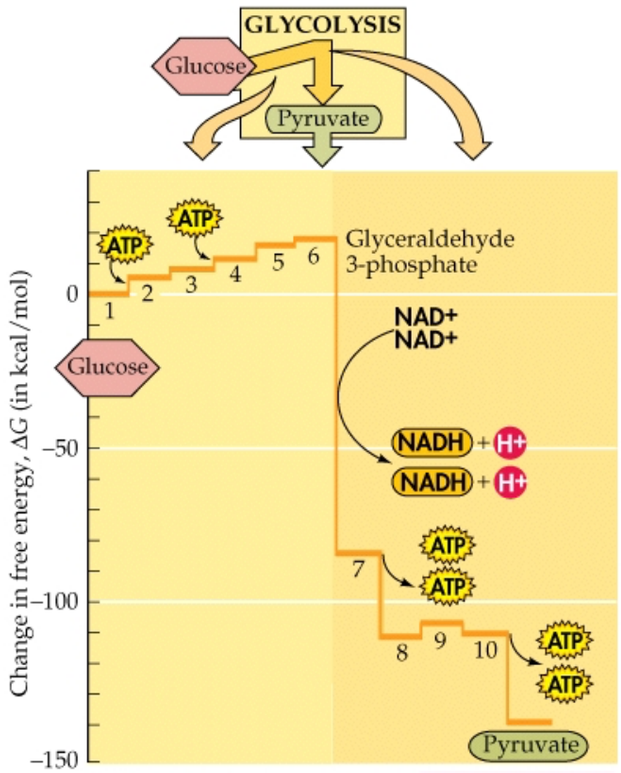
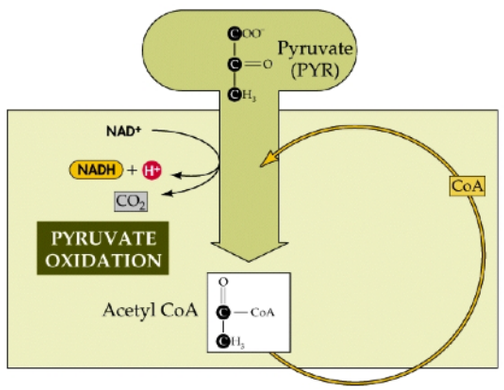
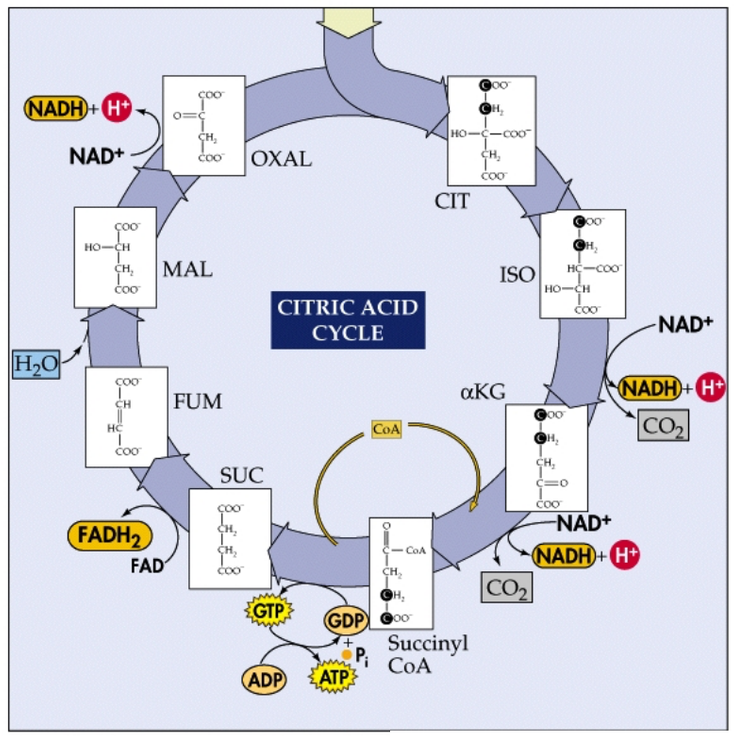
BIOL2107, Fall ’23

