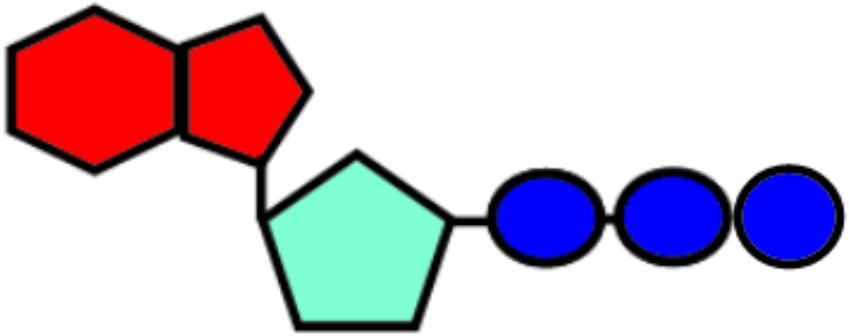


Cellular Respiration (Option C/AHL)

Stephen Taylor
Bandung International School

Cell Respiration: Spaced Learning Experiment

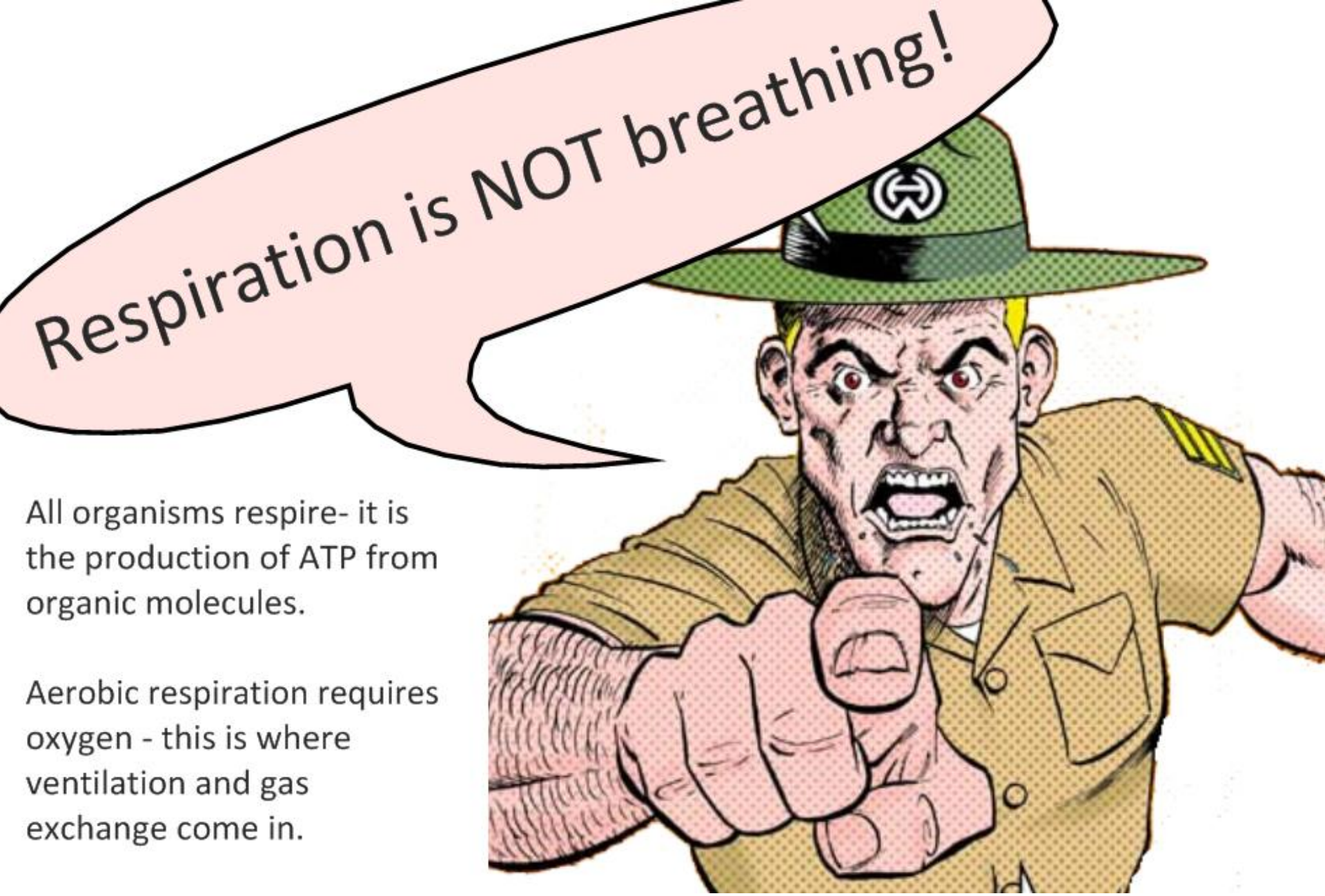
100 Slides in 20 minutes!

No pens, no notes: just *focus*

Instructions:
- work through all of these slides in one go
- focus, don't take notes
- at the end, work on ten minutes of juggling (or playing music, or exercise)
  -don't think about the topic!
- repeat the cycle two more times
- complete a vocab/comprehesion/review activity a couple of days later,
  as well as the Essential Biology: Respiration document

(Spaced learning links at the end of the presentation)

Don't use the animations in the Spaced Learning - save them for review and deeper understanding.



All organisms respire- it is the production of ATP from organic molecules.

Aerobic respiration requires oxygen - this is where ventilation and gas exchange come in.

Cell Respiration

"The controlled release of energy

by enzymes:
metabolic pathways and cycles!

Cell Respiration

"The controlled release of energy

by enzymes:
metabolic pathways and cycles!

How can cells control the rate of enzyme catalysed pathways and cycles?

Cell Respiration

"The controlled release of energy

by enzymes:

metabolic pathways and cycles!

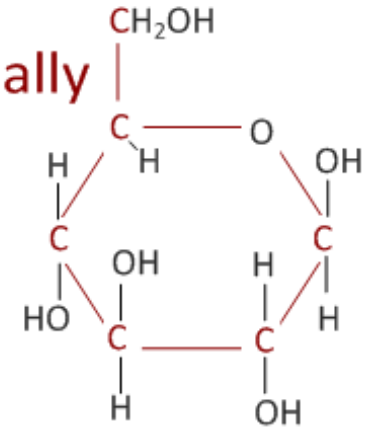
How can cells control the rate of enzyme catalysed pathways and cycles?

end product inhibition!

Cell Respiration

"The controlled release of energy from organic compounds in cells

usually

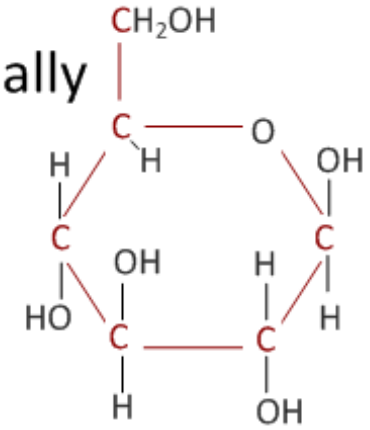


glucose/ carbohydrates

Cell Respiration

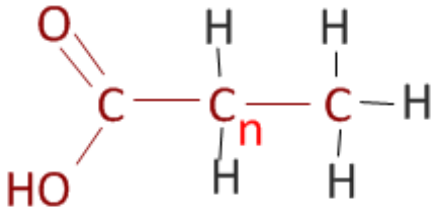
"The controlled release of energy from organic compounds in cells

usually

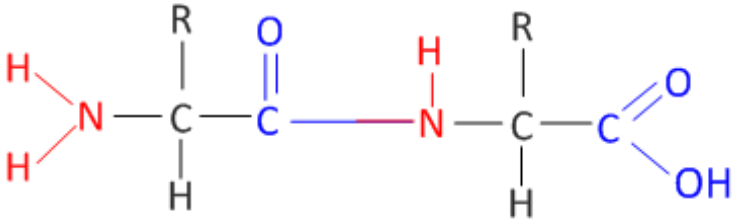


glucose/ carbohydrates

sometimes



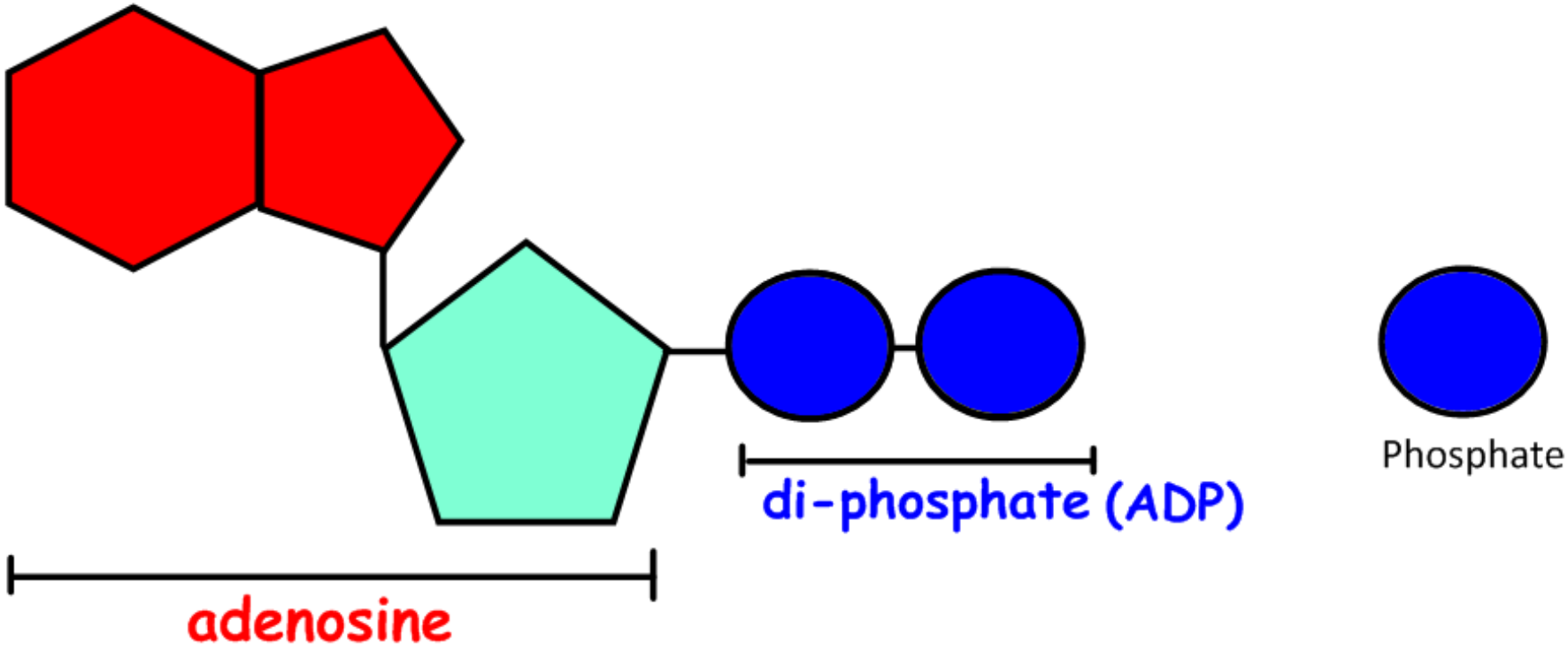
lipids/ fatty acids



proteins

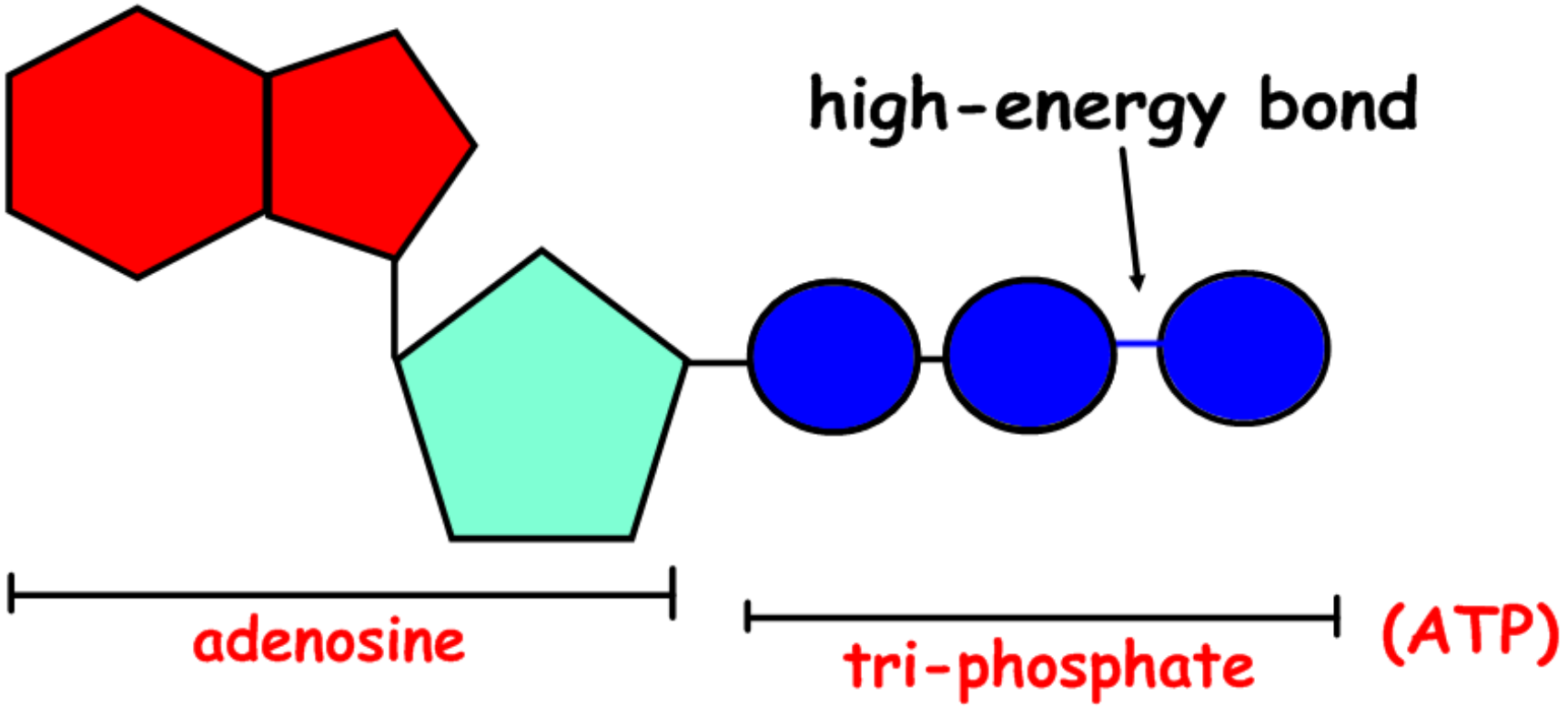
Cell Respiration

"The controlled release of energy from organic compounds in cells to form ATP"



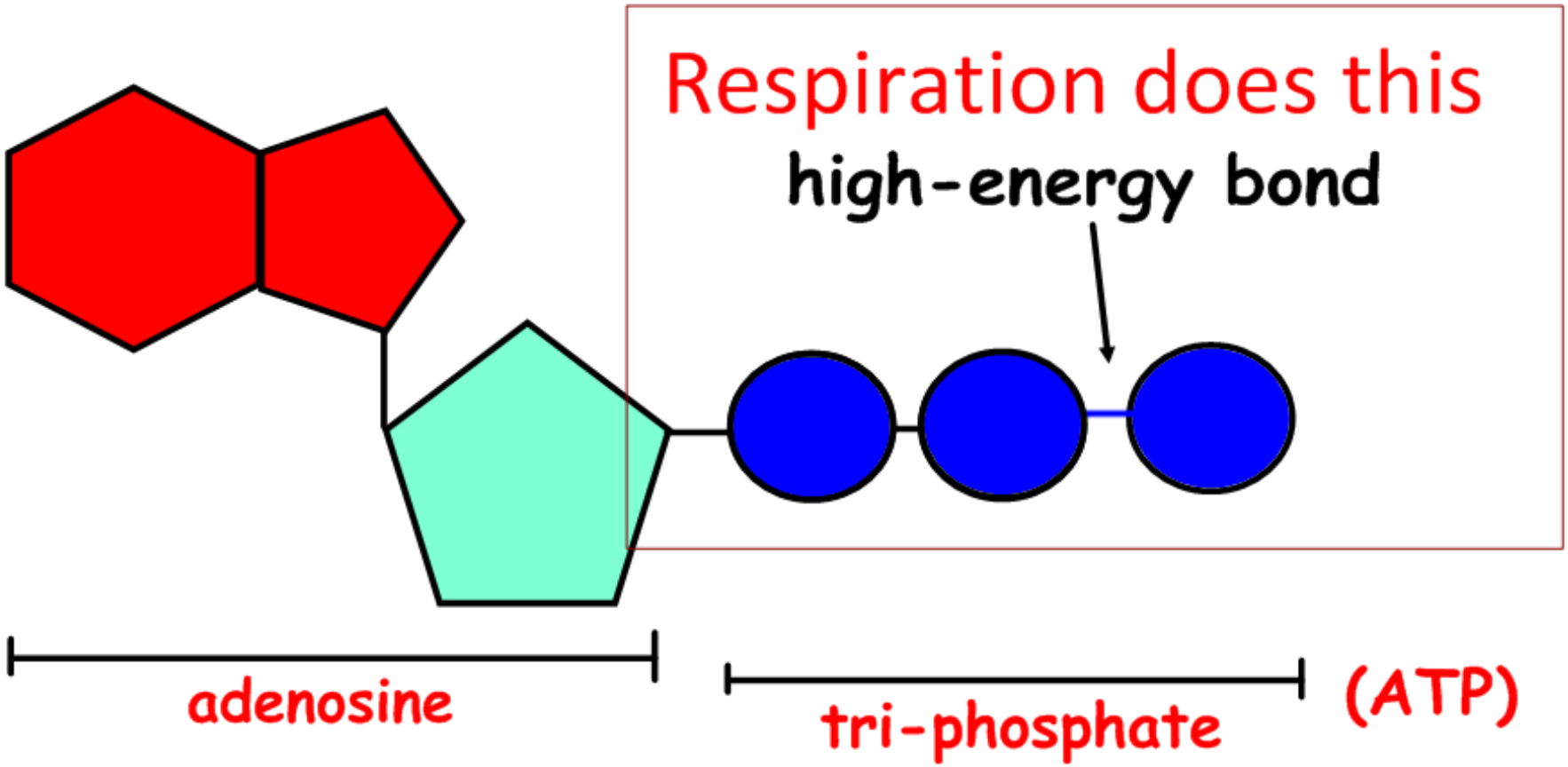
Cell Respiration

"The controlled release of energy from organic compounds in cells to form ATP"



Cell Respiration

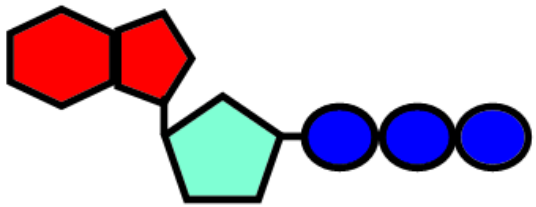
"The controlled release of energy from organic compounds in cells to form ATP"



Cell Respiration

Universality vs diversity!

"The controlled release of energy from organic compounds in cells to form ATP"



used for
energetic processes

muscle contraction

active transport

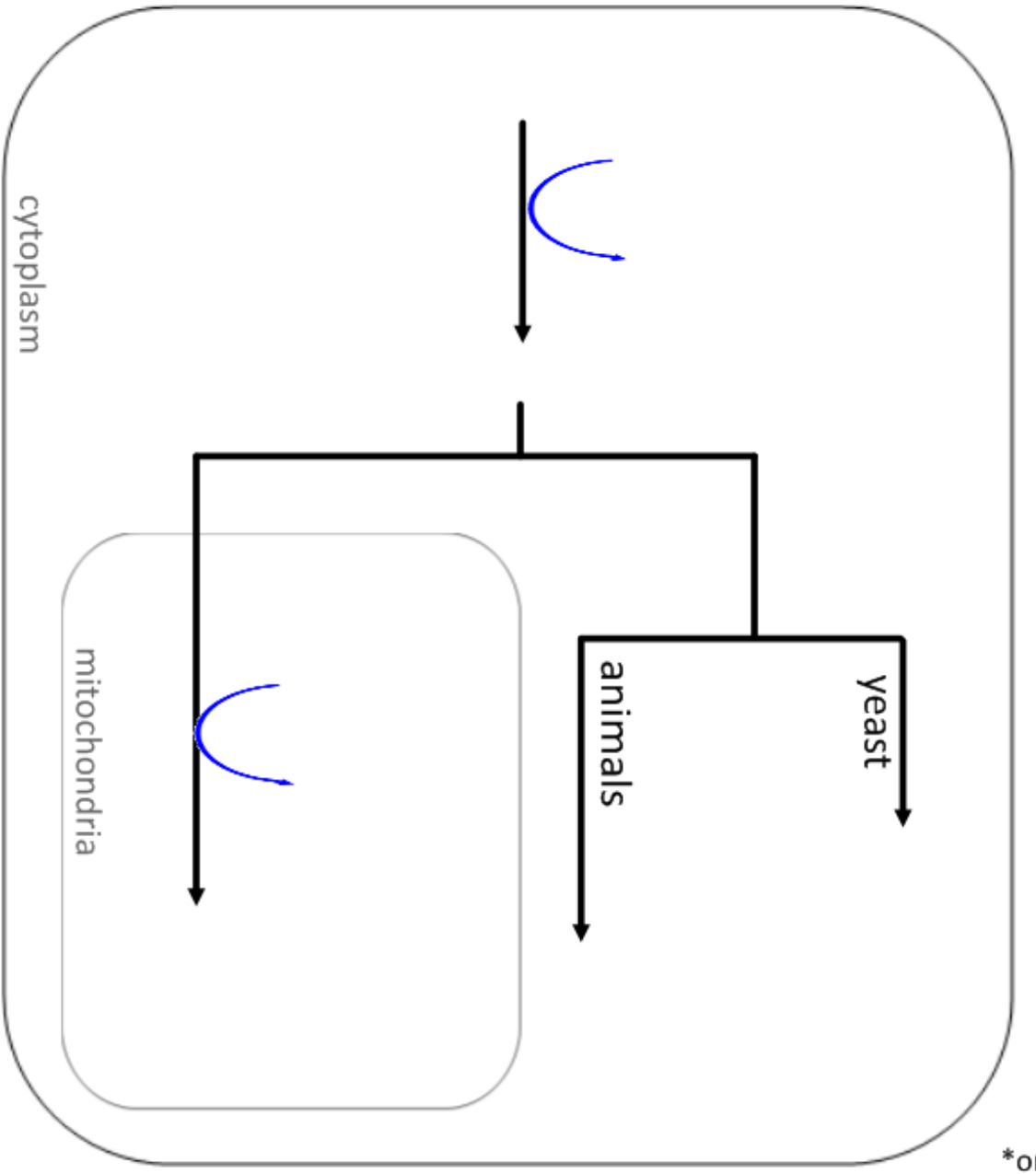
protein synthesis

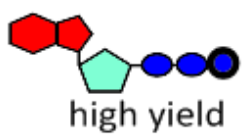
vesicle transport

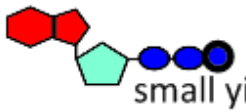
DNA/ RNA replication

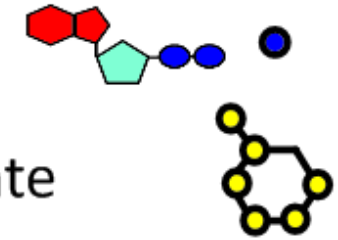
cell signalling

Drag 'n' Drop*









2 x Pyruvate

Glucose

no O_2

O_2

ethanol

lactic acid

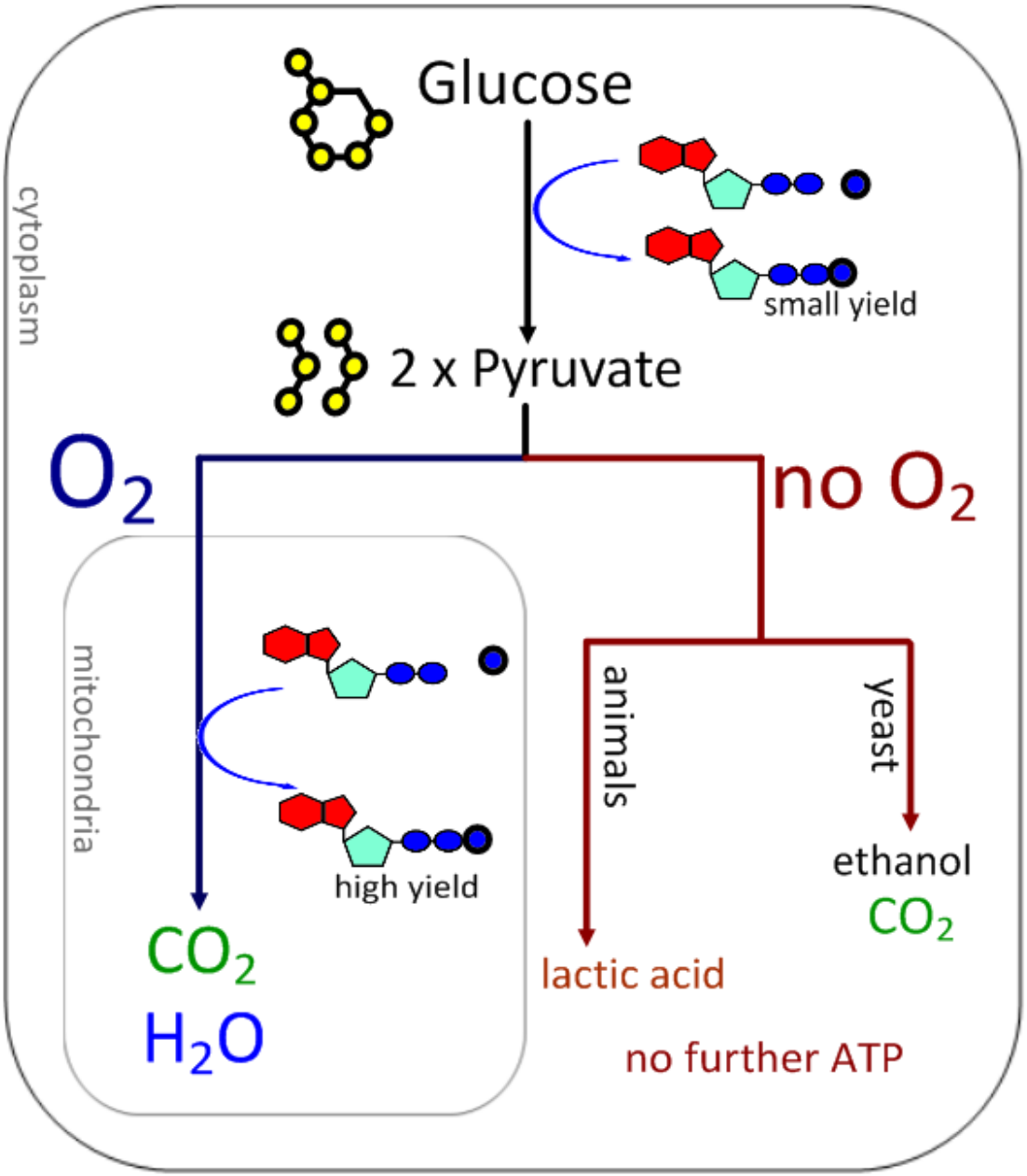
CO_2

CO_2

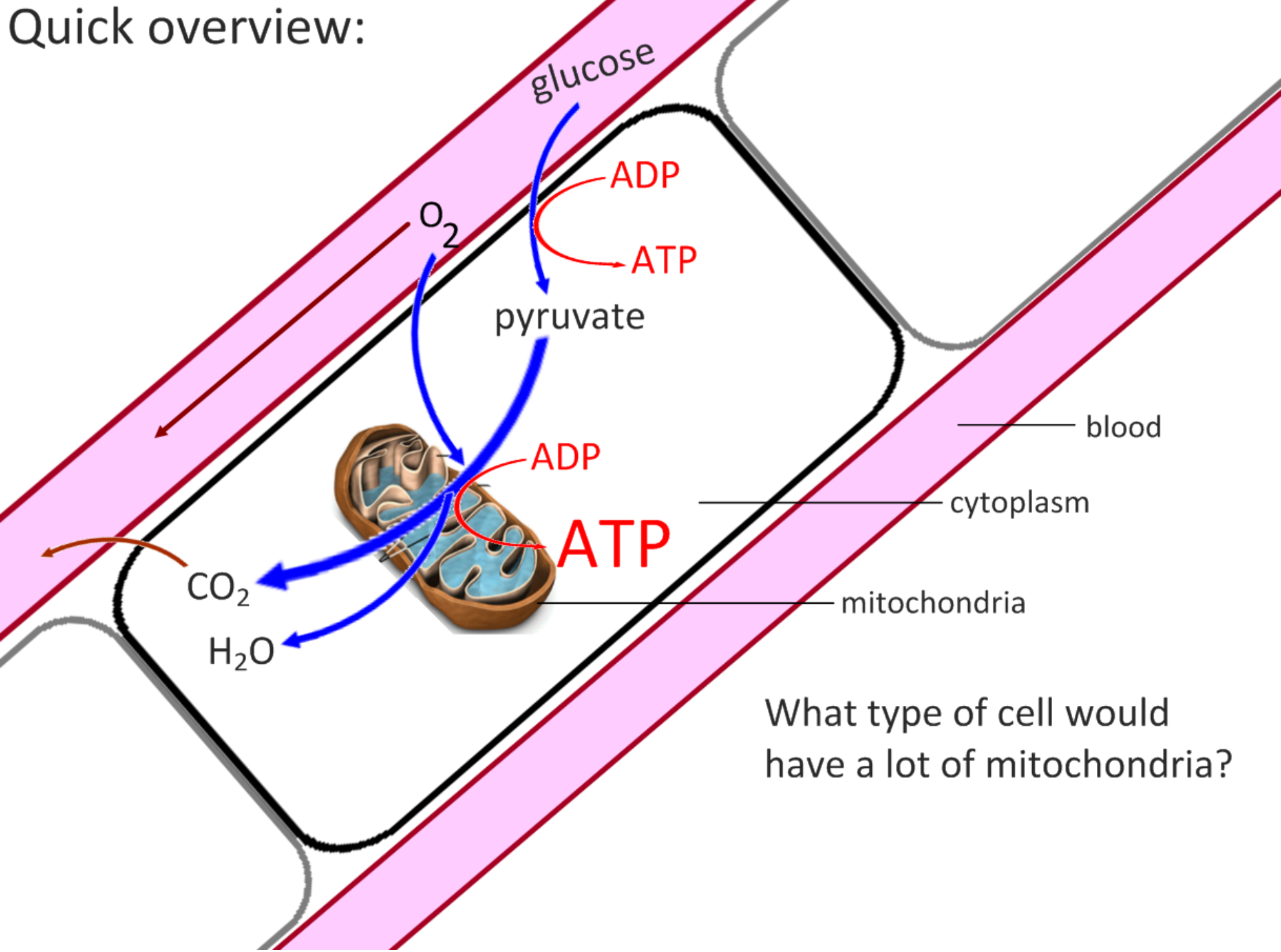
H_2O

no further ATP

*or print and write


Glucose
small yield
2 x Pyruvate
cytoplasm
O_2
no O_2
mitochondria
high yield
animals
yeast
ethanol
CO_2
CO_2
H_2O
lactic acid
no further ATP

Quick overview:



What type of cell would have a lot of mitochondria?

