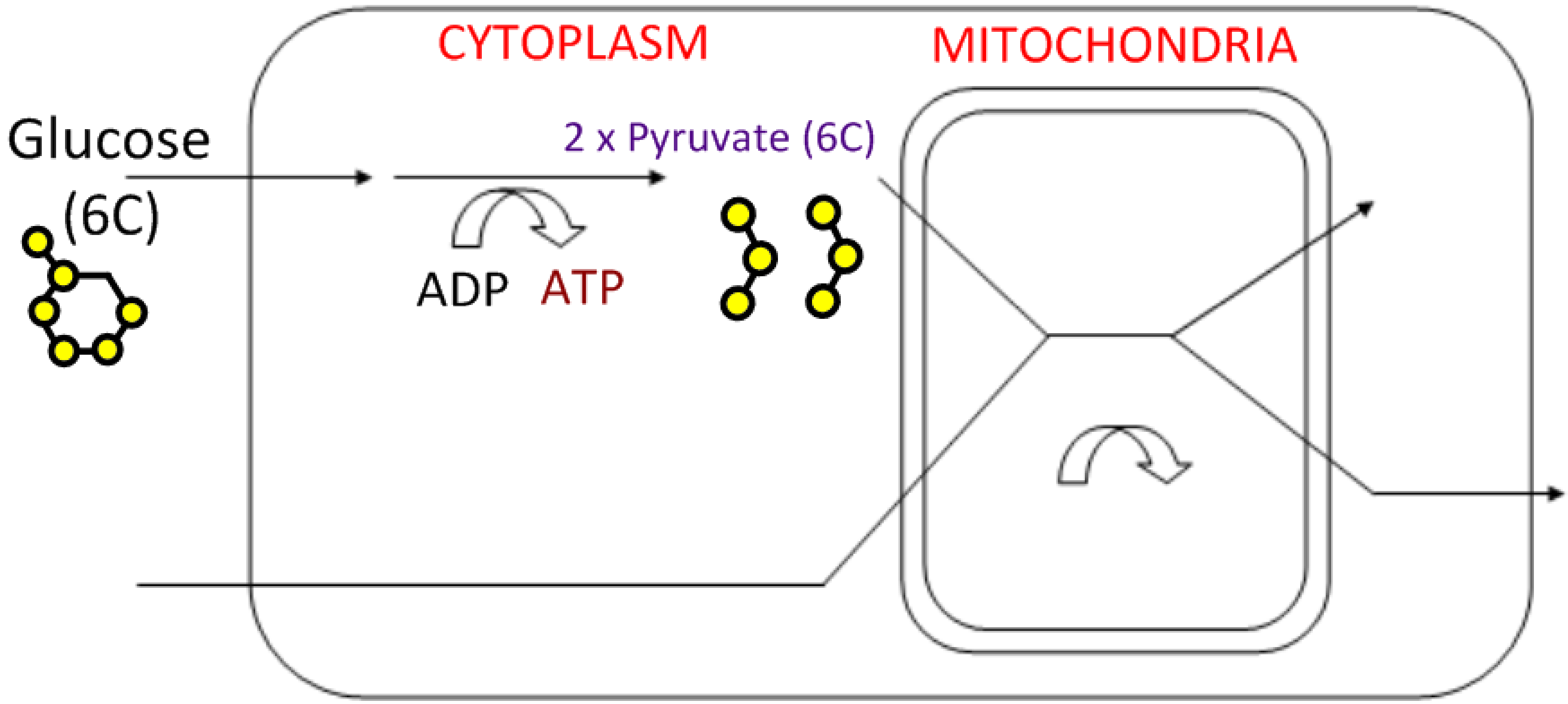
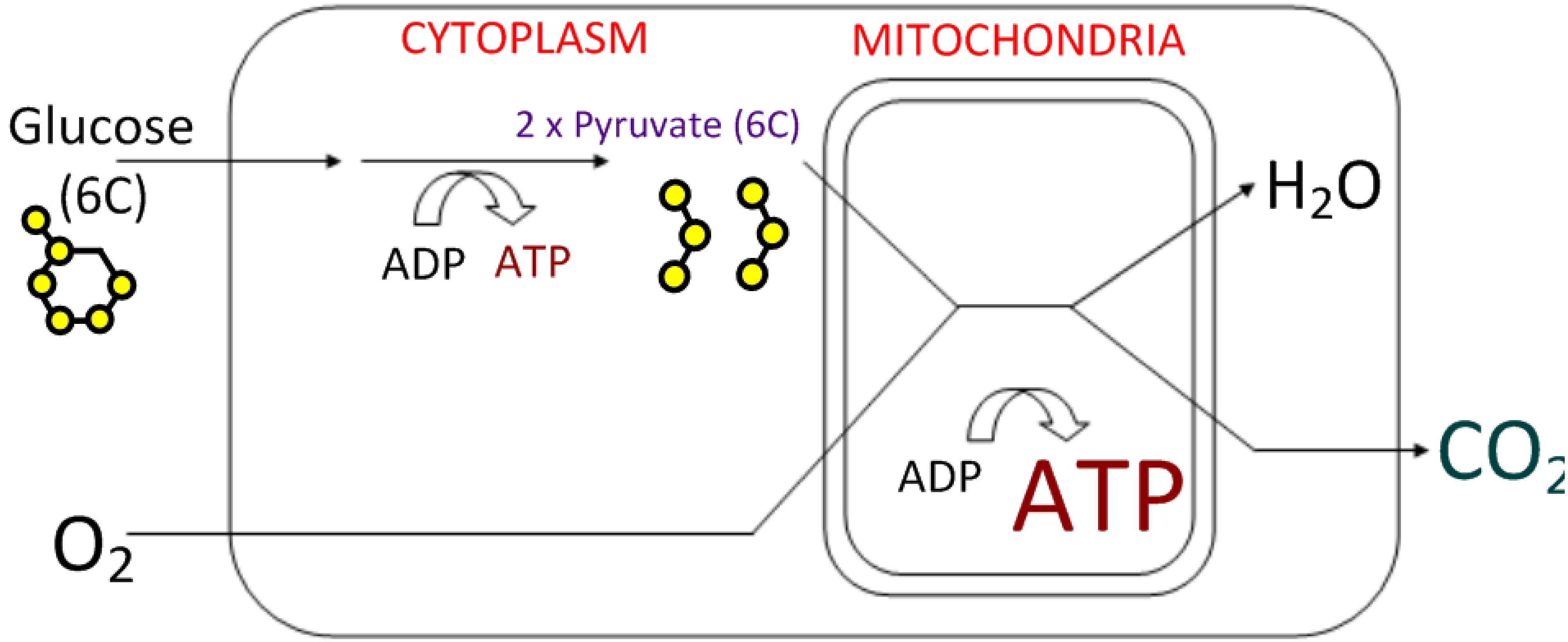
Aerobic vs. Anaerobic Respiration

Glucose is a 6-carbon organic compound which is split into two pyruvate molecules in cytoplasm, with a small yield of ATP.



Aerobic respiration occurs in the presence of oxygen.
Reactions continue in the mitochondria.

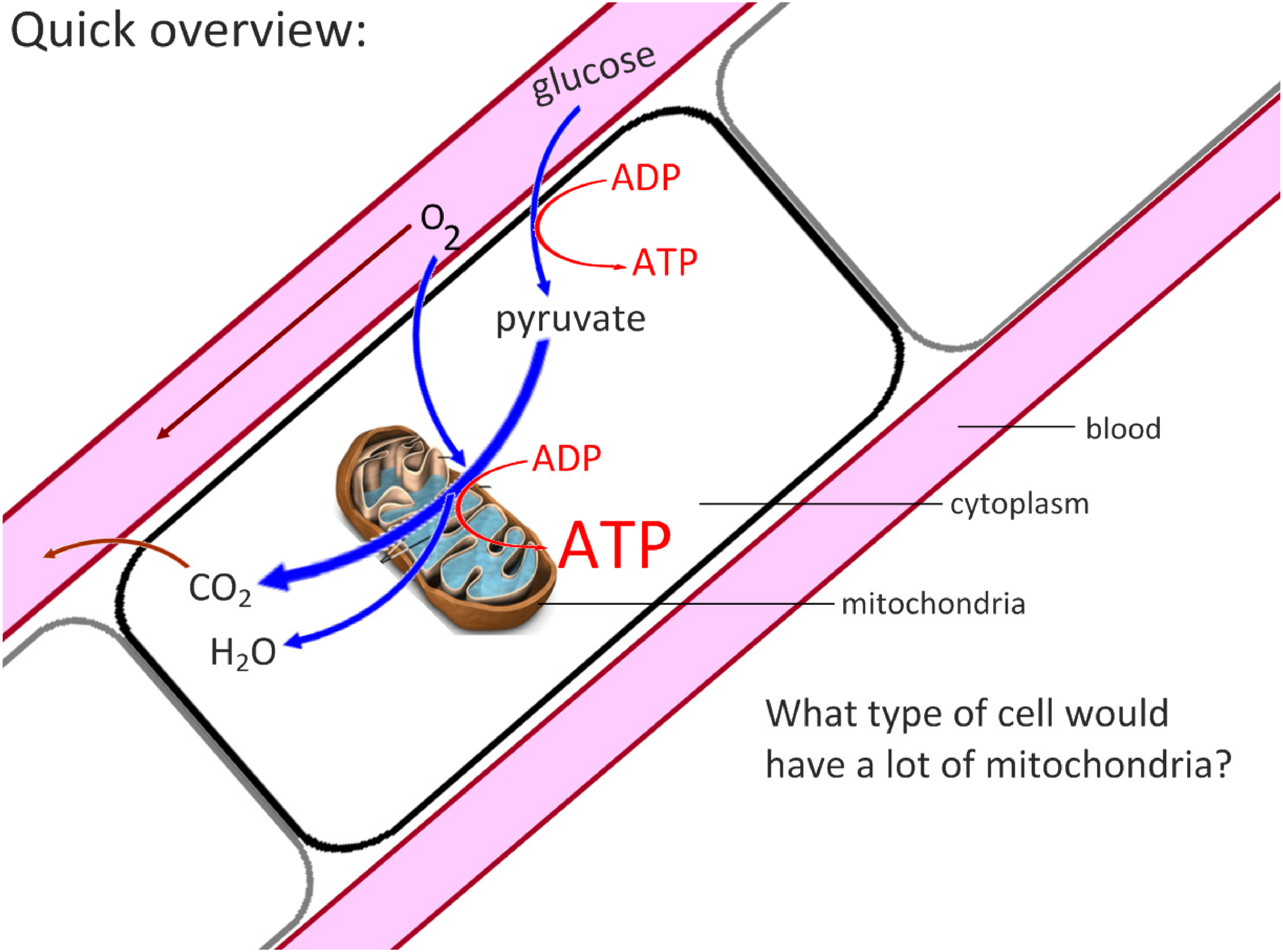


A large yield of ATP is given.

Water is a waste product recycled in the cell.

CO_2 is excreted through gas exchange.

Quick overview:



What type of cell would have a lot of mitochondria?

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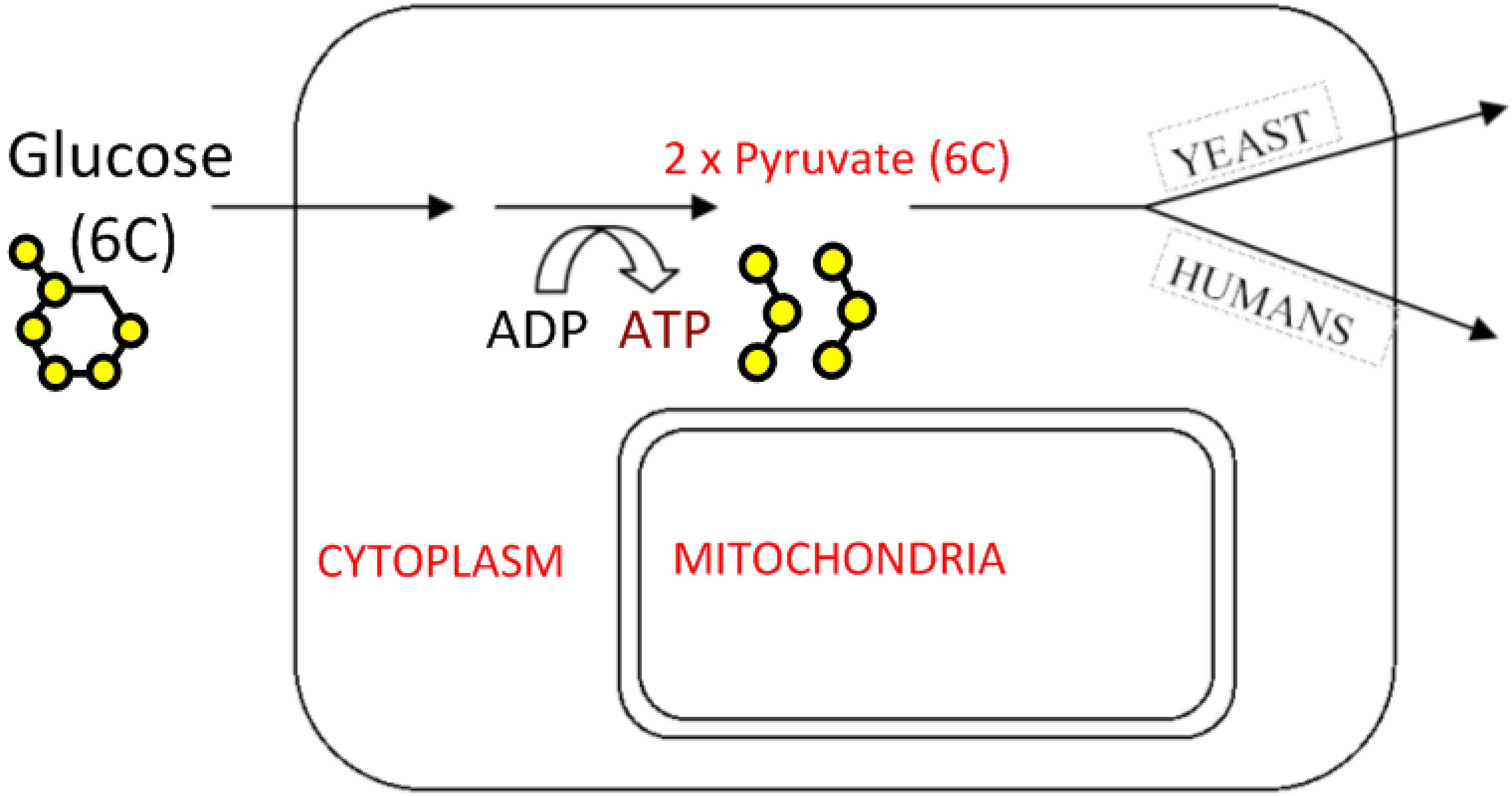
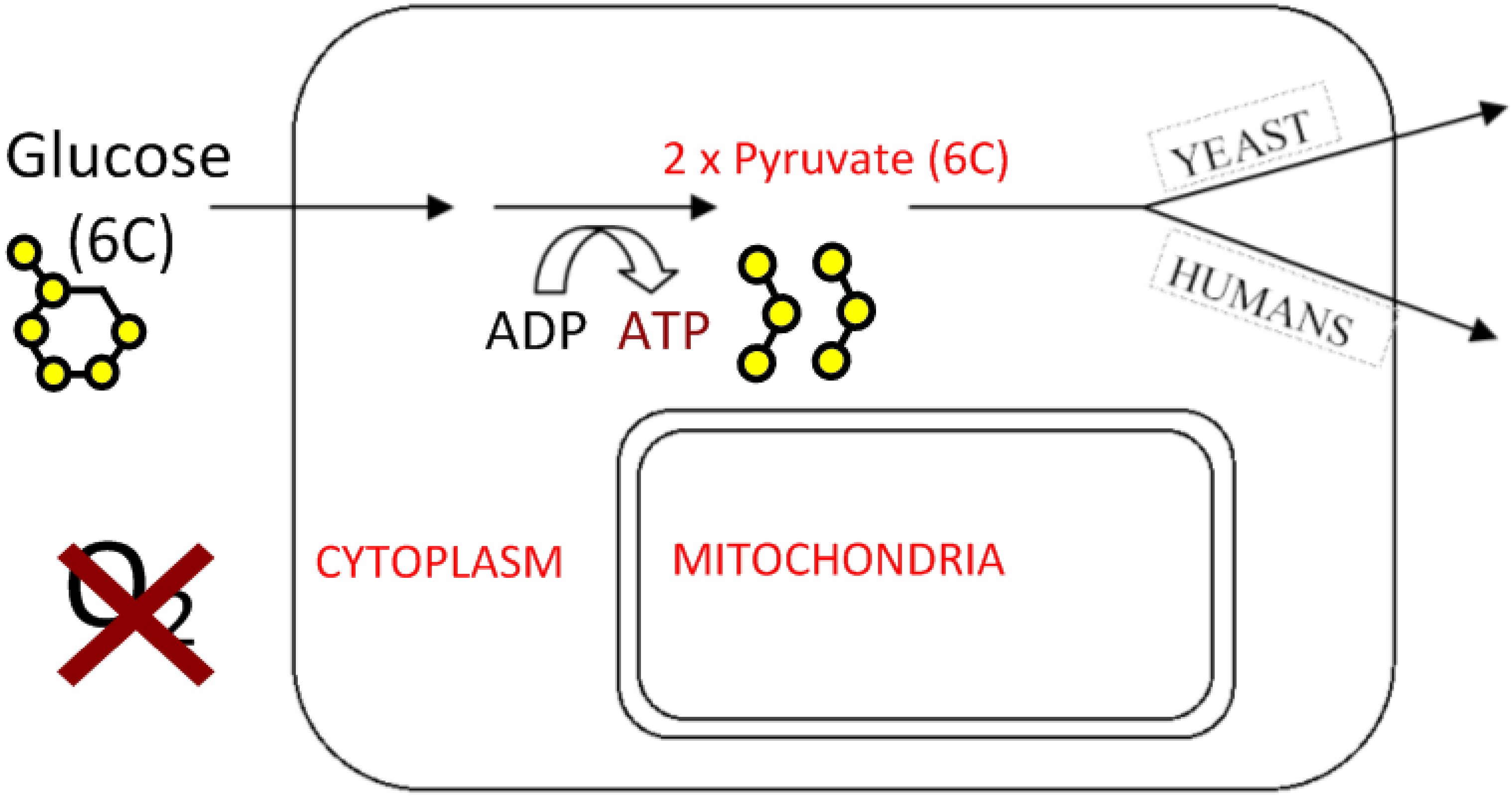
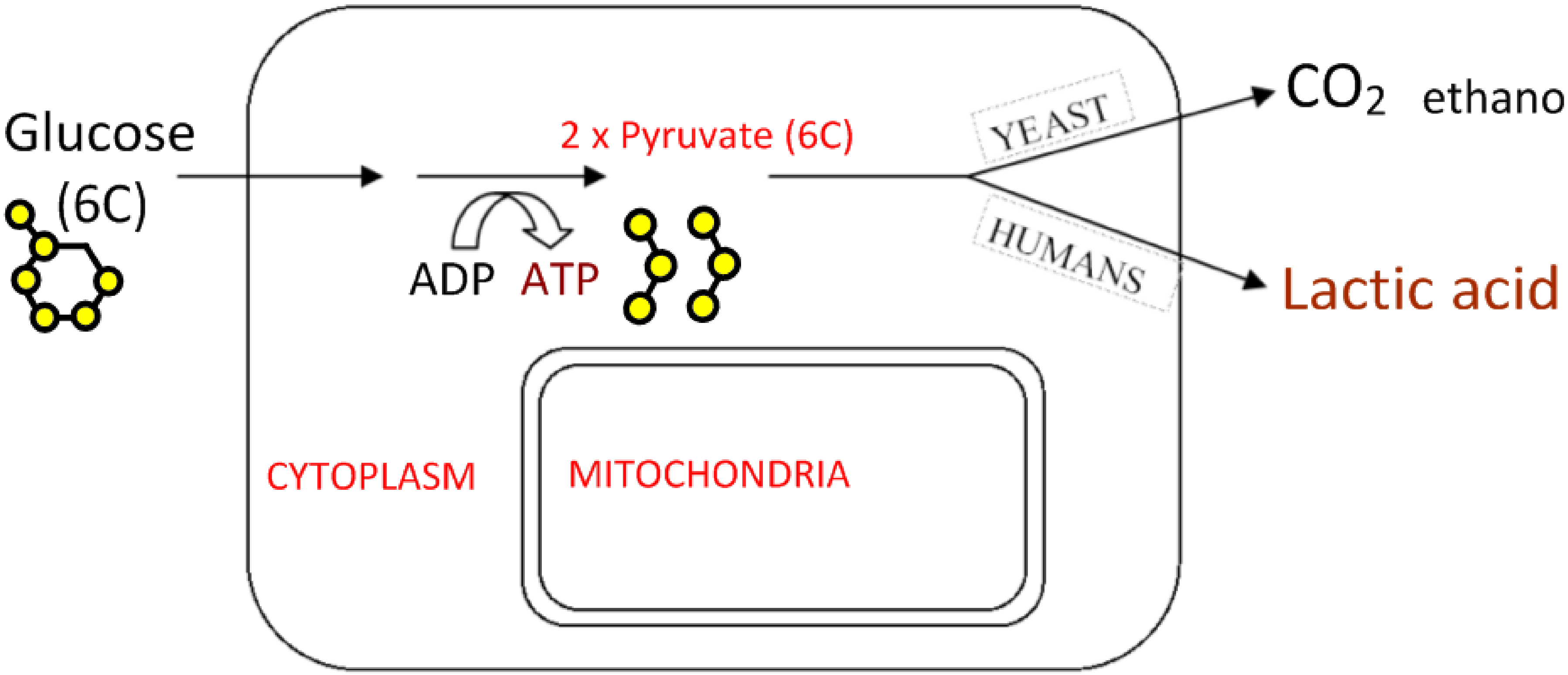


Anaerobic respiration occurs in the absence of oxygen.

Reactions do not continue in the mitochondria.