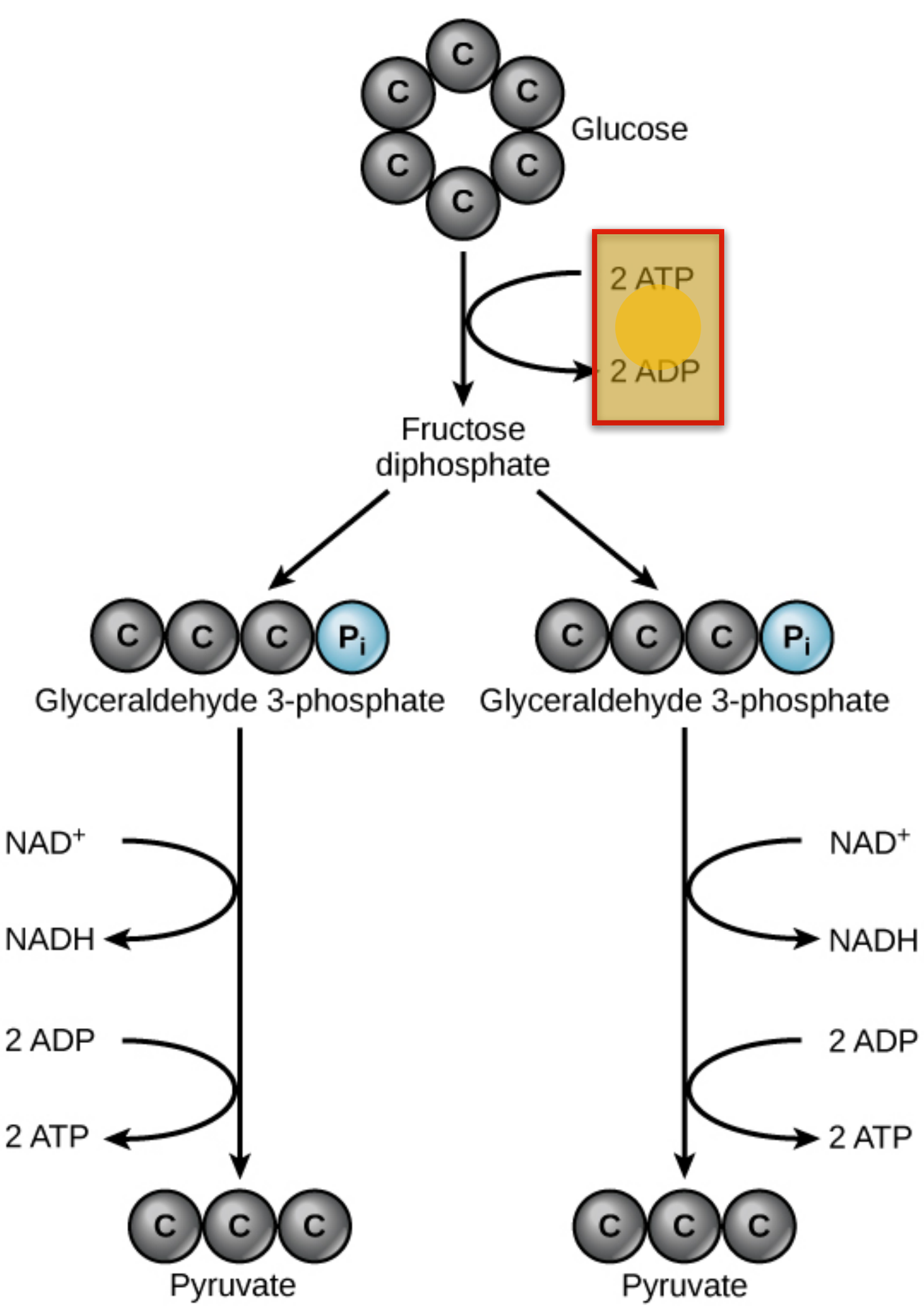
Lecture 20

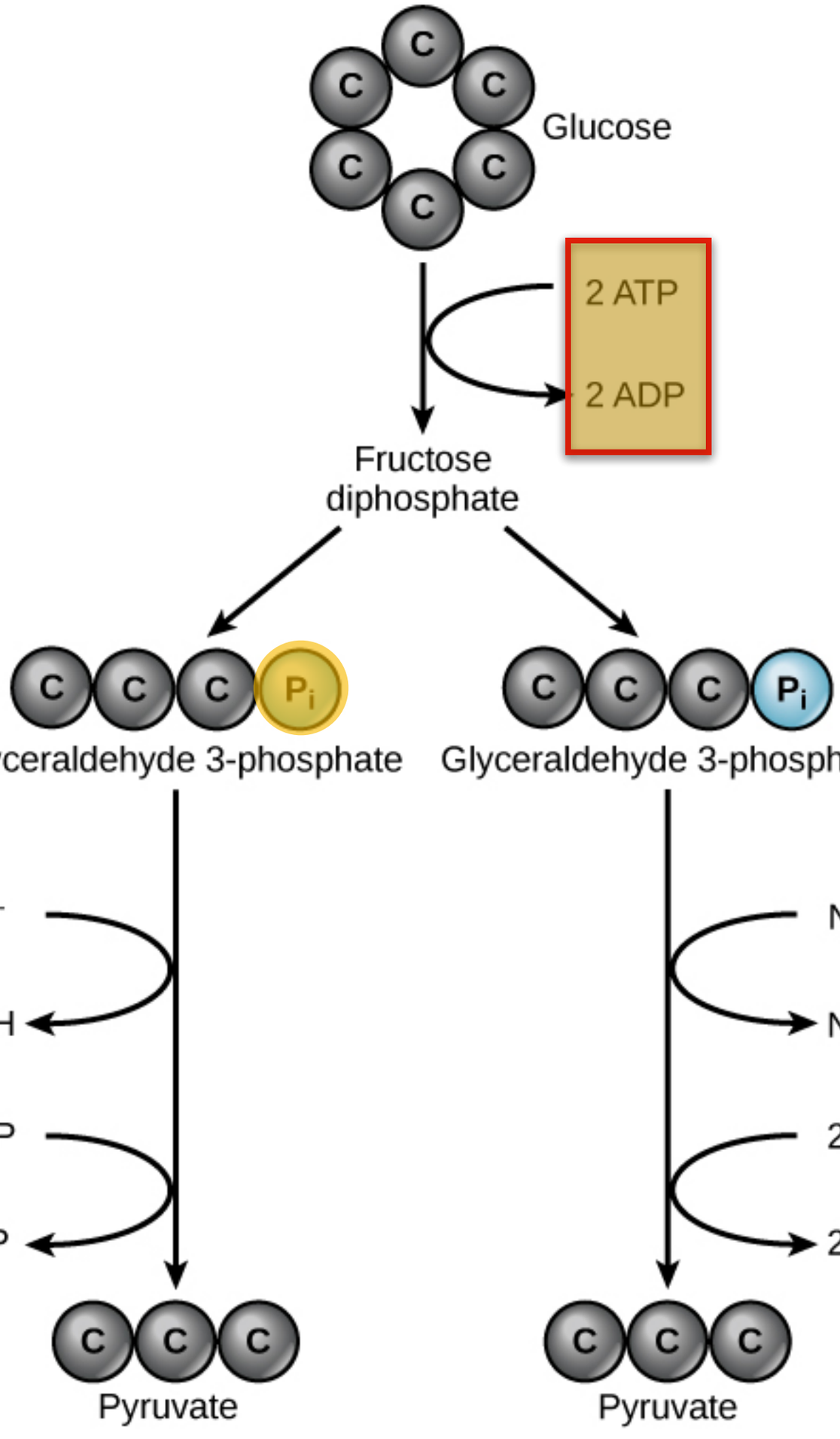


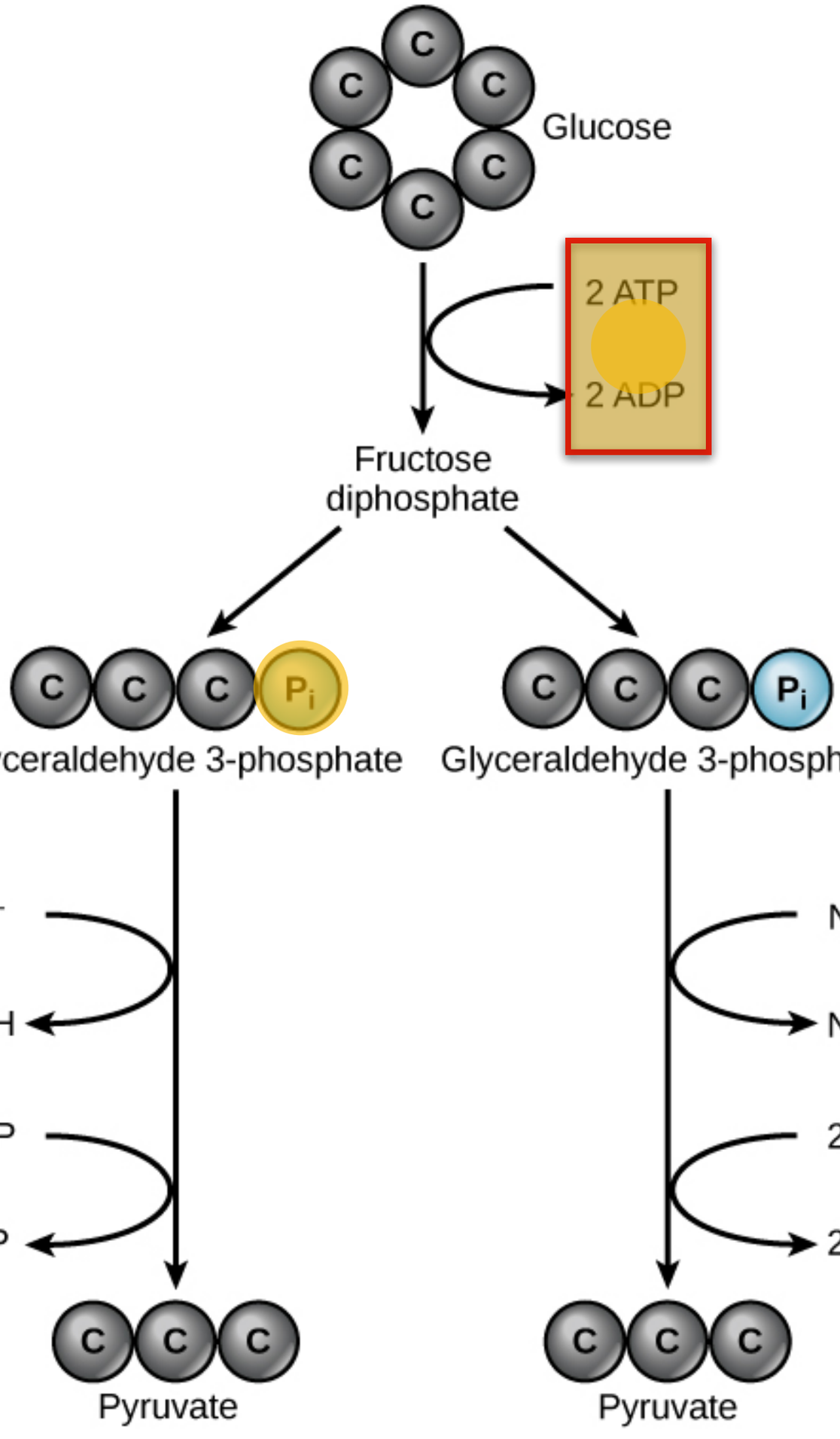