"Respiration is the controlled release of energy from organic compounds in cells to form ATP"

$C_6H_{12}O_6$

glucose
(an organic molecule)

"Respiration is the controlled release of energy from organic compounds in cells to form ATP"

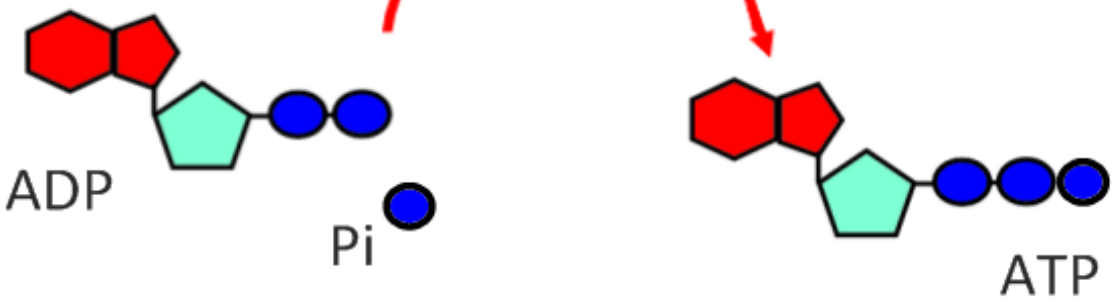
$C_6H_{12}O_6 + 6O_2$

oxygen:
aerobic respiration
gives a better
yield of
ATP

"Respiration is the controlled release of energy from organic compounds in cells to form ATP"

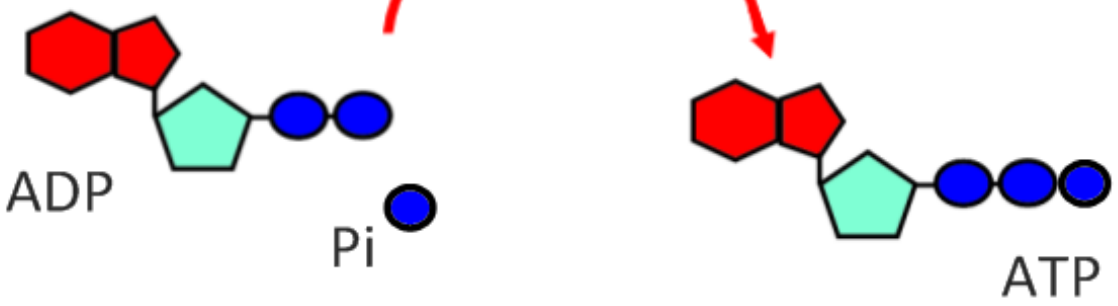
"Respiration is the controlled release of energy from organic compounds in cells to form ATP"

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



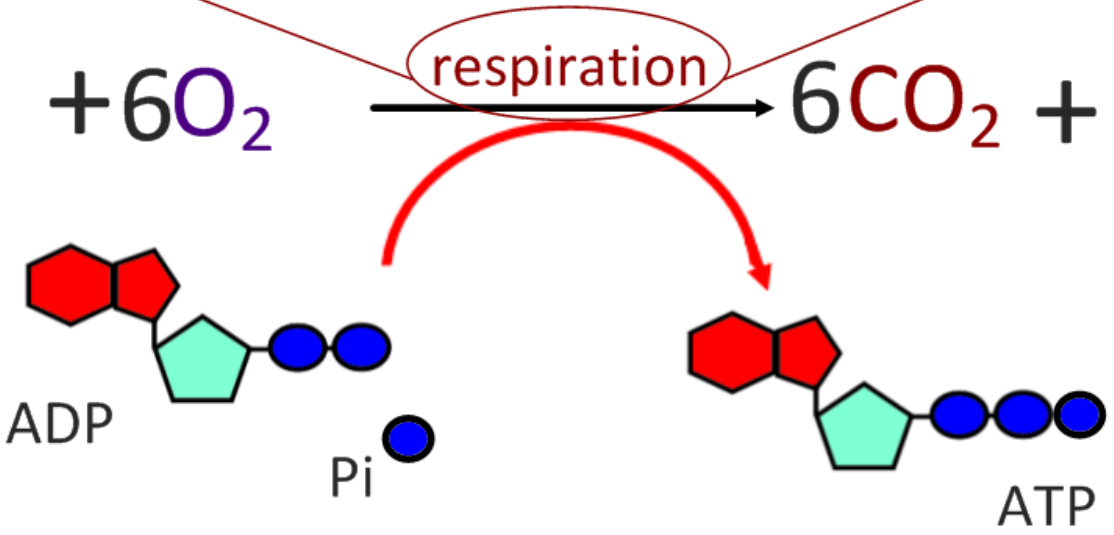
glycolysis → link reaction → Kreb's cycle → electron transport chain → oxidative phosphorylation

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



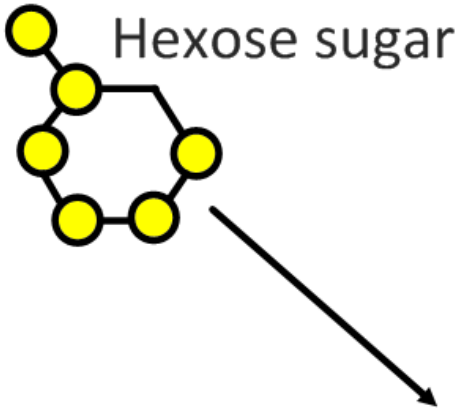
glycolysis

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



GLYCOLYSIS

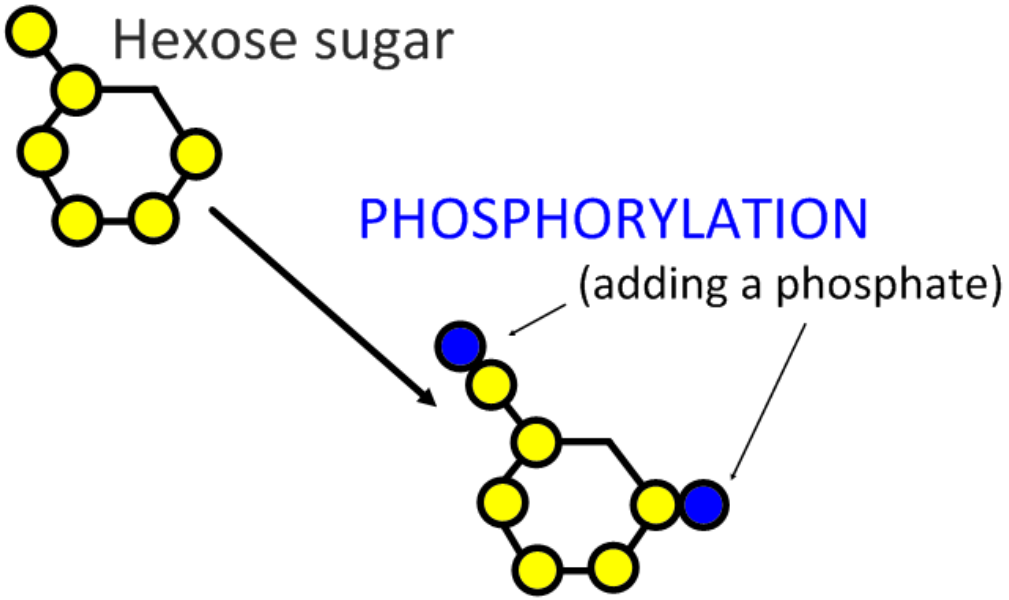
sugar splitting



(cytoplasm)

GLYCOLYSIS

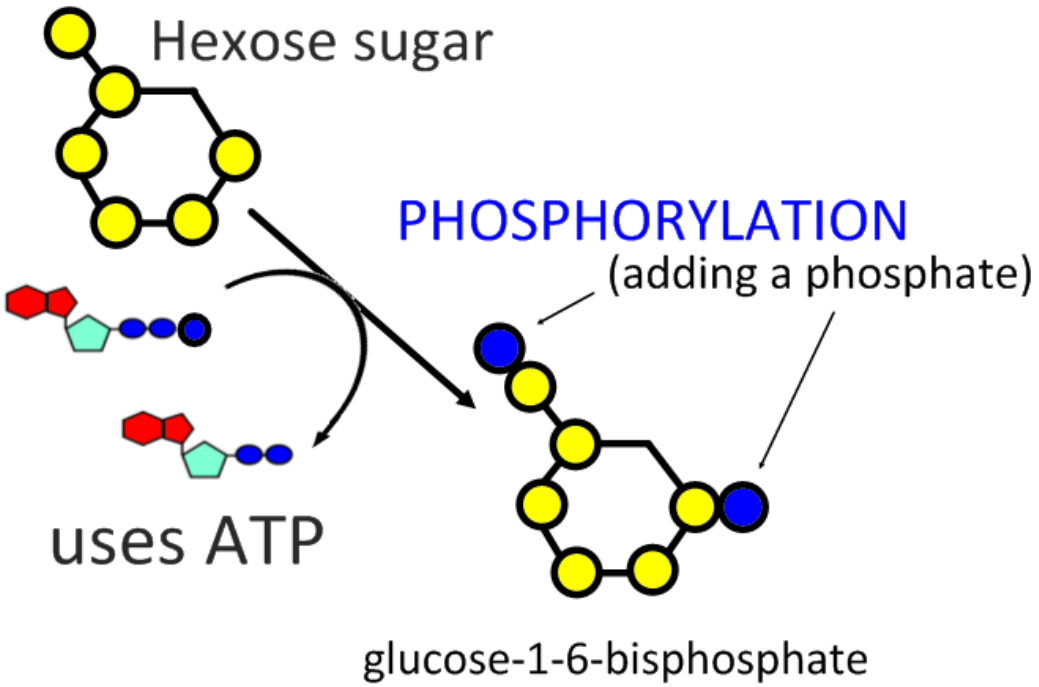
sugar splitting



(cytoplasm)

GLYCOLYSIS

sugar splitting

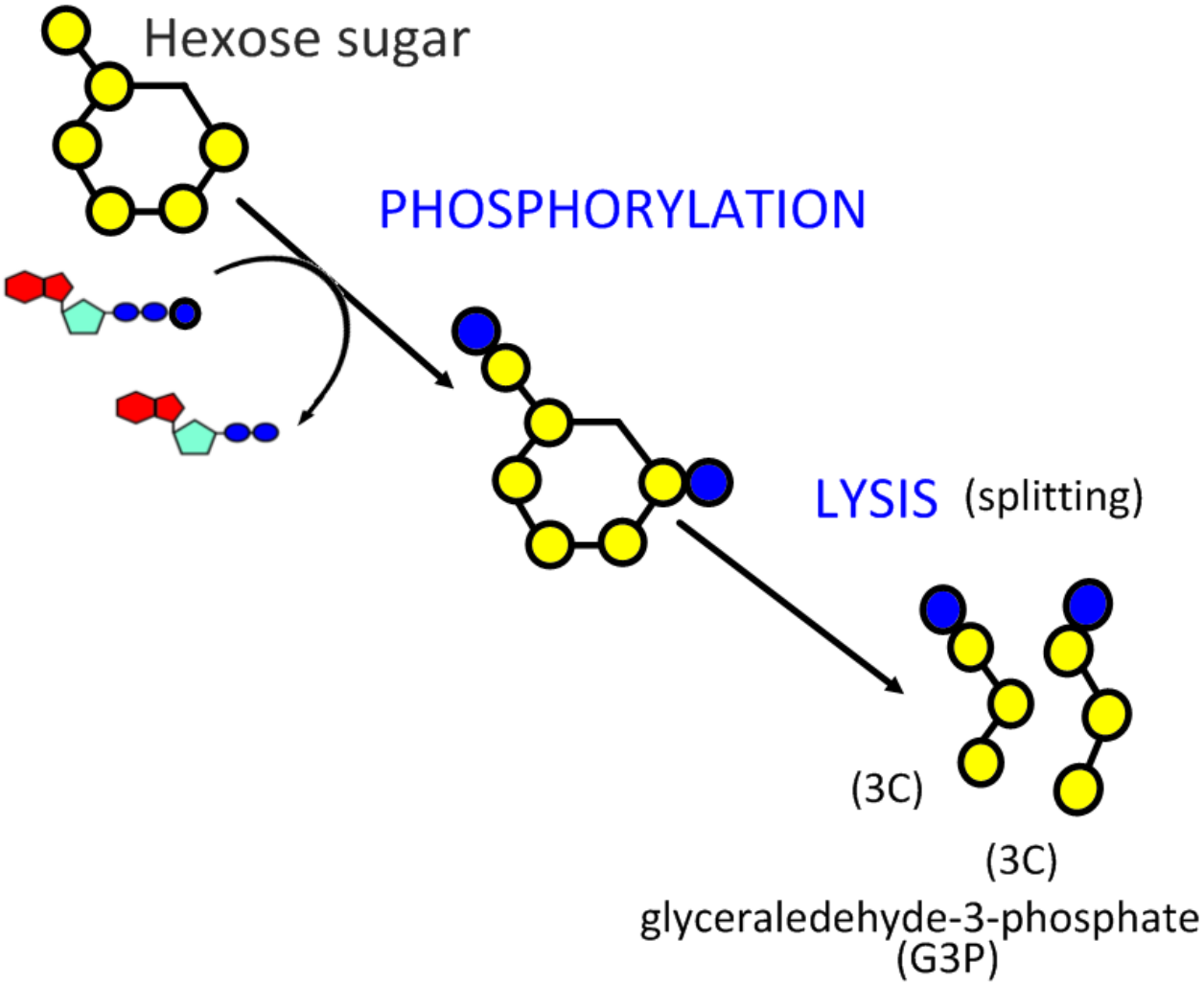


(cytoplasm)

GLYCOLYSIS

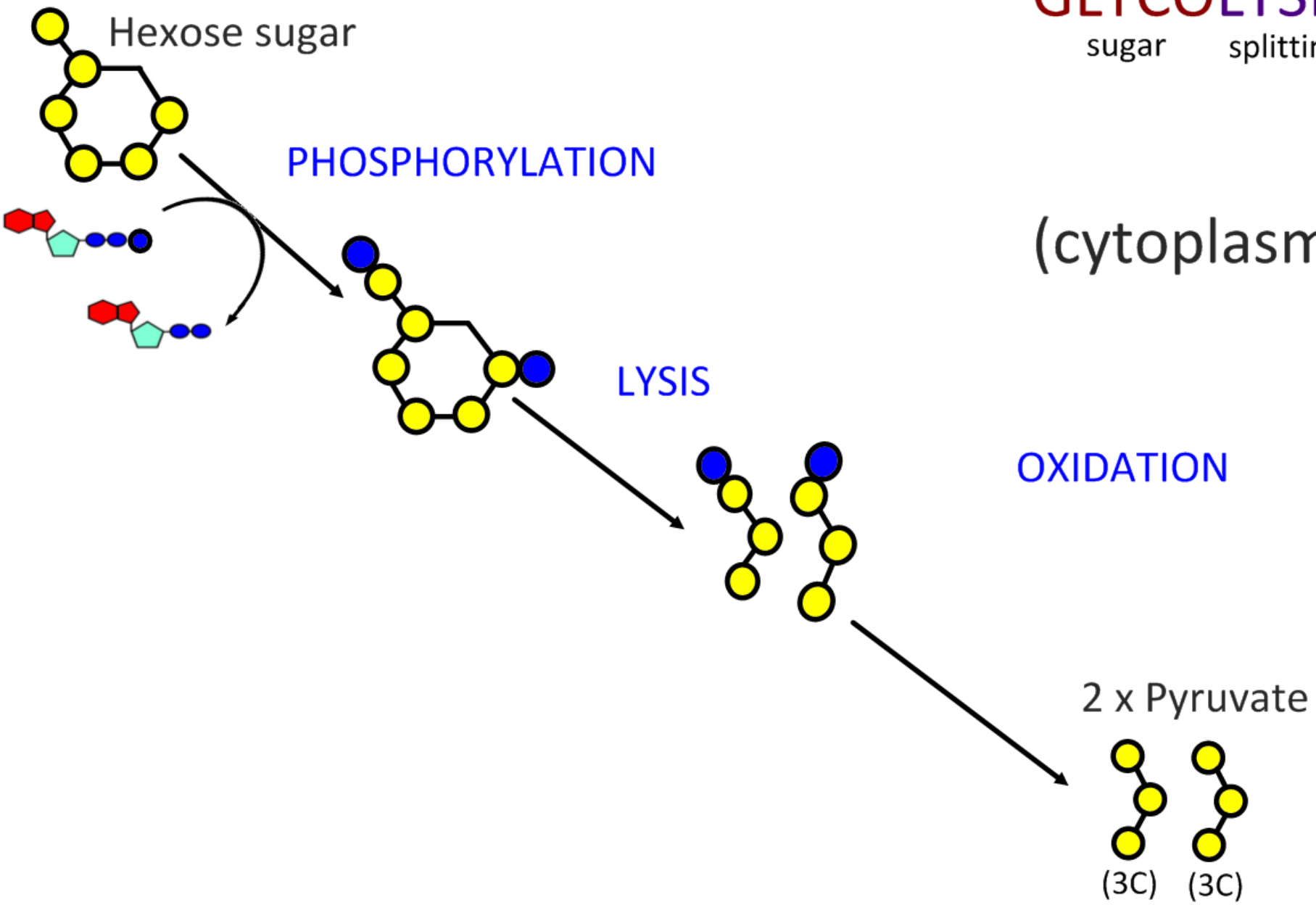
sugar splitting

(cytoplasm)



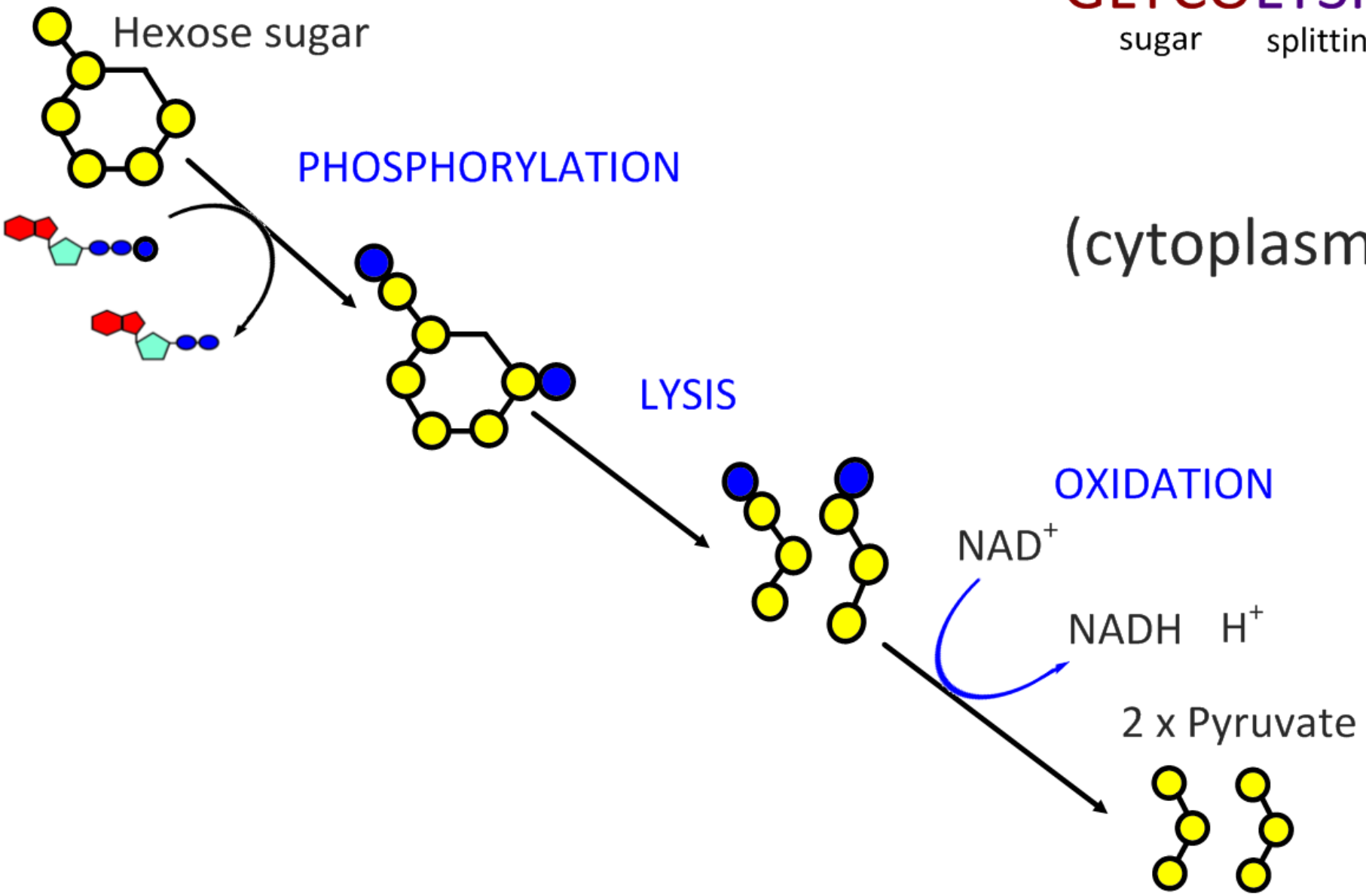
GLYCOLYSIS

sugar splitting



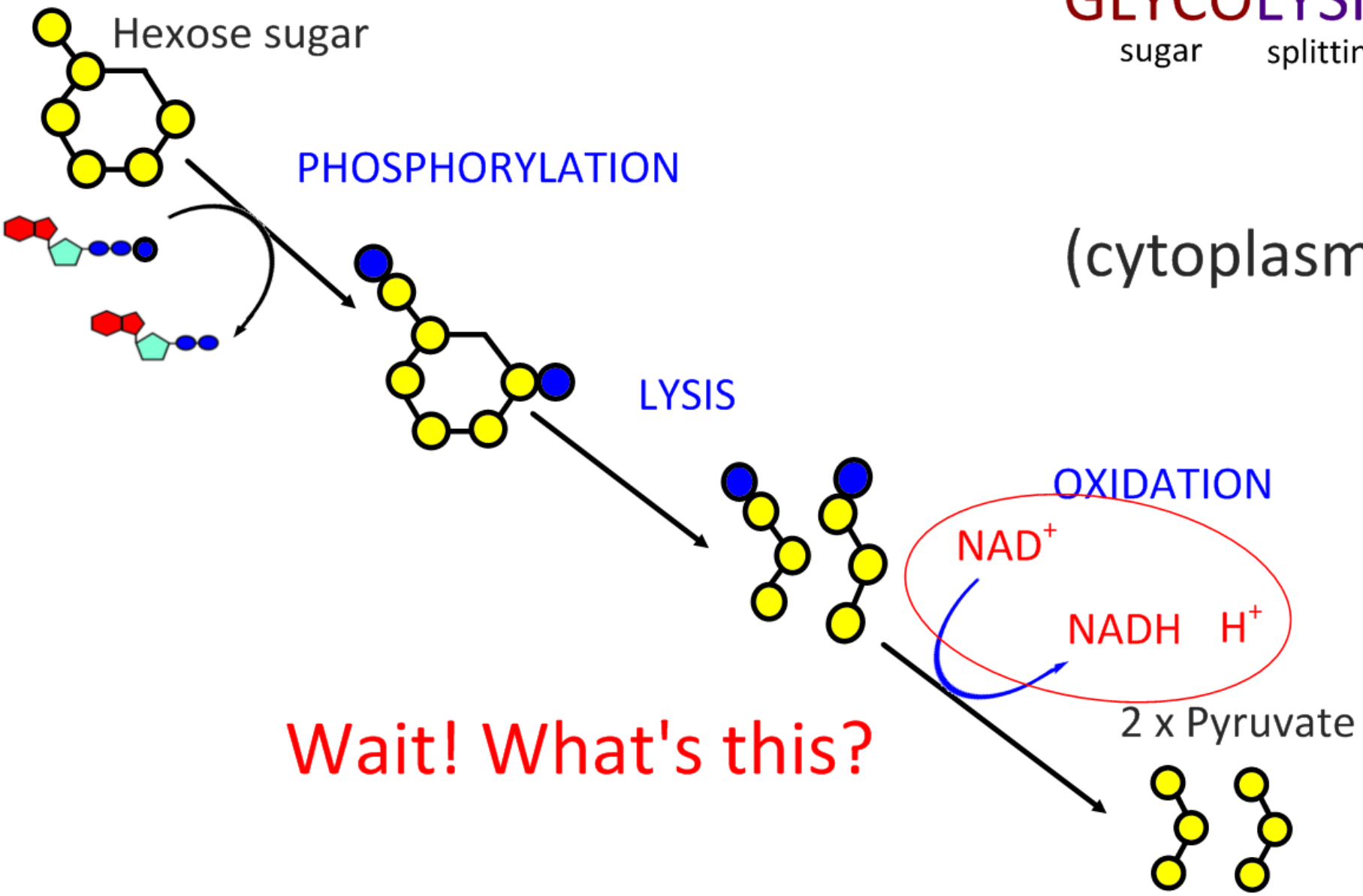
GLYCOLYSIS

sugar splitting

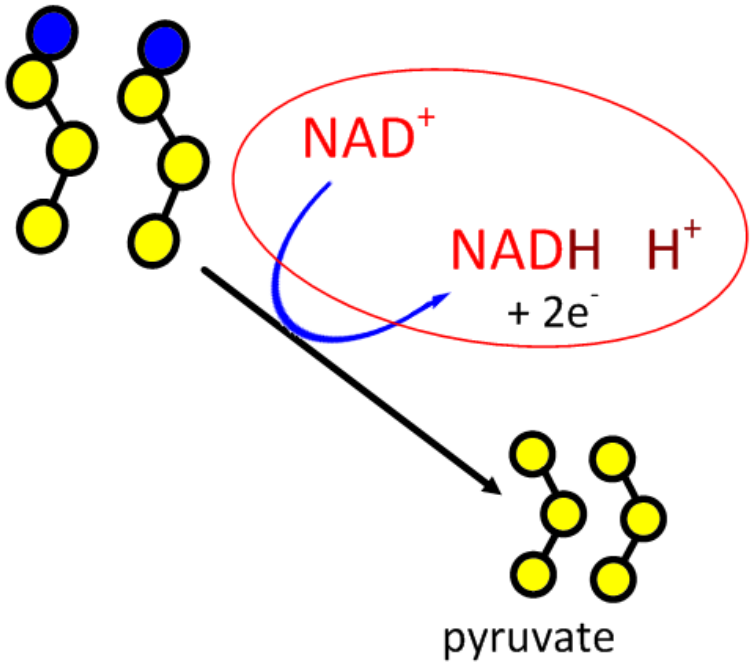


GLYCOLYSIS

sugar splitting

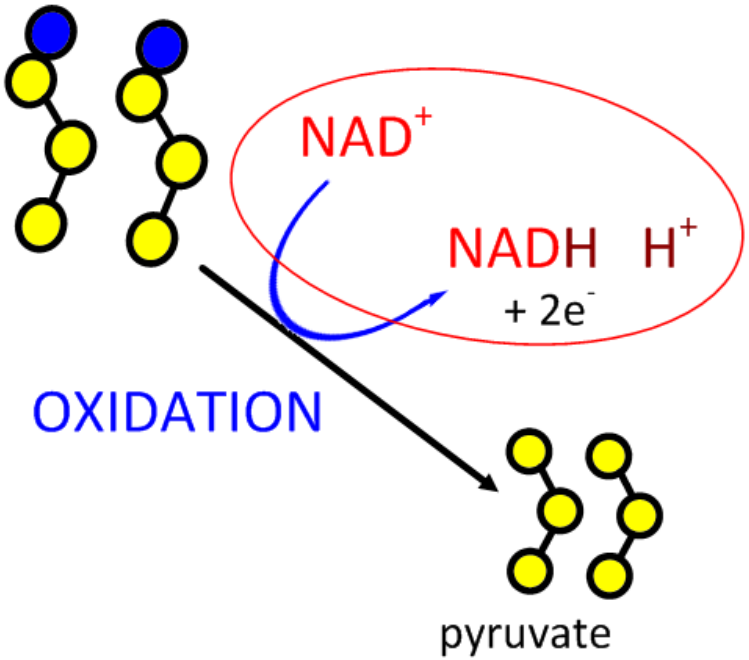


Electron Carriers carry Hydrogen ions to the Electron Transport Chain



Electron Carriers carry Hydrogen ions to the Electron Transport Chain

G3P is oxidised
(lose electrons
and hydrogens)



Electron Carriers carry Hydrogen ions to the Electron Transport Chain

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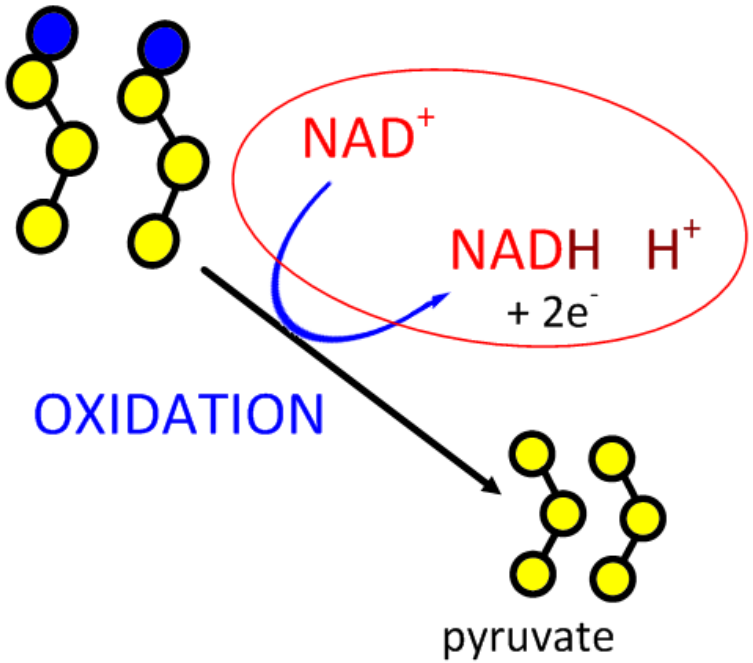
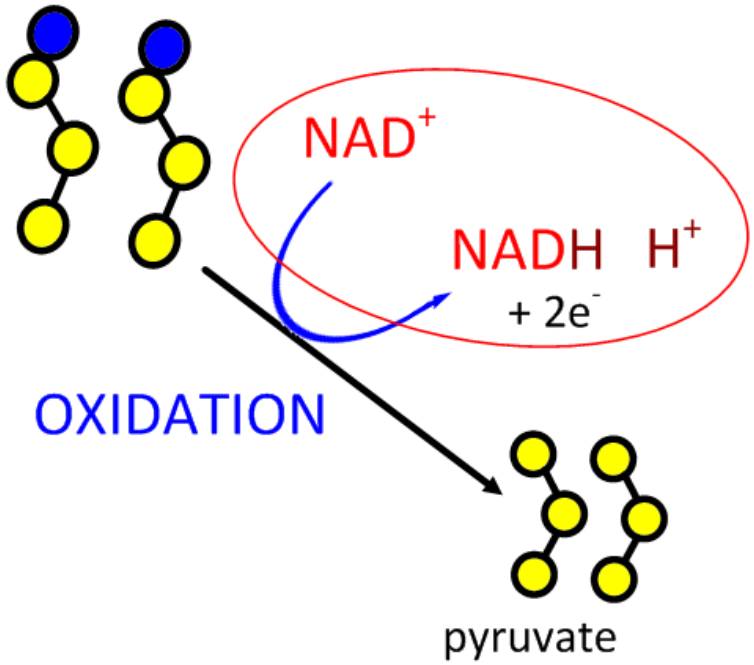