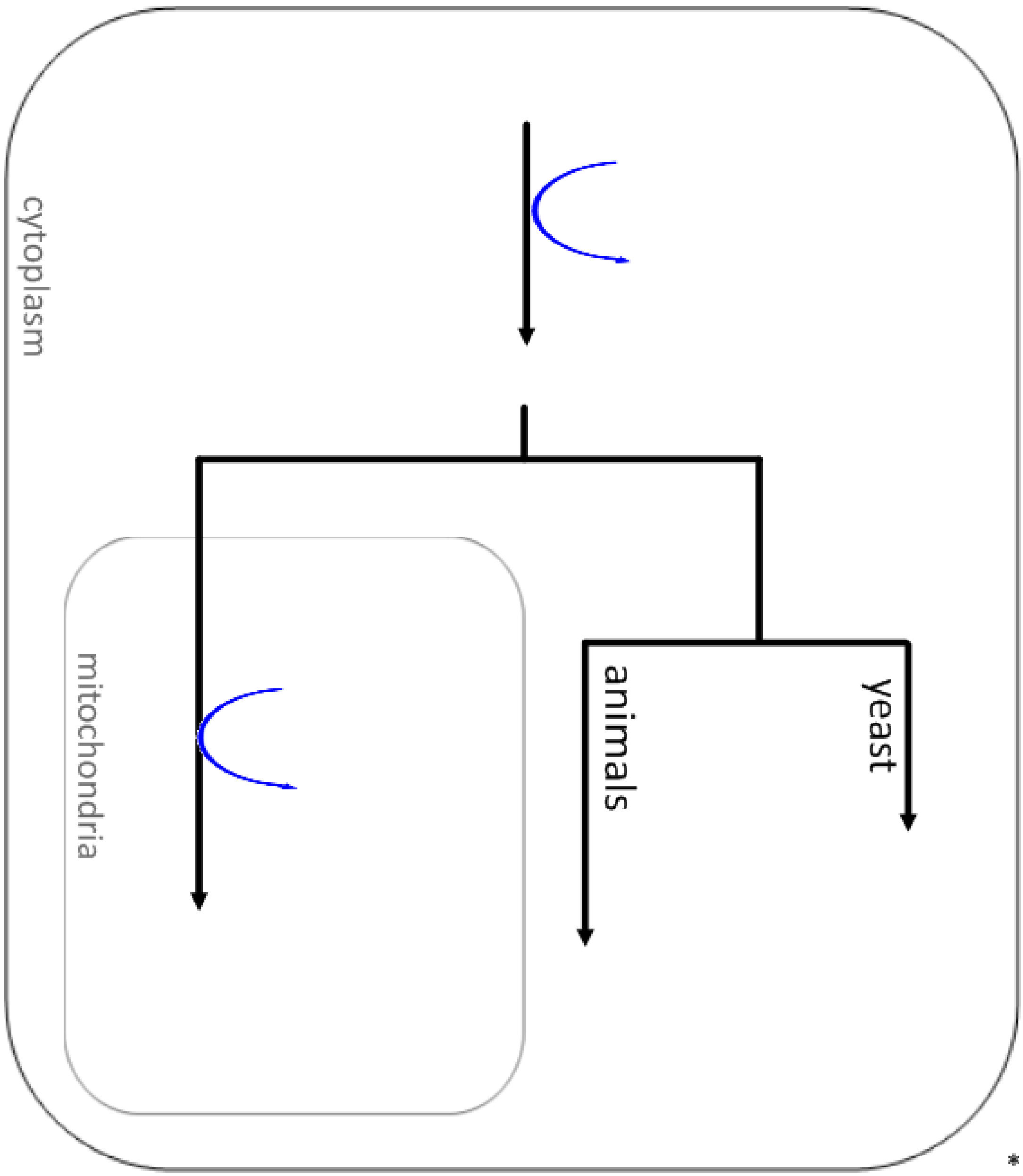


Anaerobic respiration occurs in the absence of oxygen.
Reactions do not continue in the mitochondria.

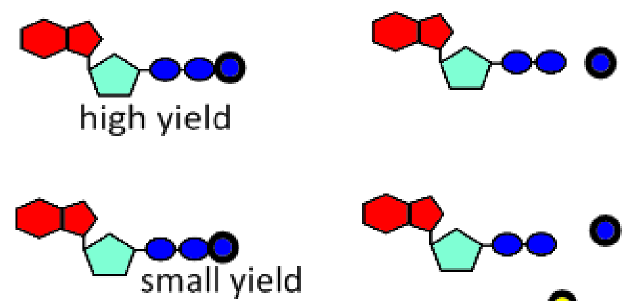


Carbon dioxide and ethanol are produced in yeast (fermentation).
Lactic acid (lactate) is produced in humans and other animals.

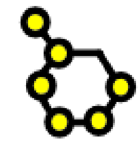
The overall yield of ATP is very low.



Drag 'n' Drop*

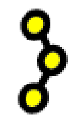


2 x Pyruvate



Glucose

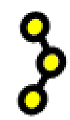
no O_2



O_2

ethanol

lactic acid



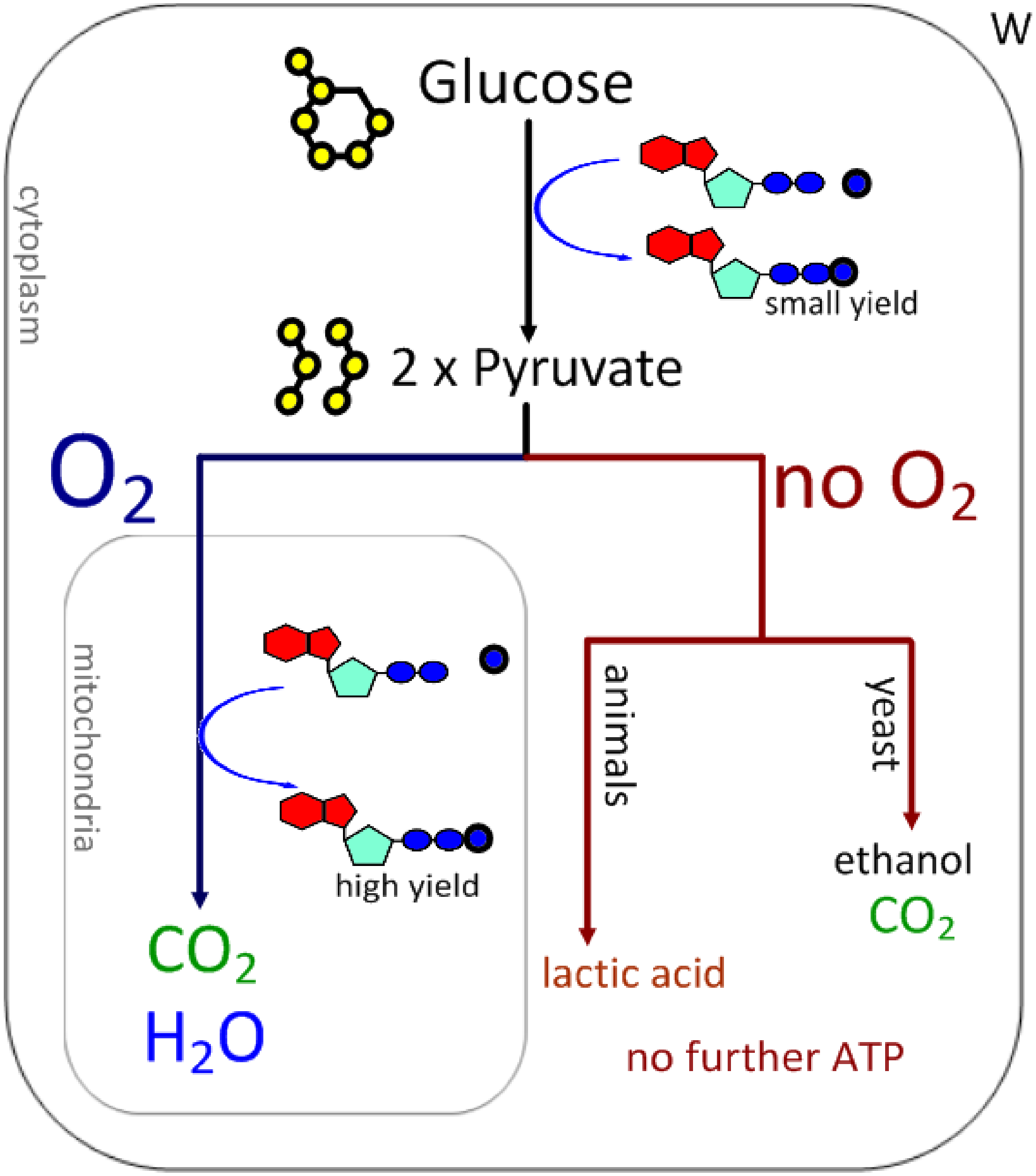
CO_2

CO_2

H_2O

no further ATP

*or print and write



Which molecules of respiration contain:

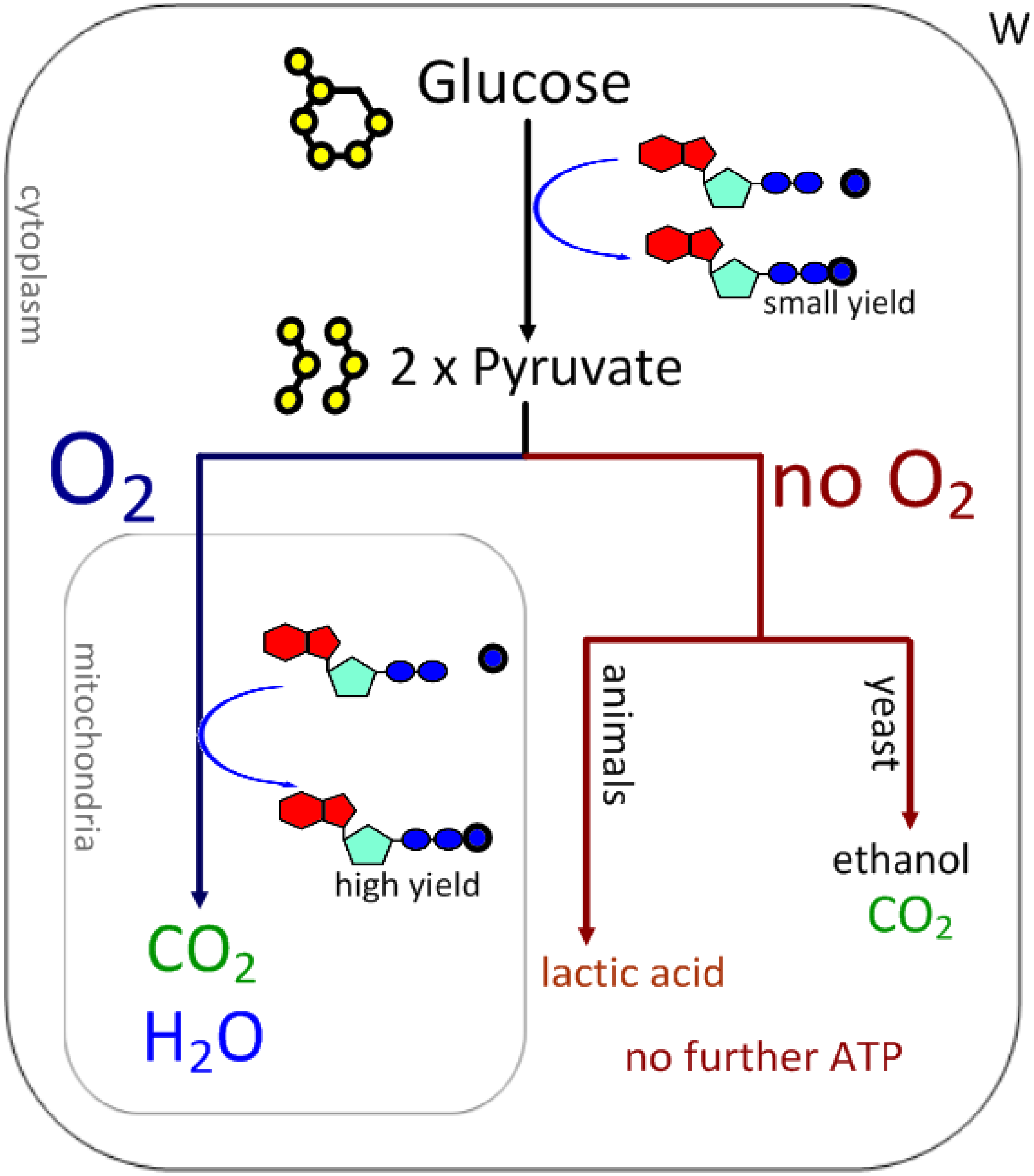
6 carbons?

3 carbons?

1 carbon?

0 carbons?

Phosphorous?



Which molecules of respiration contain:

6 carbons?

glucose

3 carbons?

pyruvate

1 carbon?

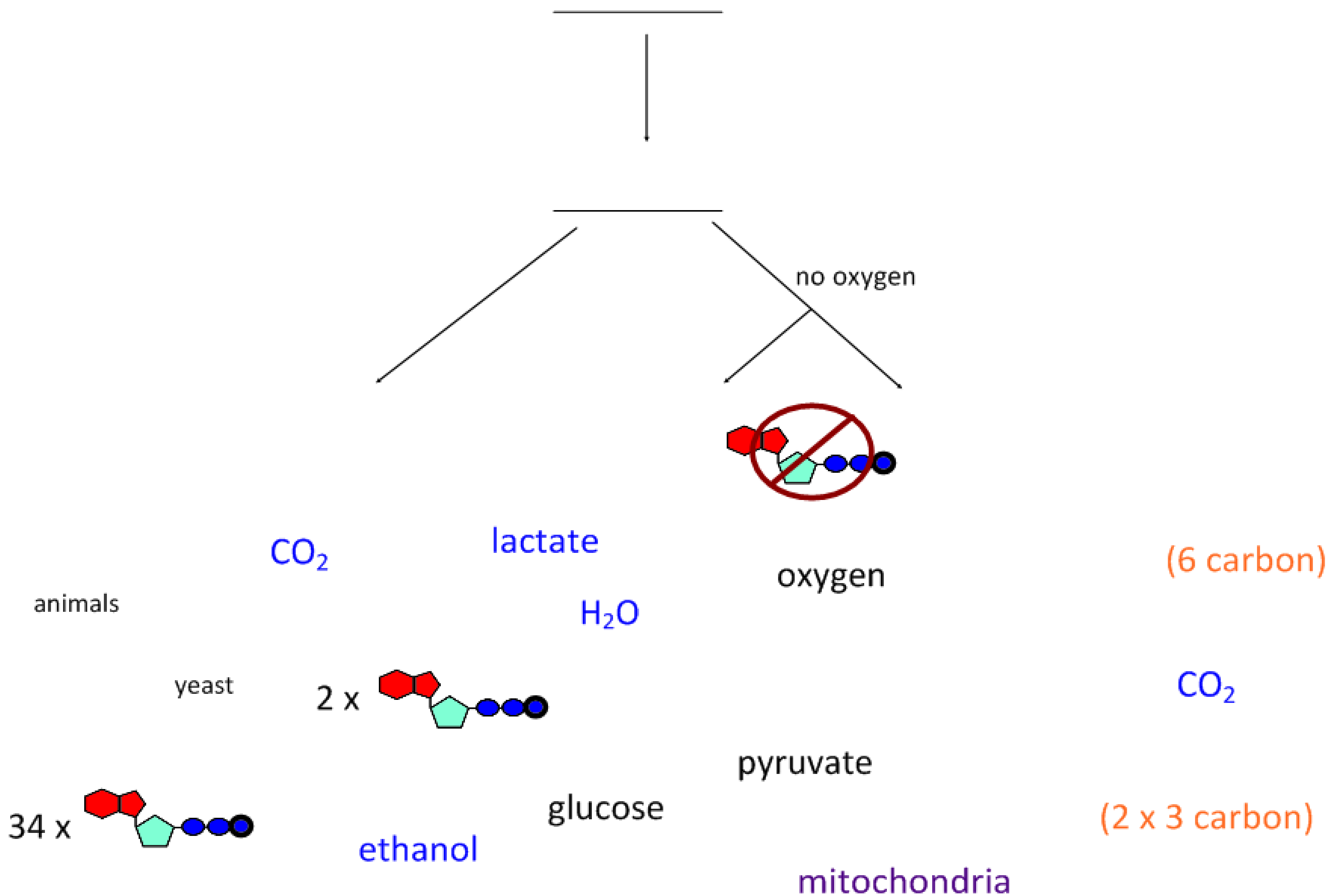
carbon dioxide

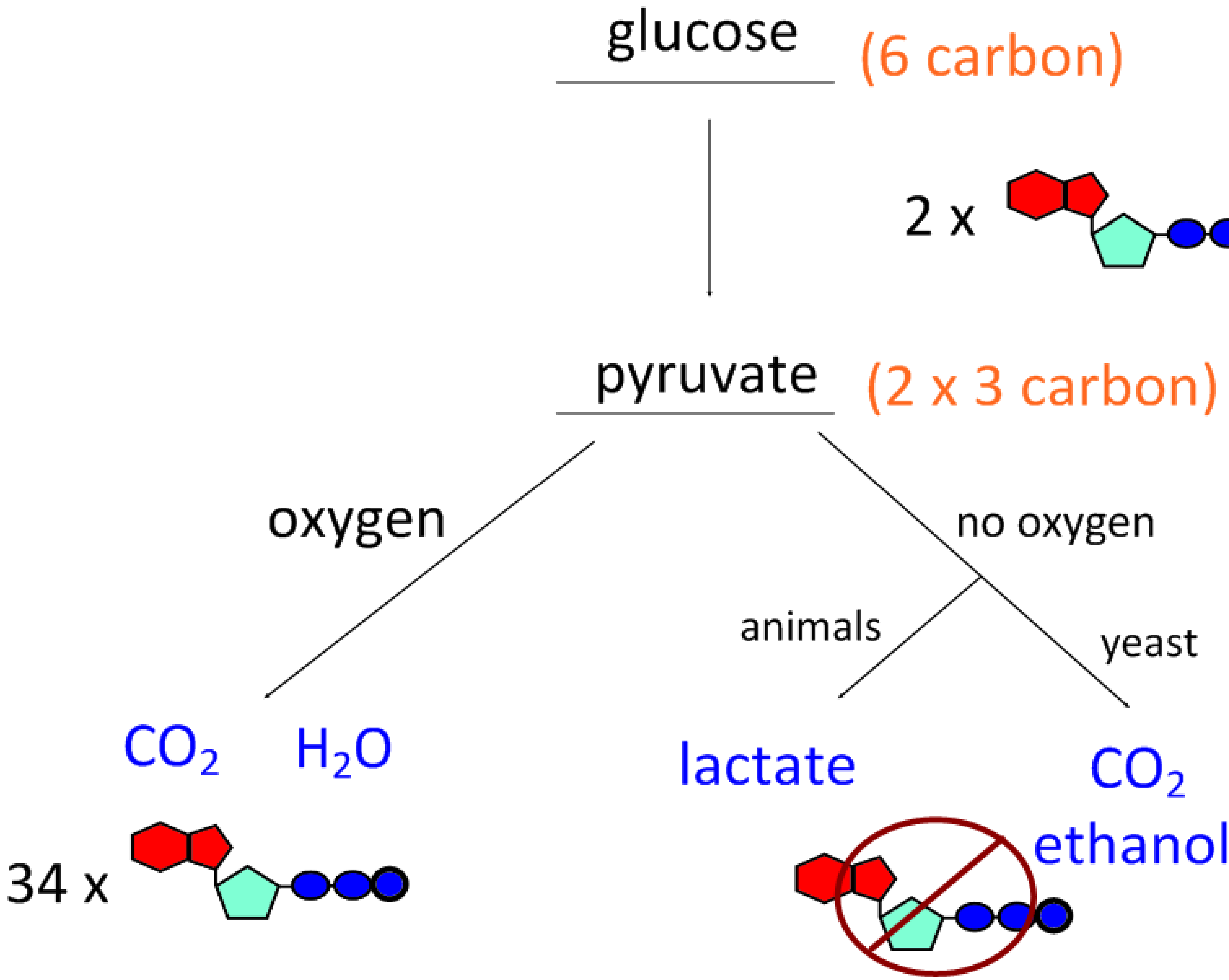
0 carbons?

water, oxygen

Phosphorous?

ATP


no oxygen
CO2
lactate
oxygen
(6 carbon)
animals
H2O
yeast
2 x
CO2
pyruvate
34 x
glucose
(2 x 3 carbon)
ethanol
mitochondria



glucose
(6 carbon)
2 x
pyruvate
(2 x 3 carbon)
oxygen
no oxygen
animals
yeast
CO_2
H_2O
lactate
CO_2
ethanol
34 x

Yogurt?

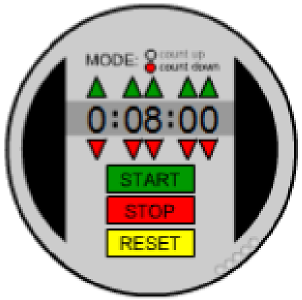
- In heterolactic acid fermentation, one molecule of pyruvate is converted to lactate; the other is converted to ethanol and carbon dioxide. In homolactic acid fermentation, both molecules of pyruvate are converted to lactate. Homolactic acid fermentation is unique because it is one of the only respiration processes to not produce a gas as a byproduct.

  Homolactic fermentation breaks down the pyruvate into lactate. It occurs in the muscles of animals when they need energy faster than the blood can supply oxygen. It also occurs in some kinds of bacteria (such as lactobacilli) and some fungi. It is this type of bacteria that converts lactose into lactic acid in yogurt, giving it its sour taste. These lactic acid bacteria can be classed as homofermentative, where the end-product is mostly lactate, or heterofermentative, where some lactate is further metabolized and results in carbon dioxide, acetate, or other metabolic products.

Compare aerobic and anaerobic cell respiration.

(8 marks)

Similarities



Differences

Aerobic	Anaerobic

Compare aerobic and anaerobic cell respiration.