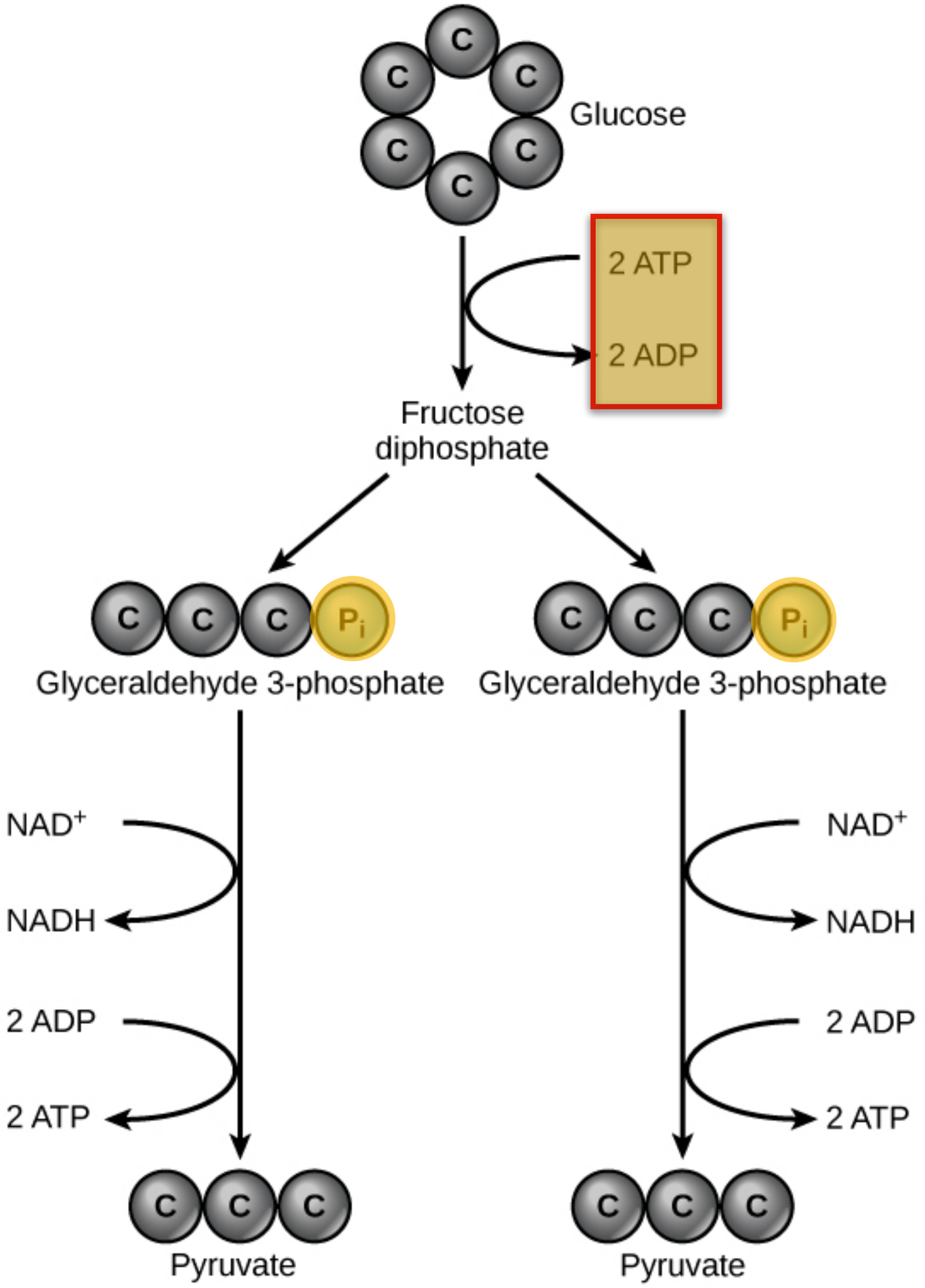


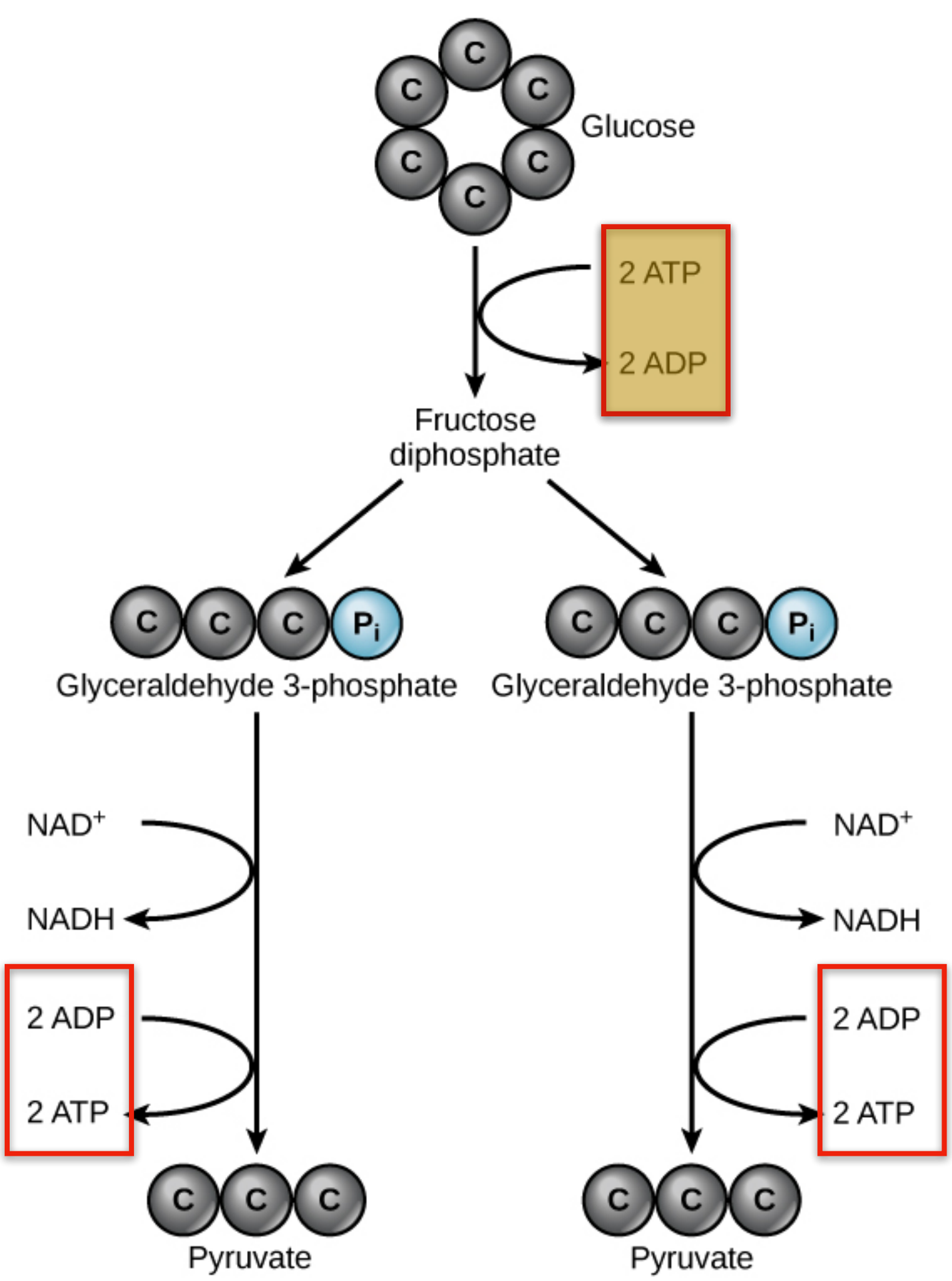
Glucose/Cell Metabolism -Respiration