NAD+ is reduced
(it gains 2 electrons and 2 hydrogens)

Electron Carriers carry Hydrogen ions to the Electron Transport Chain

G3P is oxidised
(lose electrons and hydrogens)



NAD^+ is reduced
(it gains 2 electrons and 2 hydrogens)

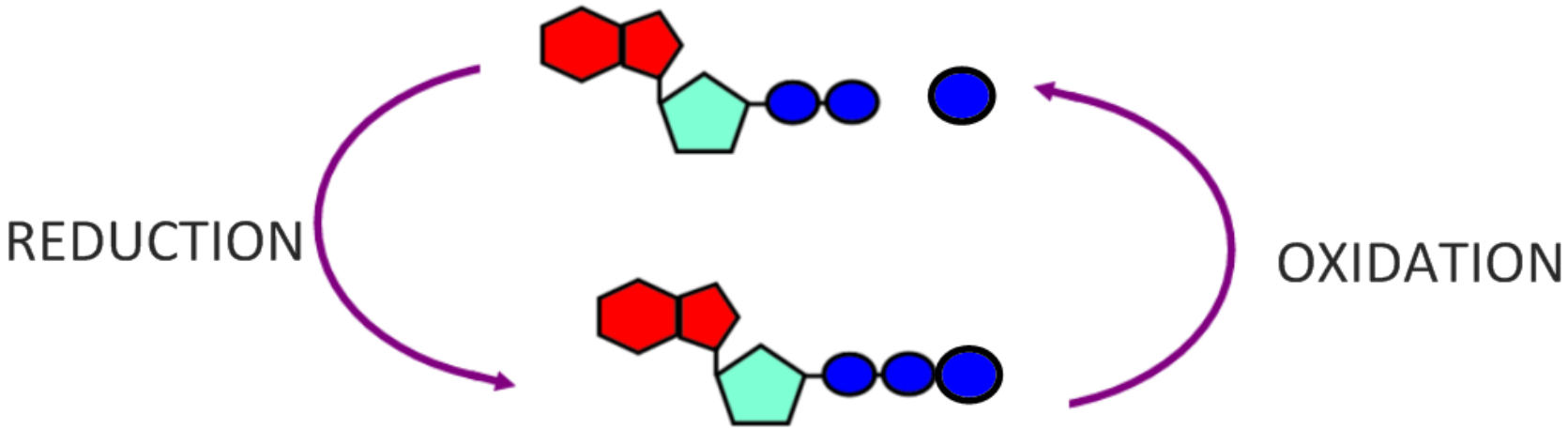
-Carried to electron transport chain
-Energy from electrons
-Pumps H^+ across inner mitochondrial membrane
-Generates H^+ concentration gradient
-Powers ATP synthase, making ATP

Another electron carrier we'll see later:

$$FADH \xrightarrow[\text{and two electrons}]{\text{add two hydrogens}} FADH_2$$

Many biochemical reactions are classed as either

REDUCTION or OXIDATION



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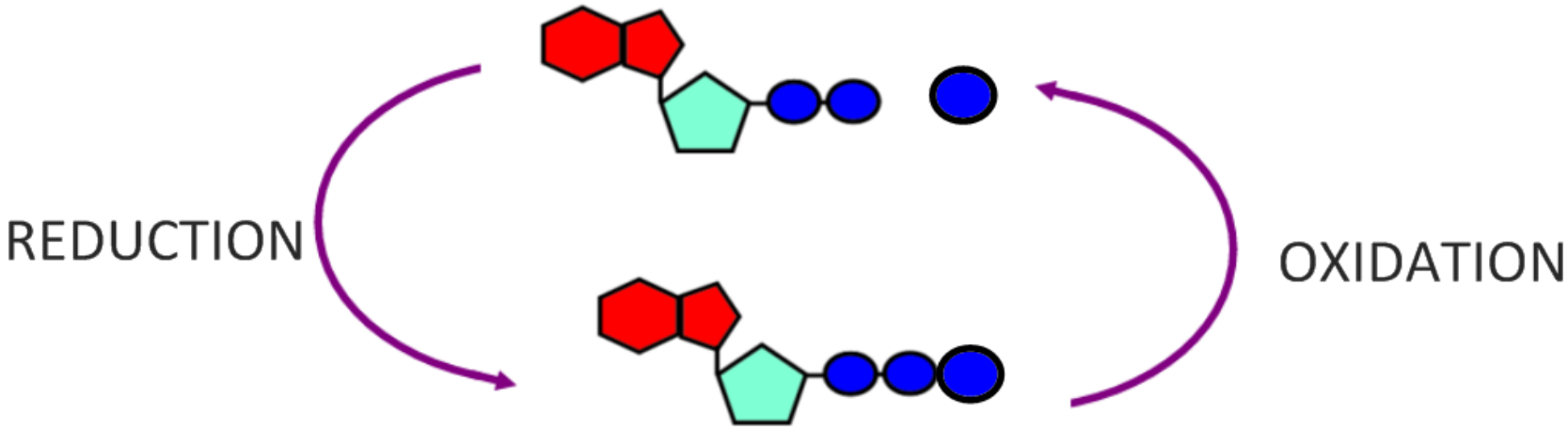


electrons are gained — electrons are lost

or

oxygen is removed — oxygen is added

or

hydrogen is gained — hydrogen is lost

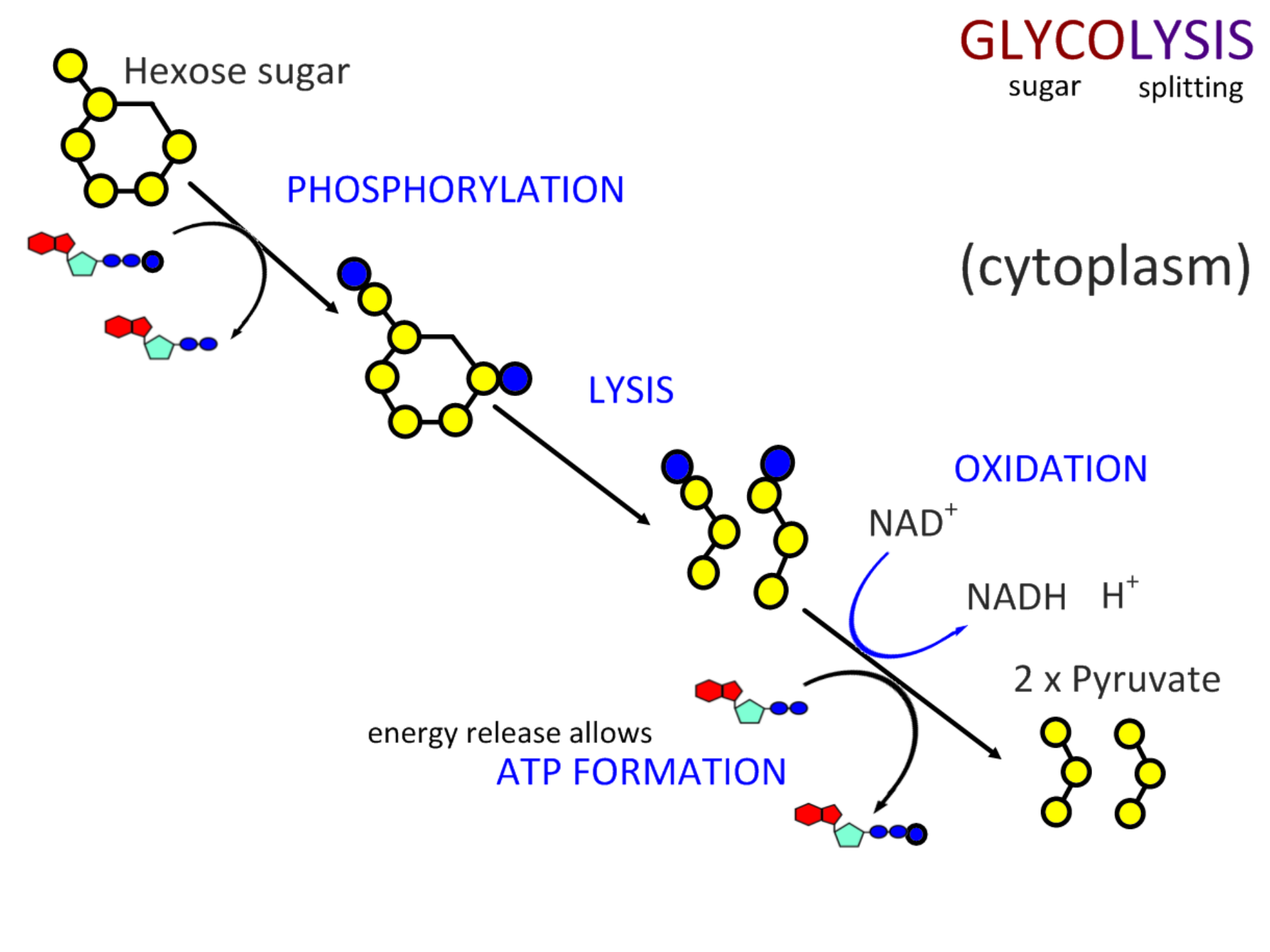
COMPARE OXIDATION AND REDUCTION

OXIDATION	REDUCTION
electrons (gained/lost?)	
oxygen	
hydrogen	

COMPARE OXIDATION AND REDUCTION

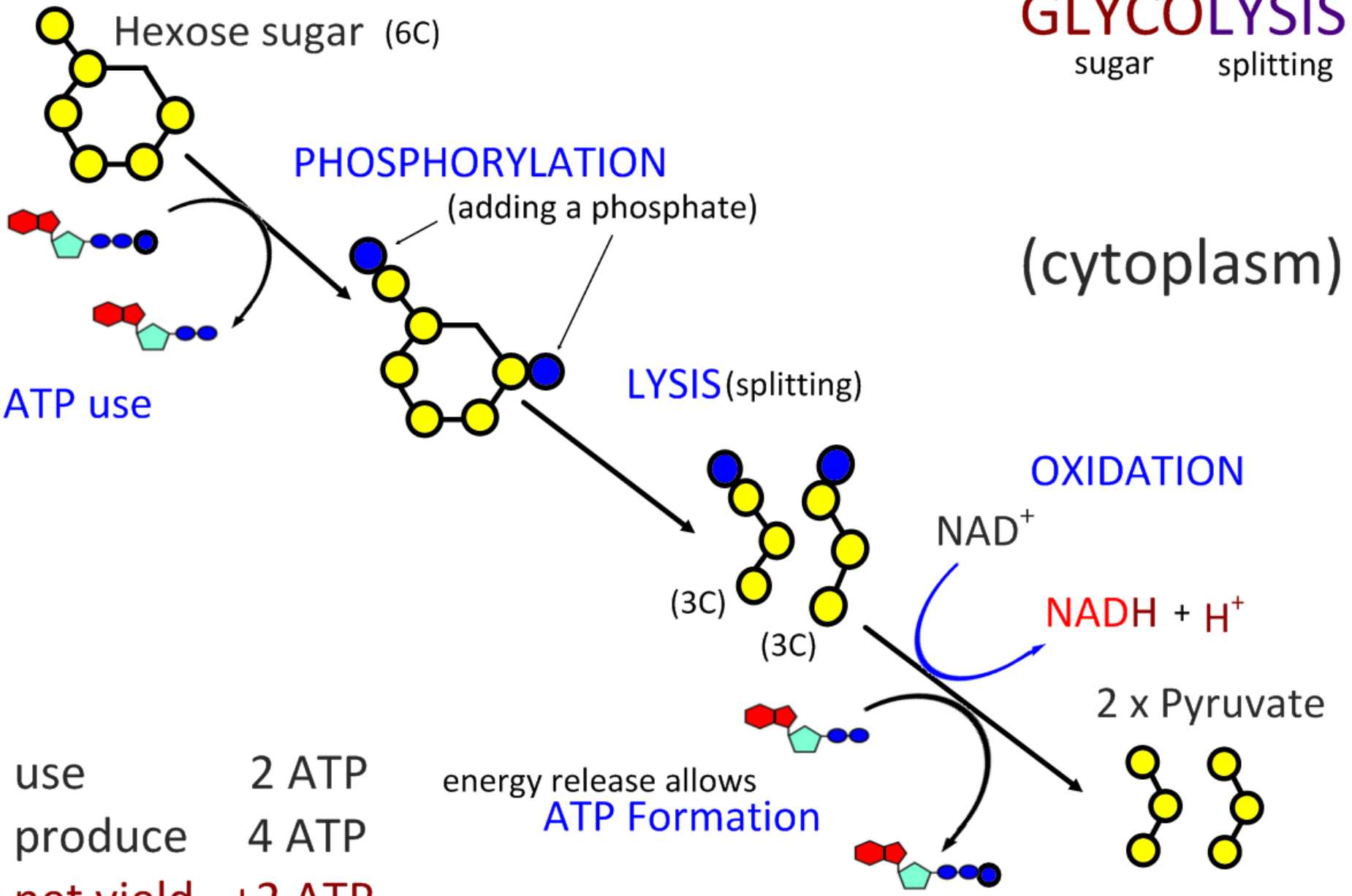
OXIDATION		REDUCTION
lost	electrons (gained/lost?)	gained
gained	oxygen	lost
lost	hydrogen	gained

remember: OILRIG


GLYCOLYSIS
sugar splitting
Hexose sugar
PHOSPHORYLATION
(cytoplasm)
LYSIS
OXIDATION
NAD+
NADH H+
2 x Pyruvate
energy release allows
ATP FORMATION

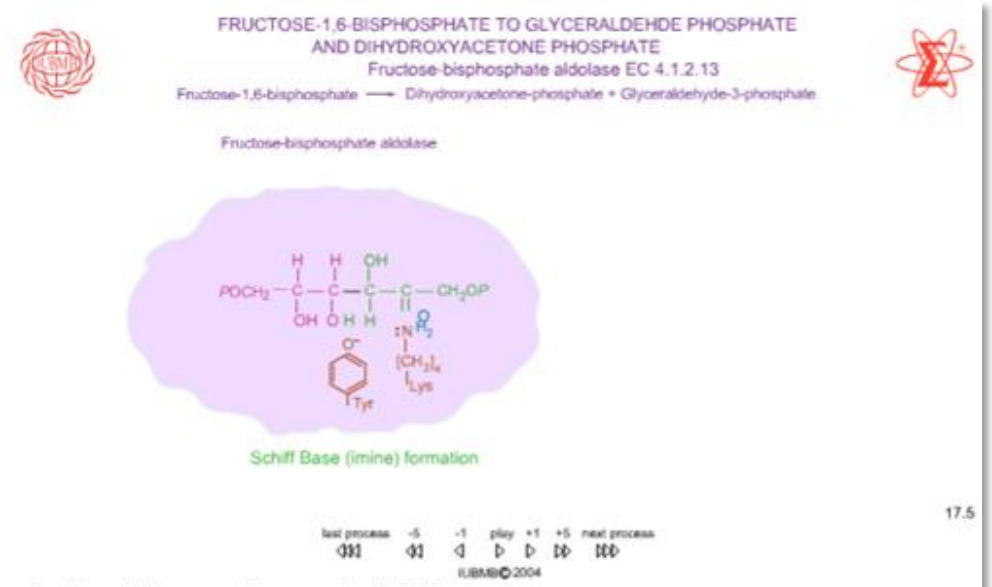
GLYCOLYSIS

sugar splitting

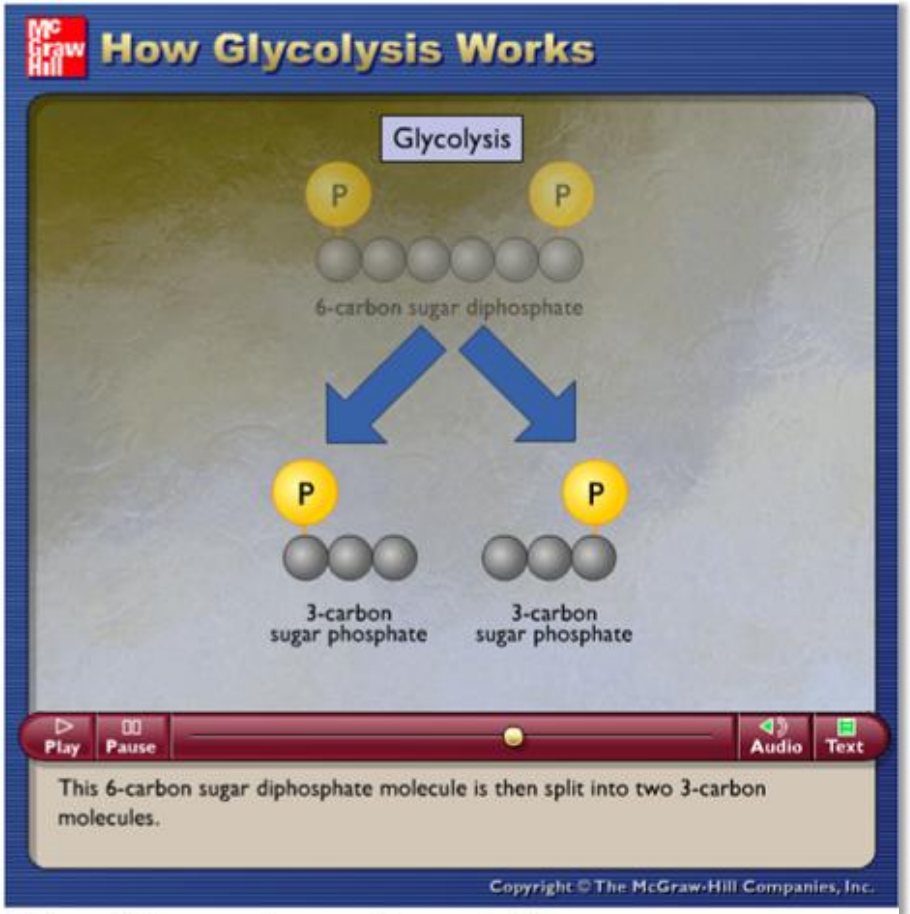


use	2 ATP
produce	4 ATP
net yield	+2 ATP

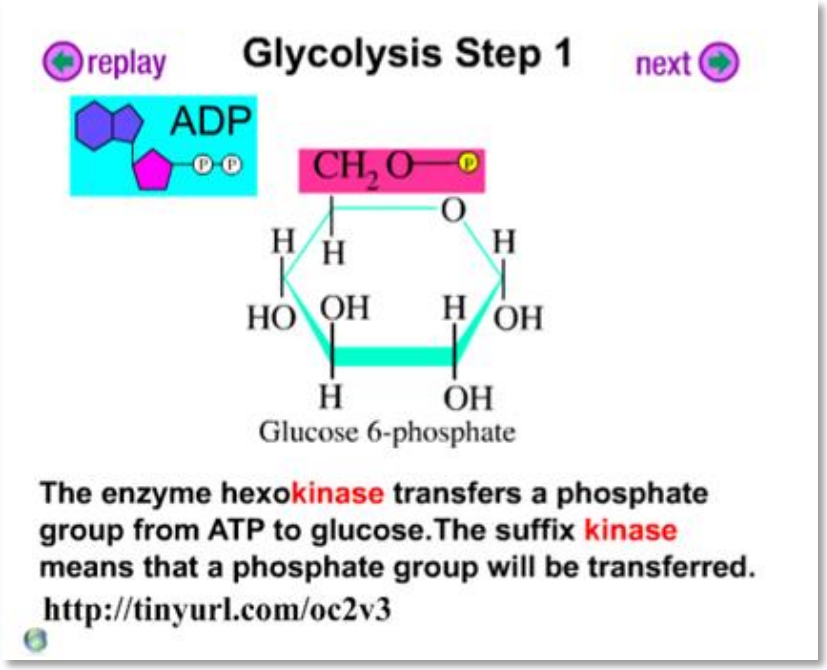
Glycolysis Animations



http://tinyurl.com/ydl5jkn



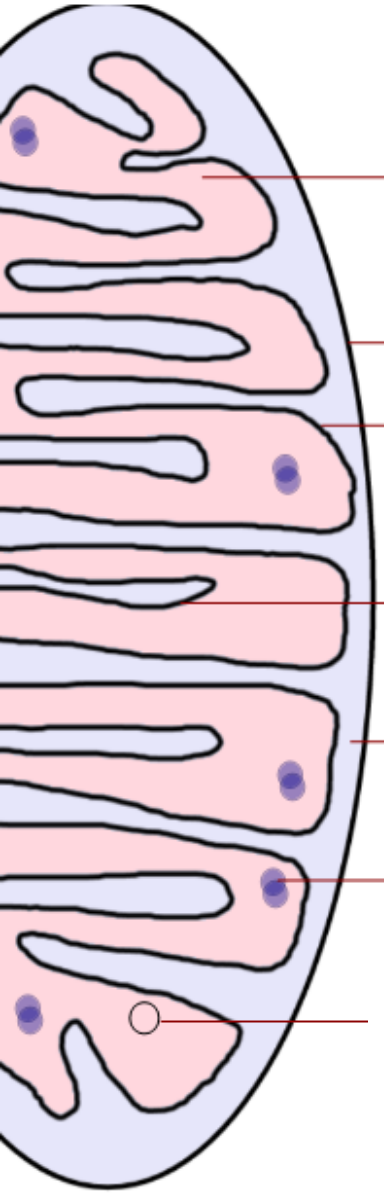
http://tinyurl.com/yayelo9



The enzyme hexokinase transfers a phosphate group from ATP to glucose.The suffix kinase means that a phosphate group will be transferred.

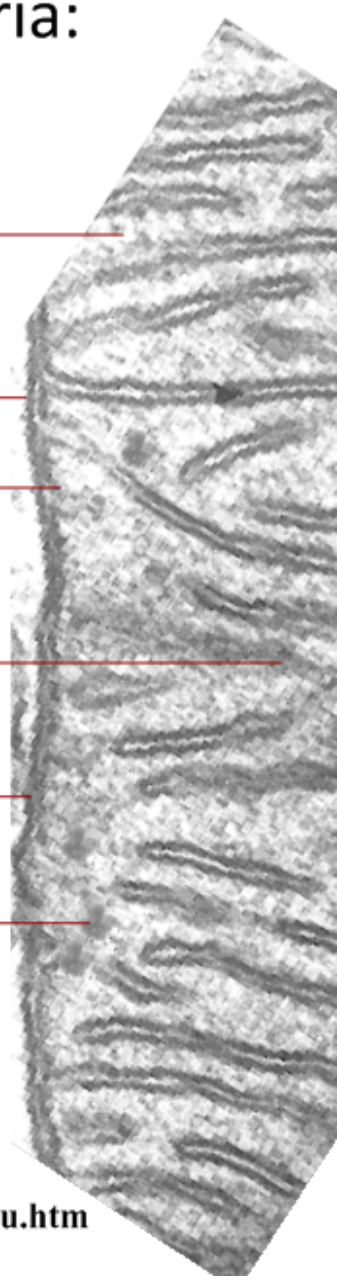
http://tinyurl.com/oc2v3

If oxygen is present, reactions move to the mitochondria:



Matrix

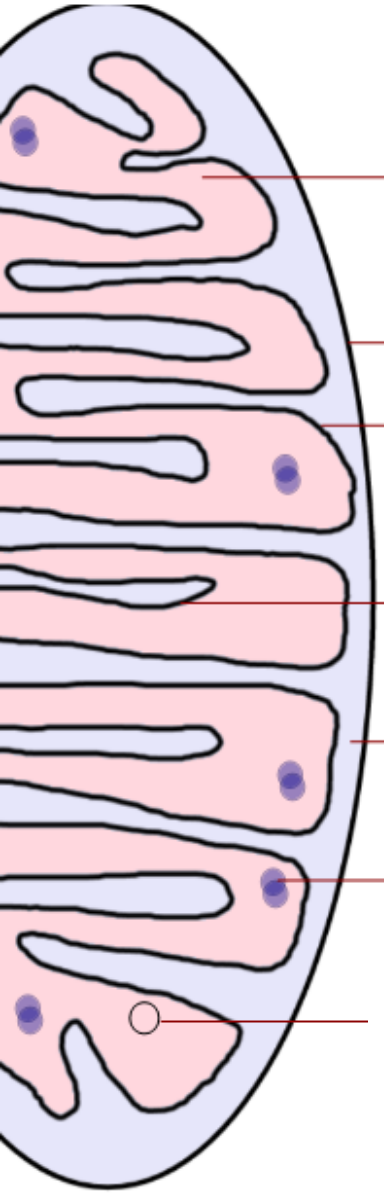
contains enzymes and solutes for
Link Reaction and Krebs Cycle



1µm

http://www.udel.edu/biology/Wags/histopage/empage/ecu/ecu.htm

If oxygen is present, reactions move to the mitochondria:



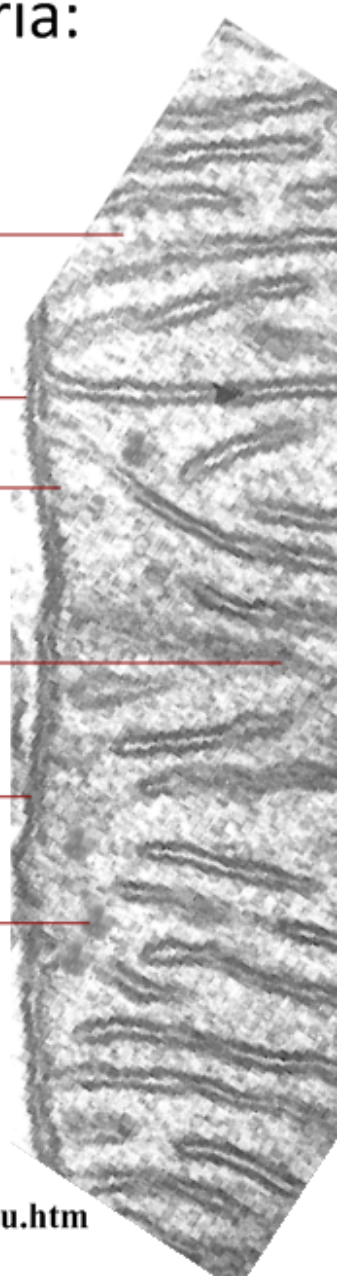
Matrix

contains enzymes and solutes for
Link Reaction and Krebs Cycle

Outer Mitochondrial Membrane

Inner Mitochondrial Membrane

site for electron transport chain and oxidative phosporylation



1µm

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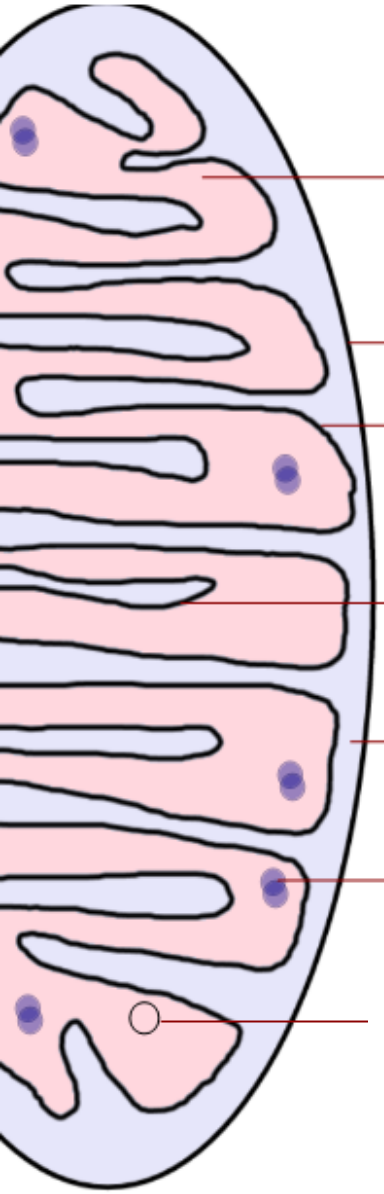
If oxygen is present, reactions move to the mitochondria:



Matrix

contains enzymes and solutes for

Link Reaction and Krebs Cycle

Outer Mitochondrial Membrane

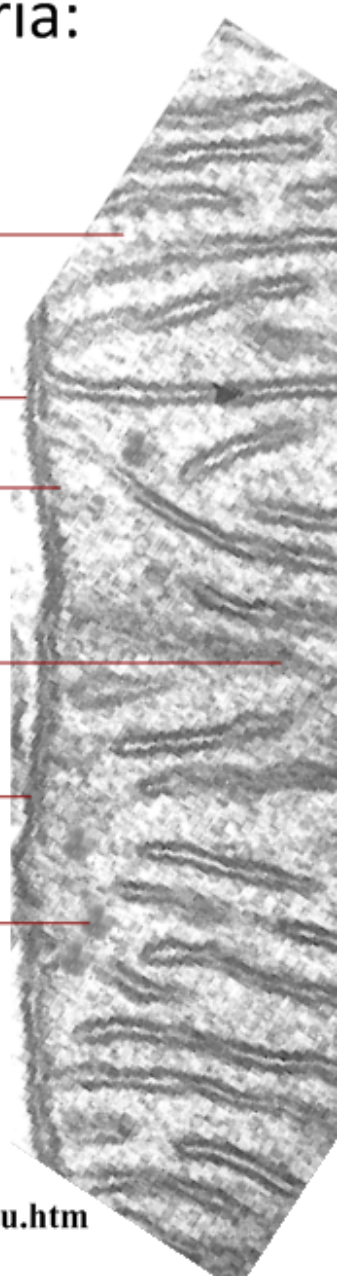
Inner Mitochondrial Membrane

site for electron transport chain and oxidative phosporylation

folded into

Cristae

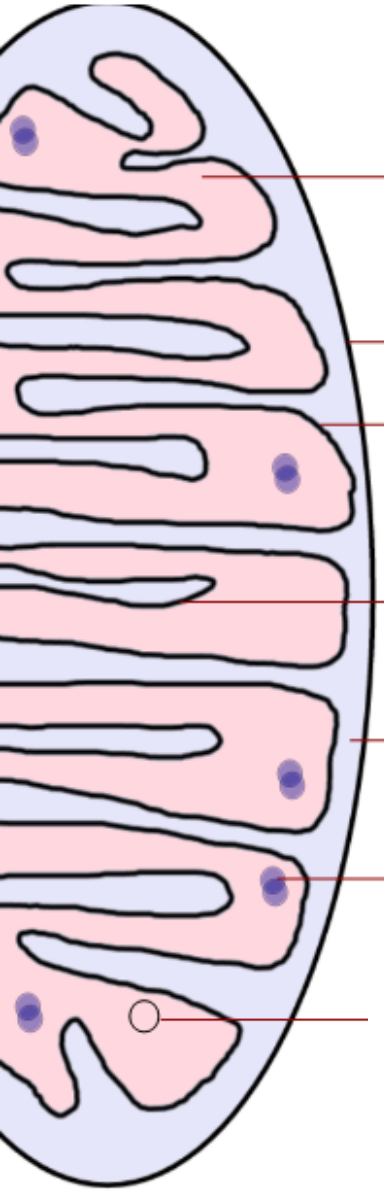
to maximise surface area for reactions



1µm

http://www.udel.edu/biology/Wags/histopage/empage/ecu/ecu.htm

If oxygen is present, reactions move to the mitochondria:



Matrix

contains enzymes and solutes for
Link Reaction and Krebs Cycle

Outer Mitochondrial Membrane

Inner Mitochondrial Membrane

site for electron transport chain and oxidative phosporylation

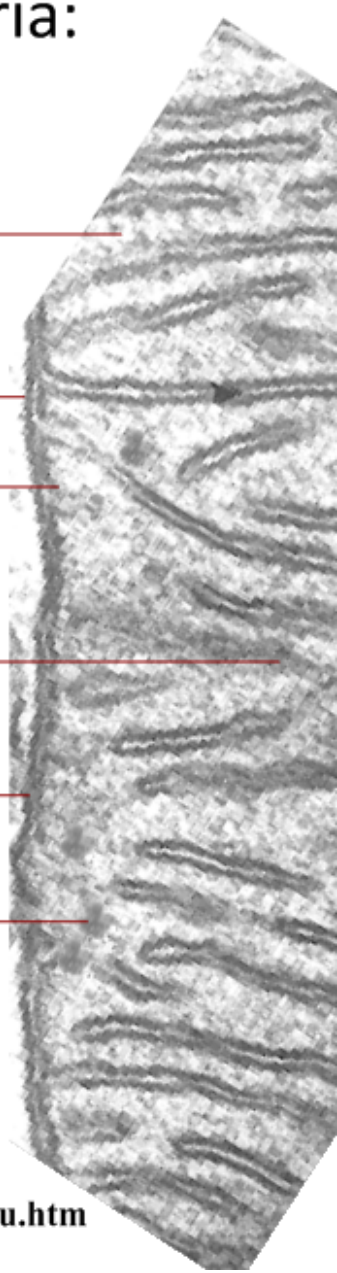
folded into

Cristae

to maximise surface area for reactions

Small Inter-membrane Space

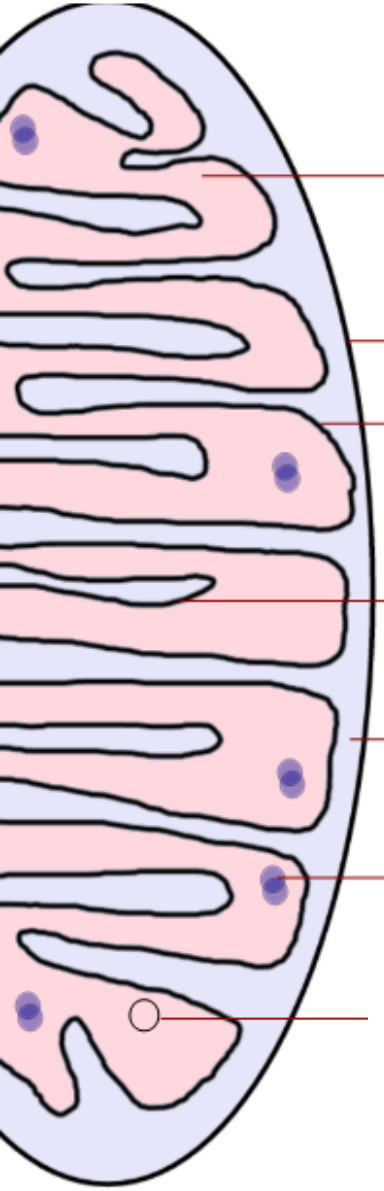
more efficient generation of H^+ concentration gradient



1µm

http://www.udel.edu/biology/Wags/histopage/empage/ecu/ecu.htm

If oxygen is present, reactions move to the mitochondria:



Matrix
contains enzymes and solutes for
Link Reaction and Krebs Cycle

Outer Mitochondrial Membrane

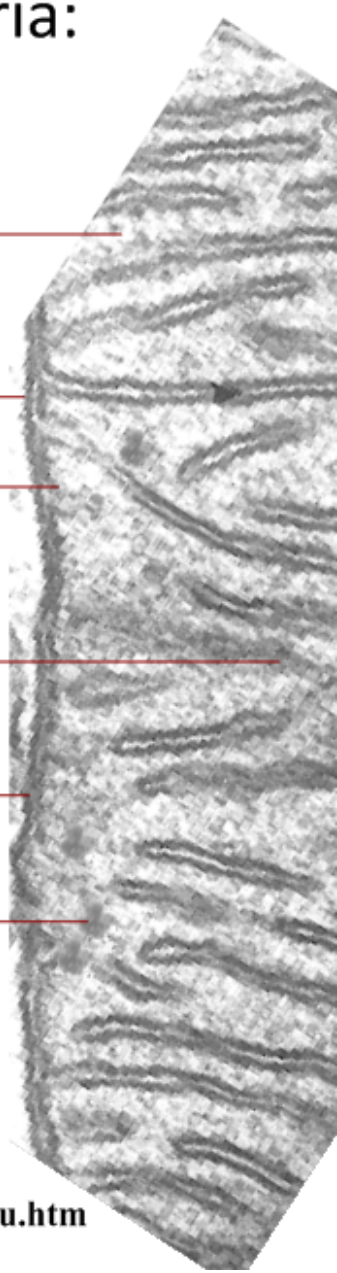
Inner Mitochondrial Membrane
site for electron transport chain and oxidative phosporylation

folded into

Cristae
to maximise surface area for reactions

Small Inter-membrane Space
more efficient generation of H^+ concentration gradient

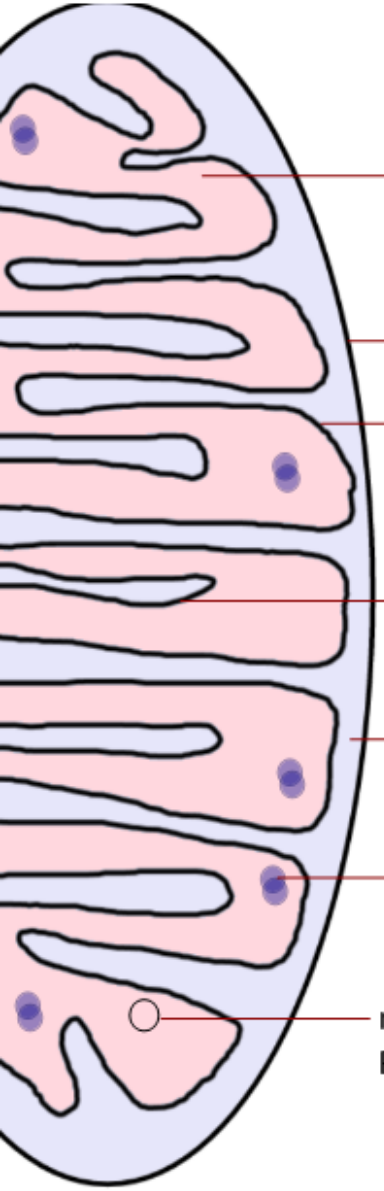
70S Ribosomes
protein production



1µm

http://www.udel.edu/biology/Wags/histopage/empage/ecu/ecu.htm

If oxygen is present, reactions move to the mitochondria:



Matrix
contains enzymes and solutes for
Link Reaction and Krebs Cycle

Outer Mitochondrial Membrane

Inner Mitochondrial Membrane
site for electron transport chain and oxidative phosporylation

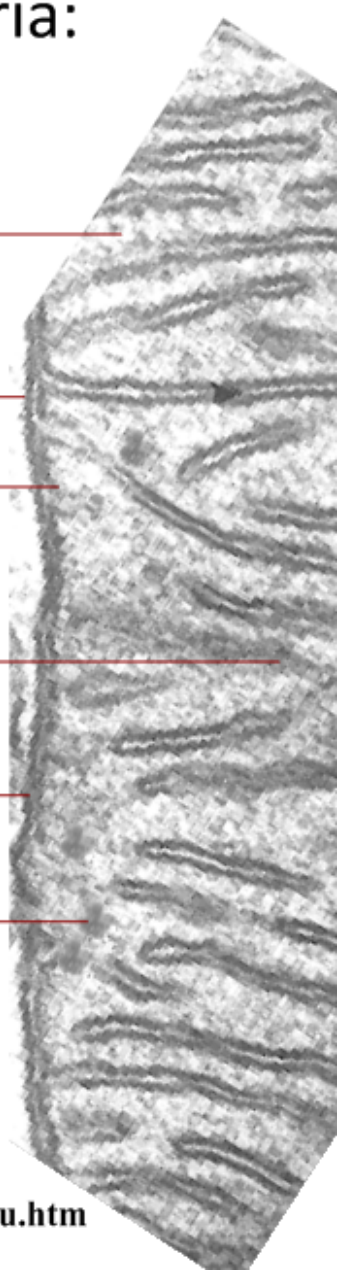
folded into

Cristae
to maximise surface area for reactions

Small Inter-membrane Space
more efficient generation of H^+ concentration gradient

70S Ribosomes
protein production

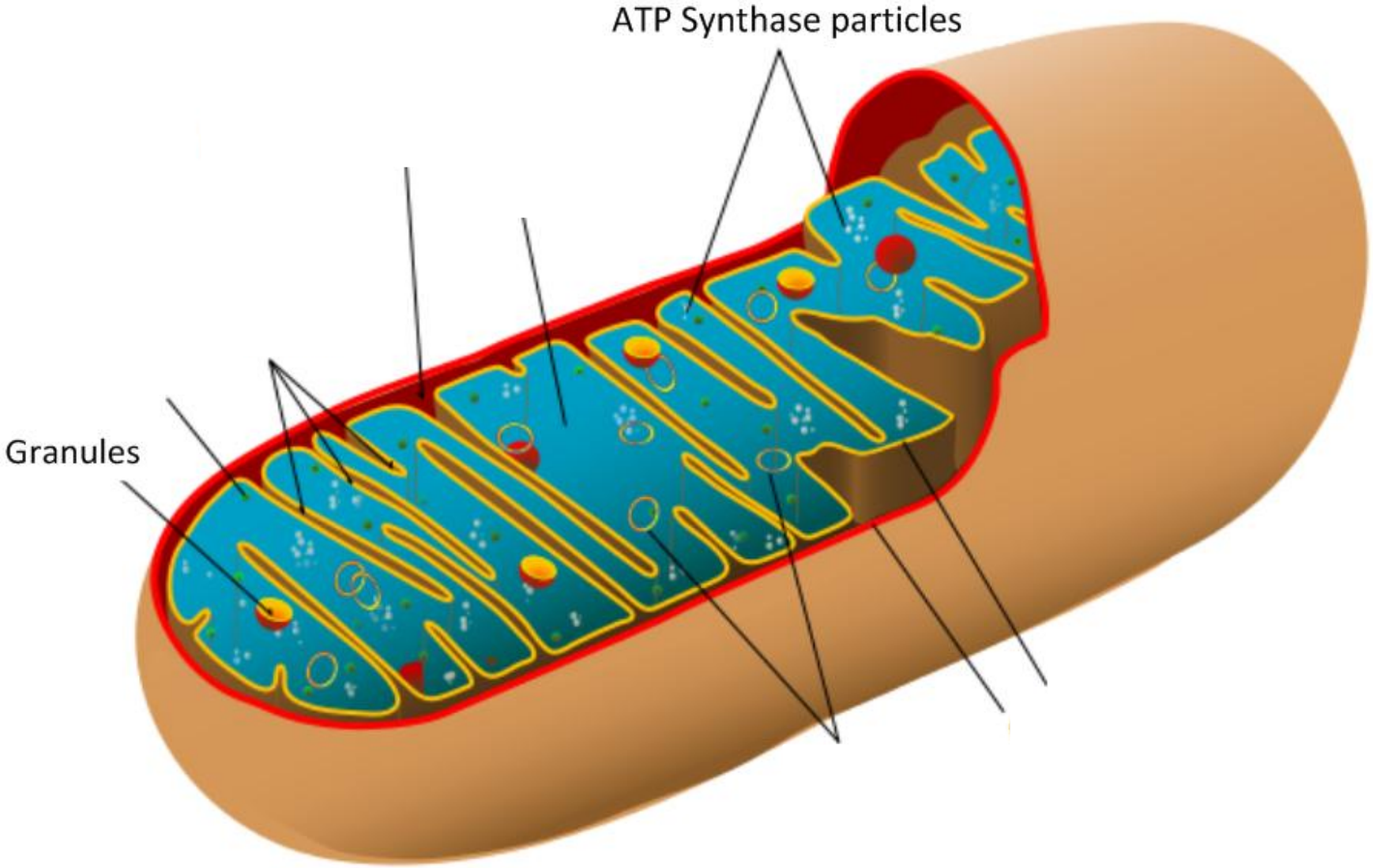
naked loops of DNA (mitochondrial DNA/ mDNA)
Passed unchanged from mother to child



1µm

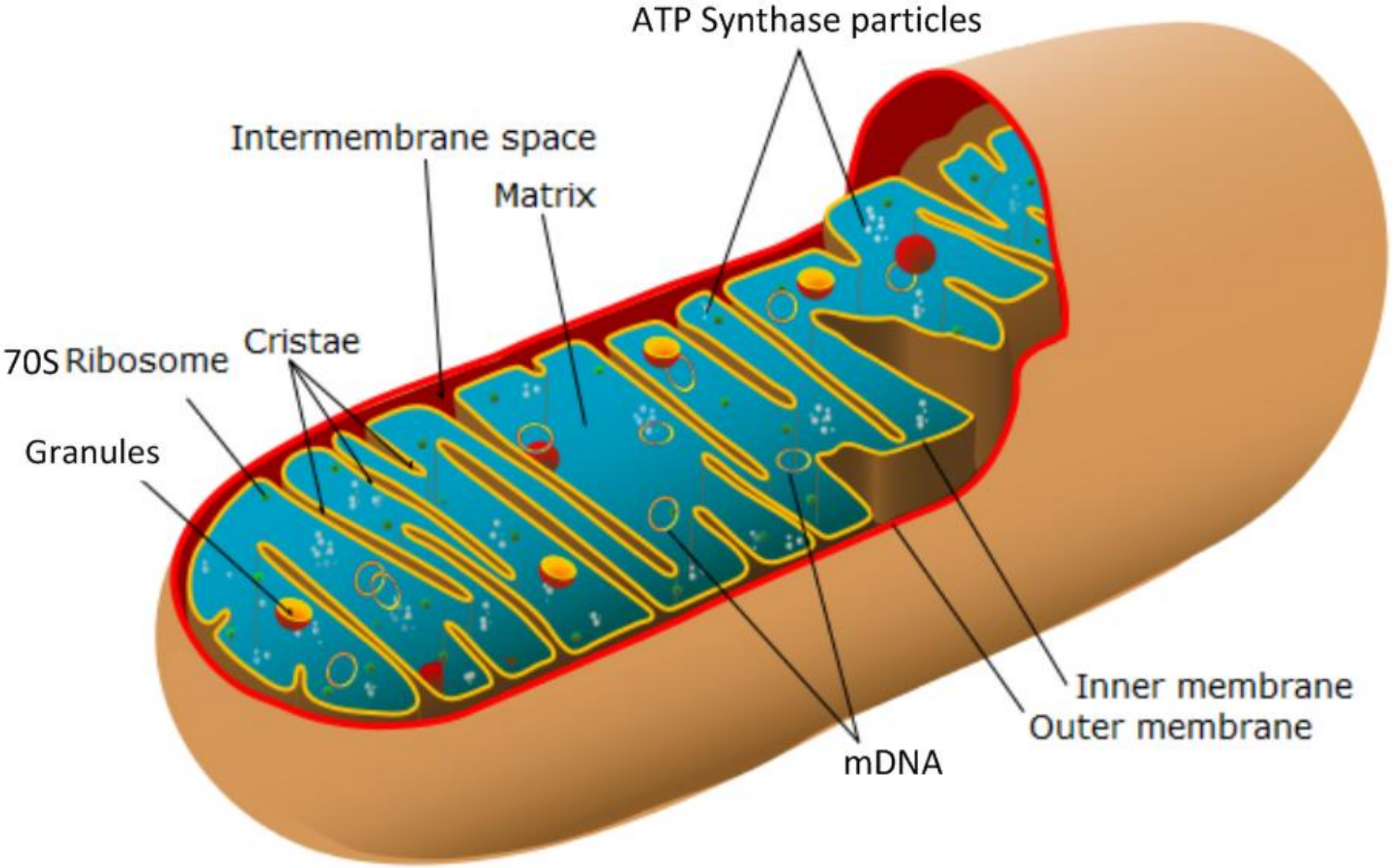
http://www.udel.edu/biology/Wags/histopage/empage/ecu/ecu.htm

Label the parts:



http://en.wikipedia.org/wiki/Mitochondrion

Label the parts:



http://en.wikipedia.org/wiki/Mitochondrion

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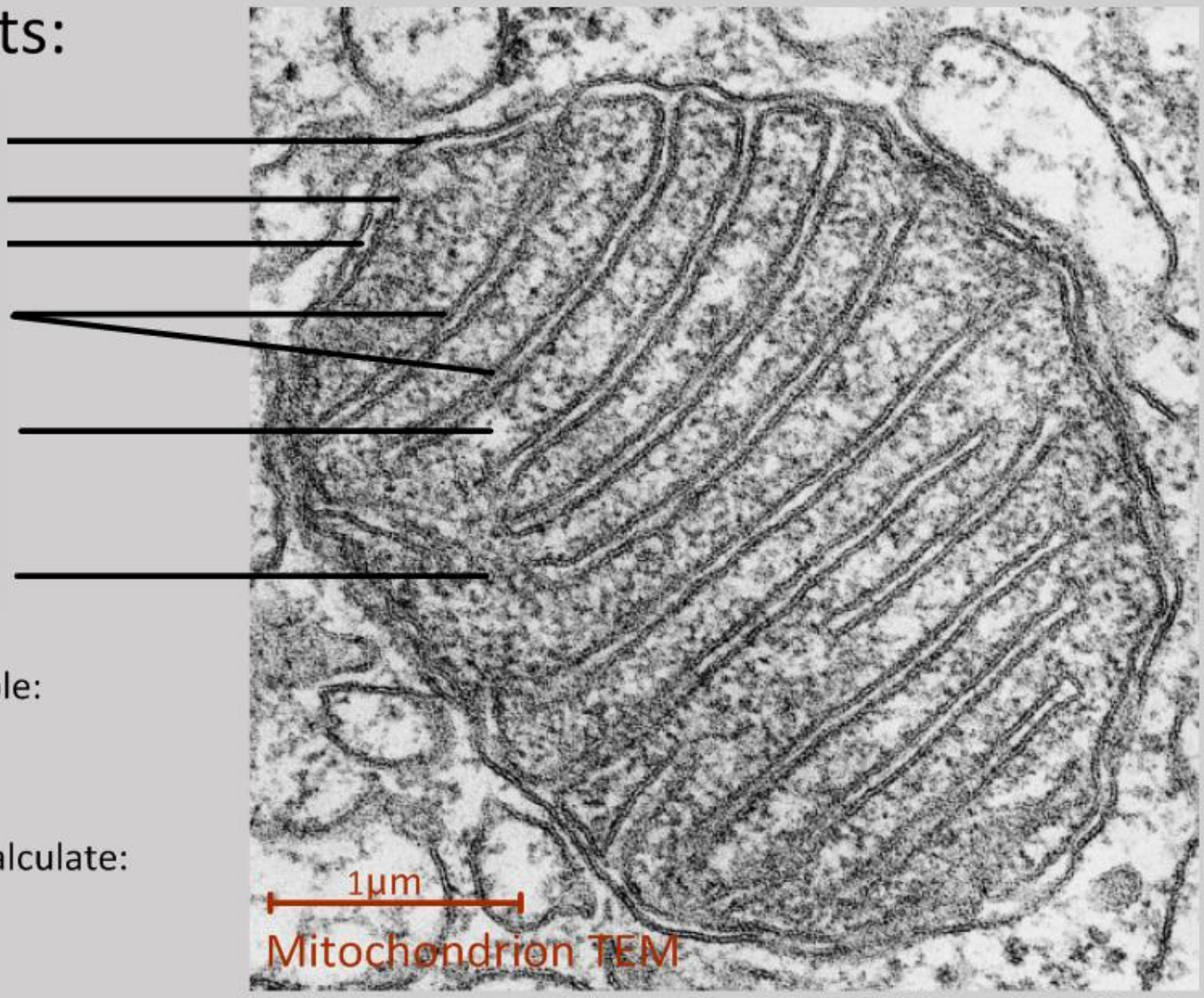


http://antiparos.zoo.ox.ac.uk/presentations/Talks/20060526-DataWeb-tech.html

not easily visible:
- mDNA

Print this image and calculate:
- magnification
- maximum length
- width of one crista

Label the parts:

outer membrane

inner membrane

inter-membrane space

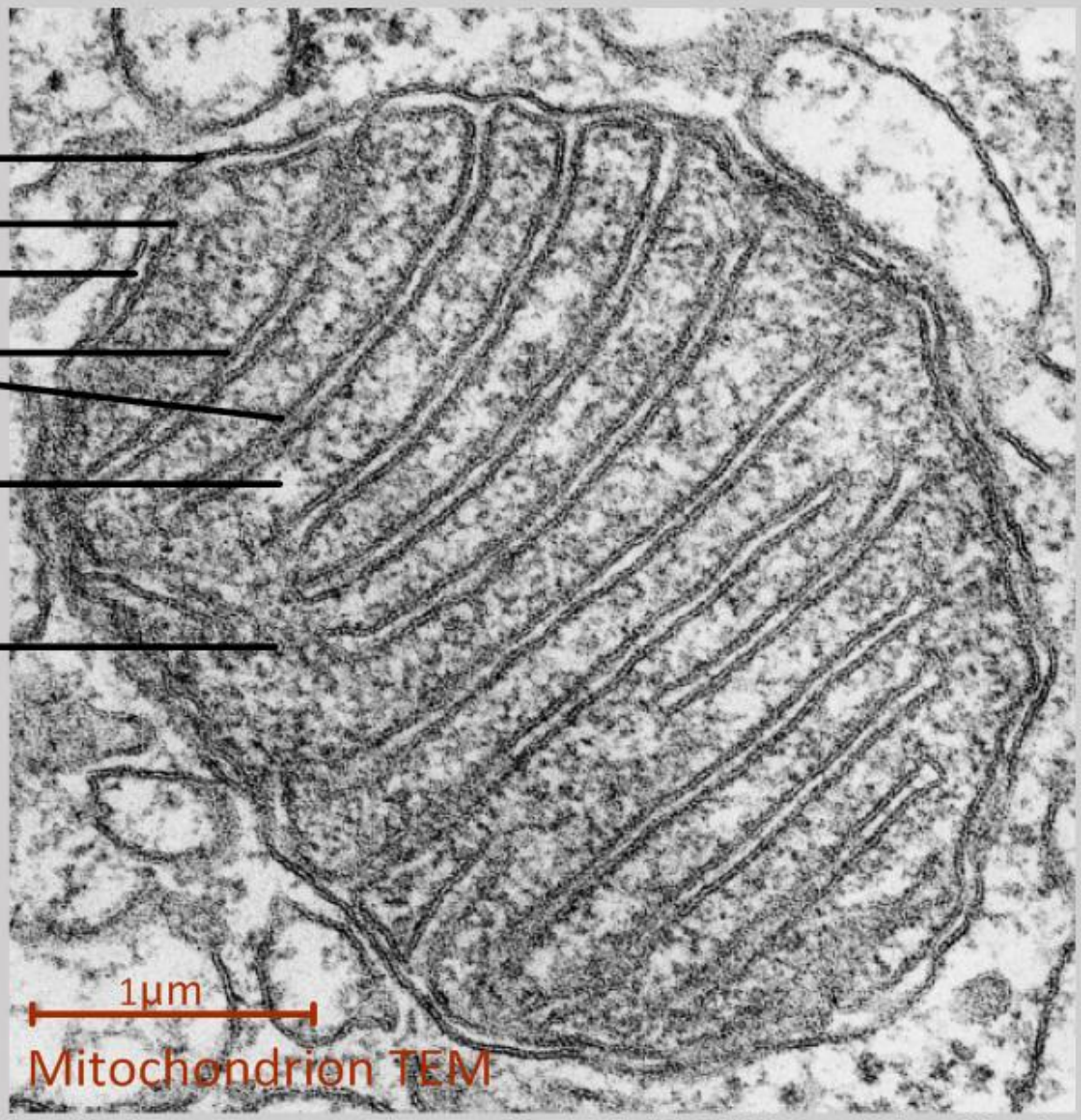
christae

matrix

70S Ribosomes

not easily visible:
- mDNA

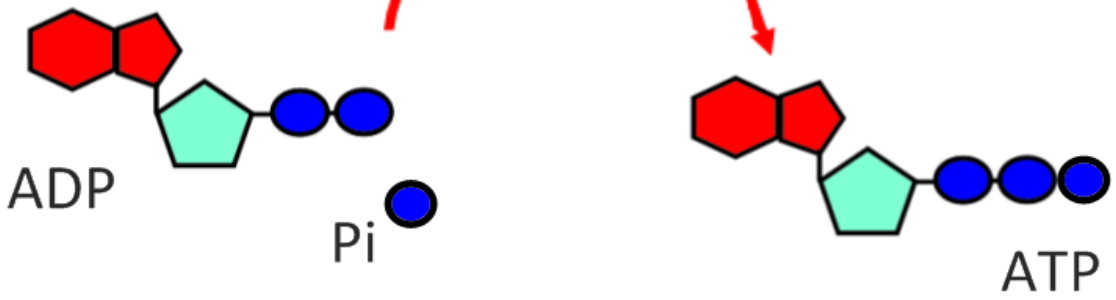
Print this image and calculate:
- magnification
- maximum length
- width of one crista



http://antiparos.zoo.ox.ac.uk/presentations/Talks/20060526-DataWeb-tech.html

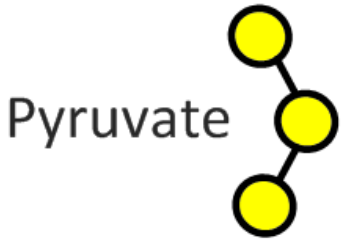
glycolysis → link reaction

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



LINK REACTION (matrix)

OXIDATIVE DECARBOXYLATION

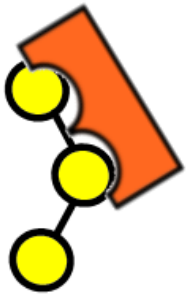


CoA

coenzyme: a carrier

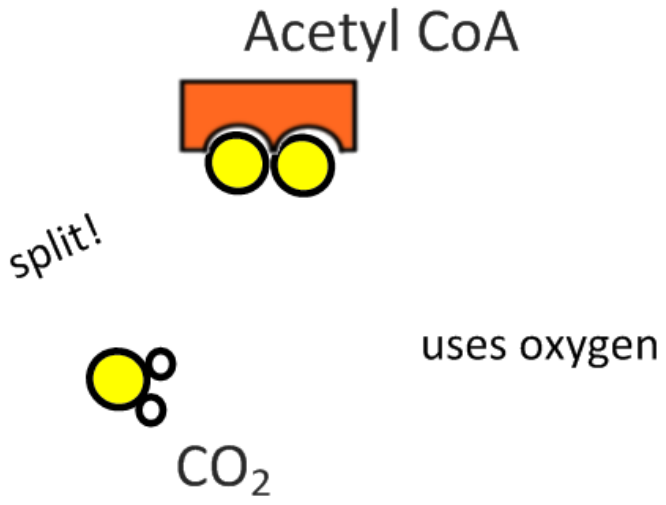
LINK REACTION
(matrix)

OXIDATIVE DECARBOXYLATION



LINK REACTION (matrix)

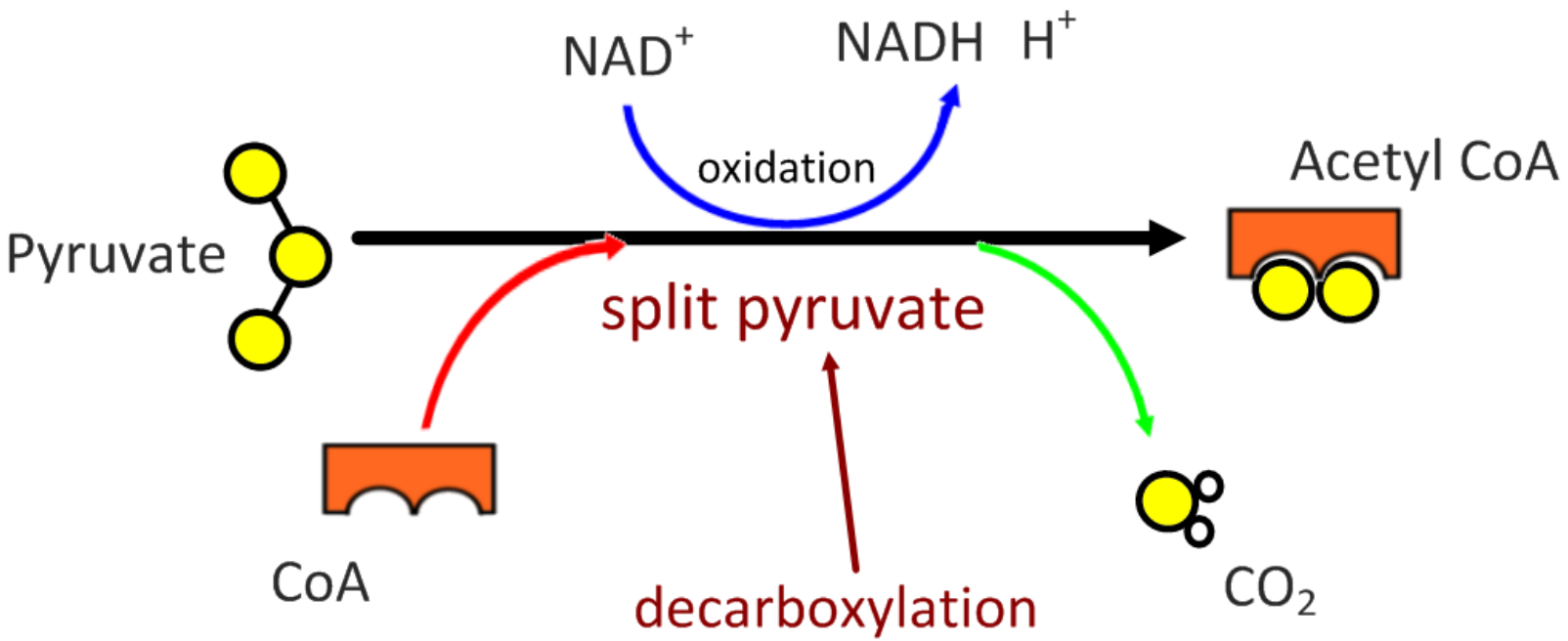
OXIDATIVE DECARBOXYLATION



OXIDATIVE DECARBOXYLATION

LINK REACTION (matrix)