(8 marks)

Similarities

Both can start with glucose

Both produce pyruvate (by glycolysis)

Both produce ATP

Both produce CO_2

Differences

Aerobic	Anaerobic

Compare aerobic and anaerobic cell respiration.

(8 marks)

Similarities

Both can start with glucose

Both produce pyruvate (by glycolysis)

Both produce ATP

Both produce CO_2

Differences

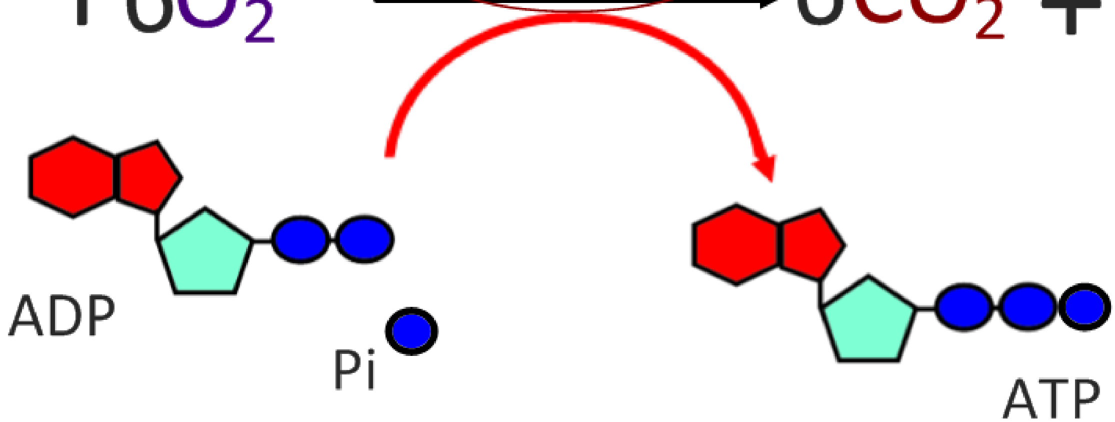
Aerobic	Anaerobic
Uses oxygen	No oxygen
High yield of ATP	Low yield of ATP
Waste products: CO_2 and water	Waste products: CO_2 and ethanol (yeast) Lactic acid (animals)
Pyruvate carried to mitochondria	Occurs in cytoplasm only
Can metabolise other molecules	

Anaerobic Resp??

- What if there is no O2?
- Process?
- Examples?
- Bread baking activity..
- Lab?
- **If enough oxygen is present is cells,** each glucose molecule will produce **~38 ATPs** - lots of energy, for lots of cellular work. However, what happens if you (or another organism) run short of oxygen? *(Like if you are a sprinter, or being chased by a LION, or in an aerobics class but WAY above your target heart rate?)* How does your body get energy to do its cellular work when oxygen is limited?

glycolysis → link reaction

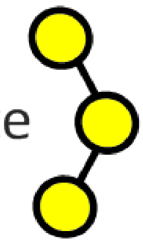
$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{respiration}} 6CO_2 + 6H_2O$$



OXIDATIVE DECARBOXYLATION

LINK REACTION
(matrix)

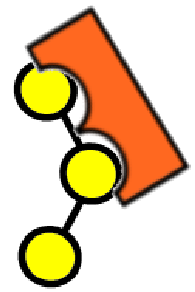
Pyruvate



CoA
coenzyme: a carrier

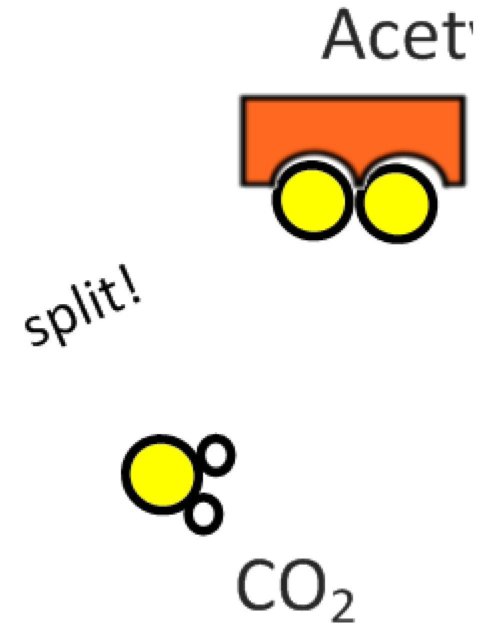
LINK REACTION
(matrix)

OXIDATIVE DECARBOXYLATION



LINK

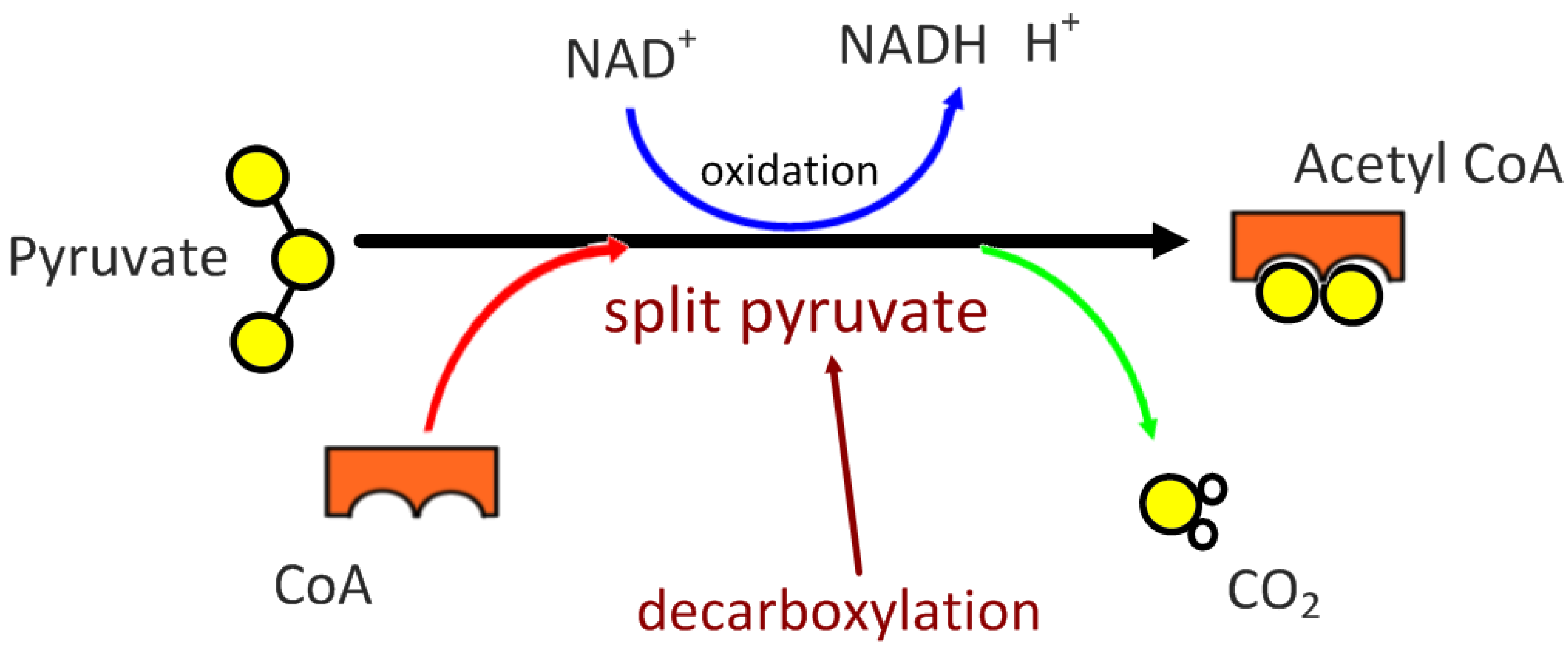
OXIDATIVE DECARBOXYLATION



OXIDATIVE DECARBOXYLATION

LINK REACTION (matrix)

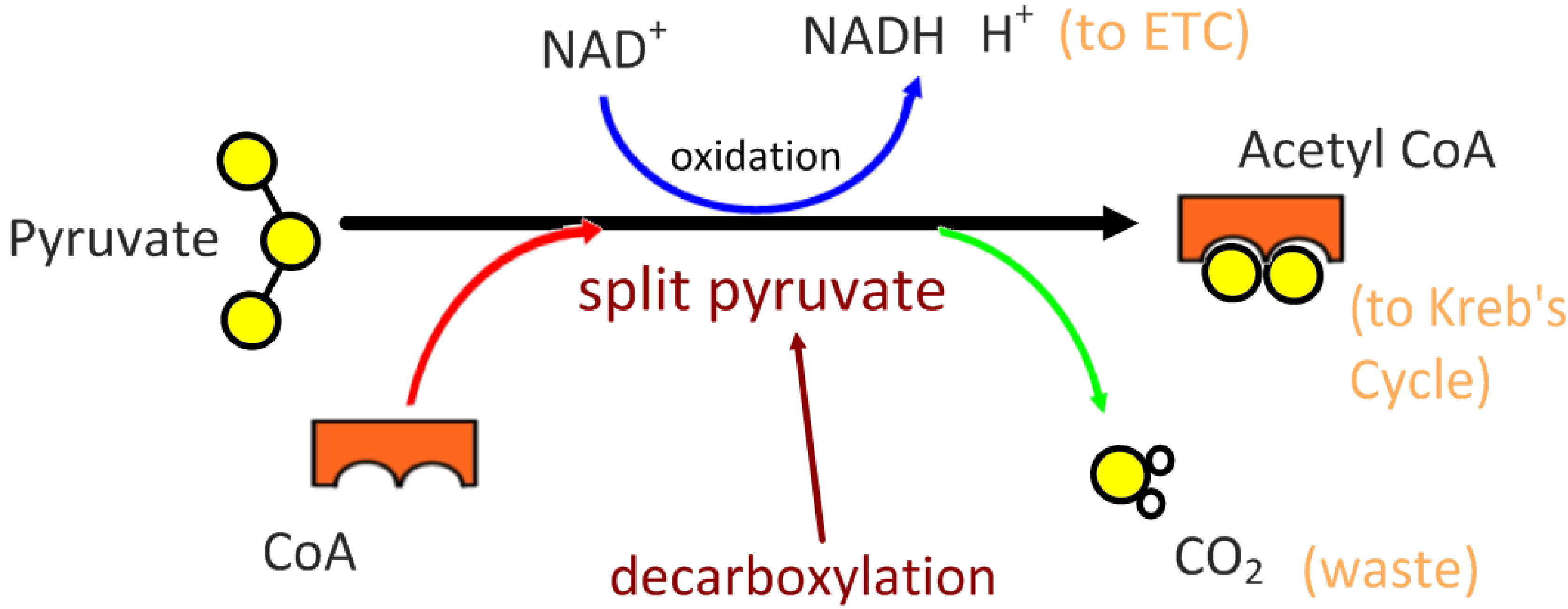
mitochondria



OXIDATIVE DECARBOXYLATION

LINK REACTION (matrix)

mitochondria



Net yield: 2 Acetyl CoA per glucose molecule

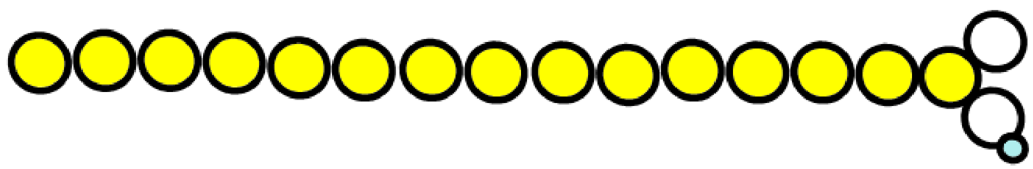
(remember the 6C glucose split into 2 x 3C pyruvate)

Cell Respiration using fatty acids

Fatty acids can also be a source of energy in respiration:

$CH_3(CH_2)_nCOOH$

Glycolysis is not needed



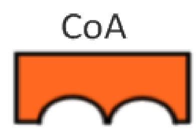
Fatty acids have a long chain of carbon atoms

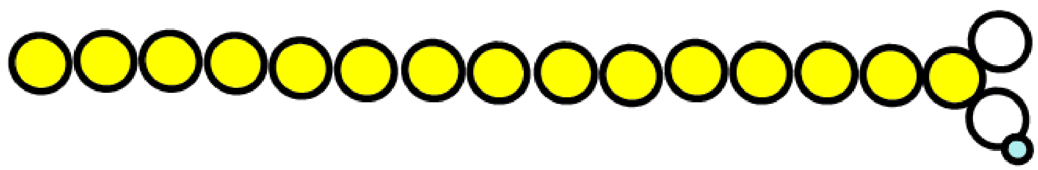
Cell Respiration using fatty acids

Fatty acids can also be a source of energy in respiration:

$CH_3(CH_2)_nCOOH$

Cut straight to the link reaction!





Fatty acids have a long chain of carbon atoms

CoA can oxidise this chain - break it down.

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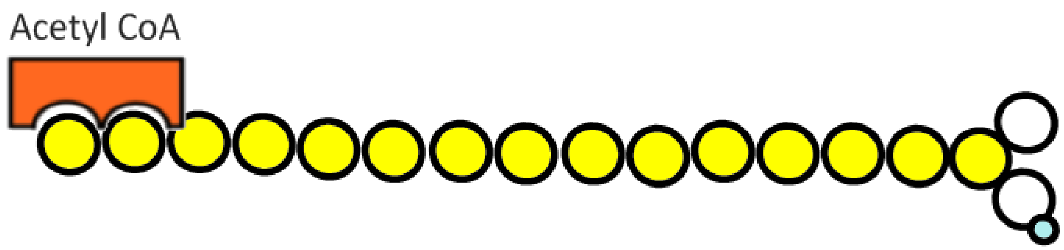

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It makes Acetyl CoA with two carbons.

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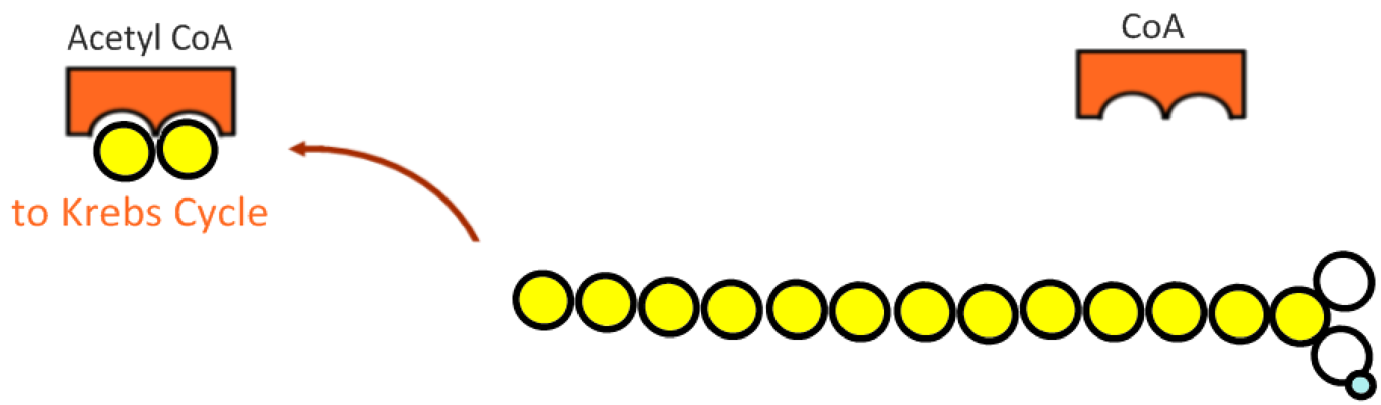

Fatty acids have a long chain of carbon atoms

CoA can oxidise this chain - break it down.

It makes Acetyl CoA with two carbons.

And carries them to the Kreb's Cycle.

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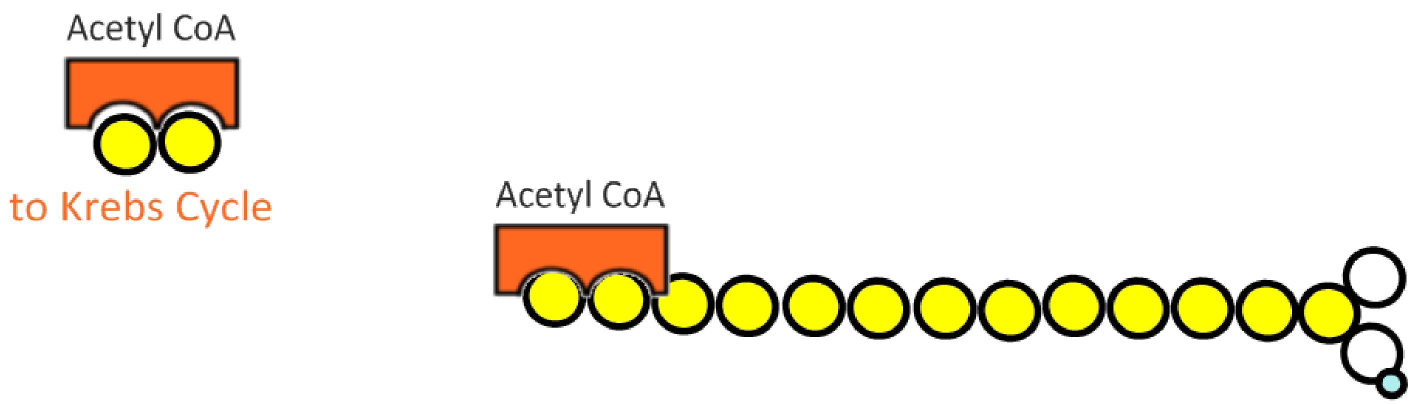

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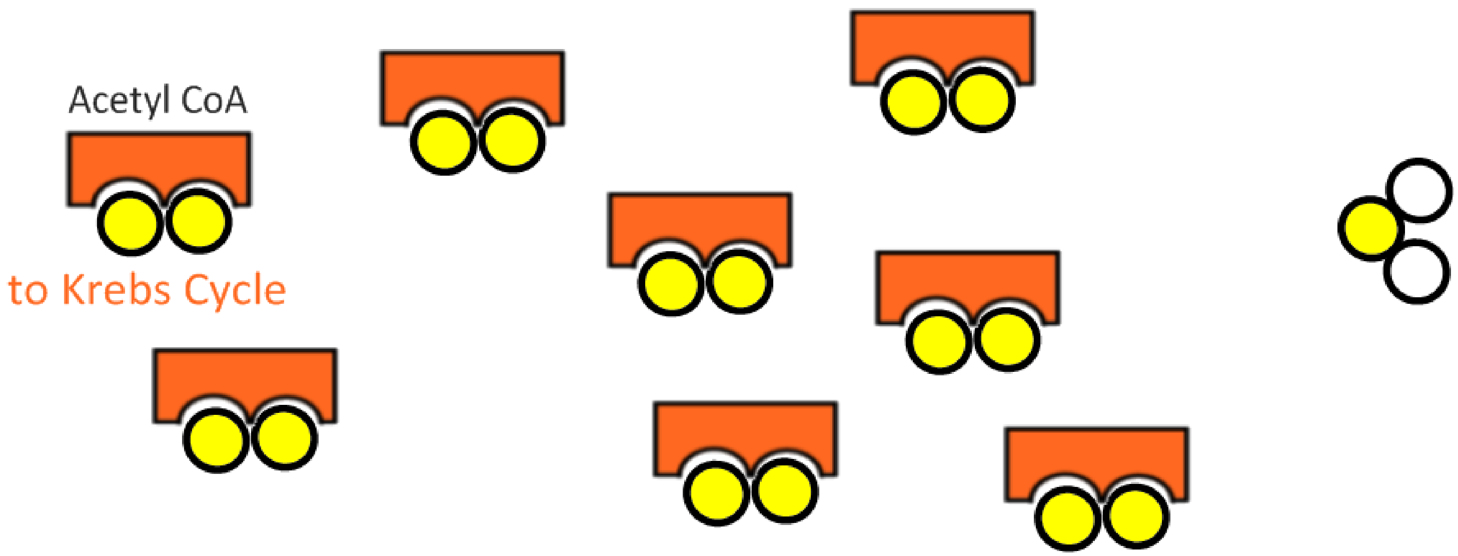

If there are an odd number of carbons, the remaining carbon atom is released as carbon dioxide

- **Fats as fuel:** Triacylglycerol reserves (located in ***unpleasantly strategic locations*** on your body ...) tend to be stored in **adipose cells. Lipases** are released into the bloodstream and break down fats in the bloodstream (from the fats and oils we eat) or travel to adipose cells.
- **Lipases** break the glycerol head away from the fatty acids.
- **Glycerol** is converted to an intermediate in glycolysis called "PGAL", and enters cellular respiration in the cytoplasm.
- **The fatty acid tails** are converted to Acetyl CoA and enter the Krebs cycle in the mitochondria
- **Result:** Still ~32-38 or so ATPs, but from fats, not glucose!

- **Proteins as fuel:** Excess proteins in our diets cannot be stored like glycogen or fats can, and must be broken down by the body.
- **Proteases** break the peptide bonds of proteins back down to amino acids
- De**amin**ases break the amino group off the **amino** acids, releasing ammonia. This toxic ammonia is converted to urea, and is excreted in urine.
- The remainder of the amino acid (mostly of carbon, hydrogen, and oxygen), and can be rearranged in cells to enter cellular respiration either as **pyruvate**, as **acetyl CoA**, or directly into the **Krebs cycle**.
- **Result:** Still ~32-38 or so ATPs, but from proteins, not glucose!

Cell Respiration using fatty acids

How many Acetyl CoA molecules can be made from:

1. A fatty acid with 24 carbons?

2. A fatty acid with 25 carbons?

3. A fatty acid with 26 carbons?

4. From stearic acid ($C_{18}H_{36}O_2$)?

5. This fatty acid:

$$CH_3(CH_2)_{54}COOH$$

Cell Respiration using fatty acids

How many Acetyl CoA molecules can be made from:

1. A fatty acid with 24 carbons? 12

2. A fatty acid with 25 carbons? 12 (plus one CO_2)

3. A fatty acid with 26 carbons? 13

4. From stearic acid ($C_{18}H_{36}O_2$)? 9

5. This fatty acid?

$CH_3(CH_2)_{54}COOH$ 28

Cellular Respiration of Proteins

- Excess proteins in our diets cannot be stored like glycogen or fats can, and must be broken down by the body.