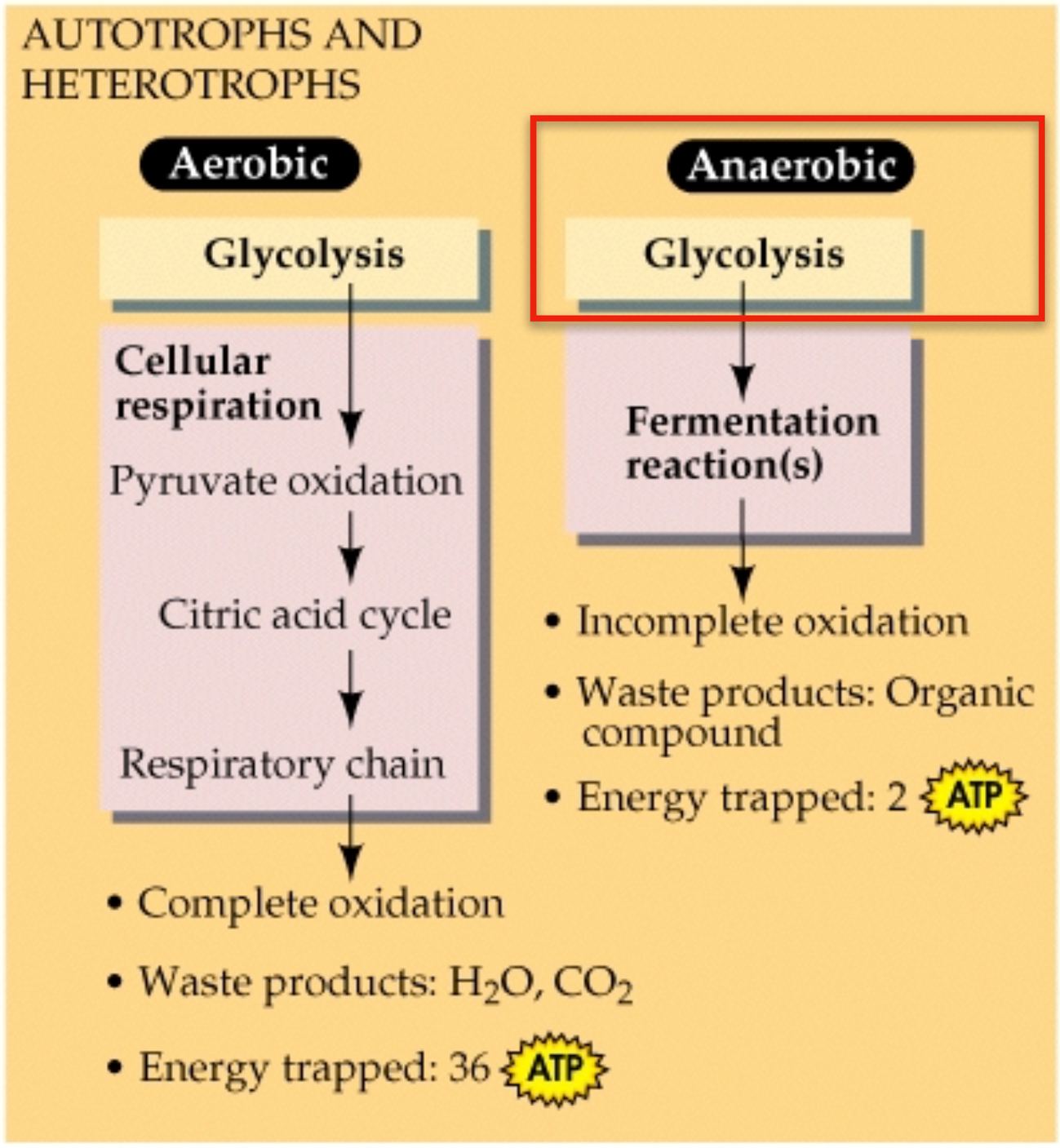

C
C
C
C
C
C
Glucose
2 ATP
2 ADP
Fructose
diphosphate
C C C Pi
C C C Pi
Glyceraldehyde 3-phosphate