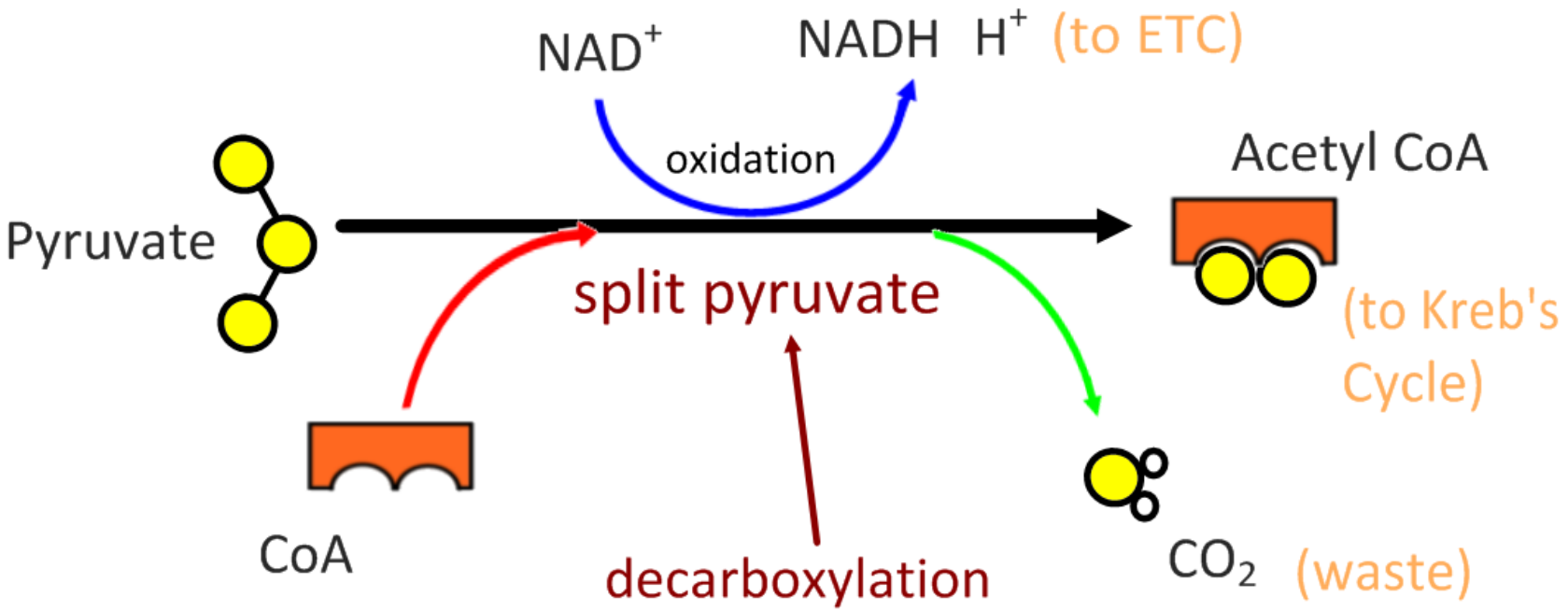
mitochondria



OXIDATIVE DECARBOXYLATION

LINK REACTION (matrix)

mitochondria



Net yield: 2 Acetyl CoA per glucose molecule

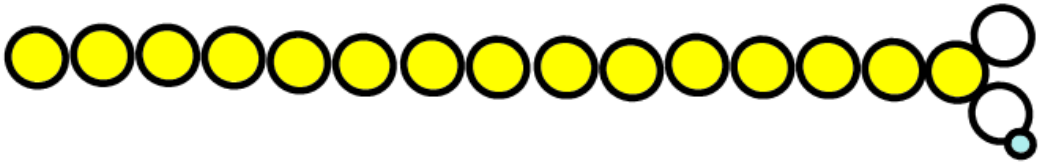
(remember the 6C glucose split into 2 x 3C pyruvate)

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



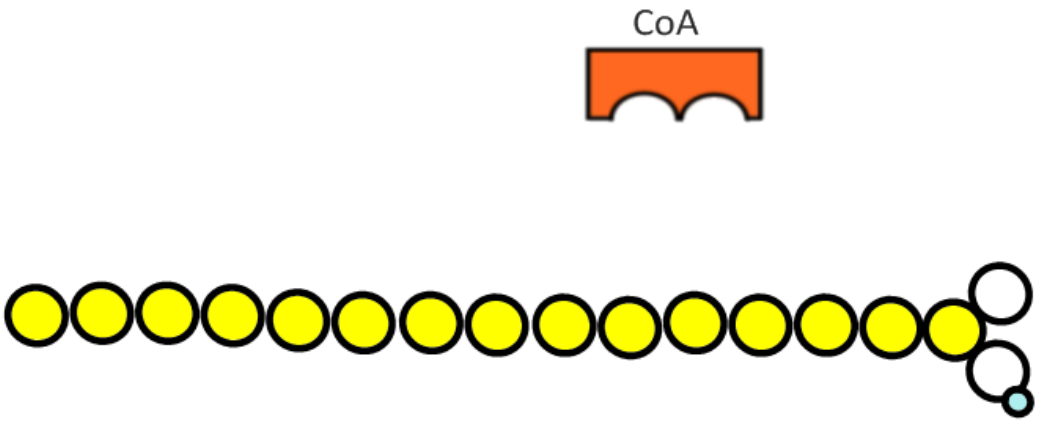
Fatty acids have a long chain of carbon atoms

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.

Cell Respiration using fatty acids

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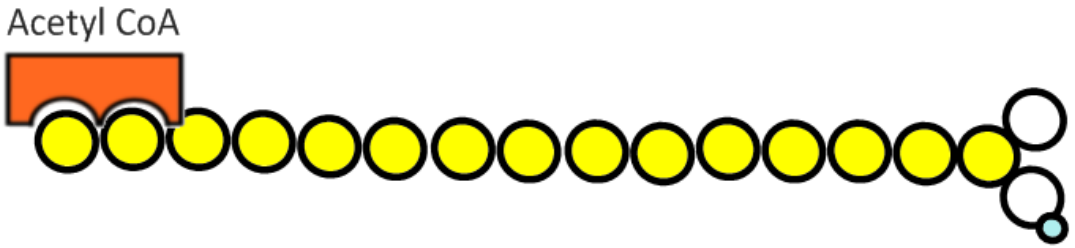

Fatty acids have a long chain of carbon atoms

CoA can oxidise this chain - break it down.

It makes Acetyl CoA with two carbons.

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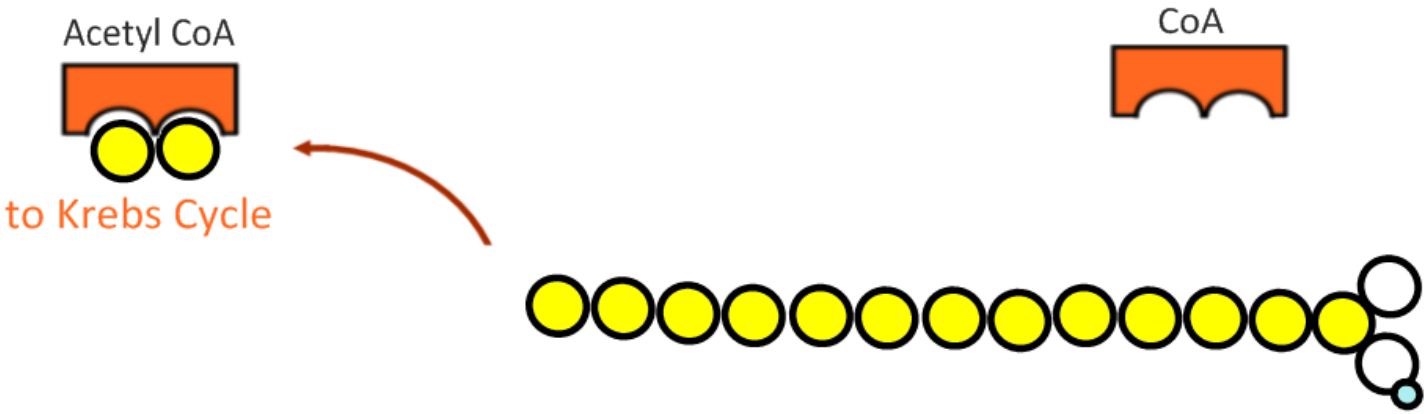
$$CH_3(CH_2)_nCOOH$$



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.

Cell Respiration using fatty acids

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

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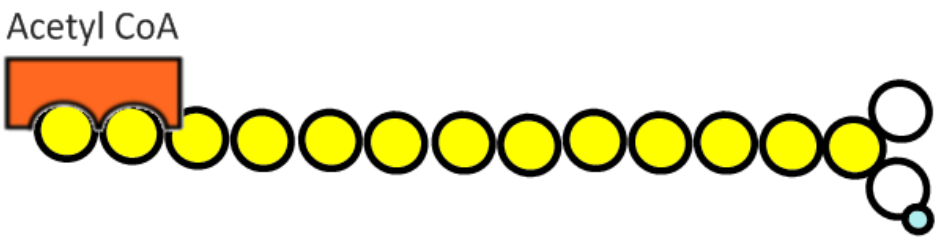

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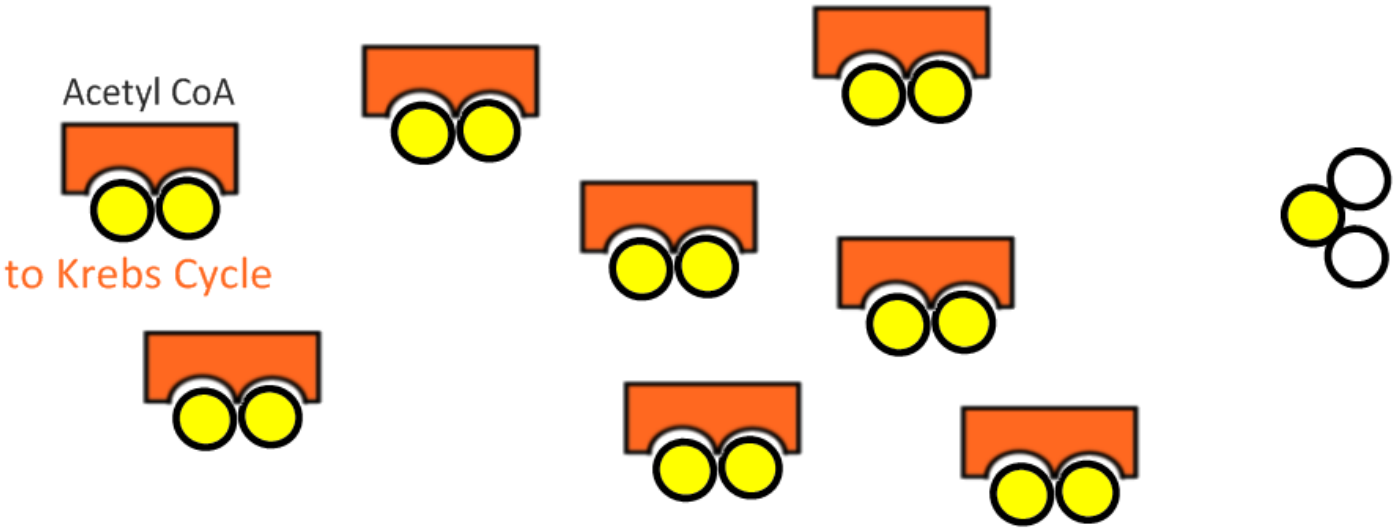


If there are an odd number of carbons, the remaining carbon atom is released as carbon dioxide

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)

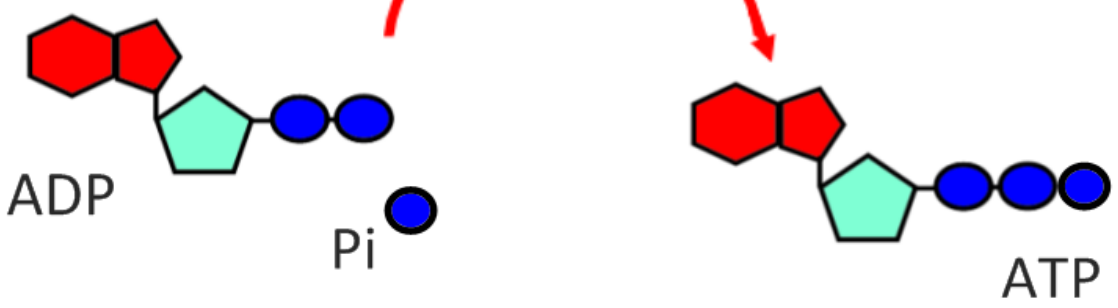
3. A fatty acid with 26 carbons? 13

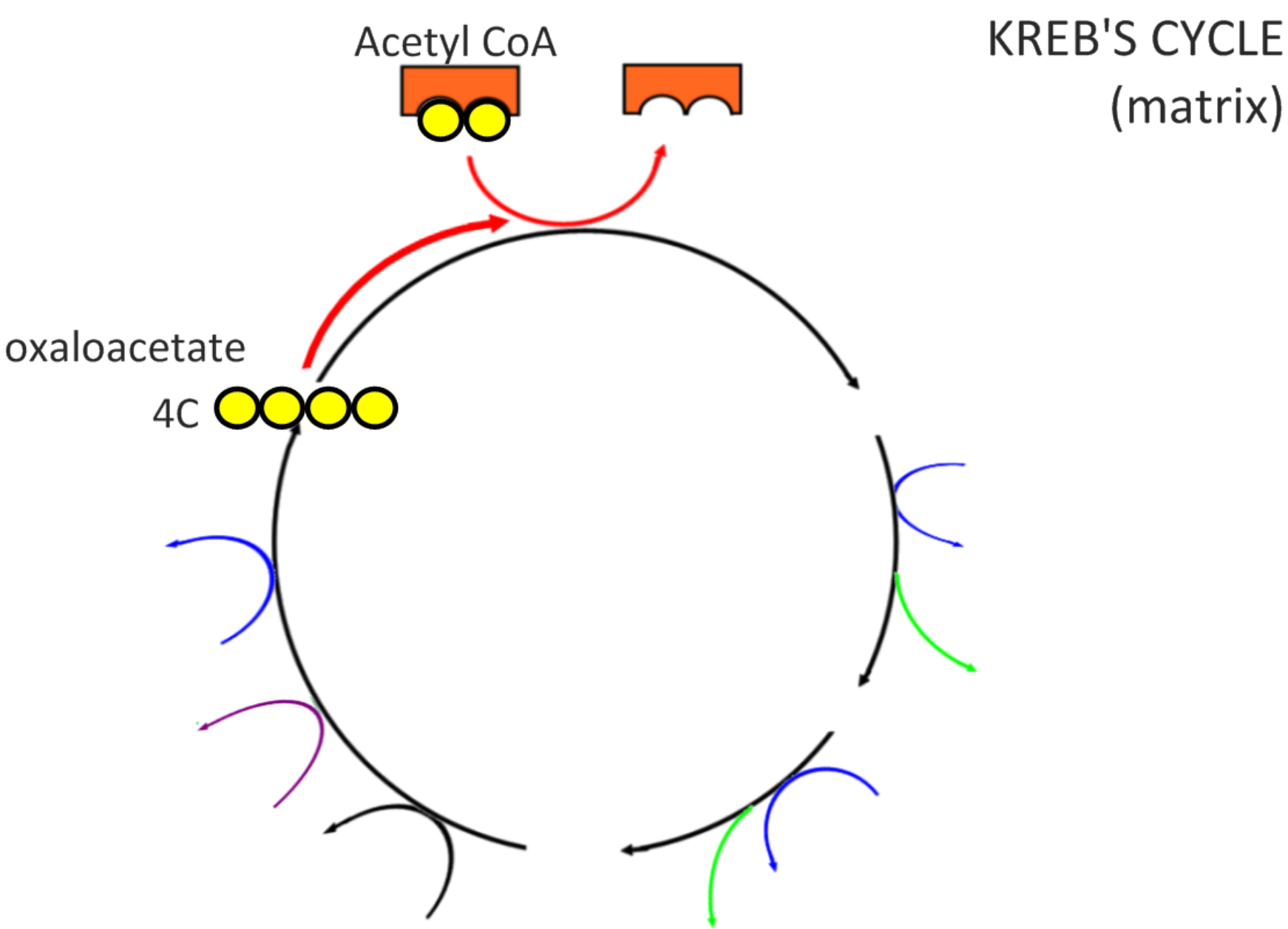
4. From stearic acid ($C_{18}H_{36}O_2$)? 9

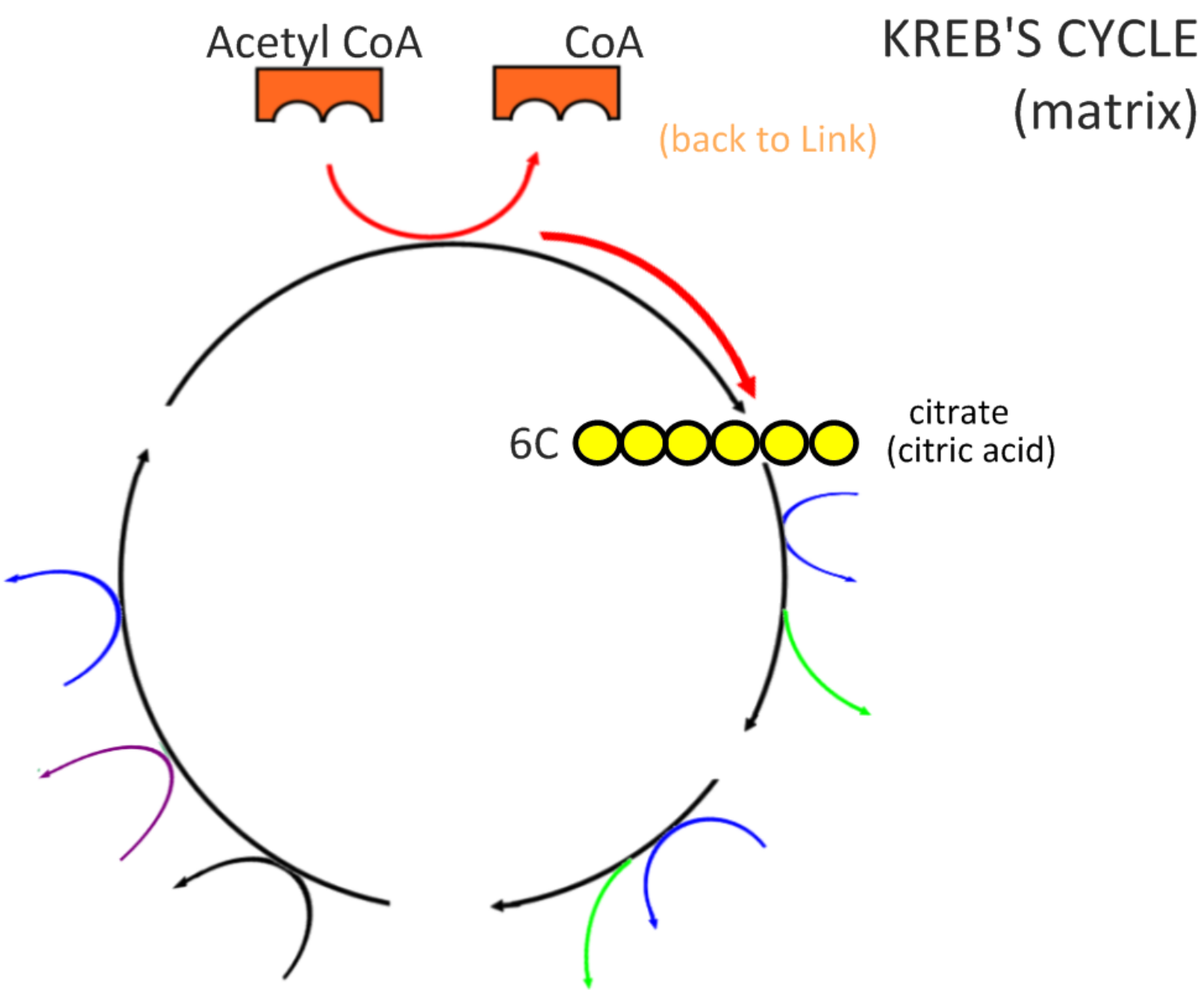
5. This fatty acid?
   $CH_3(CH_2)_{54}COOH$ 28

glycolysis → link reaction → Kreb's cycle

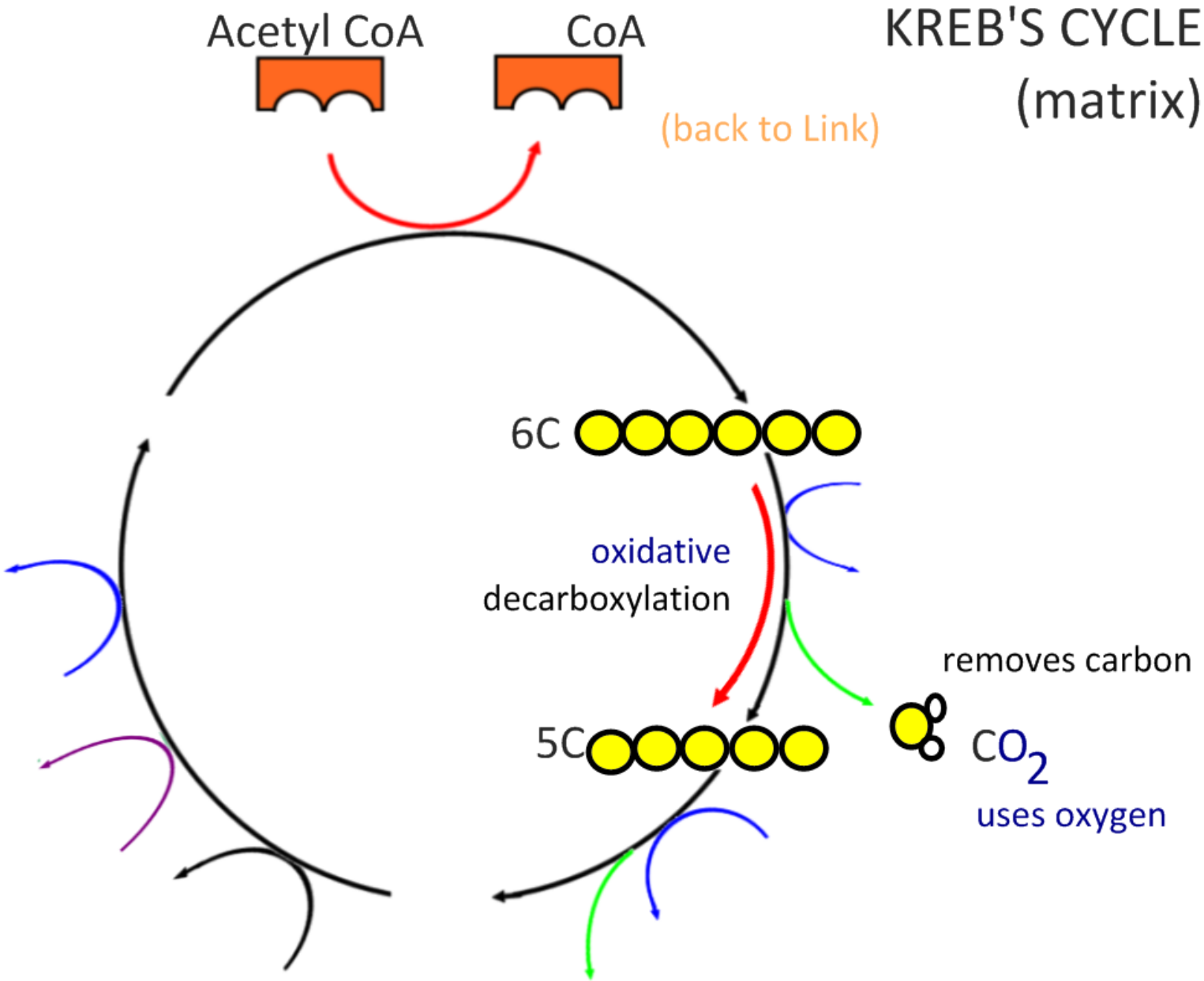
$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{respiration}} 6CO_2 + 6H_2O$



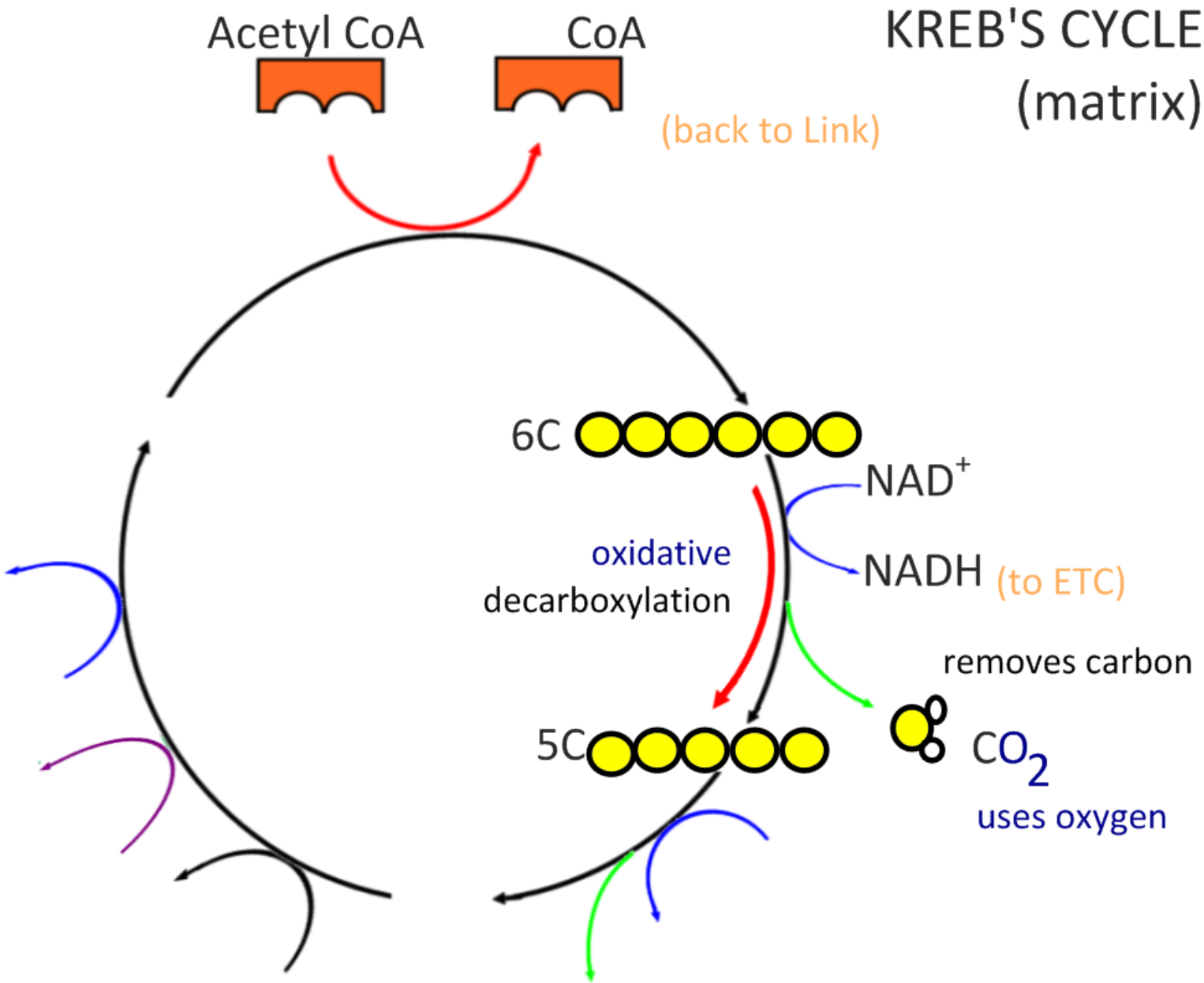

Acetyl CoA
KREB'S CYCLE
(matrix)
oxaloacetate
4C


Acetyl CoA
CoA
KREB'S CYCLE
(matrix)
(back to Link)
6C
citrate
(citric acid)