- **Proteases** break the peptide bonds of proteins back down to amino acids

- De**amin**ases break the amino group off the **amino** acids, releasing ammonia. This toxic ammonia is converted to urea, and is excreted in urine.

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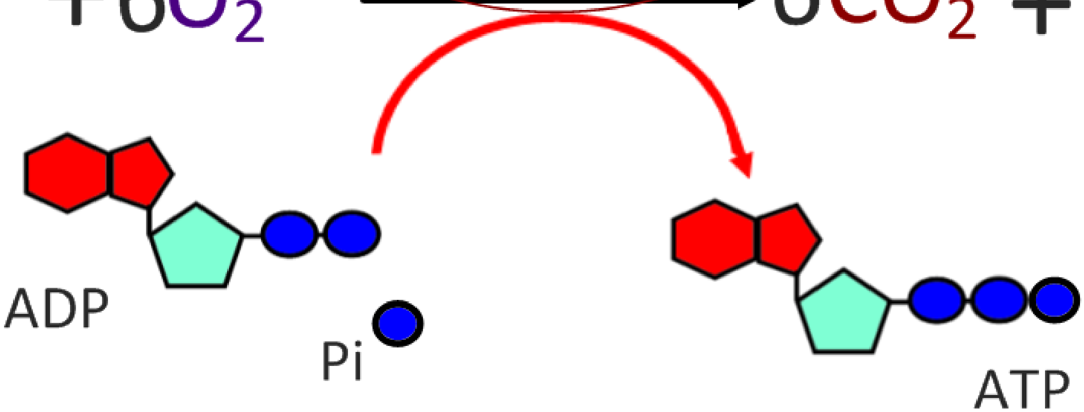
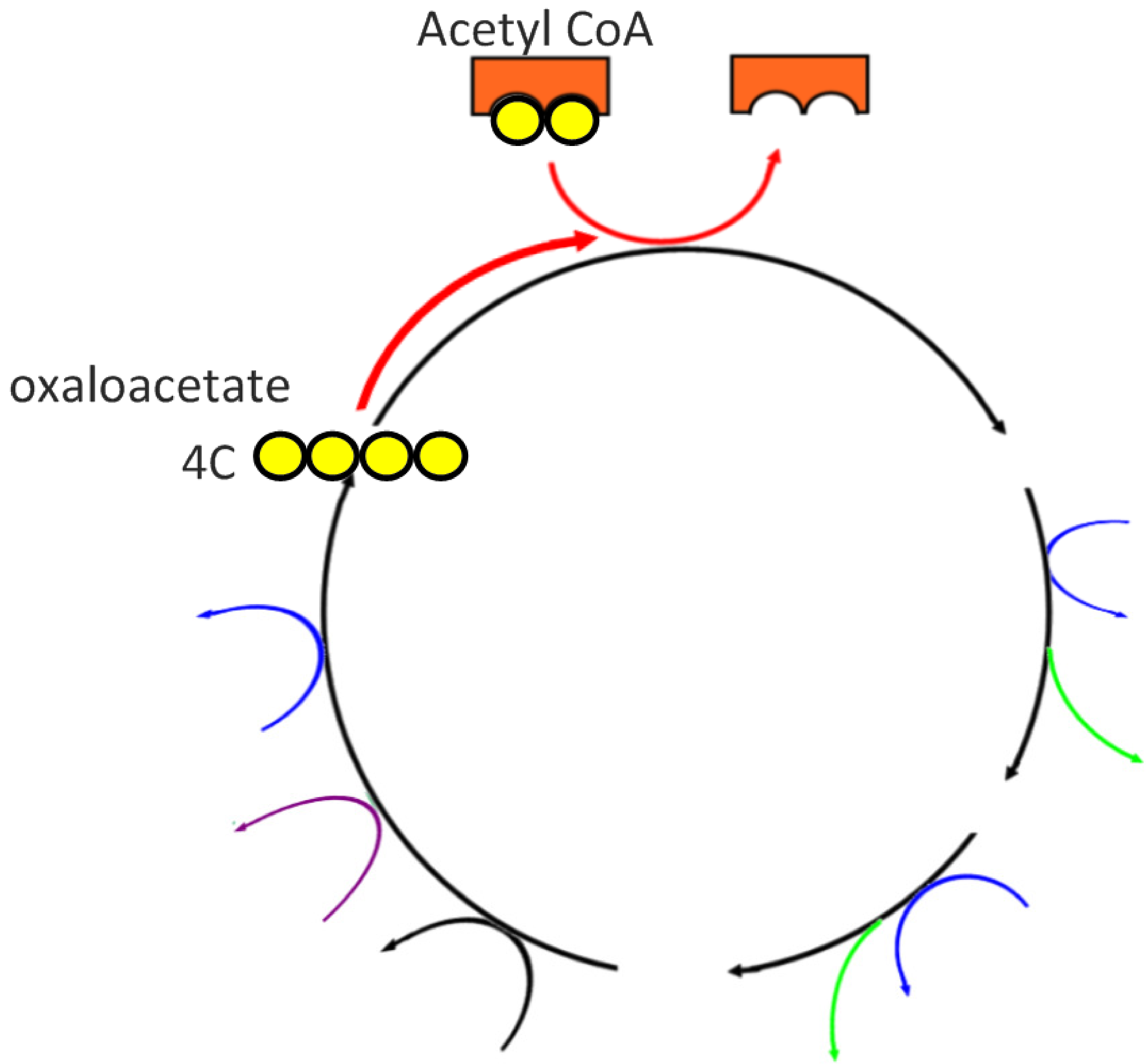
- **Result:** Still ~32-38 or so ATPs, but from proteins, not glucose!

glycolysis → link reaction → Kreb's cycle

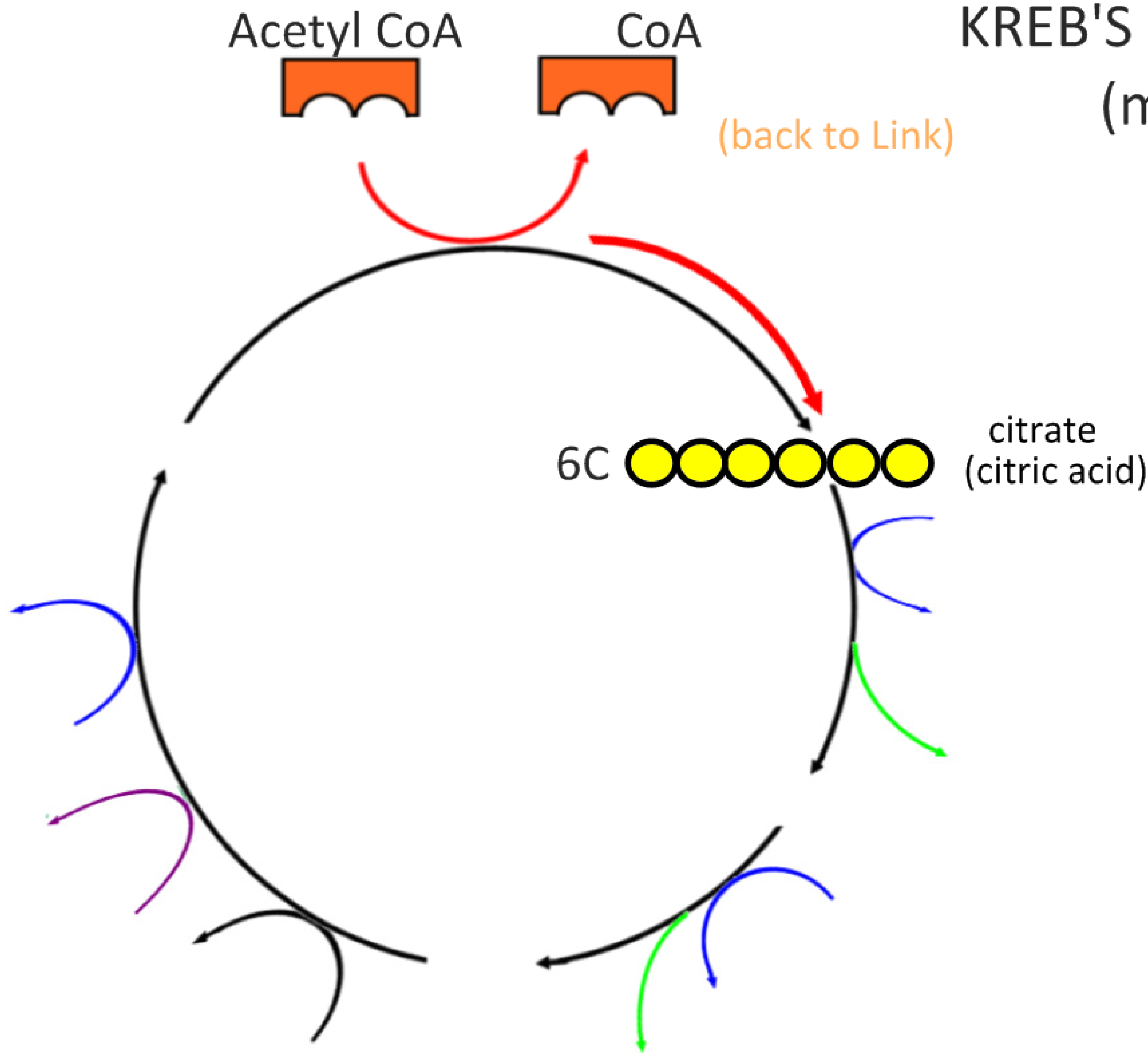
$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{respiration}} 6CO_2 + 6H_2O$$

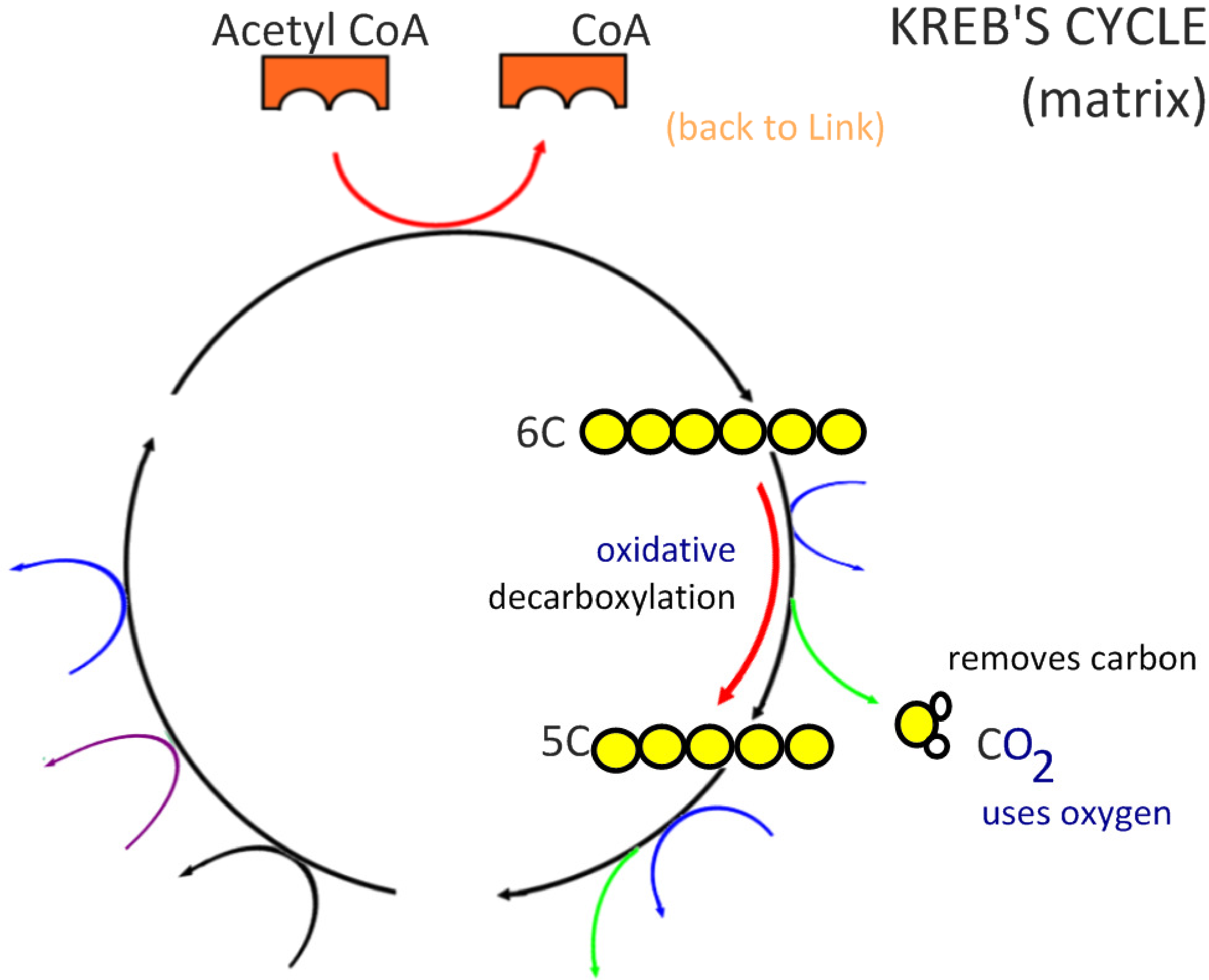


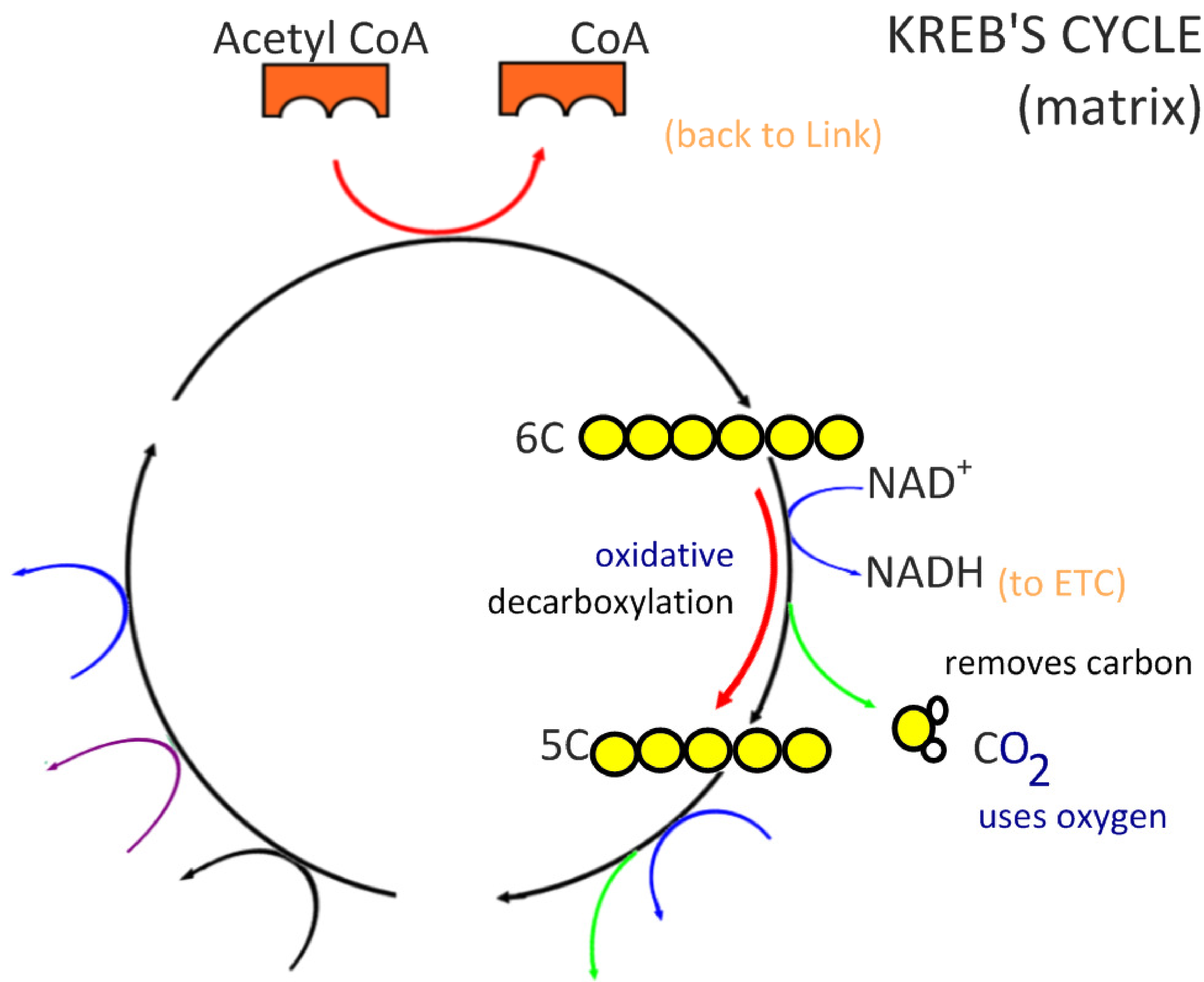
KREB'S CYCLE (matrix)



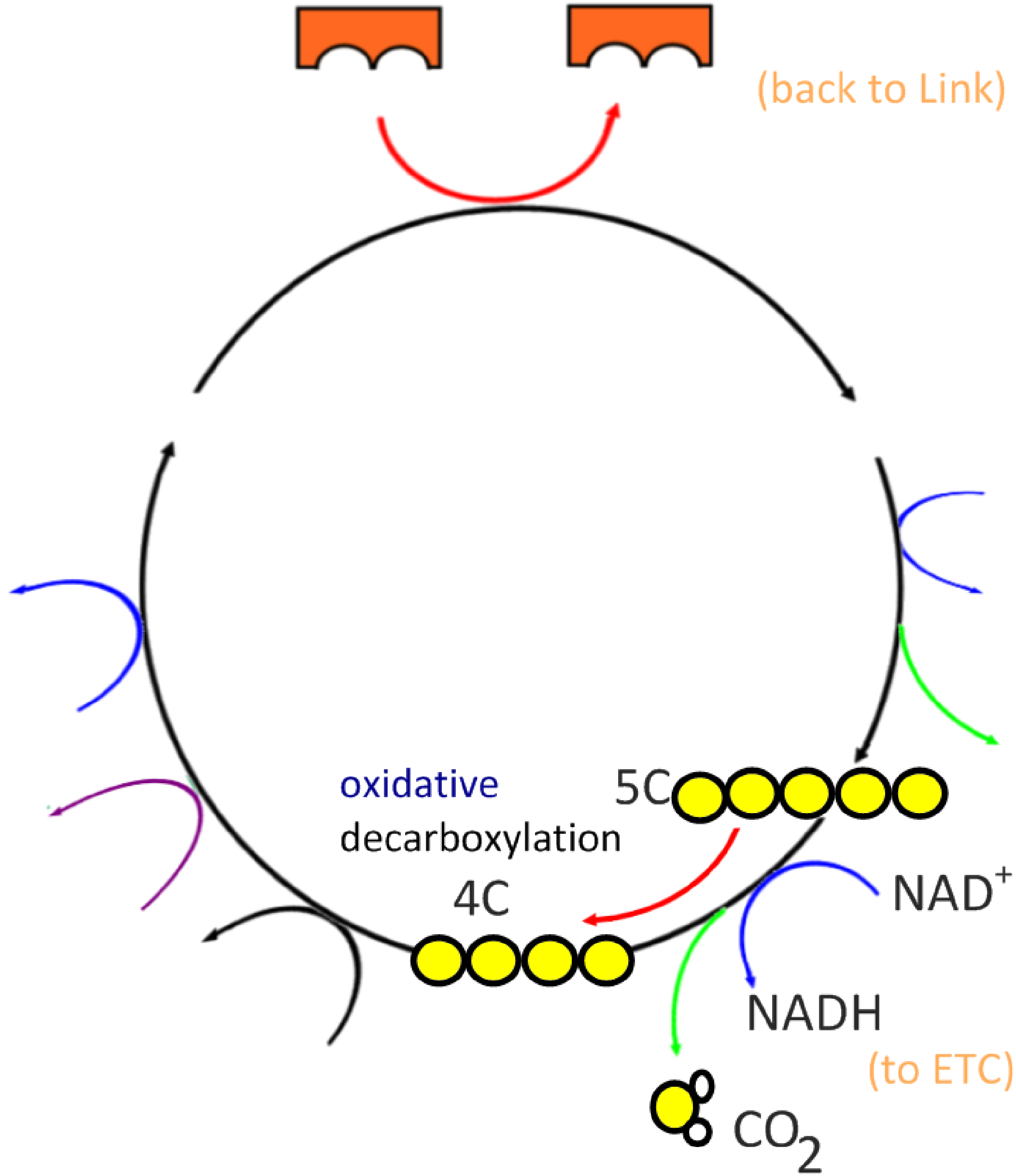
KREB'S CYCLE
(matrix)




KREB'S CYCLE
(matrix)
Acetyl CoA
CoA
(back to Link)
6C
oxidative
decarboxylation
removes carbon
5C
CO_2
uses oxygen