Glyceraldehyde 3-phosphate
NAD+
NADH
2 ADP
2 ATP
NAD+
NADH
2 ADP
2 ATP
C C C
C C C
Pyruvate
Pyruvate

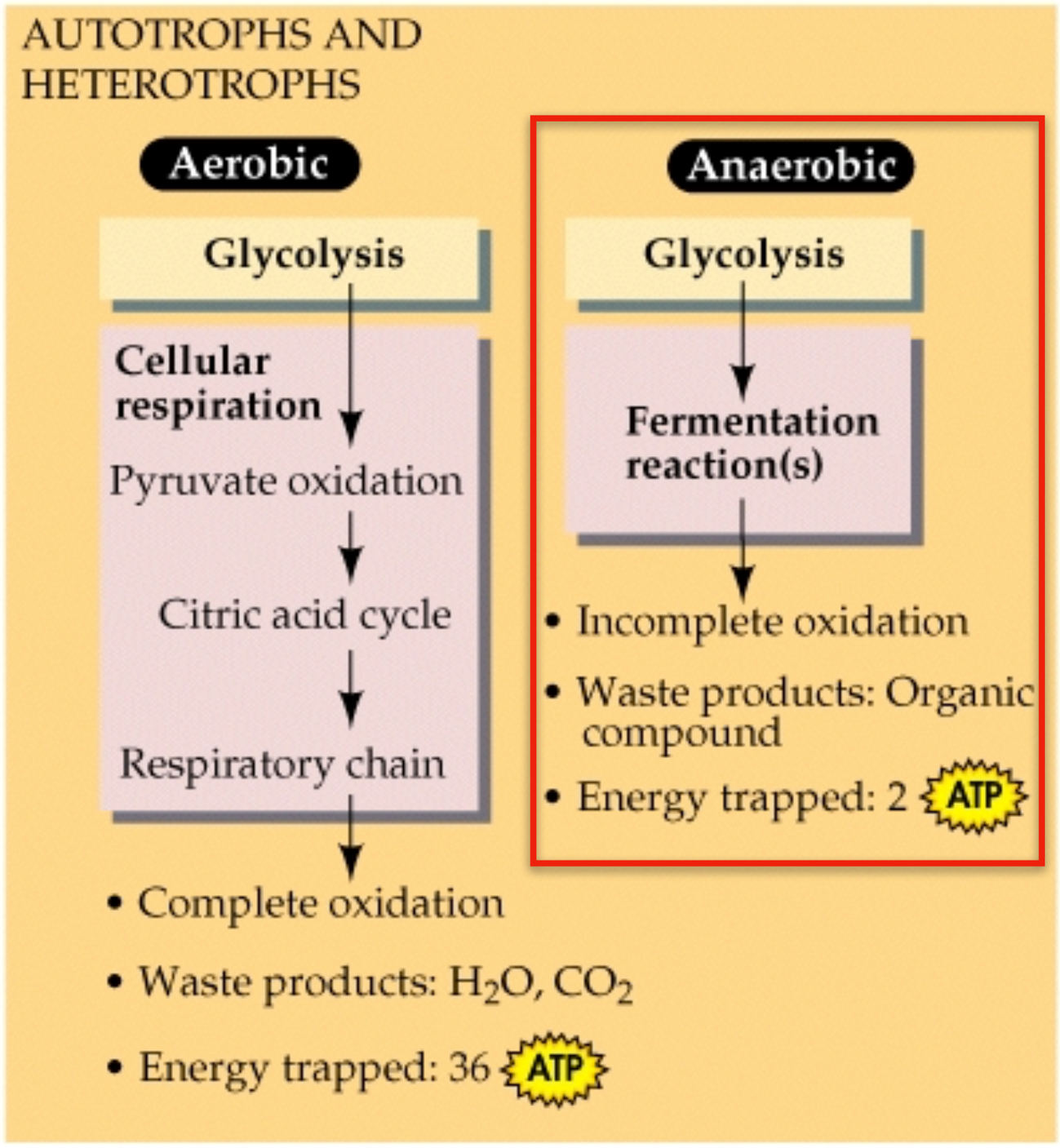