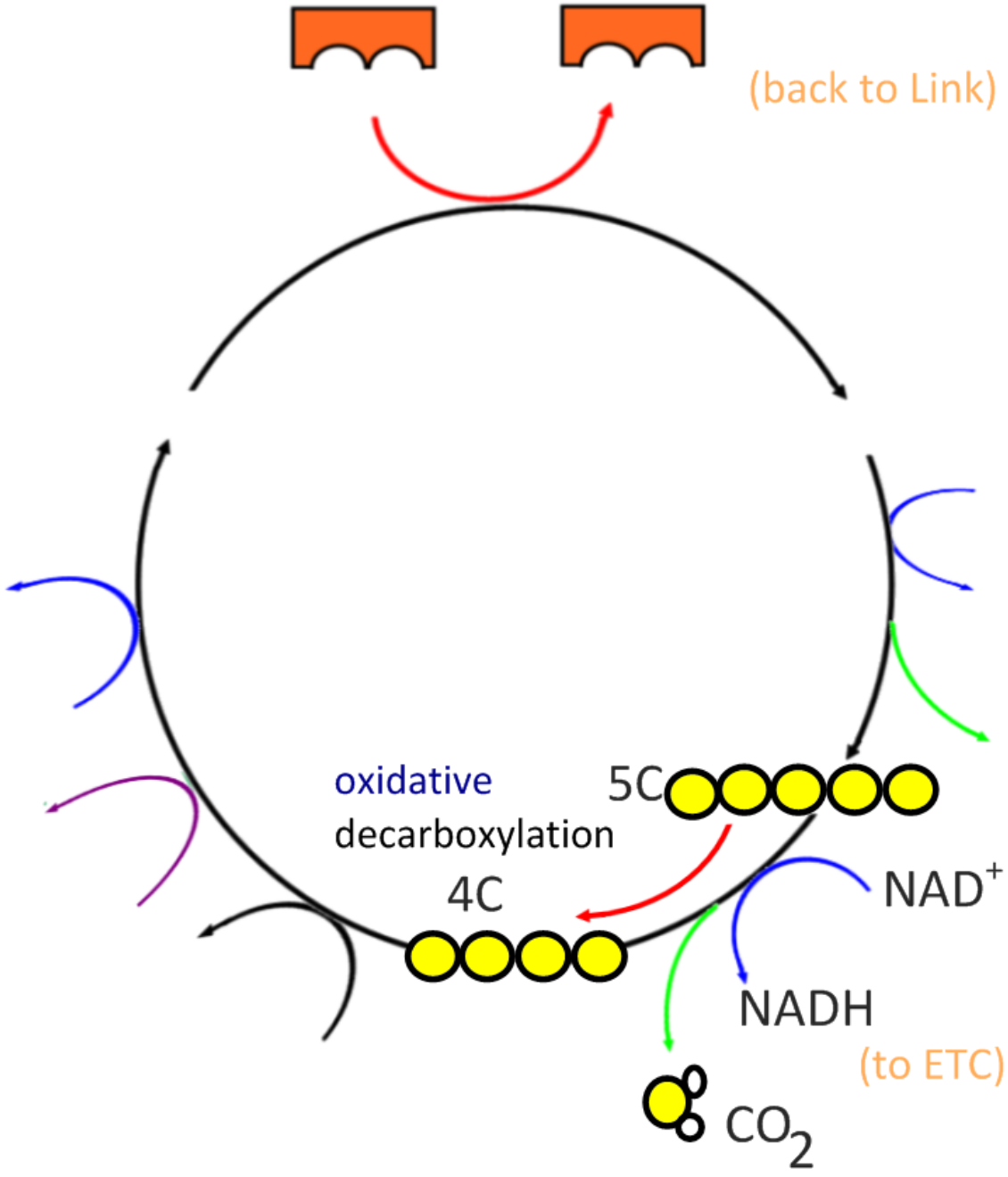
KREB'S CYCLE (matrix)



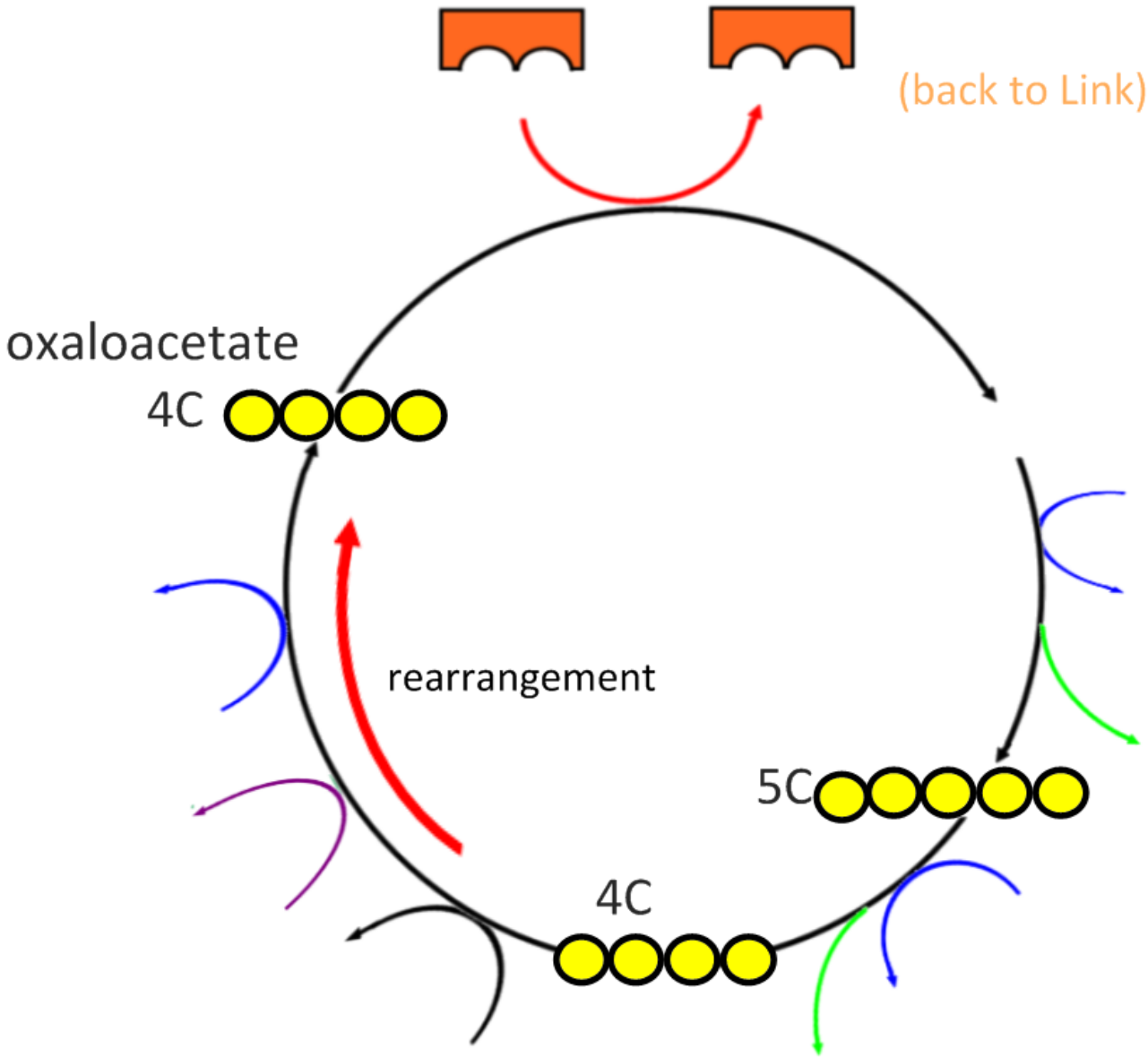
KREB'S CYCLE (matrix)



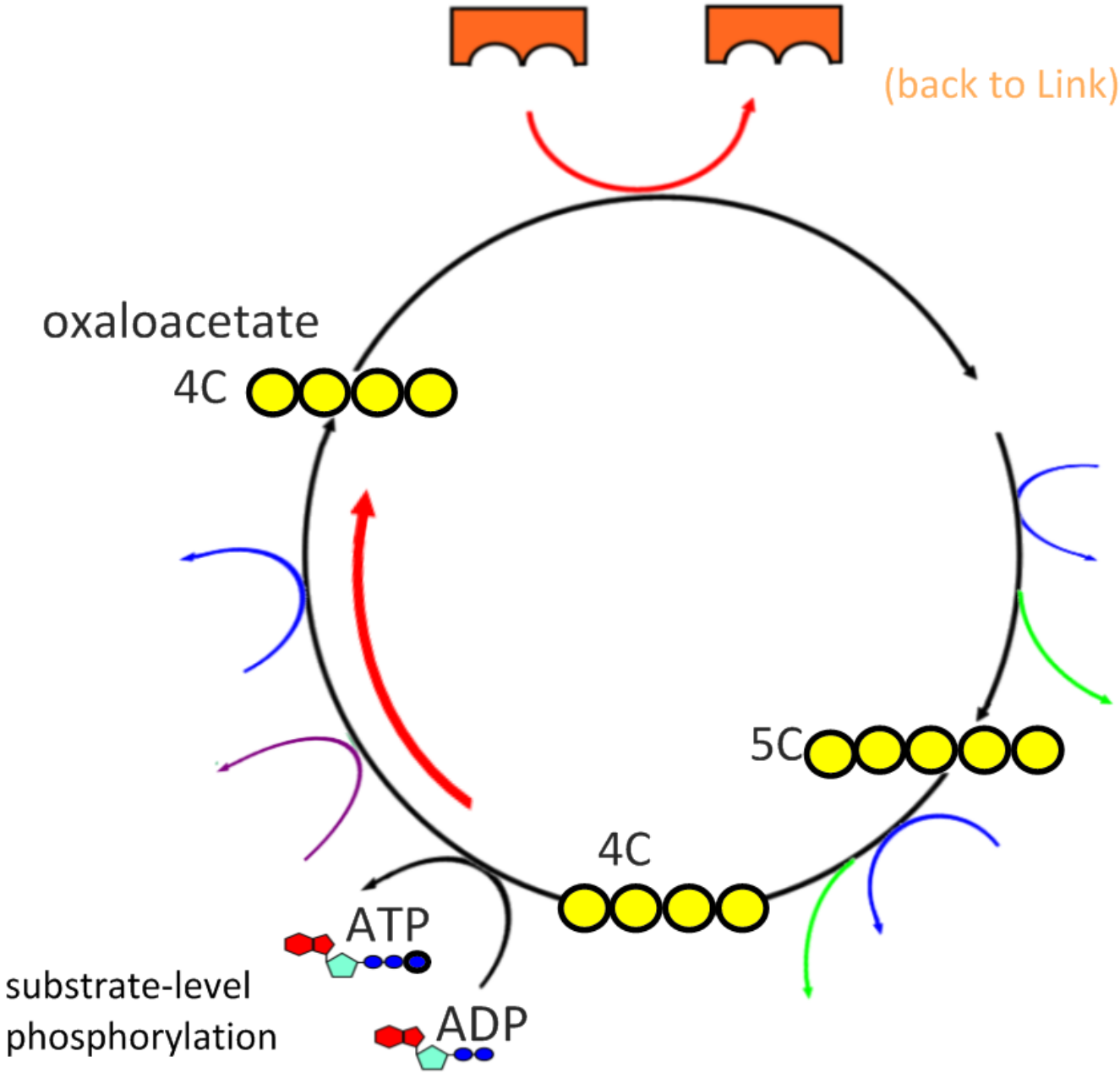
KREB'S CYCLE (matrix)



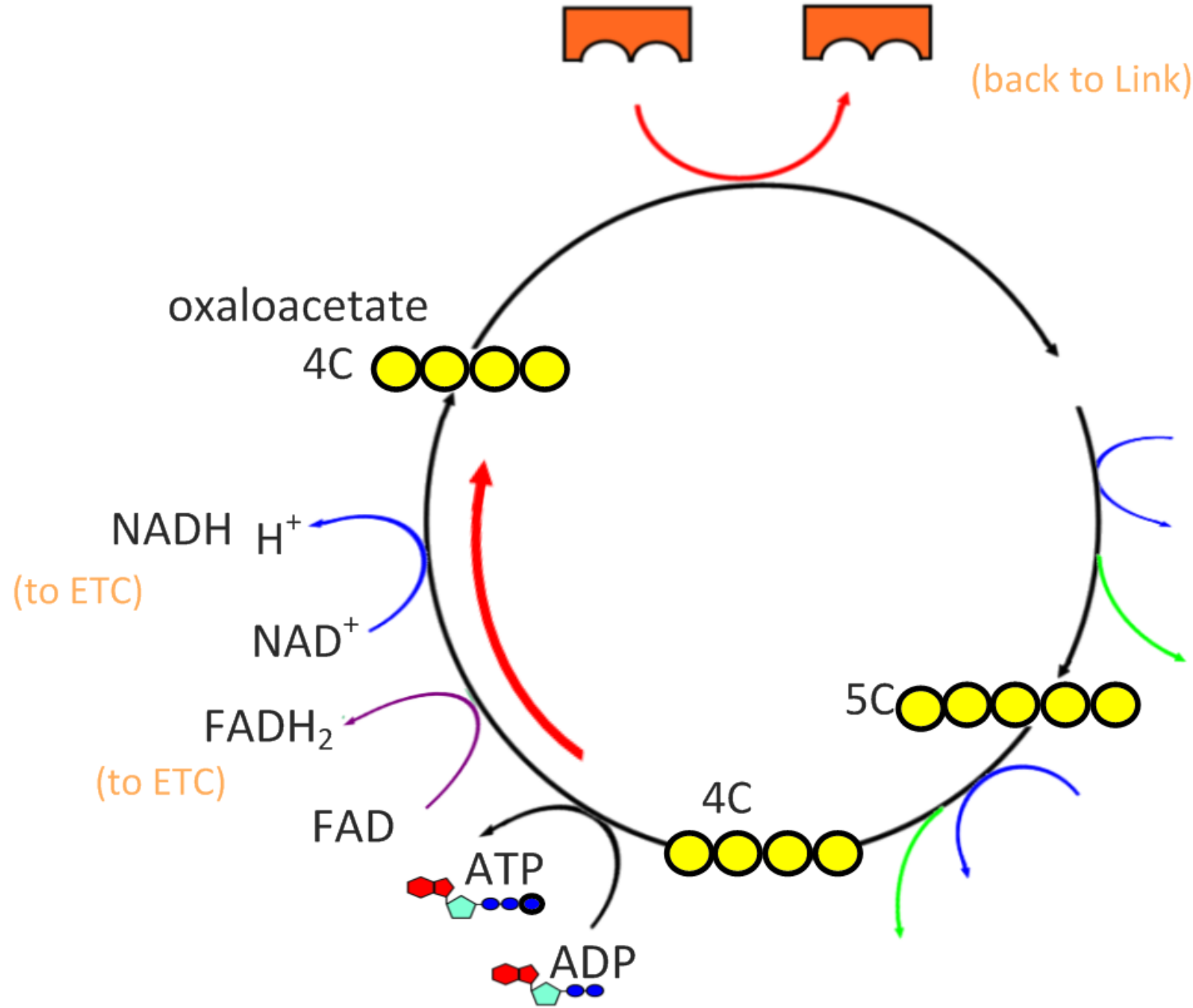
KREB'S CYCLE (matrix)

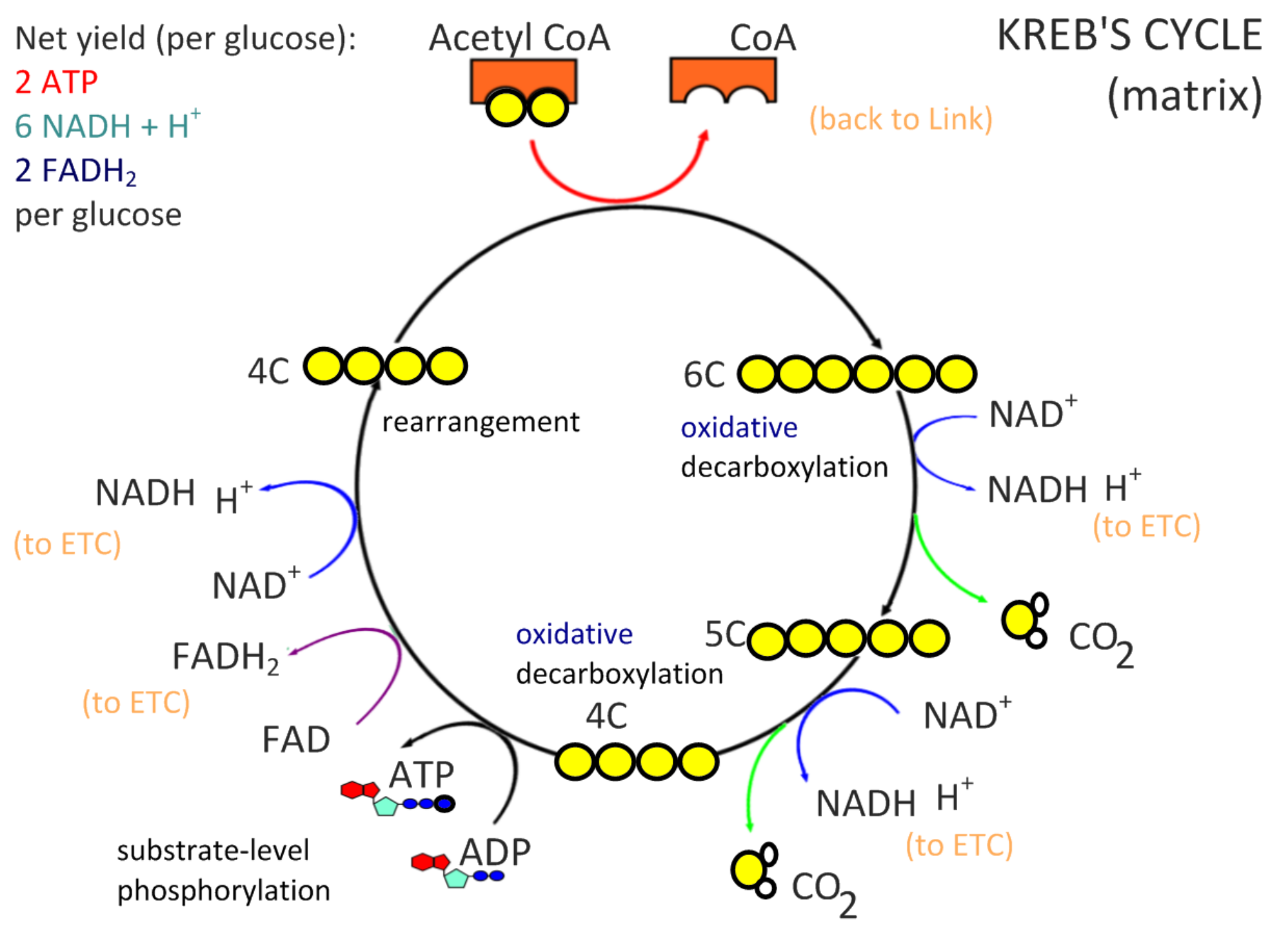


KREB'S CYCLE (matrix)

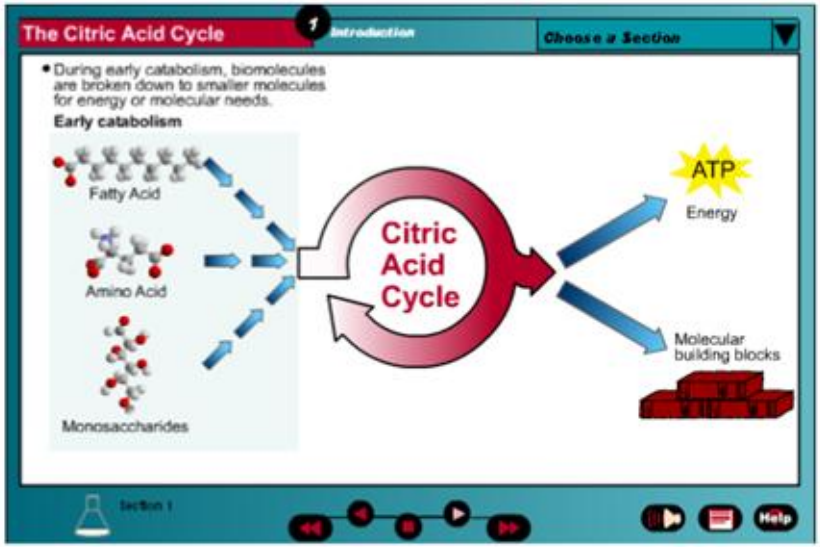


KREB'S CYCLE (matrix)

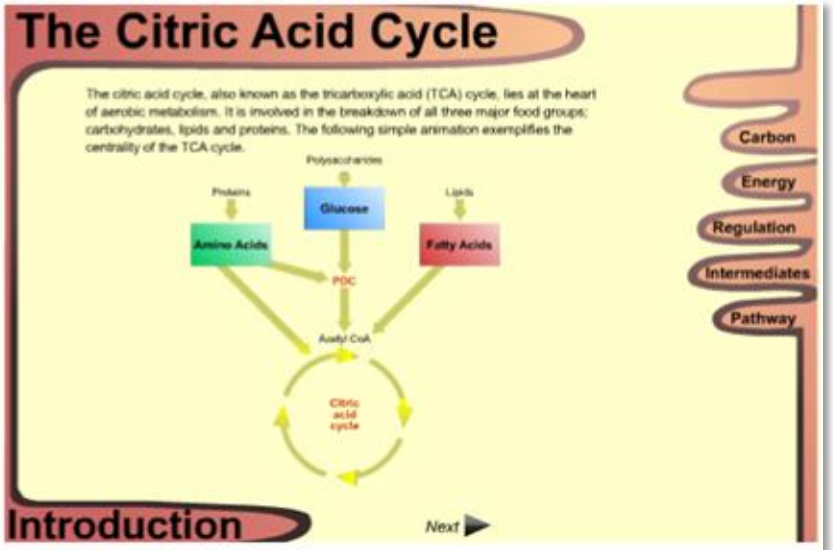



Net yield (per glucose):
2 ATP
6 NADH + H+
2 FADH2
per glucose
Acetyl CoA
CoA
KREB'S CYCLE
(matrix)
(back to Link)
4C
rearrangement
6C
oxidative
decarboxylation
NAD+
NADH H+
(to ETC)
NADH H+
(to ETC)
NAD+
FADH2
(to ETC)
FAD
oxidative
decarboxylation
5C
CO2
4C
NAD+
ATP
NADH H+
(to ETC)
ADP
substrate-level
phosphorylation
CO2

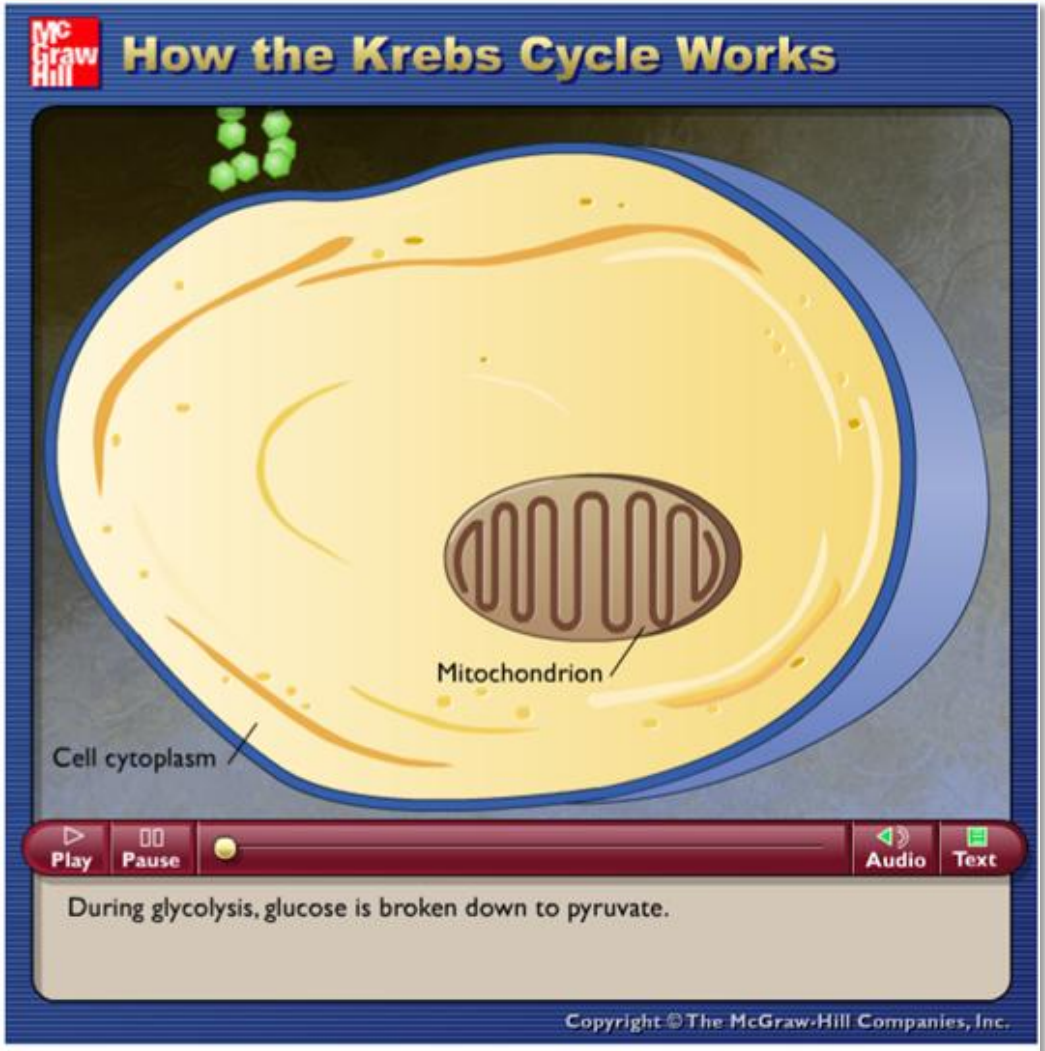
Krebs Cycle animations:



http://tinyurl.com/ewbmn



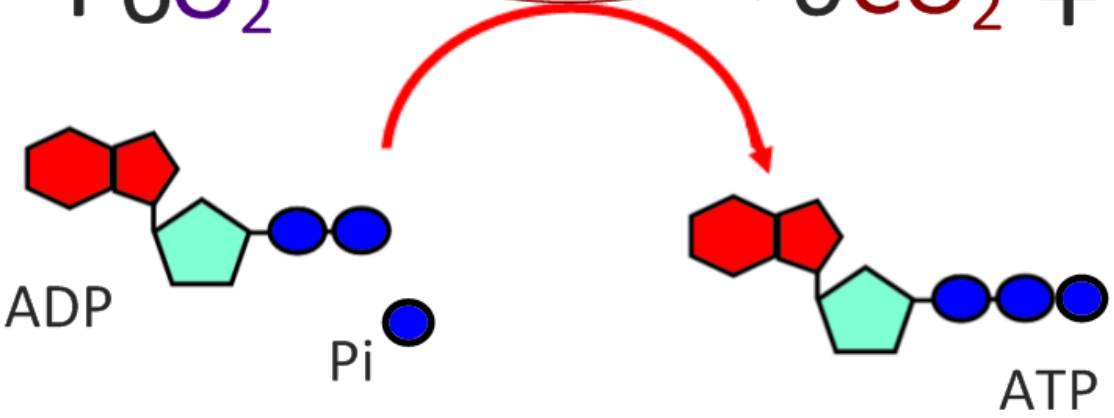
http://tinyurl.com/8hvyl

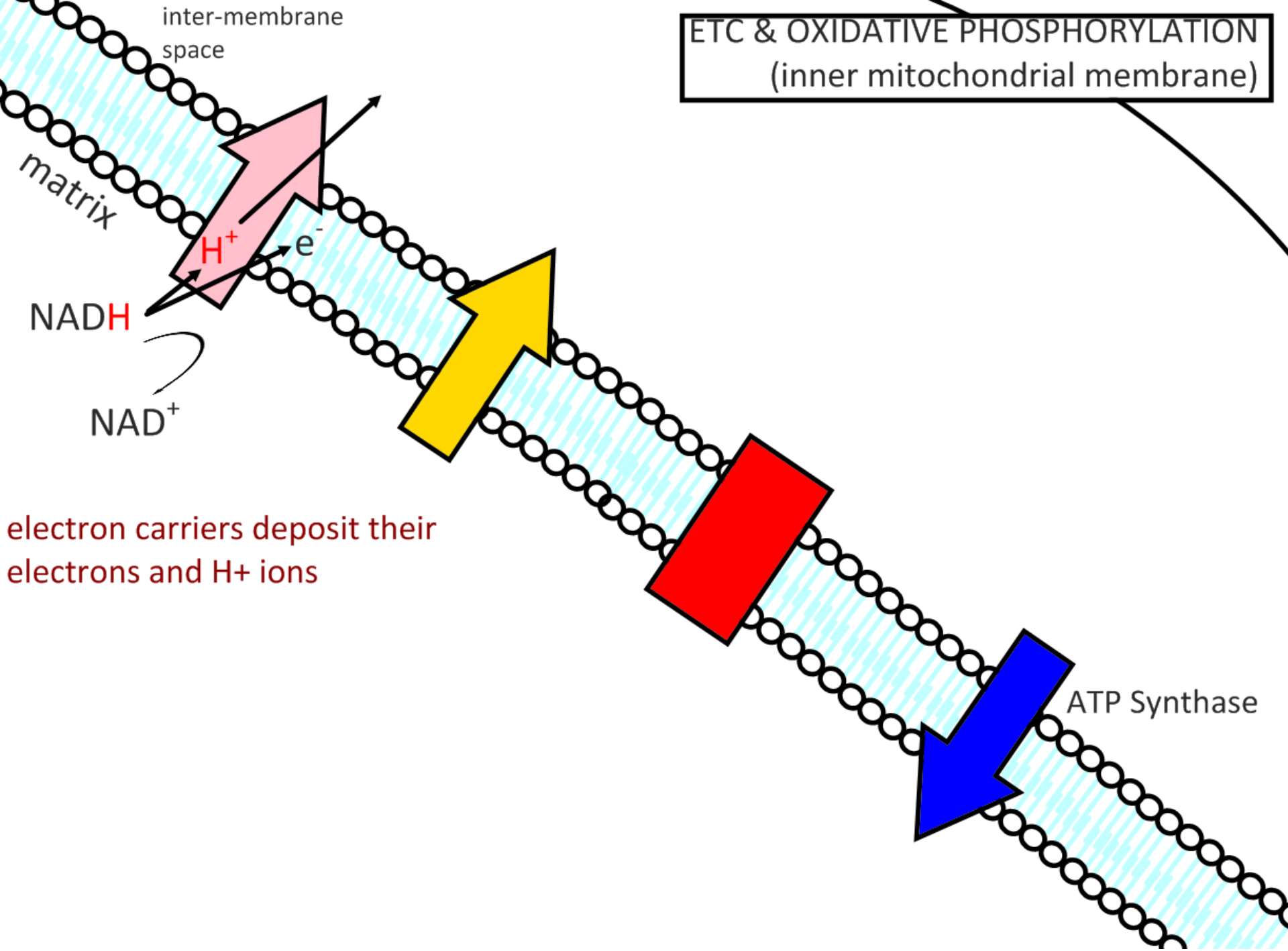


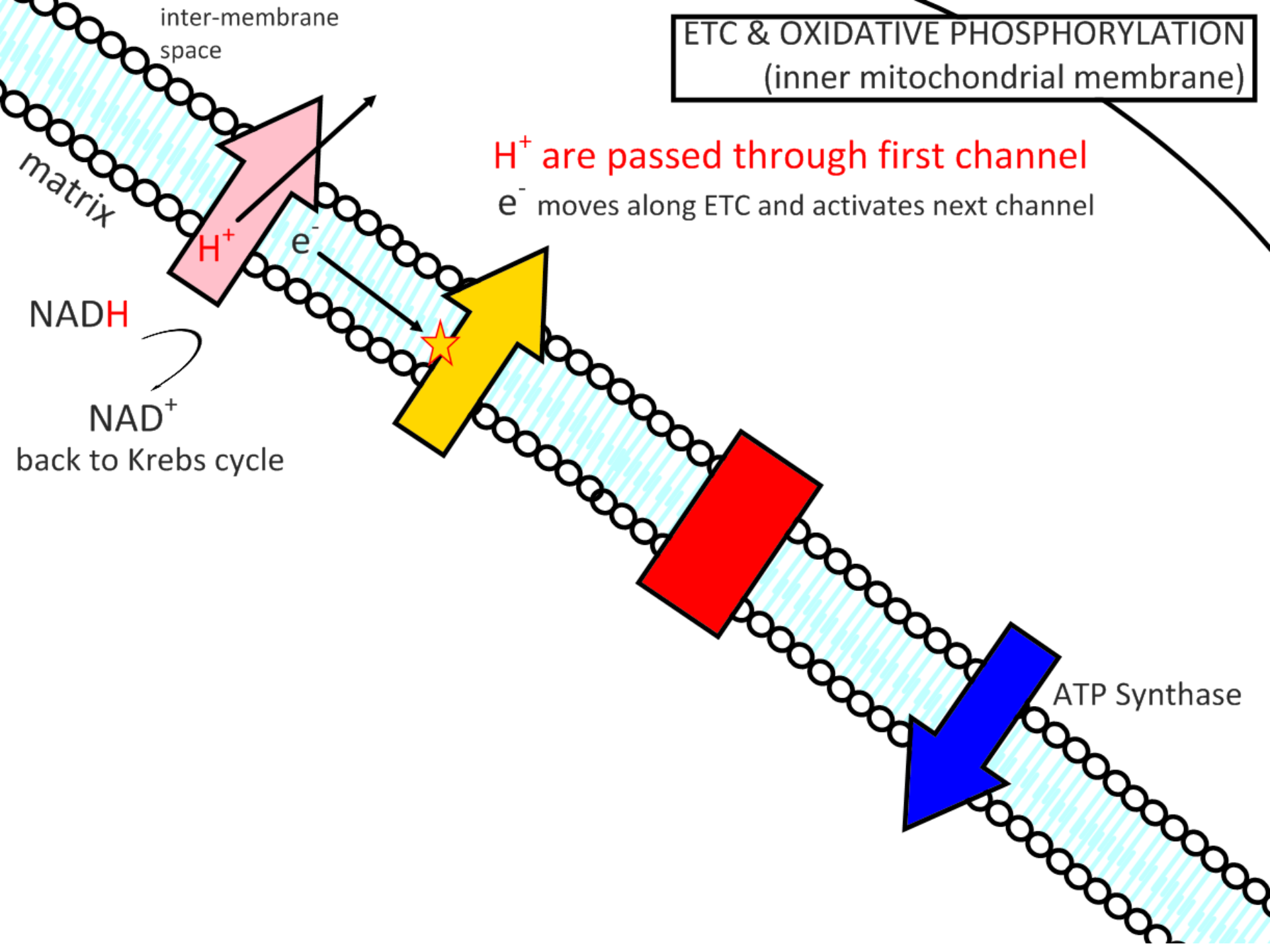
http://tinyurl.com/ydm25ah

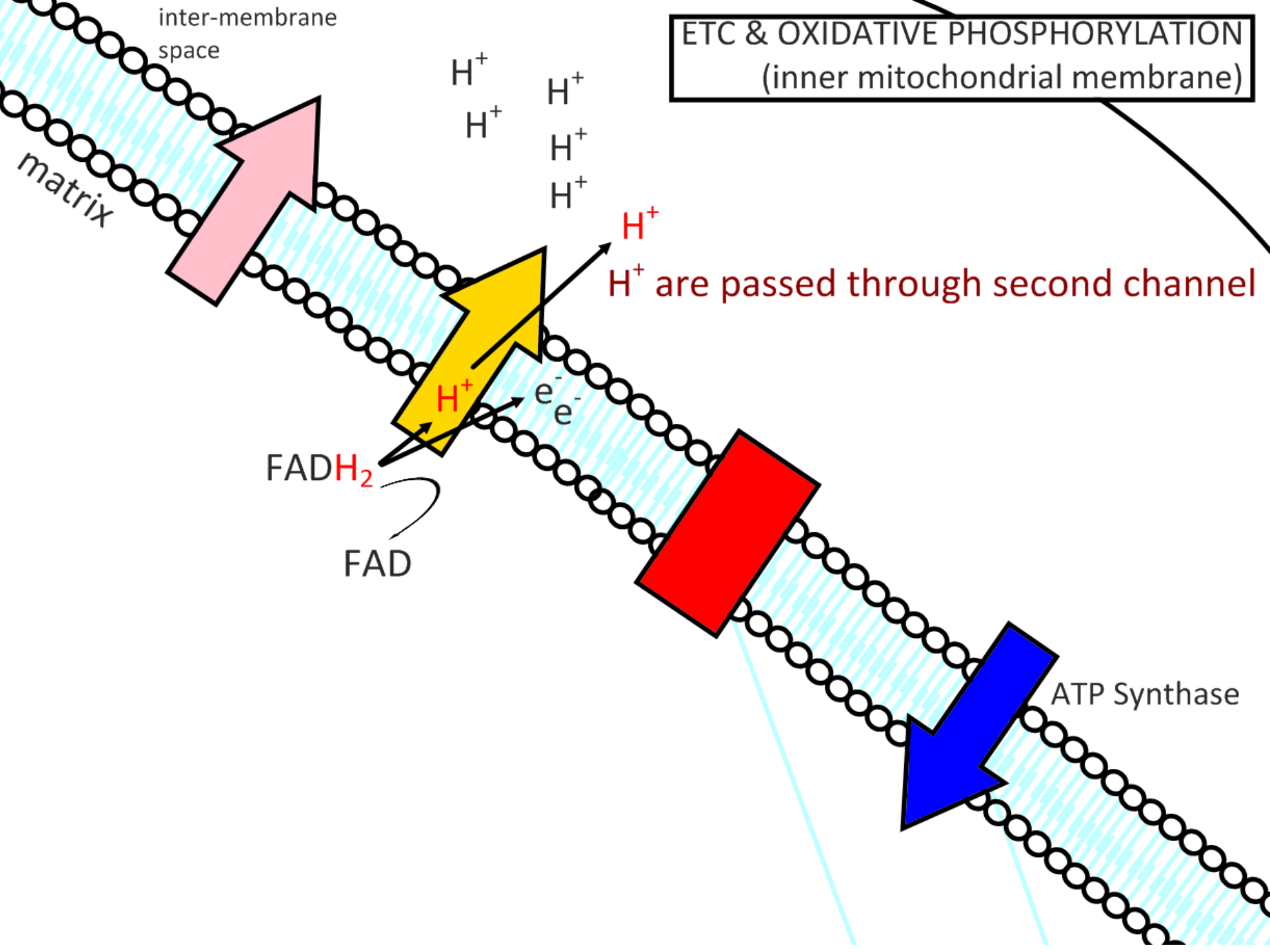
glycolysis → link reaction → Kreb's cycle → electron transport chain & oxidative phosphorylation

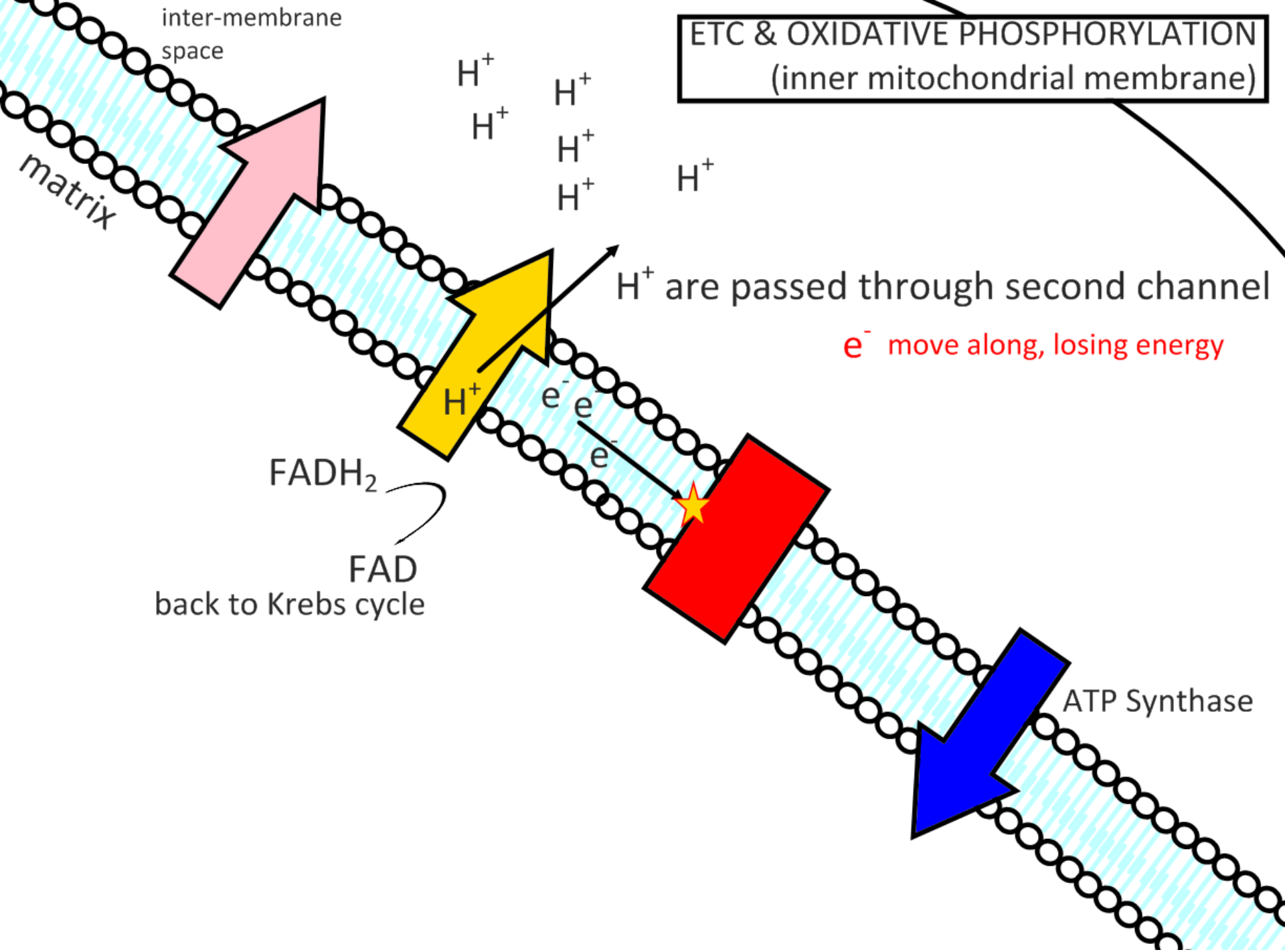
$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{respiration}} 6CO_2 + 6H_2O$

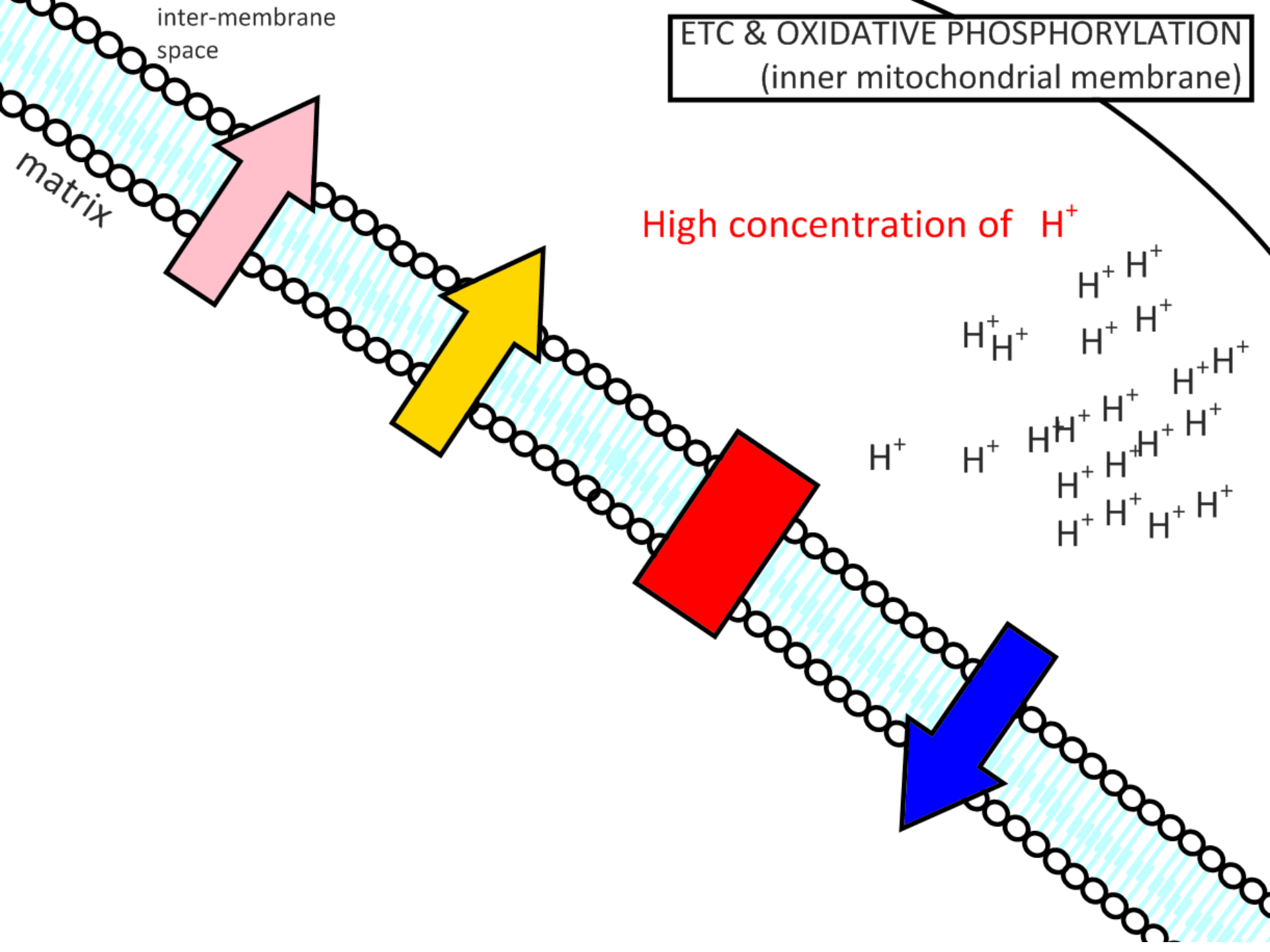



ETC & OXIDATIVE PHOSPHORYLATION
(inner mitochondrial membrane)
inter-membrane space
matrix
H+
e-
NADH
NAD+
electron carriers deposit their electrons and H+ ions
ATP Synthase


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)
inter-membrane space
matrix
H+
H+
H+
H+
H+
H+
H+ are passed through second channel
H+
e-
e-
FADH2
FAD
ATP Synthase

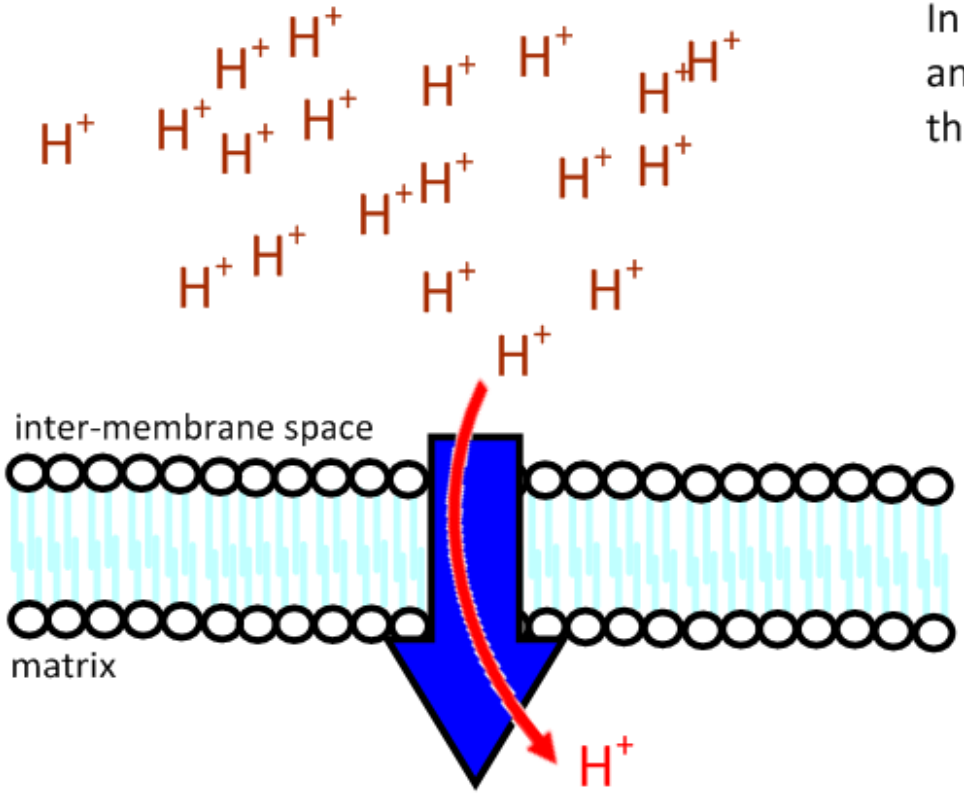

ETC & OXIDATIVE PHOSPHORYLATION
(inner mitochondrial membrane)
inter-membrane space
matrix
H+
H+
H+
H+
H+
H+
H+ are passed through second channel
e- move along, losing energy
H+
e-
e-
e-
FADH2
FAD
back to Krebs cycle
ATP Synthase


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

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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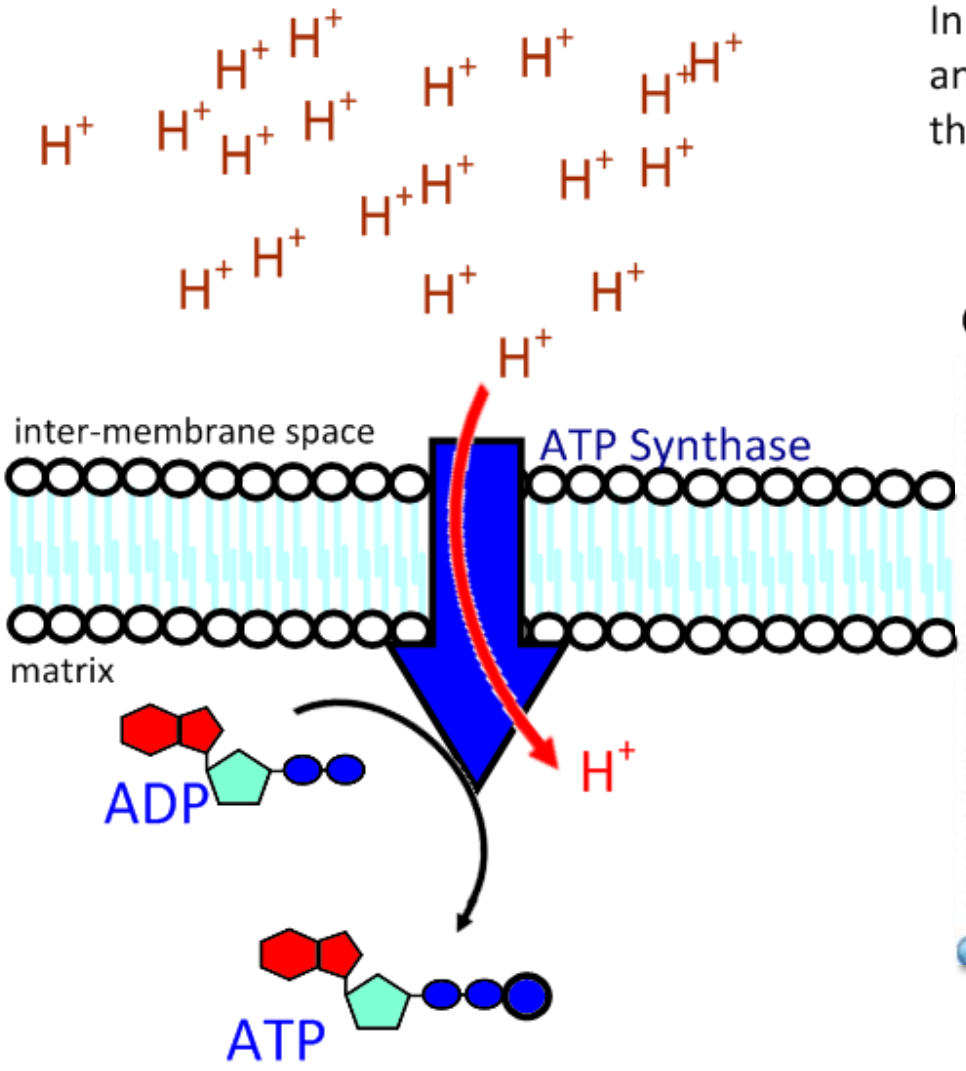
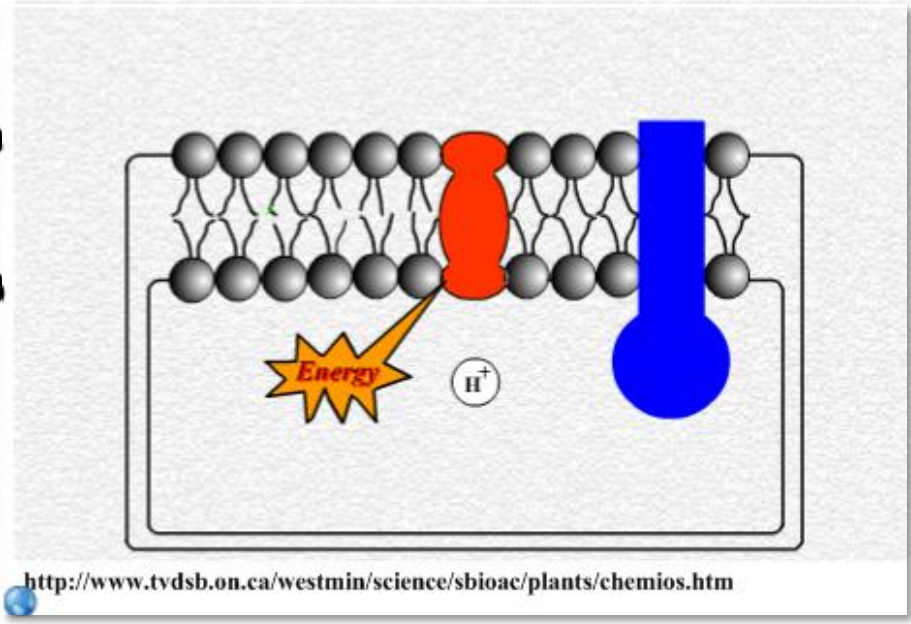


Chemiosmosis:



ETC & OXIDATIVE PHOSPHORYLATION (inner mitochondrial membrane)