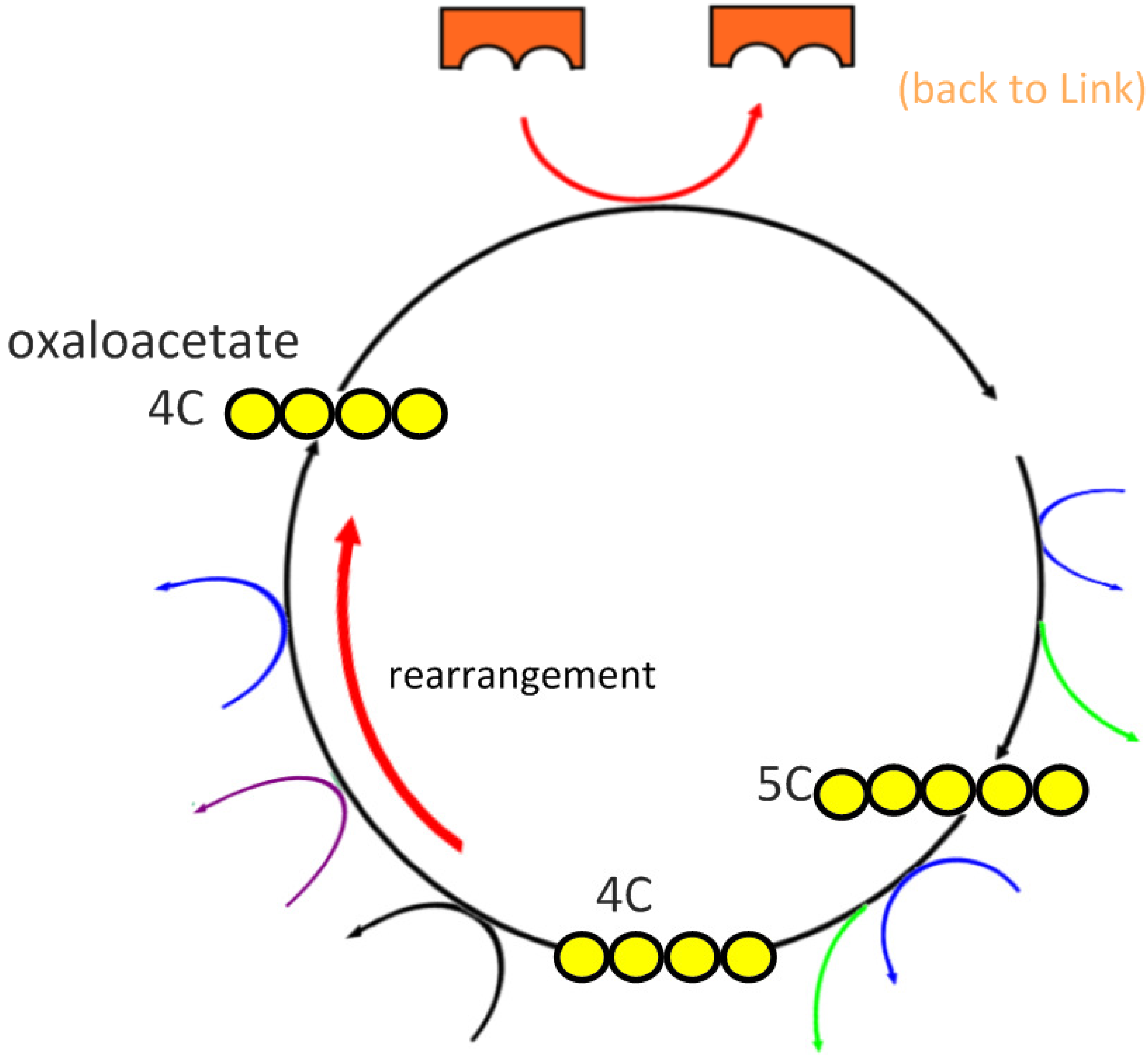

KREB'S CYCLE
(matrix)
Acetyl CoA
CoA
(back to Link)
6C
NAD+
NADH
(to ETC)
oxidative
decarboxylation
removes carbon
5C
CO2
uses oxygen

KREB'S CYCLE
(matrix)

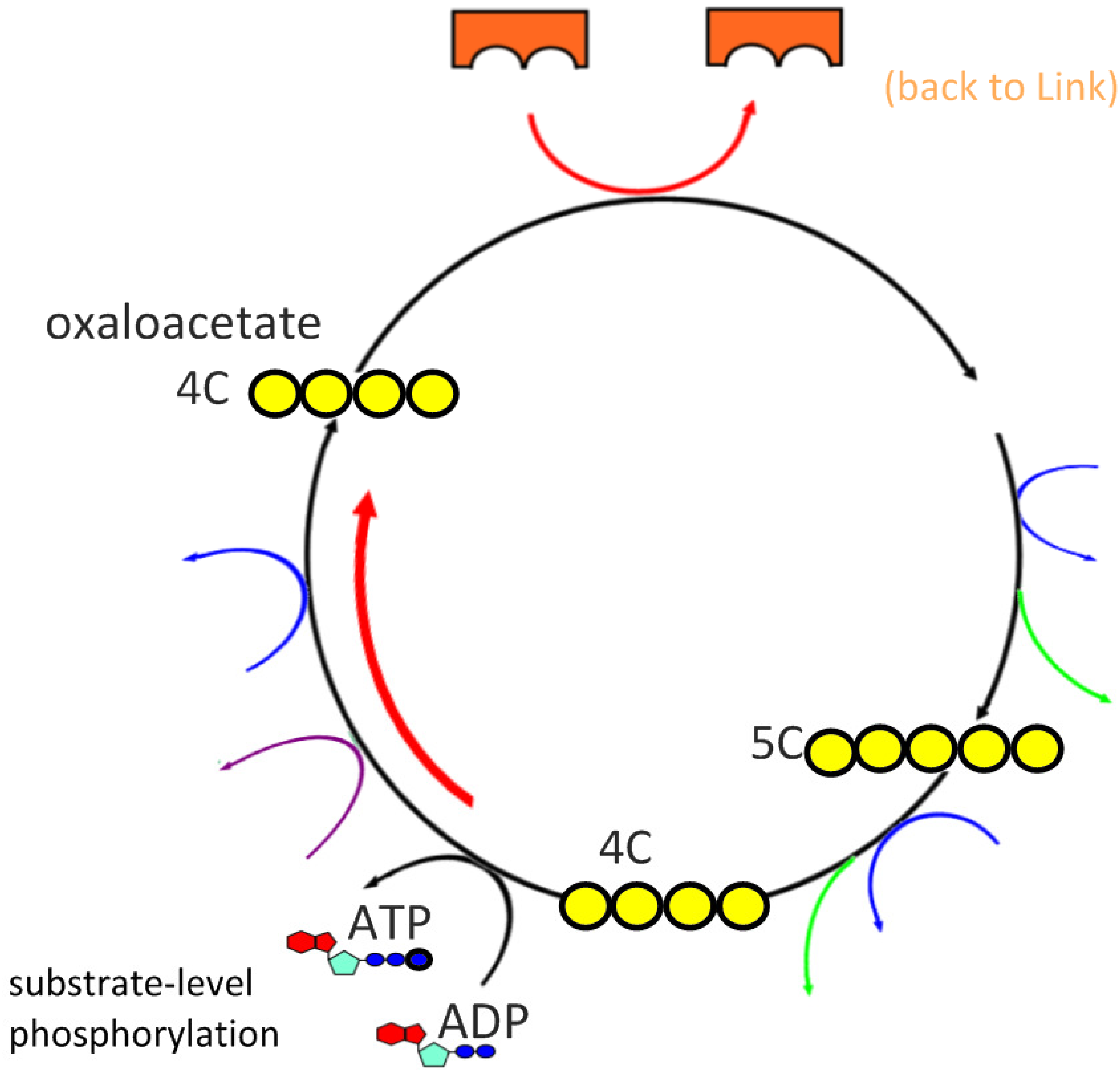


KREB'S CYCLE (matrix)

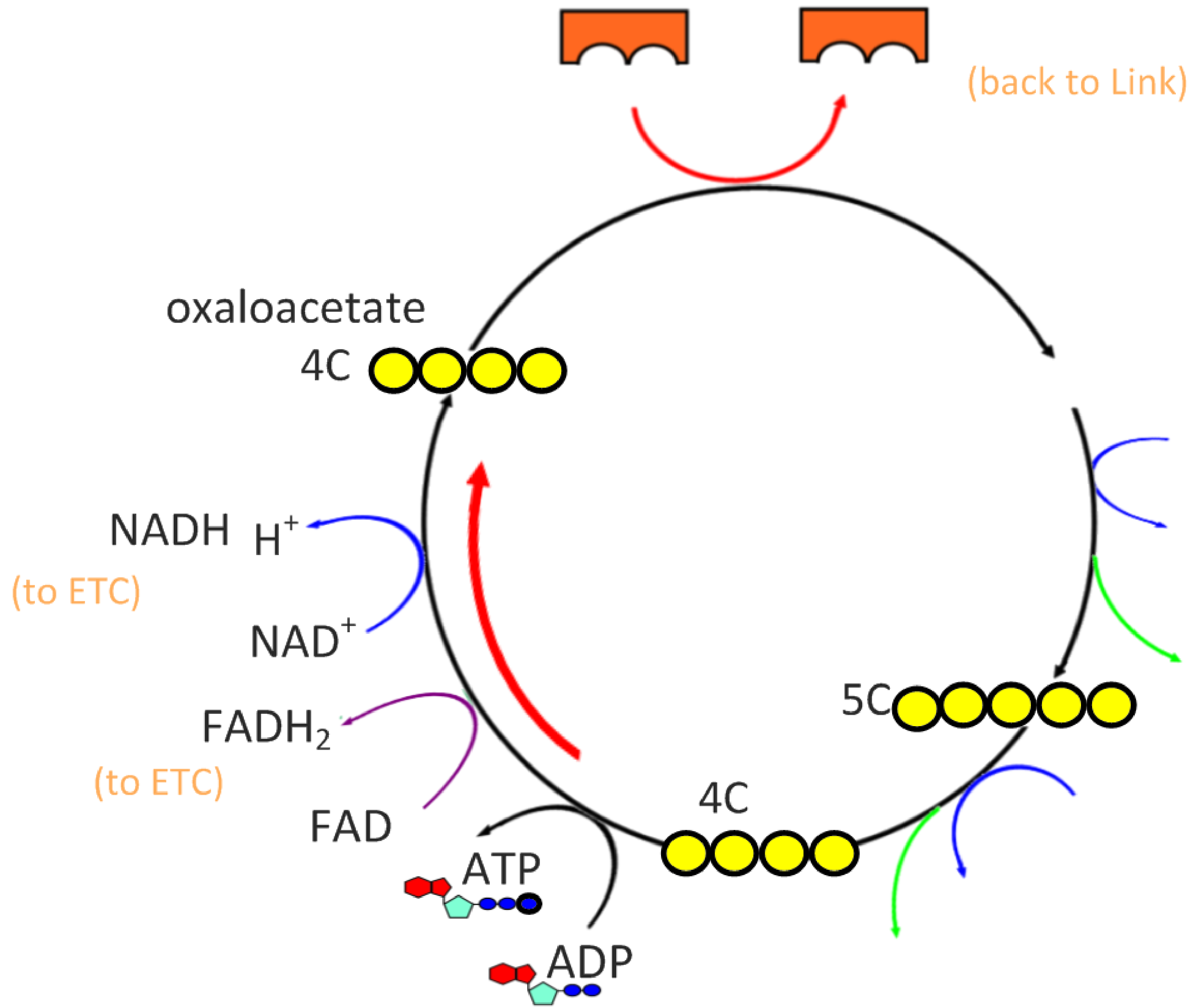
(back to Link)



KREB'S CYCLE (matrix)

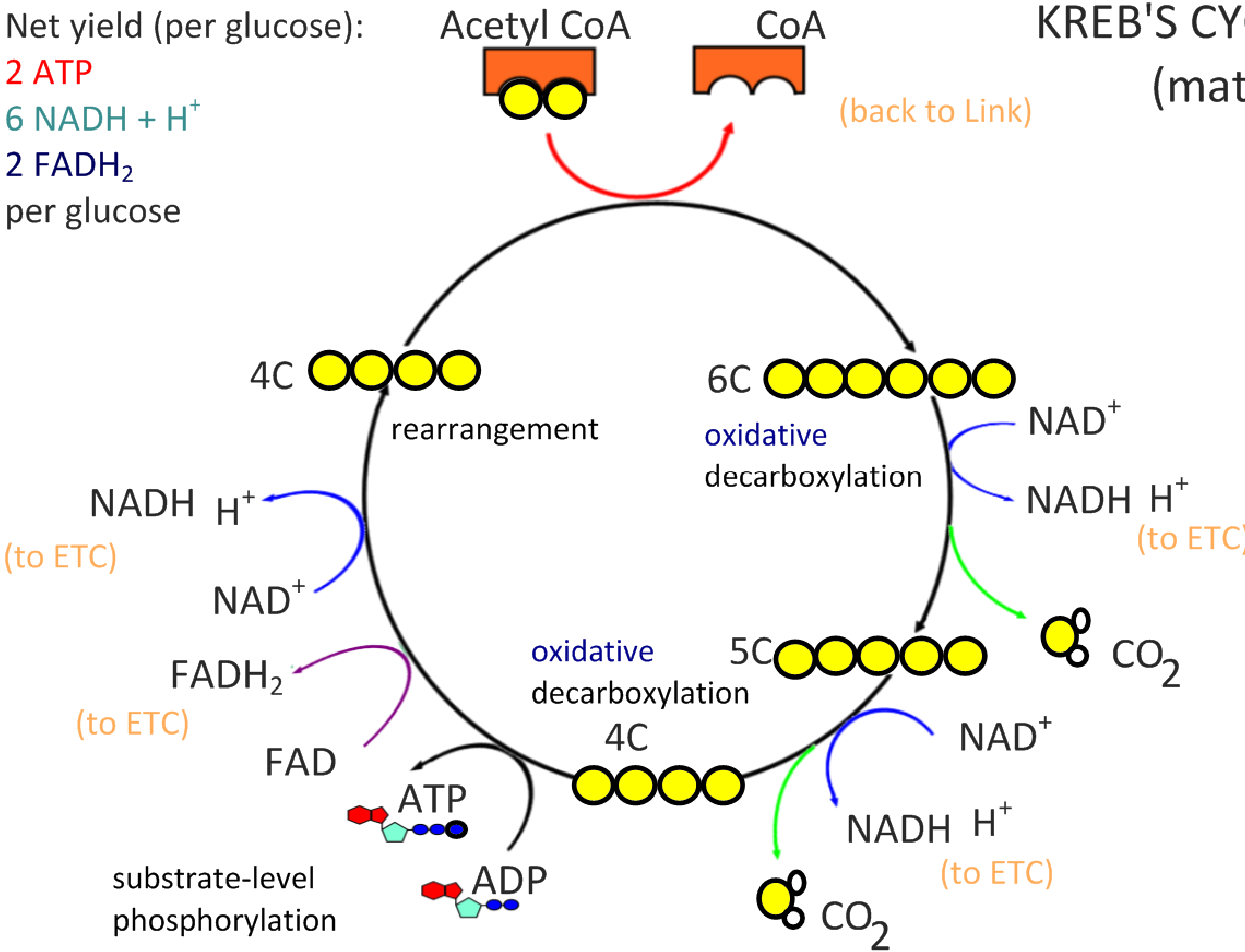


KREB'S CYCLE
(matrix)

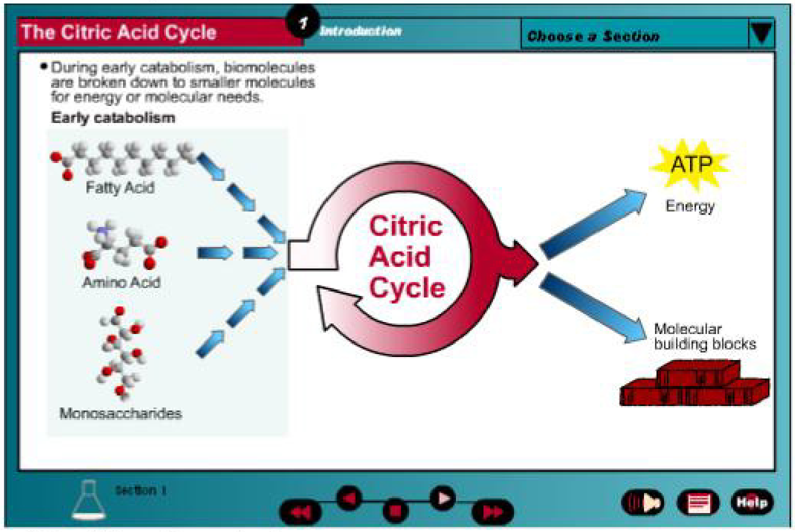


KREB'S CYCLE (matrix)

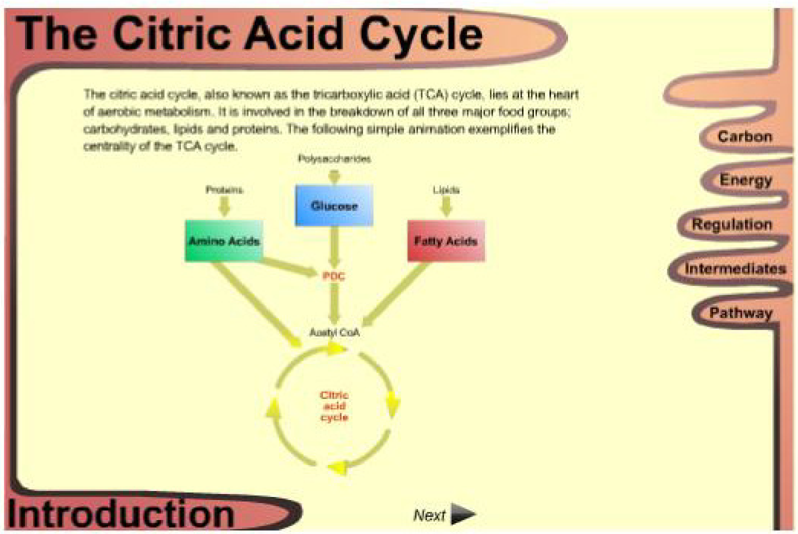
Net yield (per glucose):
2 ATP
6 NADH + H^+
2 $FADH_2$
per glucose



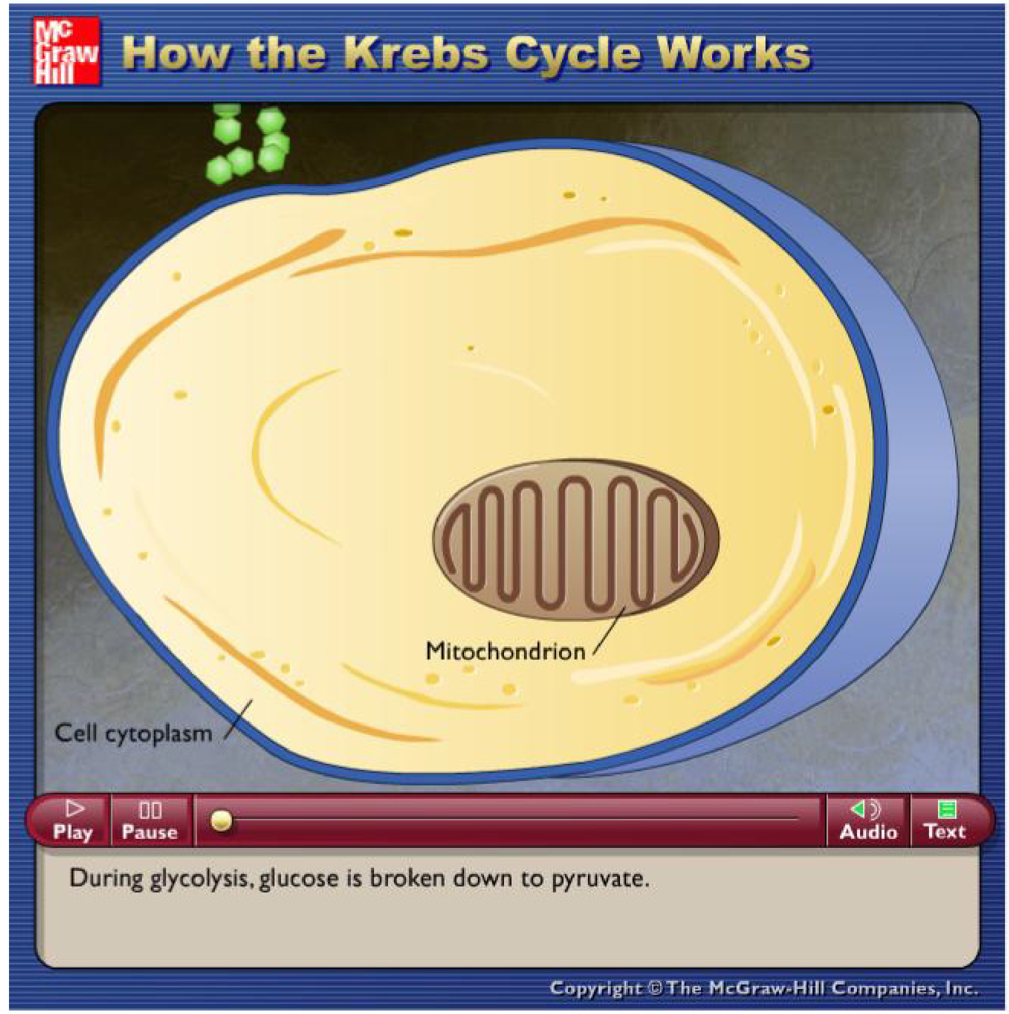
Krebs Cycle animations:



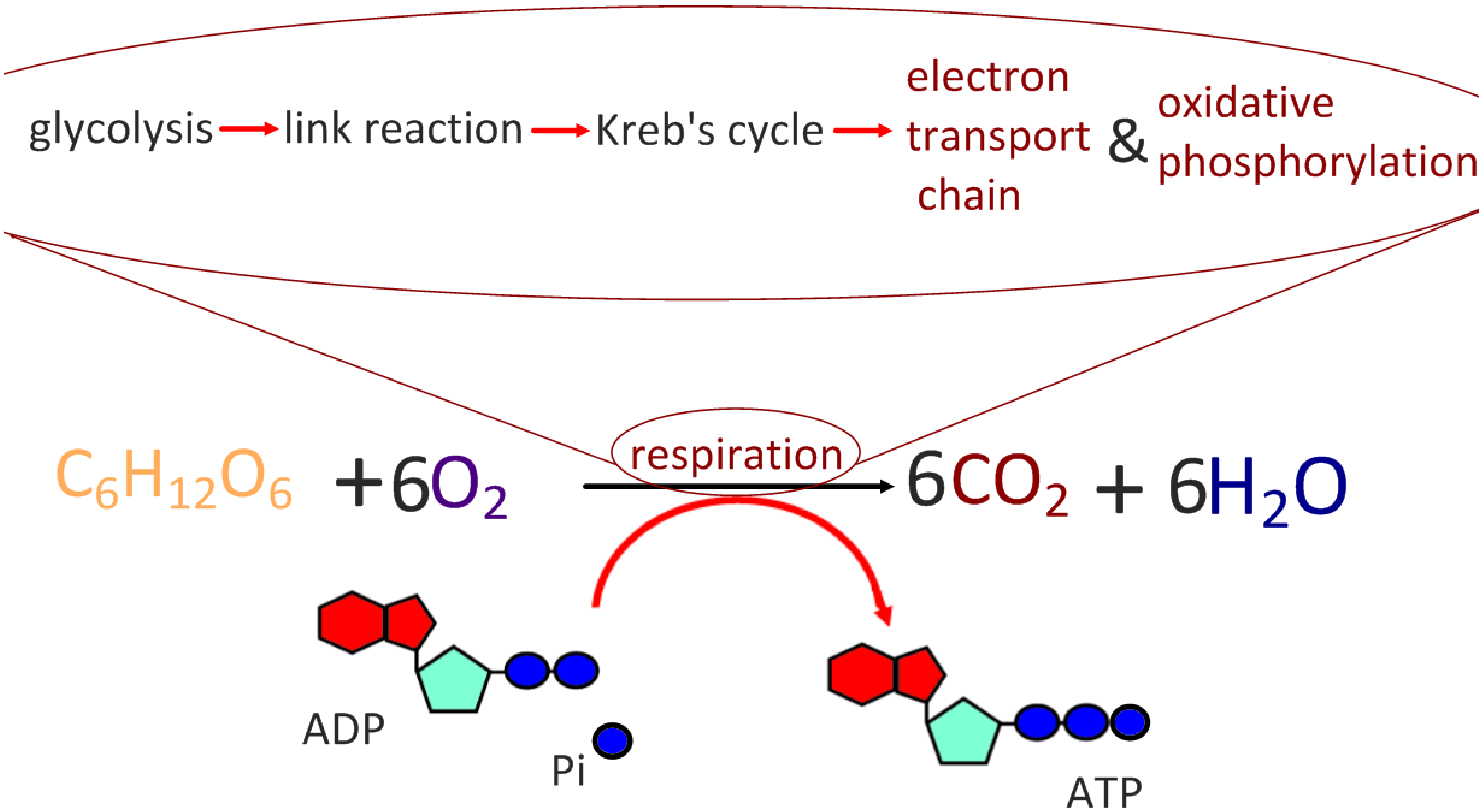
http://tinyurl.com/ewbmn



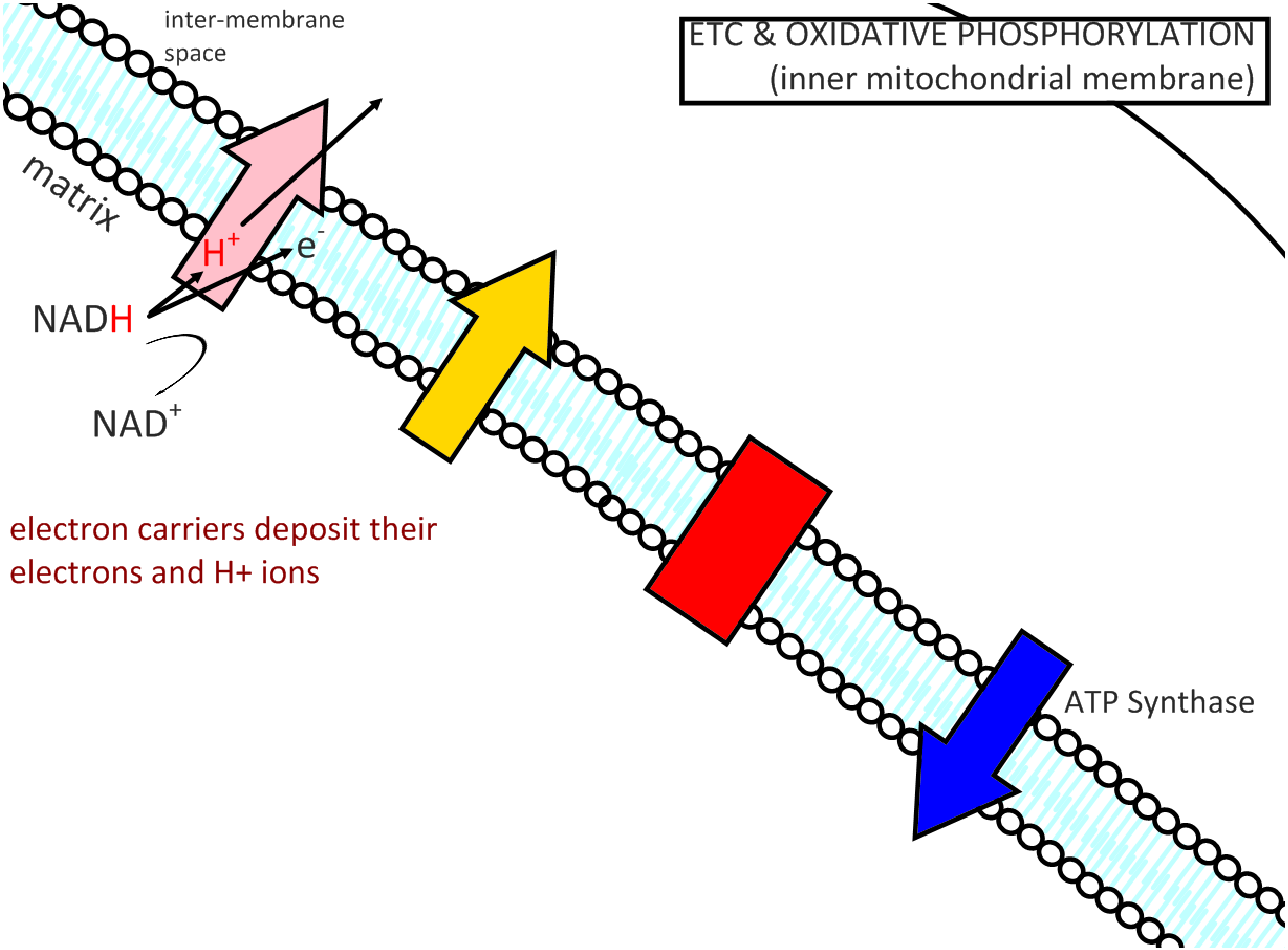
http://tinyurl.com/8hvyl



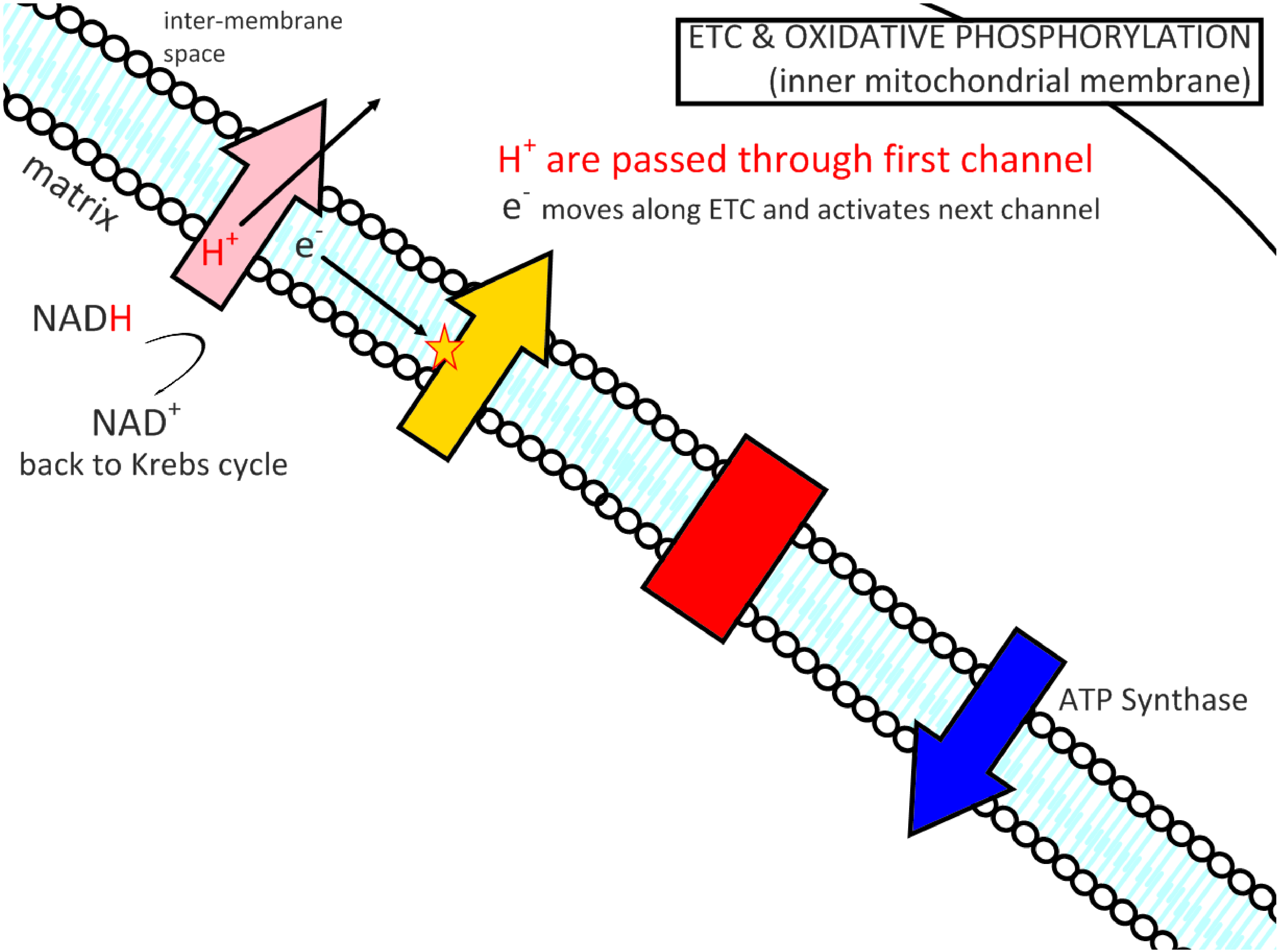
http://tinyurl.com/ydm25ah


glycolysis
link reaction
Kreb's cycle
electron transport chain
&
oxidative phosphorylation
$C_6H_{12}O_6$ + $6O_2$
respiration
$6CO_2$ + $6H_2O$
ADP
Pi
ATP

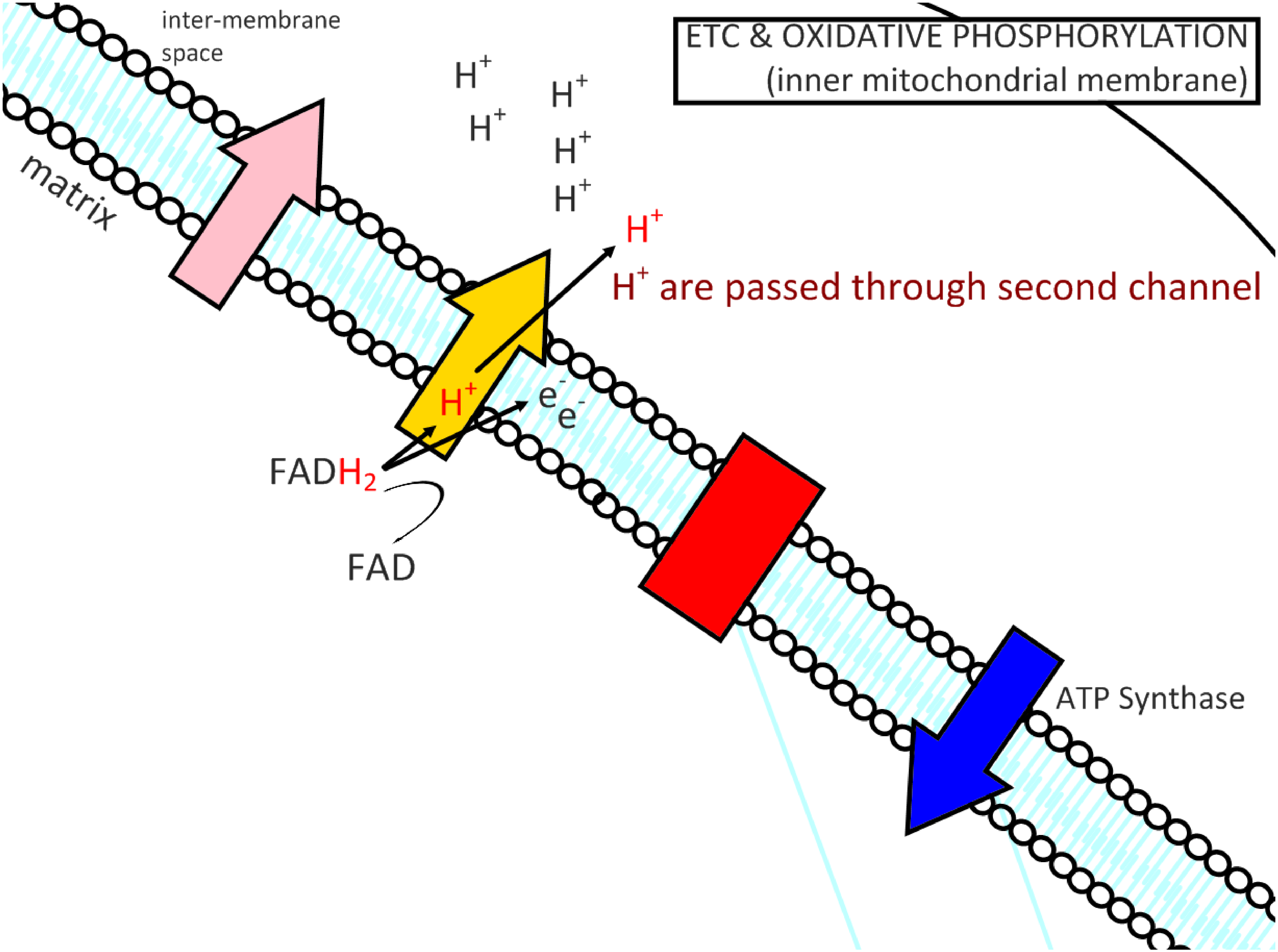
ETC & OXIDATIVE PHOSPHORYLATION (inner mitochondrial membrane)



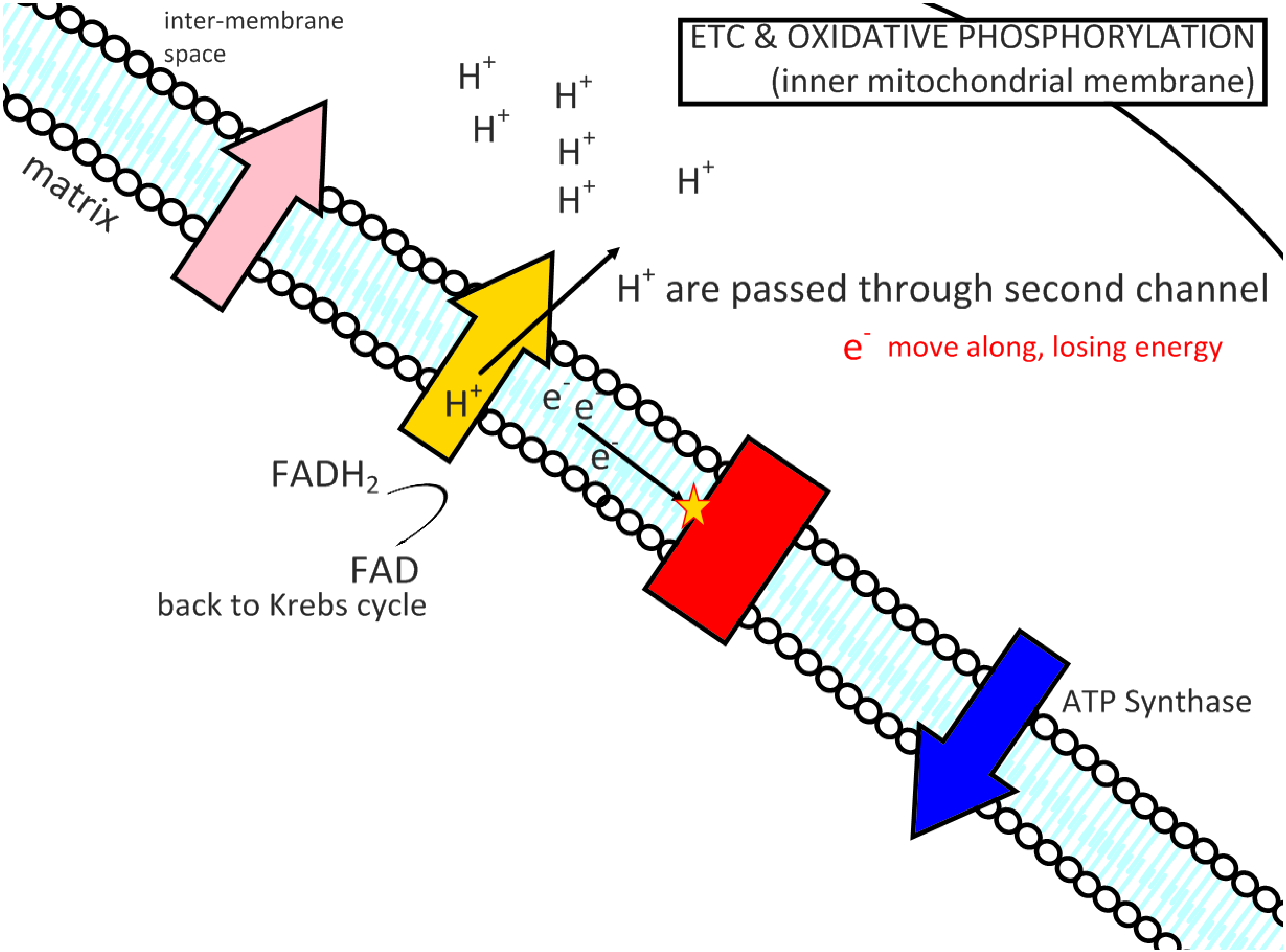
electron carriers deposit their electrons and H+ ions

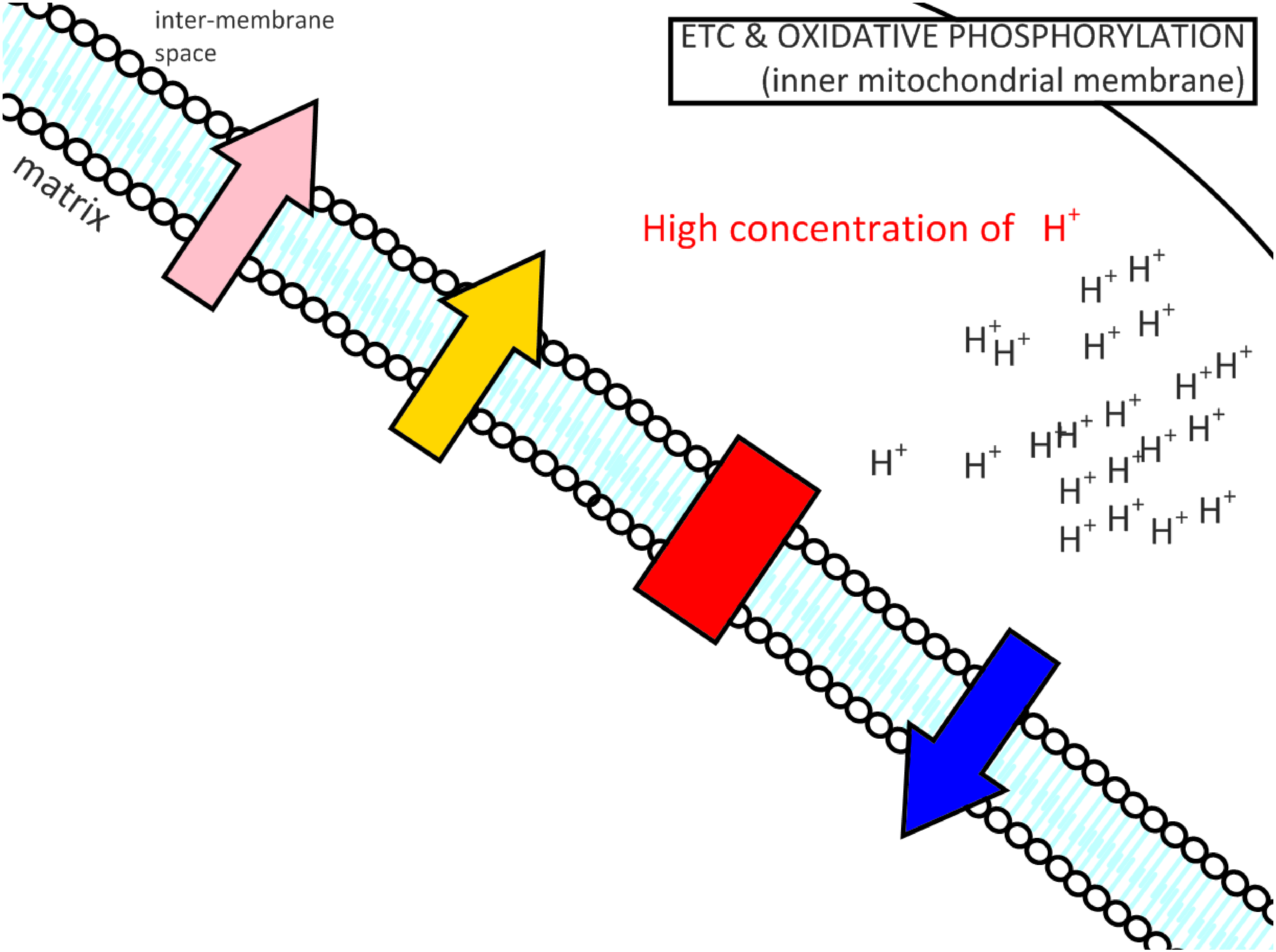

ETC & OXIDATIVE PHOSPHORYLATION
(inner mitochondrial membrane)
inter-membrane
space
matrix
H^+ are passed through first channel
e^- moves along ETC and activates next channel
H^+
e^-
NADH
NAD^+
back to Krebs cycle
ATP Synthase

