows aerobic respiration to occur.
In its absence, the cell will undergo anaerobic respiration.

To Do:

Answer questions on p. 485 & 487

18.3

Summary questions

1 *ATP* – three phosphate groups (1); one ribose (1); one nitrogenous base (1); *NAD* – two phosphate groups (1); two riboses (1); two nitrogenous bases (1) (max 3 comparisons)

2 Idea that it is used to link reactions (1); idea that energy is released as a result of the activity of one enzyme and used by another enzyme (1).

3 Students answers may vary but must include: glucose to triose phosphate (1); triose phosphate to pyruvate (1); addition of two ATP (1); production of four ATP **and** two reduced NAD (1) (2 max).

4 One per turn (1) two in total (1).

5 Hydrogen needs to be removed for cycle to continue (1); hydrogen removed using NAD/FAD and reduced (1), then NAD/FAD are oxidised at electron transport chain (1); oxygen required for electron transport (1).

6 Enzymes are specific (1); active site complementary to substrate (1); different steps have different substrates (1); different steps require different enzymes (1); different enzymes (may) require different coenzymes (1); only one step in cycle has enzyme which requires FAD coenzyme (1).

18.4

Summary questions

1 Actively pumped to increase concentration gradient (1); energy required as moving from low to high concentration (1); membrane impermeable to ions so ions diffuse down concentration gradient (1); ATP synthase provides hydrophilic channel (1).

2 Reduced NAD releases electrons to carriers at the start of the ETC (1); reduced FAD releases electrons to carriers after the start of the ETC (1); with FAD electrons transported a shorter distance (1); so fewer protons are actively transported (1).

3 Stops flow of electrons (1); stops active transport of protons (1); proton gradient not formed (1); (less) ATP synthesised; so less energy available for (vital) metabolic processes (1).

4 *ATP synthase is not actually part of the electron transport chain* – agree (1); not an electron carrier (1).

Oxygen is required for the transfer of electrons along the electron transport chain – agree (1); oxygen is final electron acceptor, required for electron transport (1) *Hydrogen ions return to the matrix by facilitated diffusion* – agree (1); diffuse through hydrophilic channels (of ATP synthase) (1).

ANAEROBIC RESPIRATION