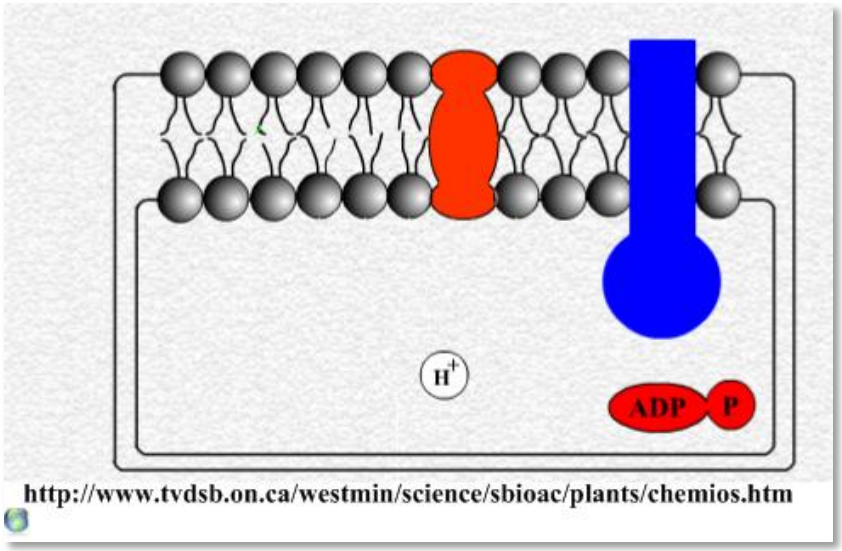
inter-membrane space

matrix

High concentration of H^+

e^- e^- e^- e^-

H^+ move through ATP synthase by chemiosmosis

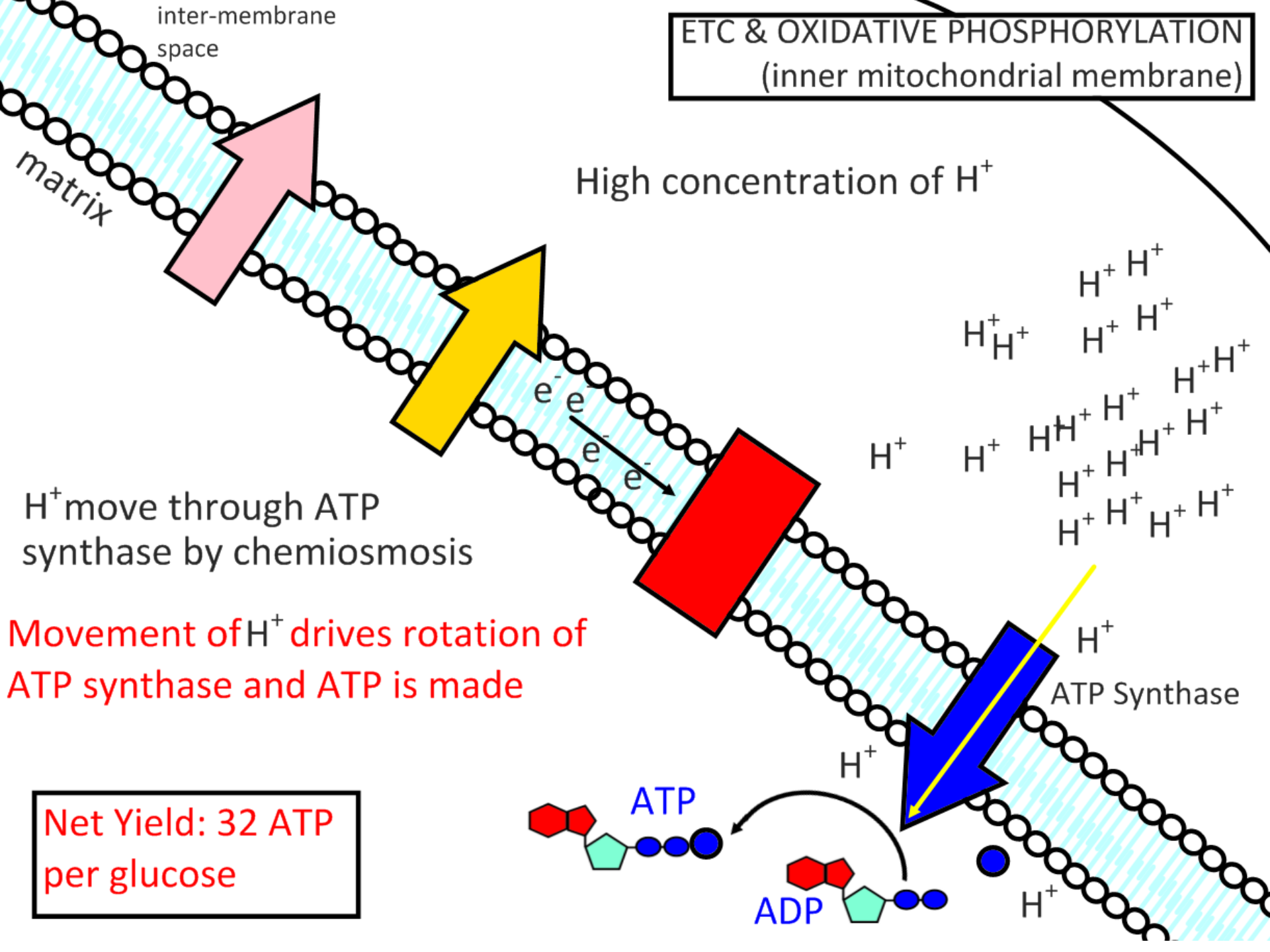


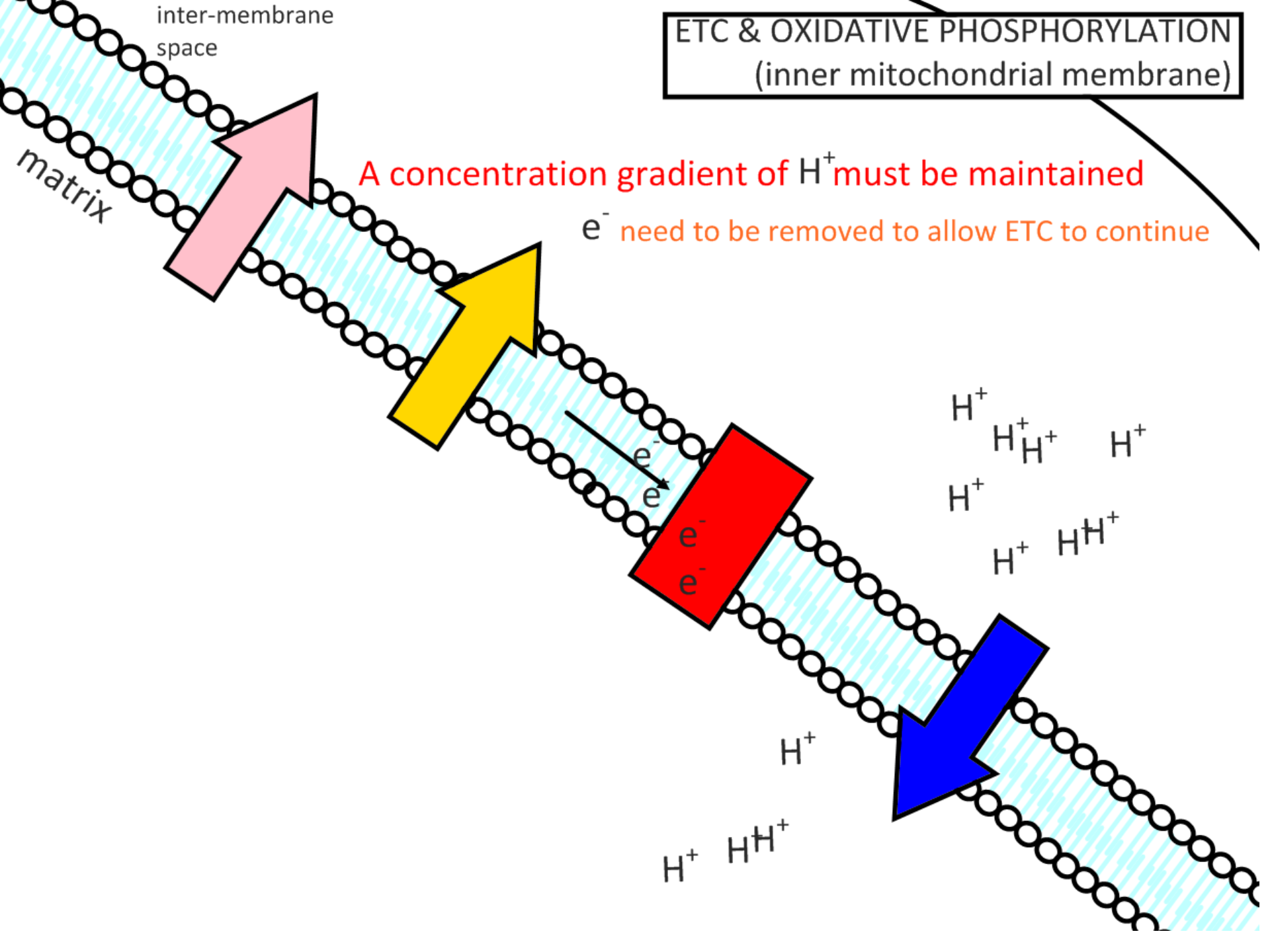
H^+

ATP Synthase

H^+

H^+


ETC & OXIDATIVE PHOSPHORYLATION
(inner mitochondrial membrane)
inter-membrane space
matrix
High concentration of H+
e- e- e- e-
H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+ H+
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)
inter-membrane space
matrix
A concentration gradient of H+ must be maintained
e- need to be removed to allow ETC to continue
e-
e-
e-
e-
H+
H+
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H+
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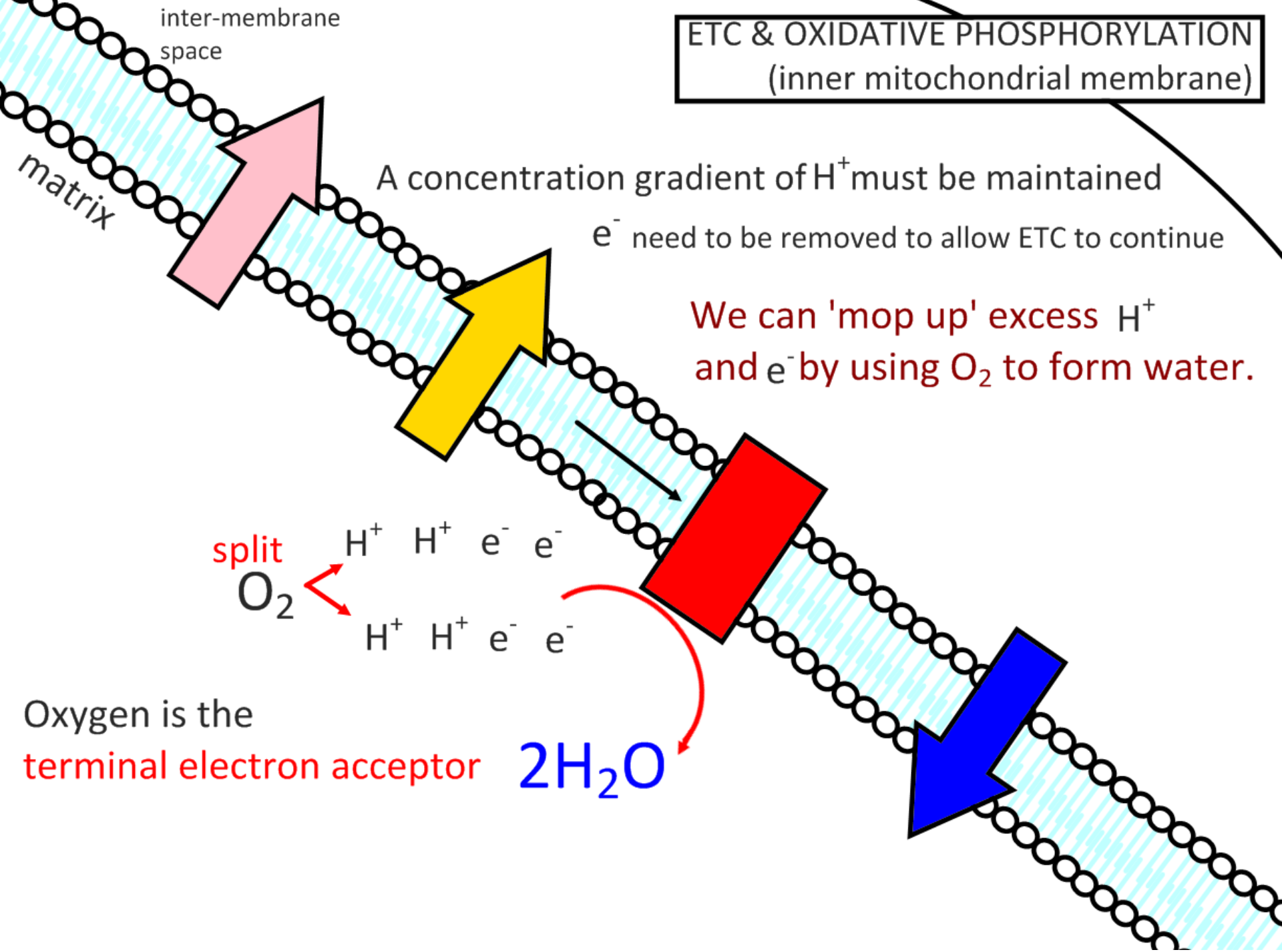
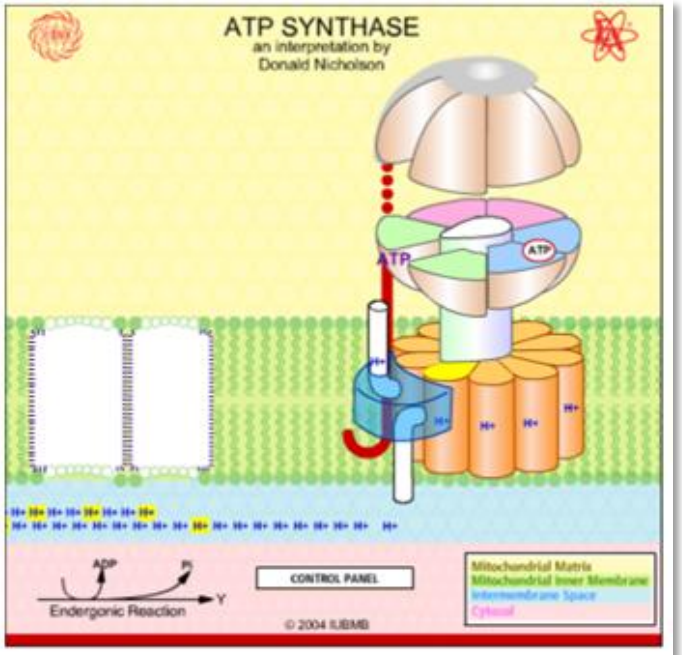
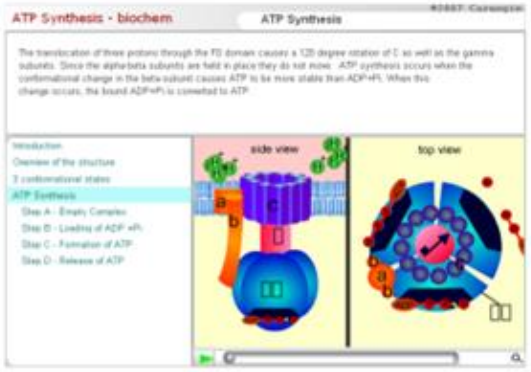

inter-membrane space
matrix
ETC & OXIDATIVE PHOSPHORYLATION (inner mitochondrial membrane)
A concentration gradient of H^+ must be maintained
e^- need to be removed to allow ETC to continue
We can 'mop up' excess H^+ and e^- by using O_2 to form water.
split
O_2
H^+ H^+ e^- e^-
H^+ H^+ e^- e^-
Oxygen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

ATP Synthase & ETC Animations

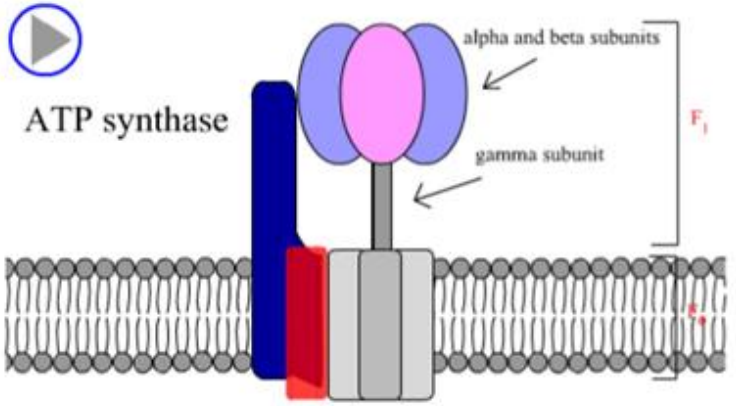
http://www.youtube.com/watch?v=uOoHKCMAUMc



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

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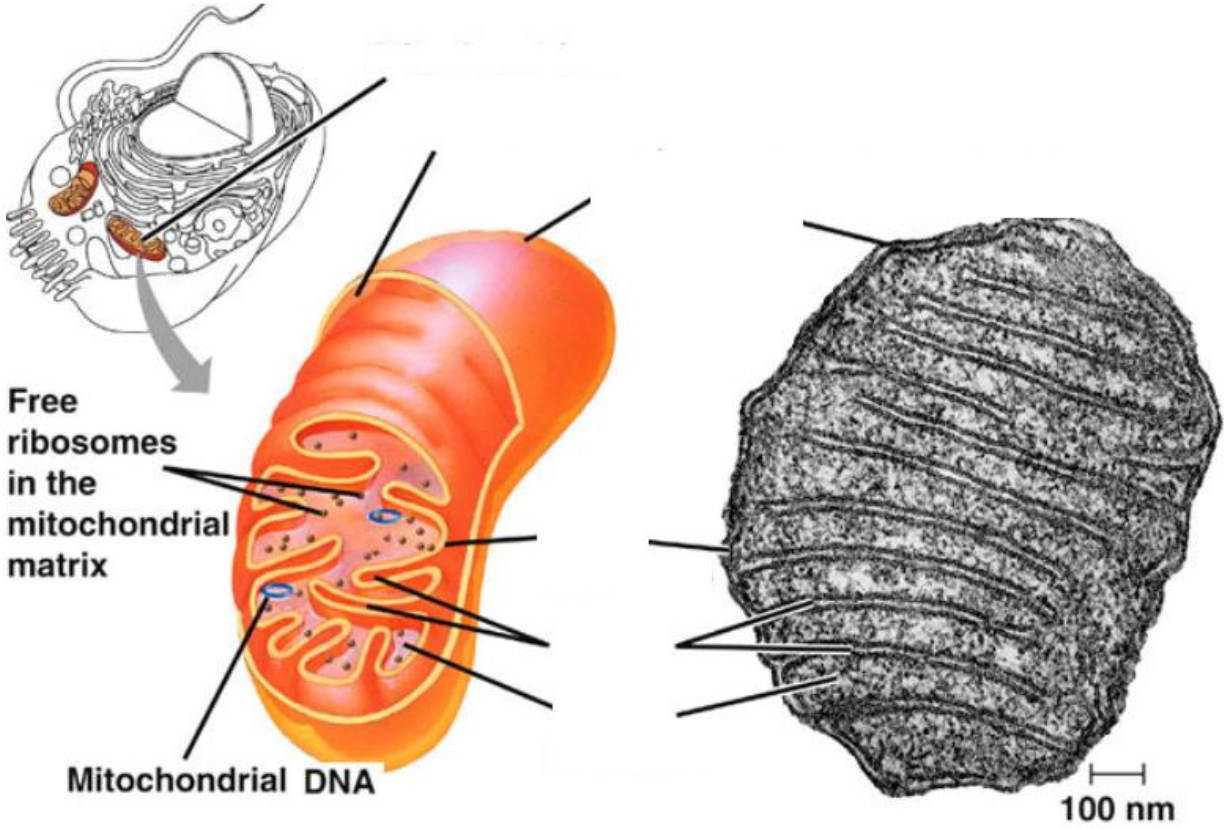
Total ATP yield by aerobic respiration: 36

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



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

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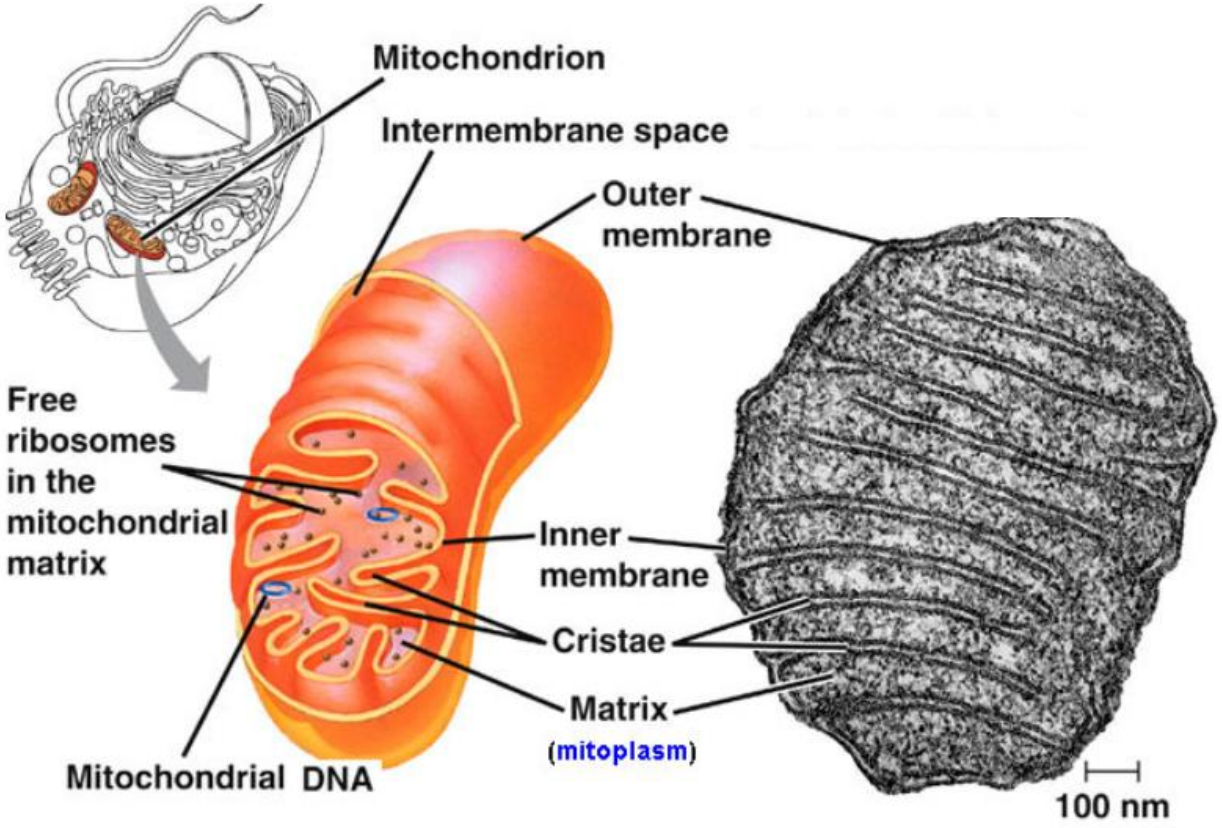

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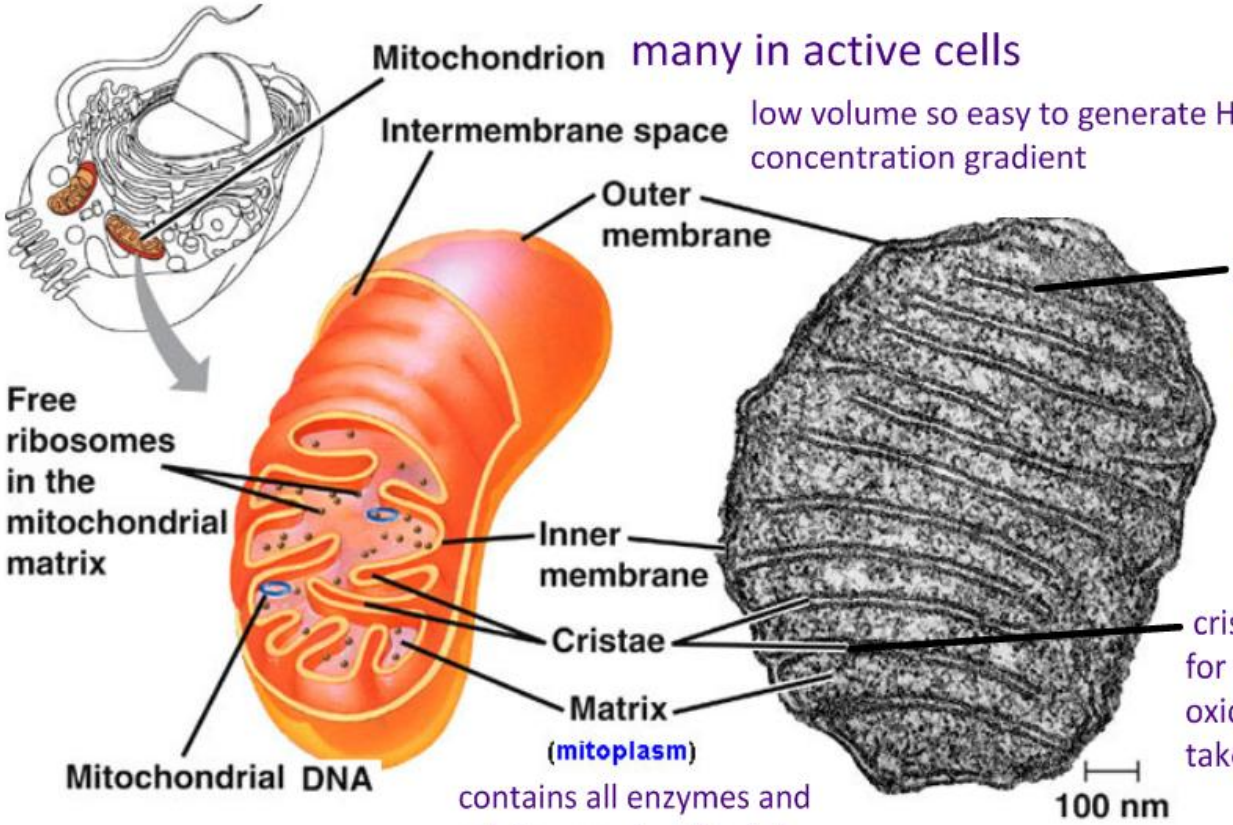
Structure vs function



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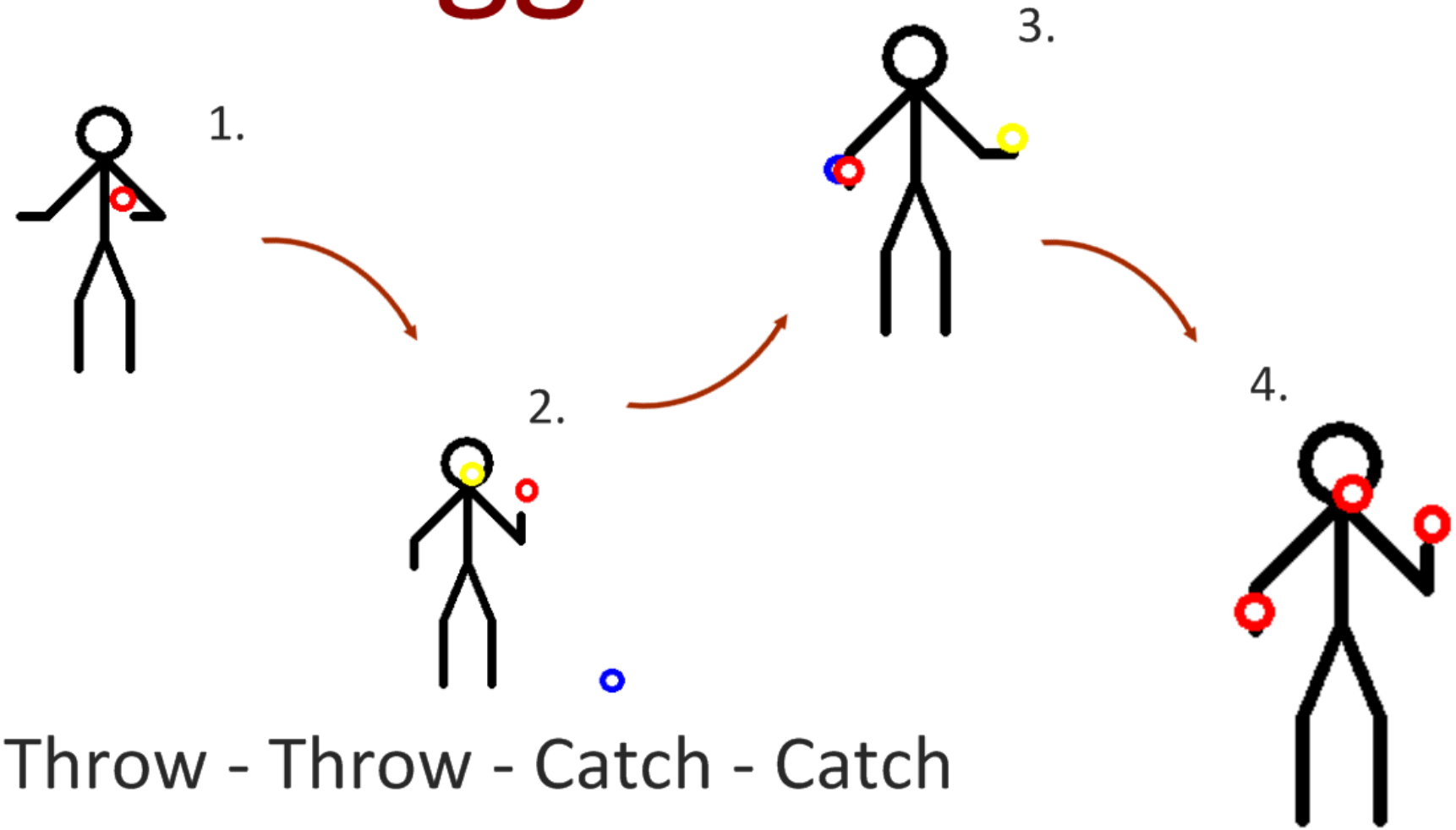
Let's Juggle!



Throw - Throw - Catch - Catch

http://www.instructables.com/id/How-to-Juggle:-the-3-ball-cascade/

Spaced Learning links:

Wikipedia introduction:

http://en.wikipedia.org/wiki/Spaced_learning

Guardian News story:

http://www.guardian.co.uk/education/2009/feb/13/gcses-teaching

Monkseaton school (the original idea):

http://www.monkseaton.org.uk/Making_Minds/Pages/Spaced%20Learning%208%20minute%20lessons.aspx

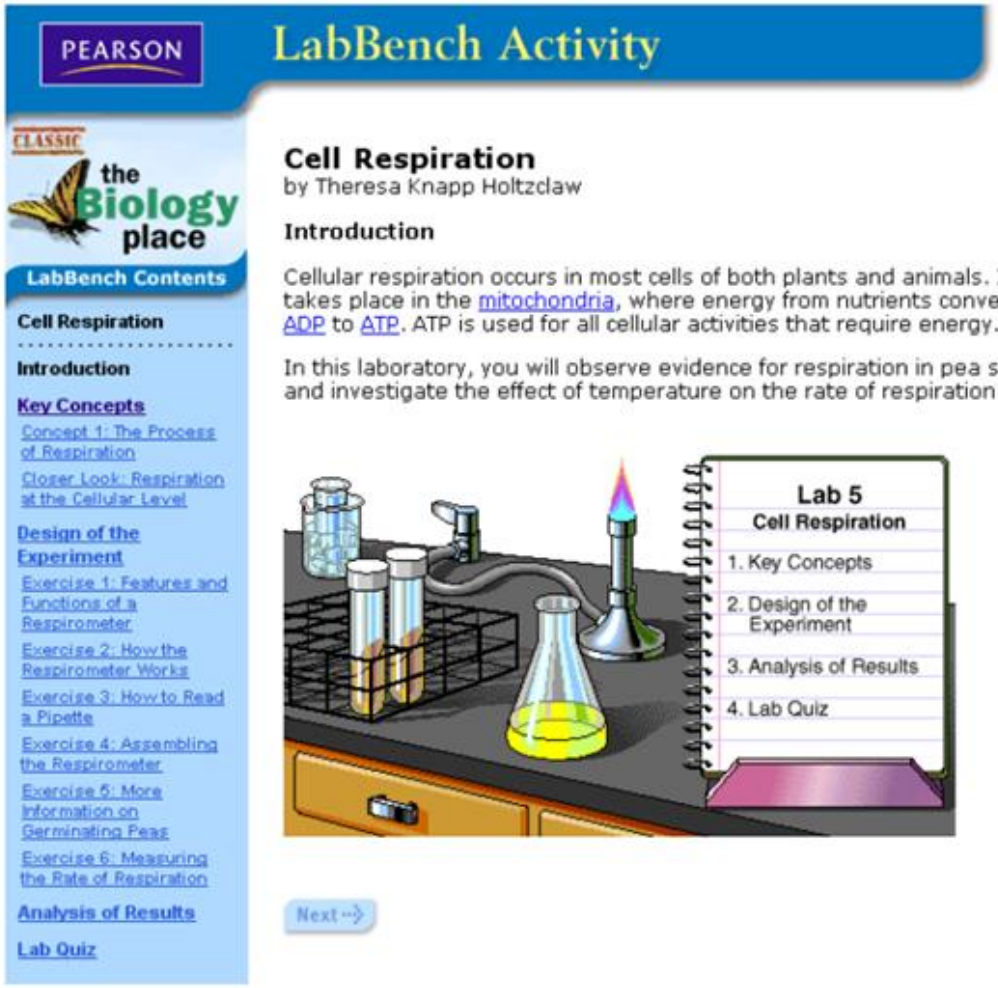
Making Memories Stick (Scientific American):

http://www.sciam.com/article.cfm?id=making-memories-stick

Quick how-to for revision:

http://ezinearticles.com/?How-to-Study-For-a-Test-Using-Spaced-Learning&id=1216261

Try this virtual lab activity:



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

Remember:

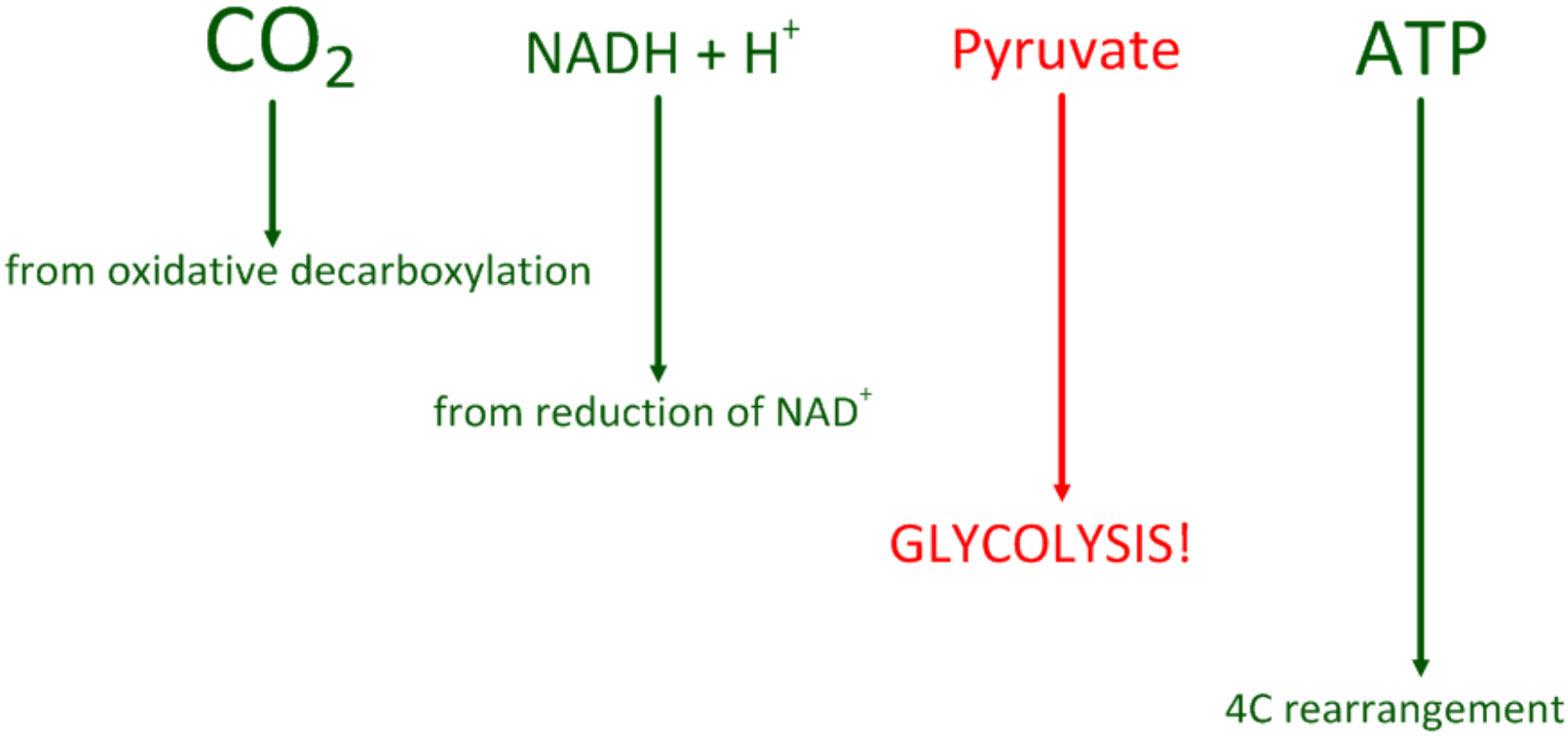
Respiration is a process controlled by enzymes - how will various factors affect the rate of reaction?

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

Which is not a product of the Krebs cycle?

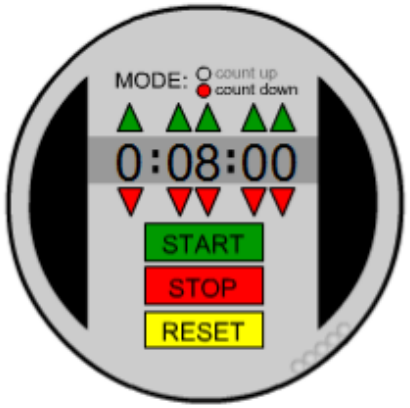
CO_2 NADH + H^+ Pyruvate ATP

Which is not a product of the Krebs cycle?



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;

For more IB Biology resources:

http://sciencevideos.wordpress.com