ETC & OXIDATIVE PHOSPHORYLATION
(inner mitochondrial membrane)



H^+ are passed through second channel


ETC & OXIDATIVE PHOSPHORYLATION
(inner mitochondrial membrane)
inter-membrane space
matrix
H+
H+
H+
H+
H+
H+
H+ are passed through second channel
e- move along, losing energy
H+
e-
e-
e-
FADH2
FAD
back to Krebs cycle
ATP Synthase

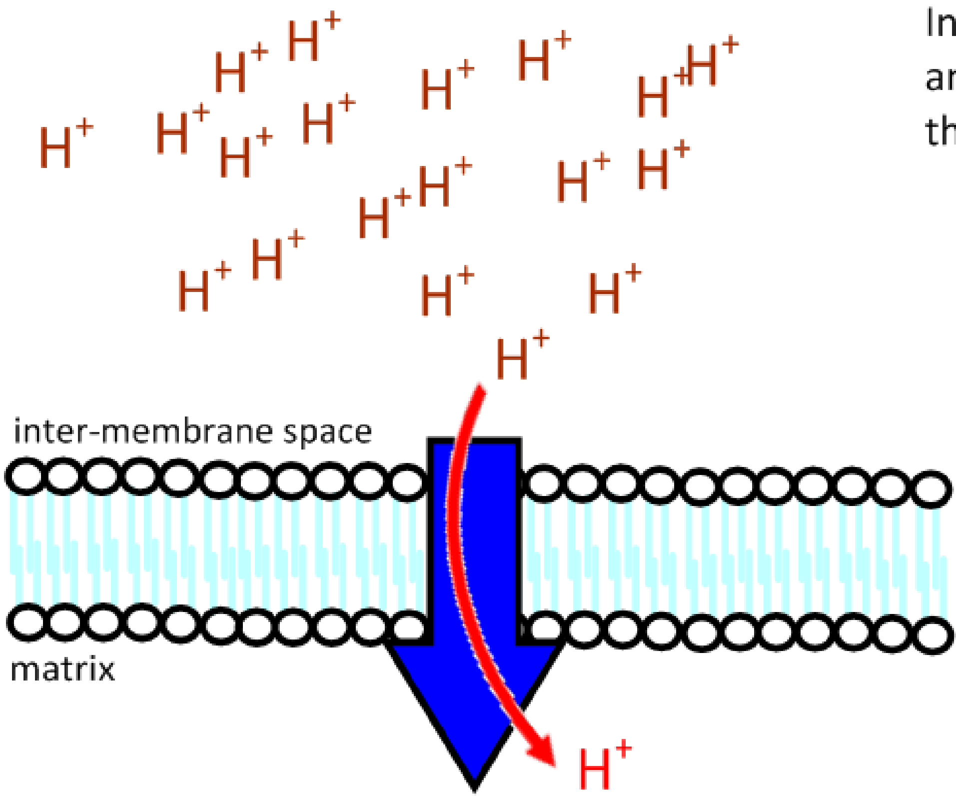


ETC & OXIDATIVE PHOSPHORYLATION
(inner mitochondrial membrane)
inter-membrane space
matrix
High concentration of H^+
H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+

Chemiosmosis

the diffusion of ions across a semi-permeable membrane, through a carrier protein.

In this case, the ions are hydrogen protons and the carrier is ATP Synthase. The flow of the H^+ through ATP Synthase generates ATP.



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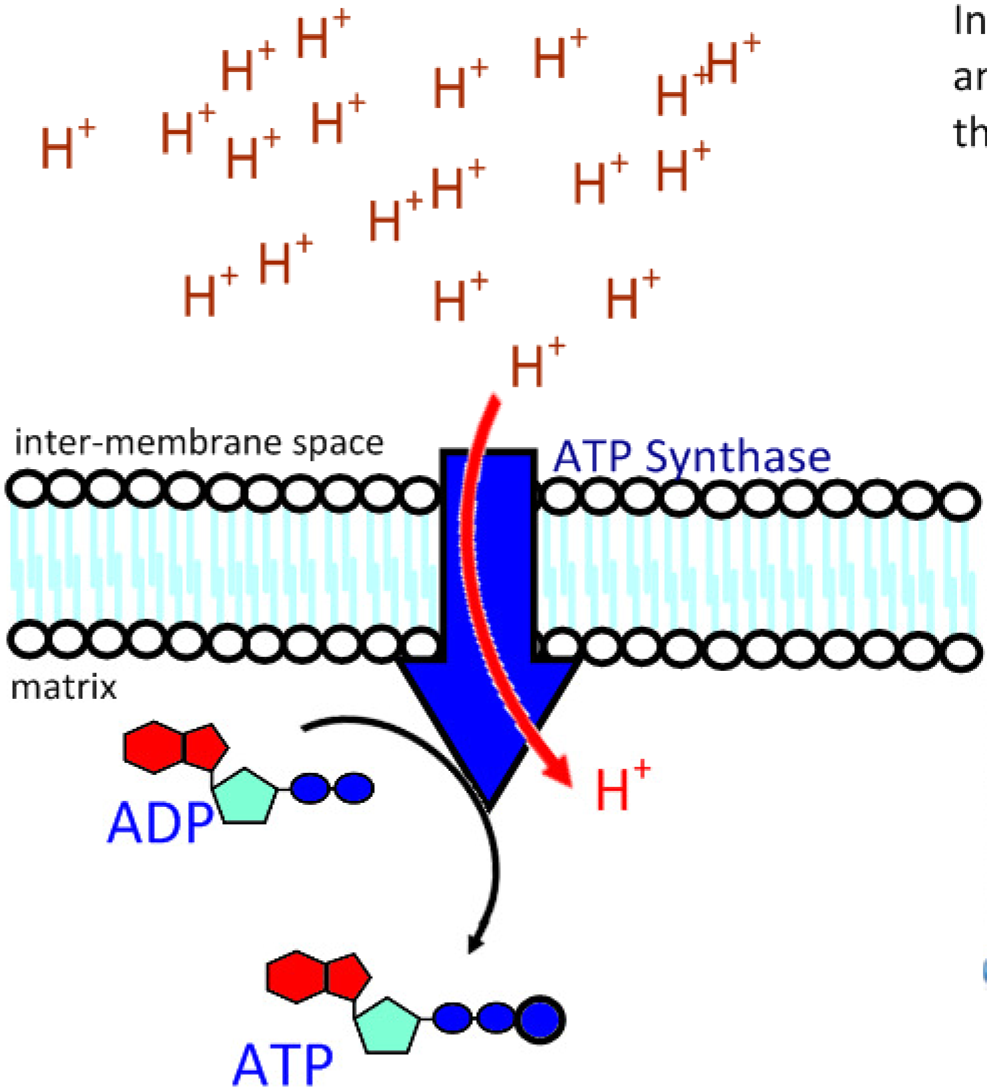
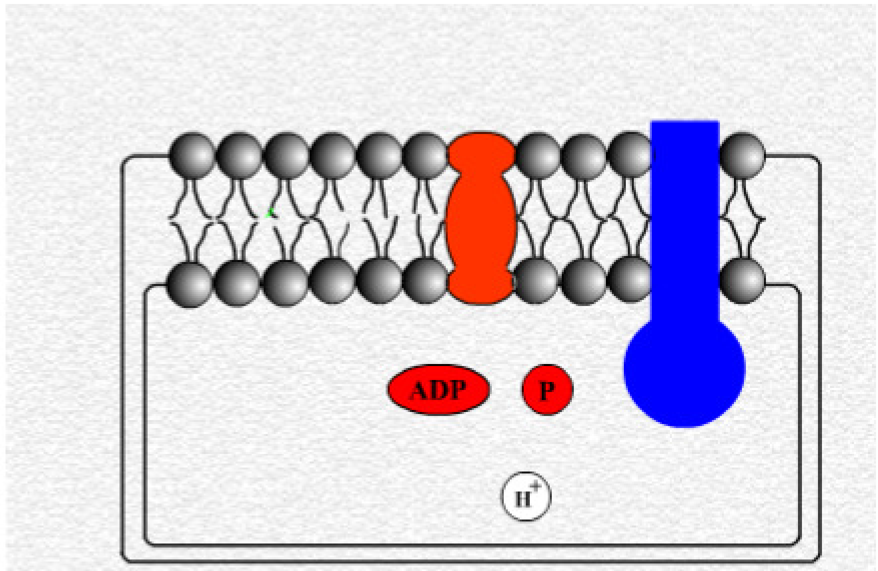
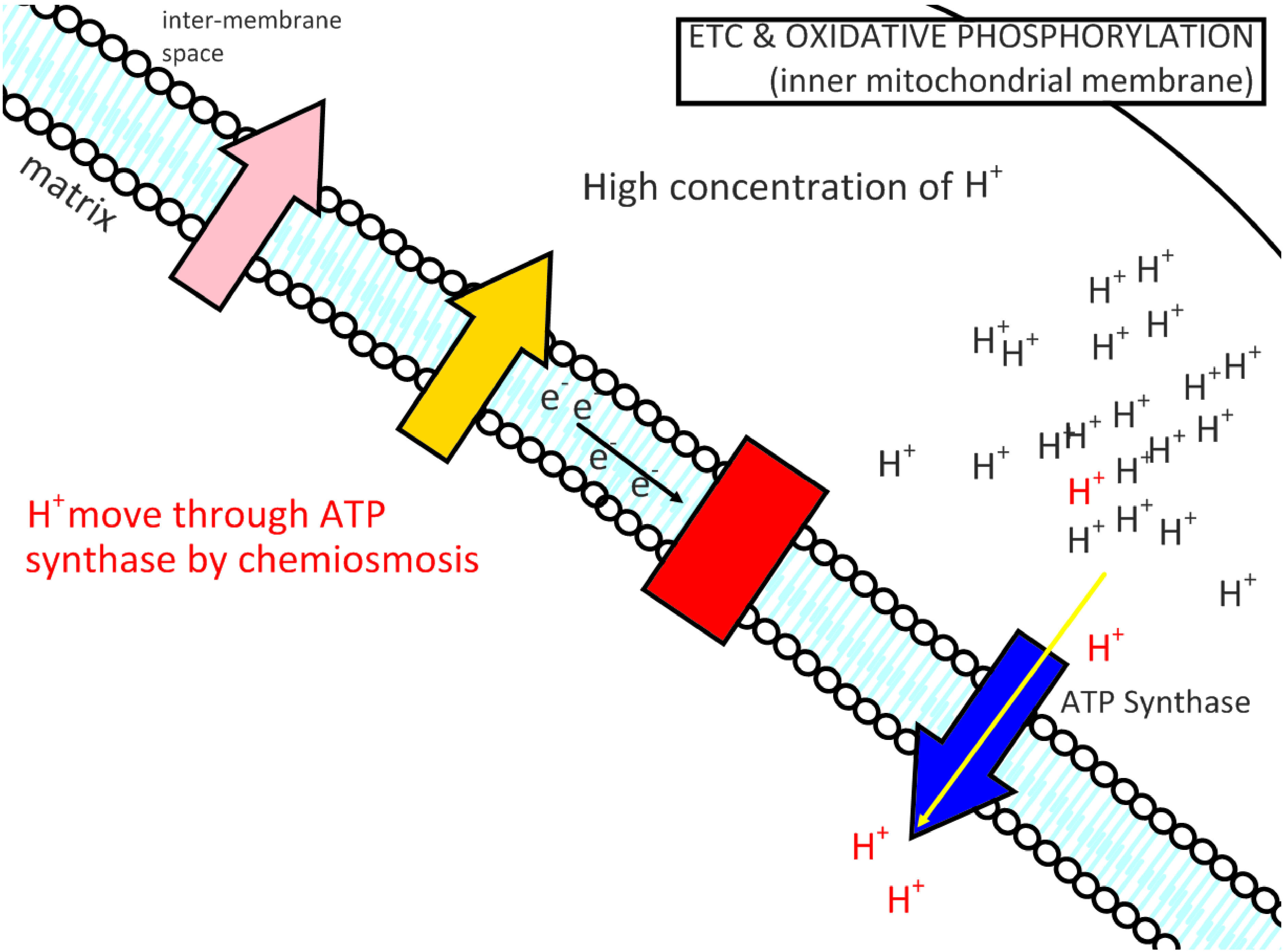
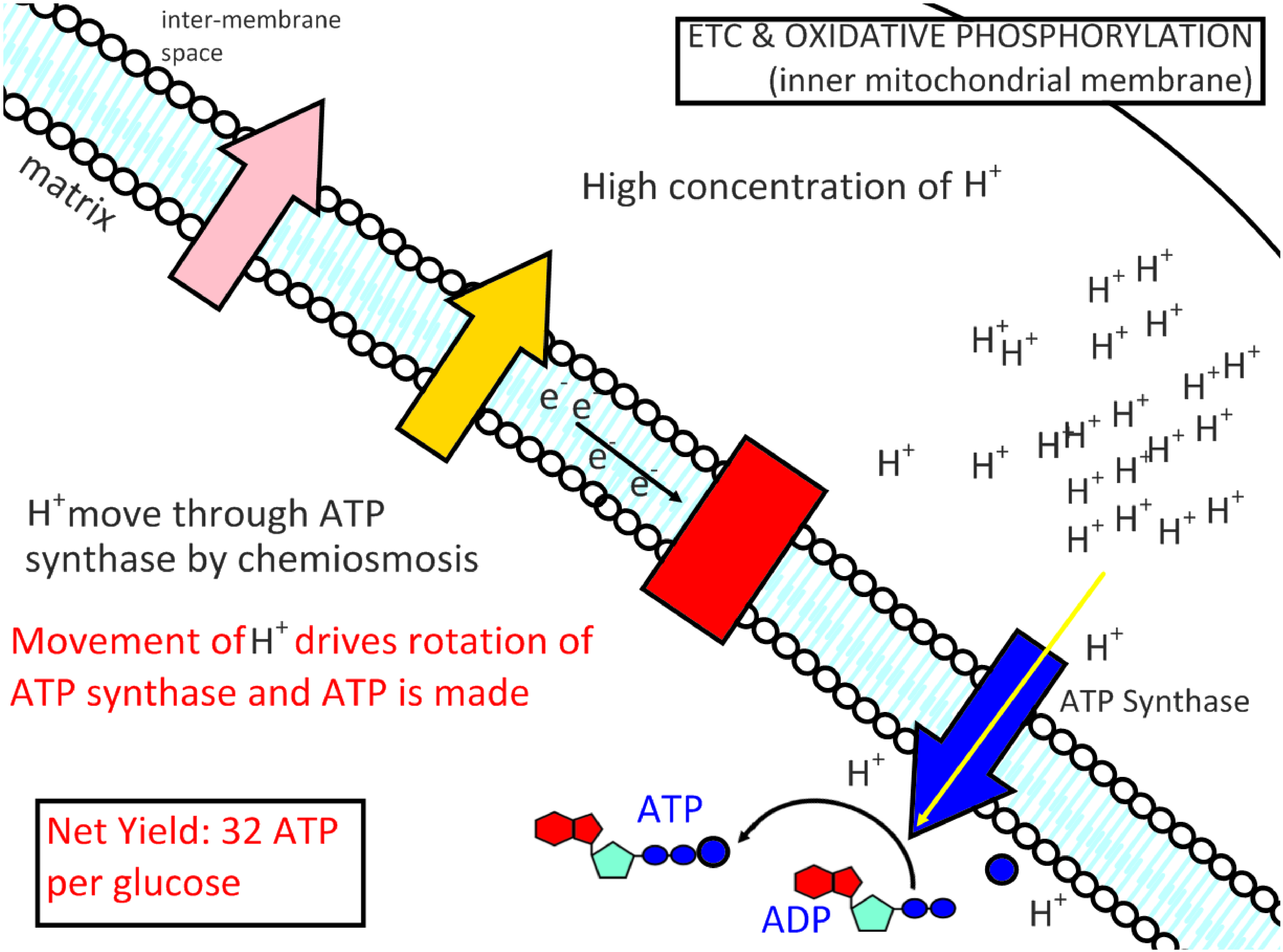


Chemiosmosis:



http://www.tvdsb.on.ca/westmin/science/sbioac/plants/chemios.htm

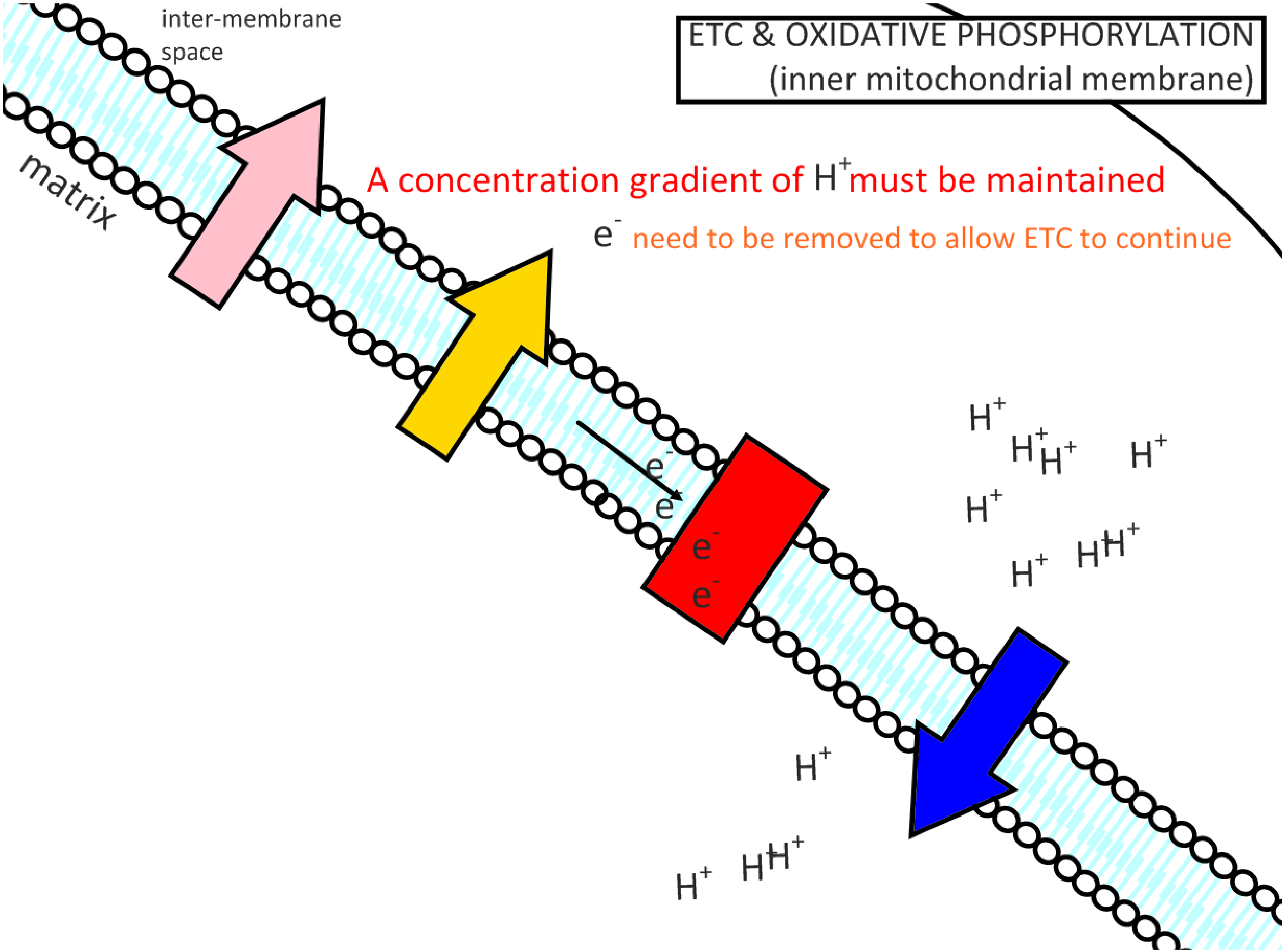

ETC & OXIDATIVE PHOSPHORYLATION
(inner mitochondrial membrane)
inter-membrane space
matrix
High concentration of H+
e-
H+
ATP Synthase
H+ move through ATP synthase by chemiosmosis

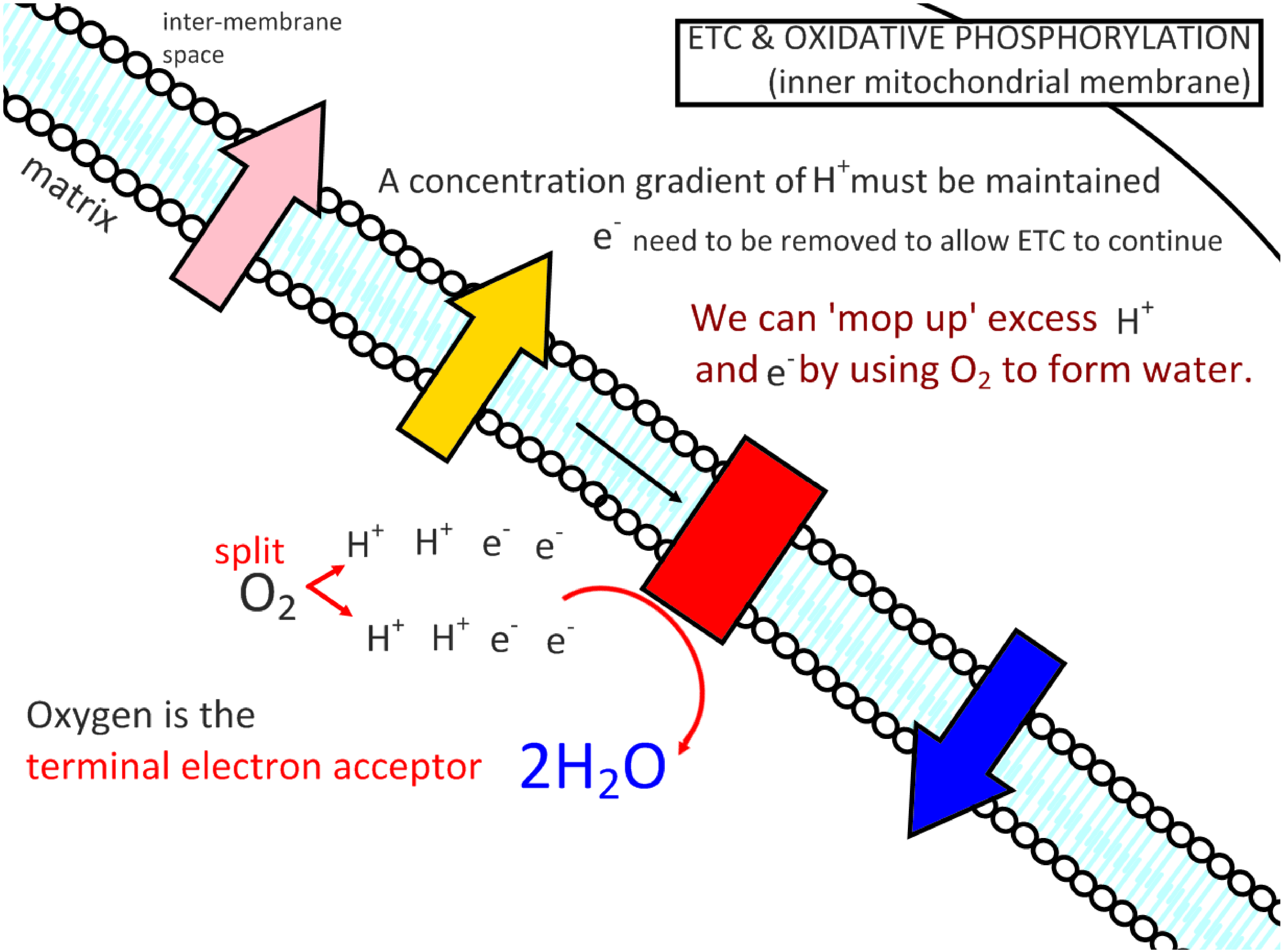

ETC & OXIDATIVE PHOSPHORYLATION
(inner mitochondrial membrane)
inter-membrane space
matrix
High concentration of H^+
e^-
H^+ move through ATP synthase by chemiosmosis
Movement of H^+ drives rotation of ATP synthase and ATP is made
ATP Synthase
ATP
ADP
Net Yield: 32 ATP per glucose

ETC & OXIDATIVE PHOSPHORYLATION (inner mitochondrial membrane)

A concentration gradient of H^+ must be maintained

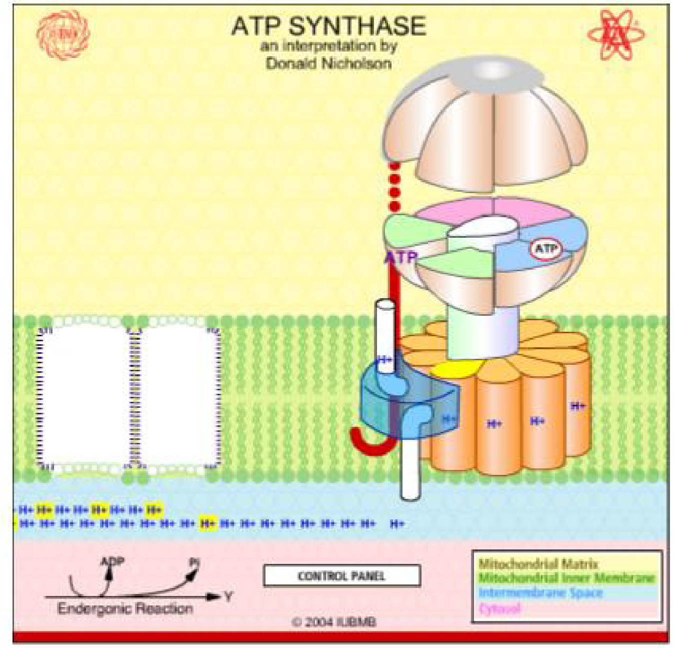
e^- need to be removed to allow ETC to continue



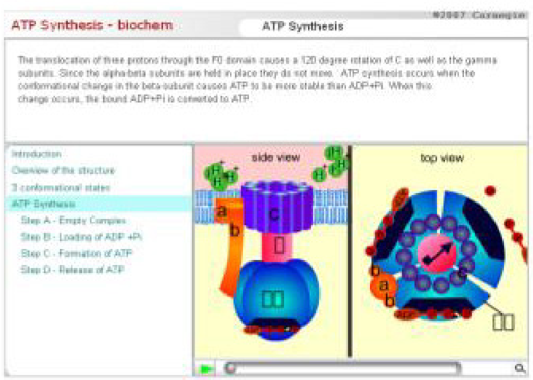

ETC & OXIDATIVE PHOSPHORYLATION
(inner mitochondrial membrane)
inter-membrane
space
matrix
A concentration gradient of H^+ must be maintained
e^- need to be removed to allow ETC to continue
We can 'mop up' excess H^+
and e^- by using O_2 to form water.
split
O_2
H^+ H^+ e^- e^-
H^+ H^+ e^- e^-
Oxygen is the
terminal electron acceptor
$2H_2O$

ATP Synthase & ETC Animations

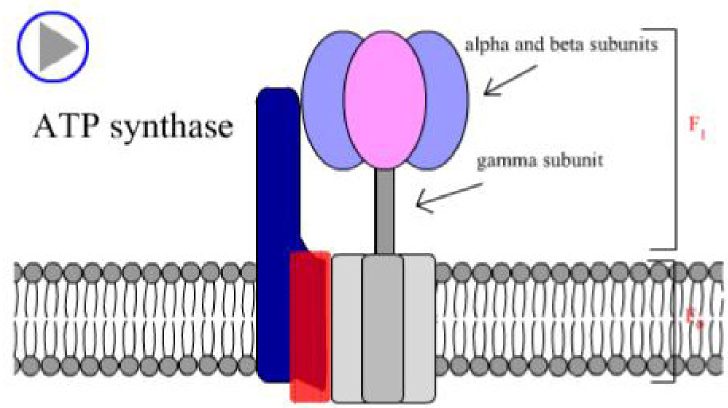
http://www.youtube.com/watch?v=uOoHKCMAUMc



http://www.iubmb-nicholson.org/swf/ATPSynthase.swf



http://tinyurl.com/yewuyg8



http://www.stolaf.edu/people/giannini/flashanimat/metabolism/atpsyn1.swf

Summary of aerobic cell respiration

REACTION/ STAGE	LOCATION	PURPOSE	ATP YIELD

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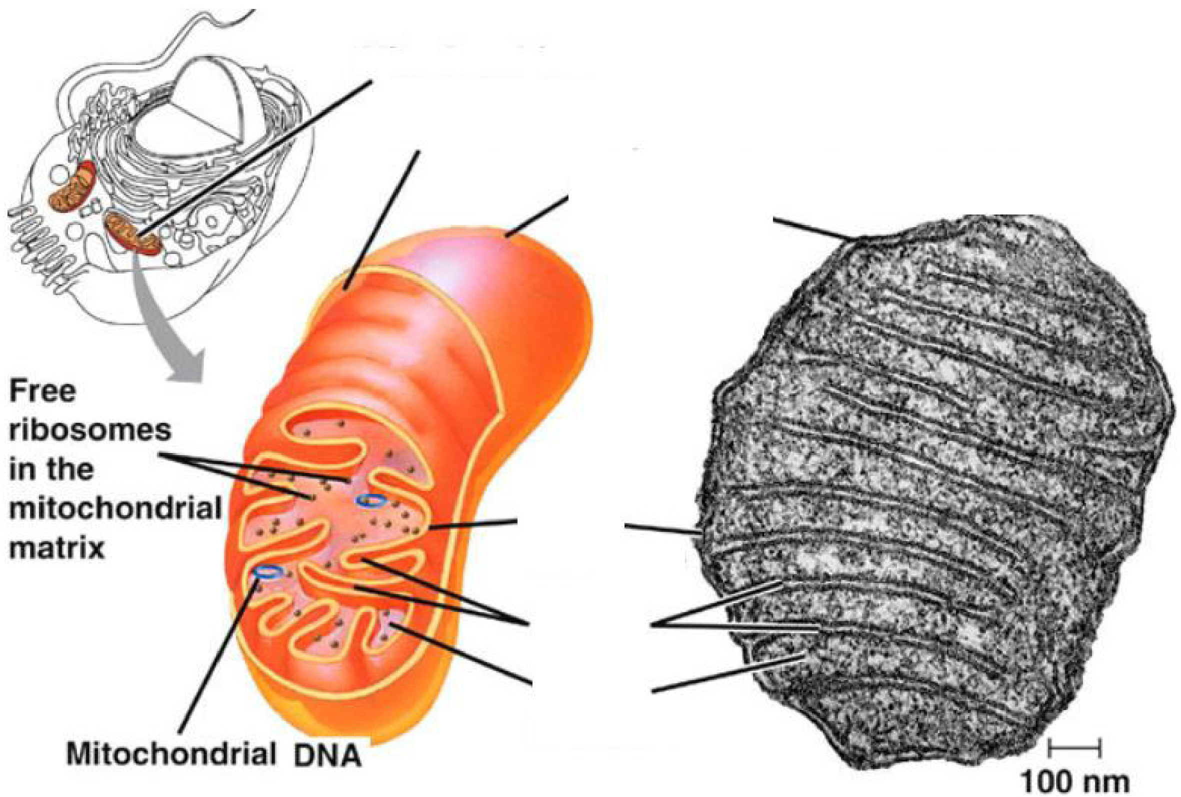
Total ATP yield by aerobic respiration: 36

This is only a rough #...why?

Look at the mitochondrion again:
How is it adapted to carry out its function?

Structure vs function



http://www.bio.miami.edu/~cmallery/150/cells/c7.6.17.mitochondrion.jpg

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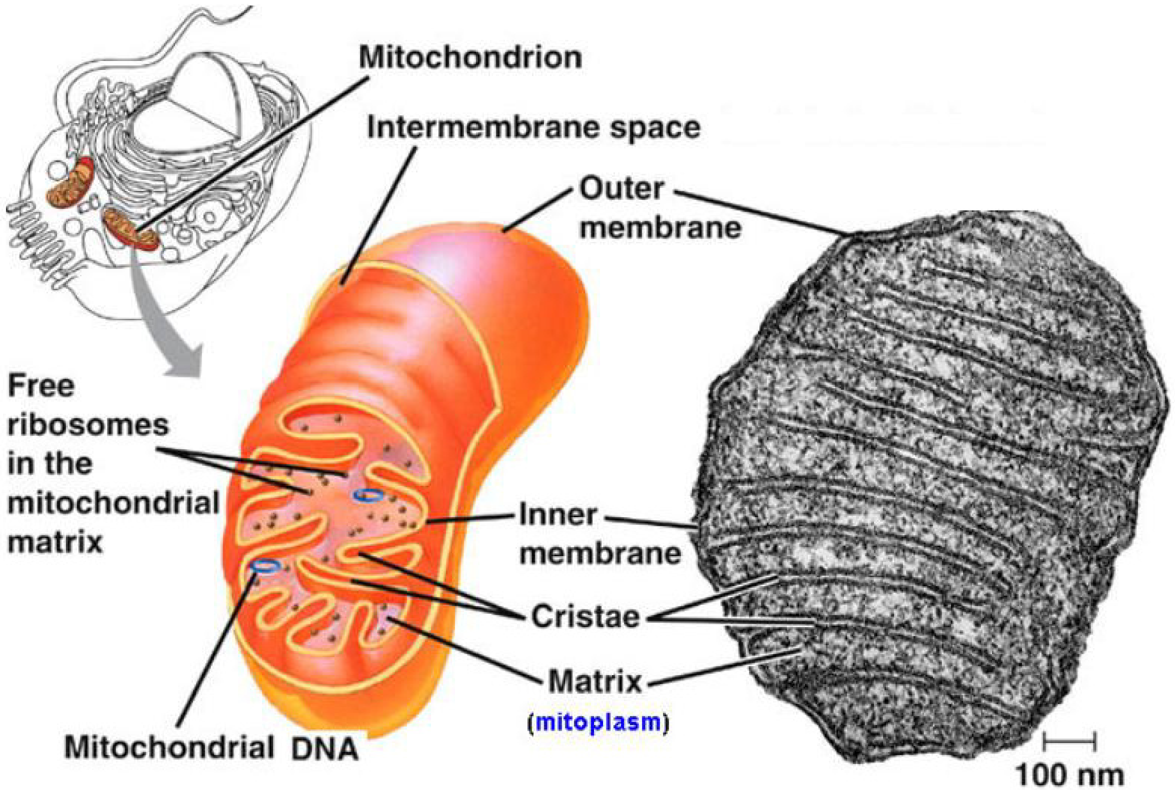

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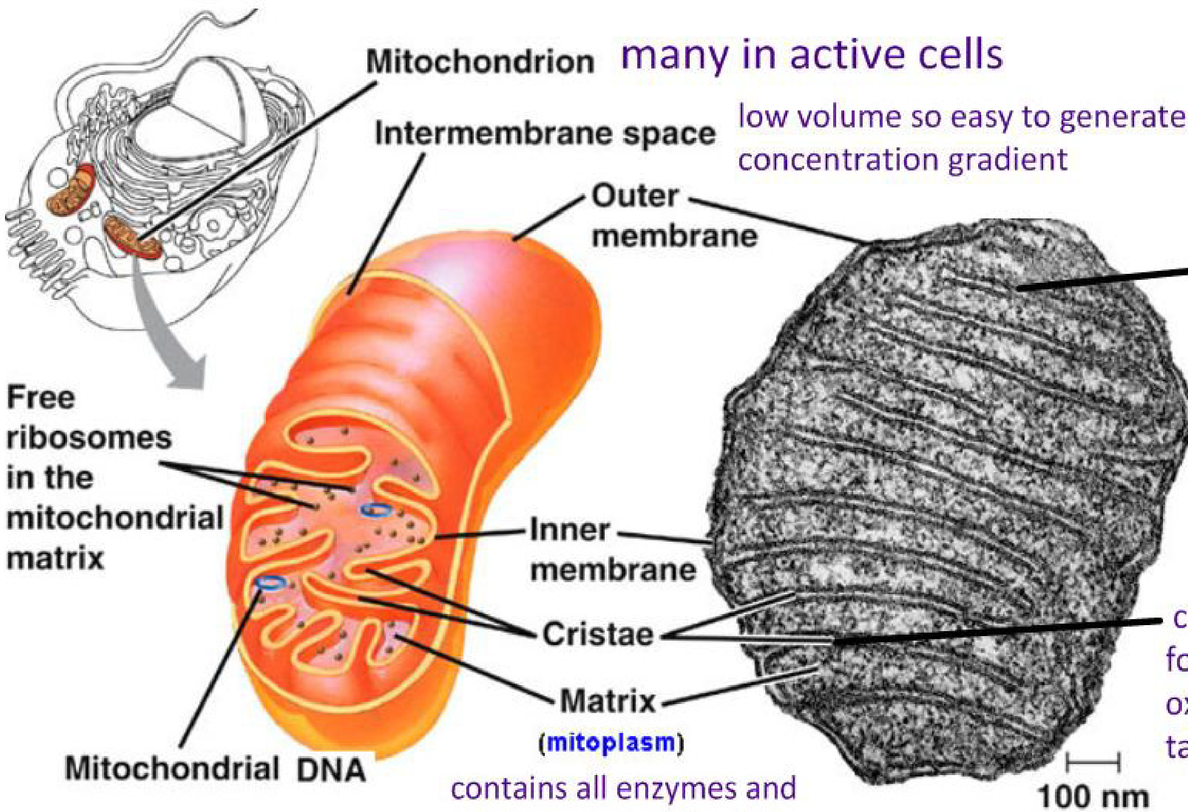


Mitochondrion: many in active cells

Intermembrane space: low volume so easy to generate H^+ concentration gradient

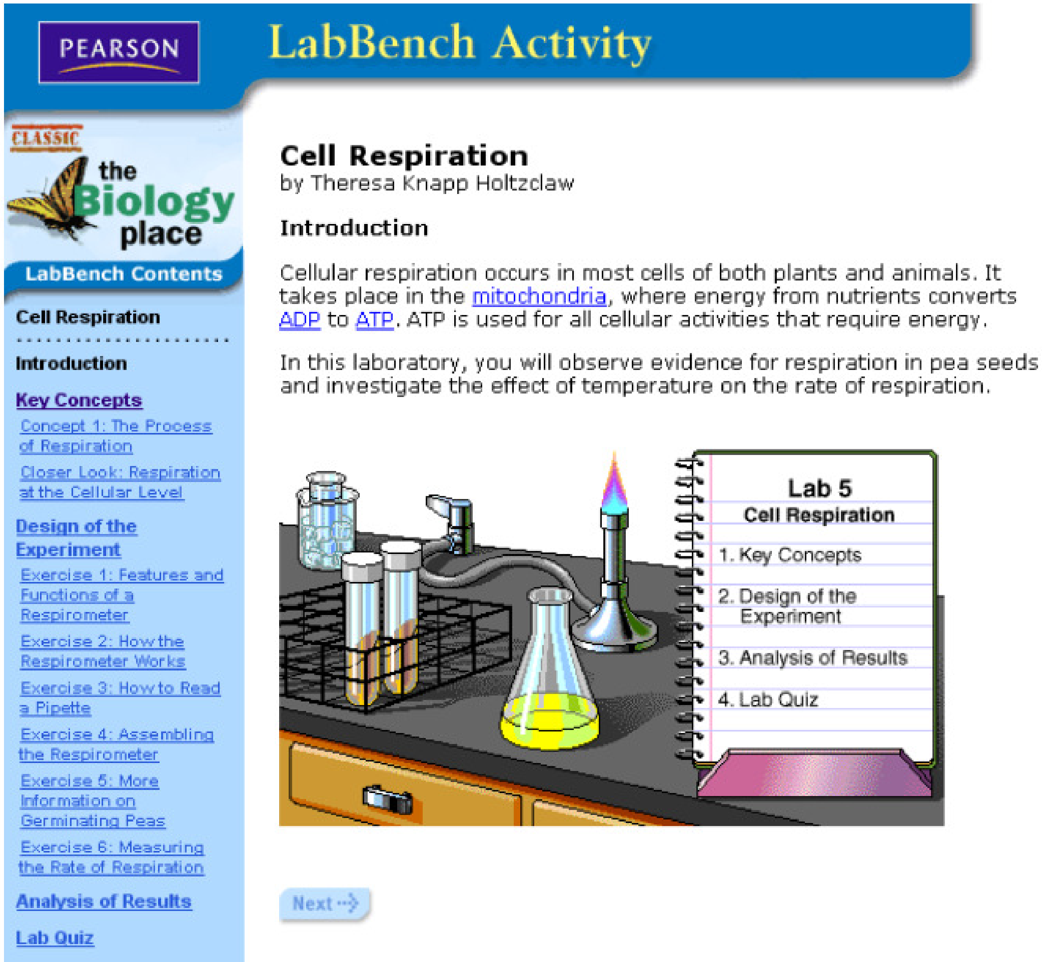
transport proteins and ATP Synthase bound to inner mitochondrial membrane

cristae increase surface area for reactions (ETC and oxidative phosphorylation) to take place

Matrix: contains all enzymes and solutes required for link reaction and Krebs cycle

http://www.bio.miami.edu/~cmallery/150/cells/c7.6.17.mitochondrion.jpg

Try this virtual lab activity:



http://www.phschool.com/science/biology_place/labbench/lab5/intro.html

Remember:

Respiration is a process controlled by enzymes - how will various factors affect the rate of reaction?

Pay attention to the rubric and write up the investigation for DCP and CE.

Which is not a product of the Krebs cycle?

CO_2 NADH + H^+ Pyruvate ATP

Which is not a product of the Krebs cycle?

CO_2 → from oxidative decarboxylation

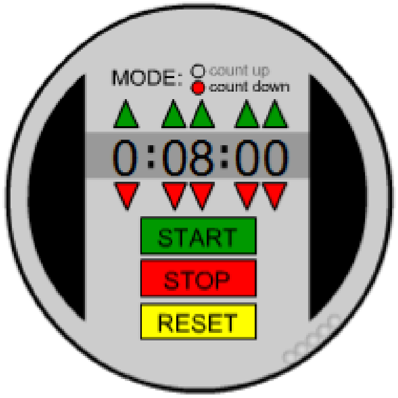
NADH + H^+ → from reduction of NAD^+

Pyruvate → GLYCOLYSIS!

ATP → 4C rearrangement

Explain the process of aerobic cellular respiration.

(8 marks)



Explain the process of aerobic cellular respiration.

(8 marks)

glucose is broken down to pyruvate in the cytoplasm;
with a small yield of ATP/net yield of 2 ATP;
and NADH + H^+/NADH;

aerobic respiration in the presence of oxygen;
pyruvate converted to acetyl CoA;
acetyl CoA enters Krebs cycle;

Krebs cycle yields a small amount of ATP/one ATP per cycle;
and $FADH_2$ / FADH + H^+ / NADH/ NADH + H^+ /
reduced compounds / electron collecting molecules;

these molecules pass electrons to electron transport chain;
oxygen is final electron acceptor/water produced;
electron transport chain linked to creation of an electrochemical gradient;
electrochemical gradient/chemiosmosis powers creation of ATP;
through ATPase;

From the QuestionBank CDRom

Cellular Respiration Song

- http://www.youtube.com/watch?v=3aZrkdzrd04

"Oxidate it or love it" / "Electron to the next one" (Stanford)

- http://www.youtube.com/watch?v=VCpNk92uswY

Kickstarting his group, the Rhymbosomes:
(http://therhymebosome.wordpress.com/2012/02/29/oxidate-it-or-love-it-electron-to-the-next-one-lyrics/)

- http://www.youtube.com/watch?v=PjdPTY1wHdQ
- http://www.iubmb-nicholson.org/swf/ATPSynthase.swf
- http://www.stolaf.edu/people/giannini/flashanimat/metabolism/atpsyn1.swf