C
C
C
C
C
C
Glucose
2 ATP
2 ADP
Fructose
diphosphate
C C C Pi
C C C Pi
Glyceraldehyde 3-phosphate
Glyceraldehyde 3-phosphate
NAD+
NADH
2 ADP
2 ATP
NAD+
NADH
2 ADP
2 ATP
C C C
C C C
Pyruvate
Pyruvate

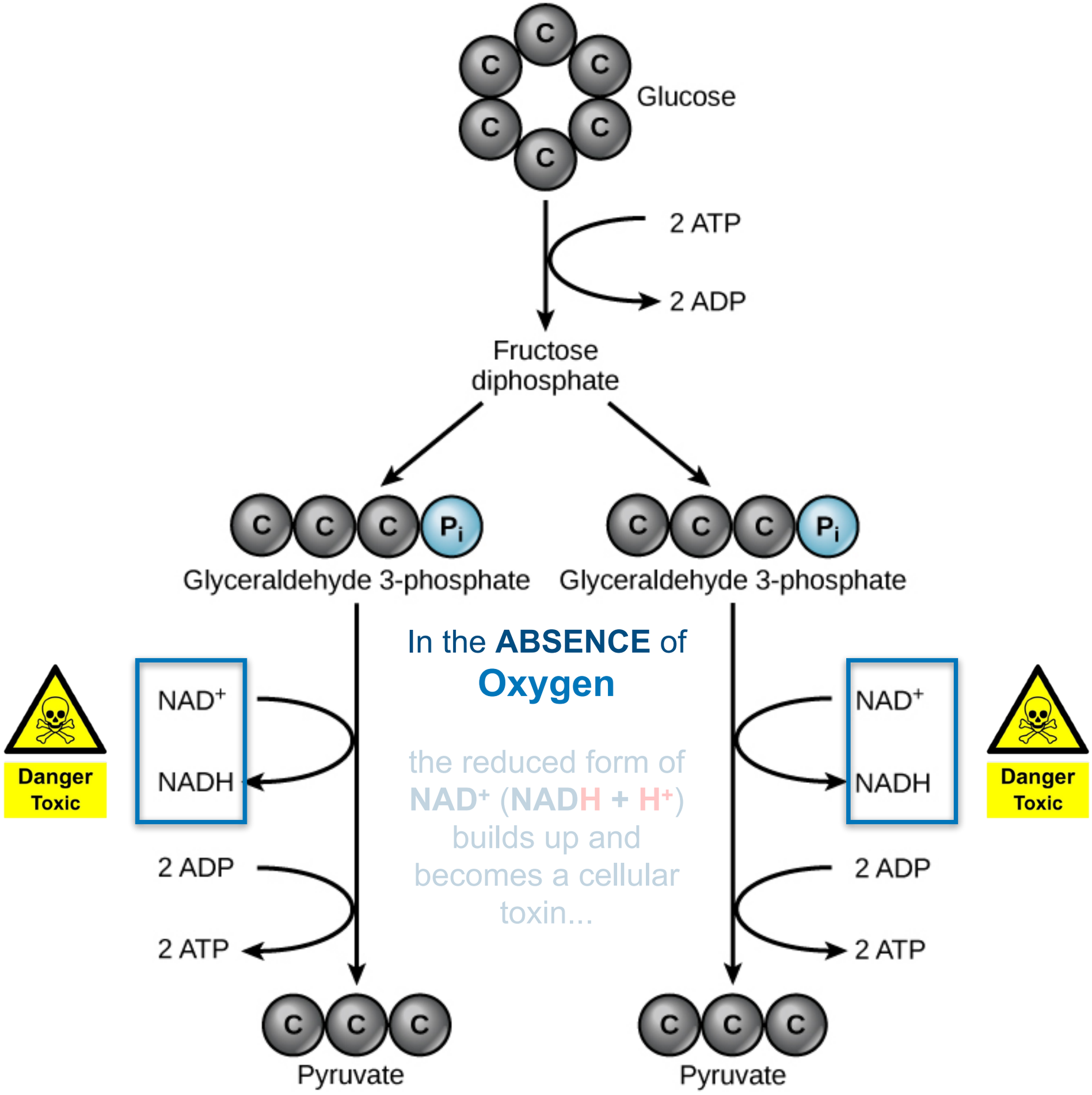

C
C
C
C
C
C
Glucose
2 ATP
2 ADP
Fructose
diphosphate
C C C Pi
C C C Pi
Glyceraldehyde 3-phosphate
Glyceraldehyde 3-phosphate
NAD+
NADH
2 ADP
2 ATP
NAD+
NADH
2 ADP
2 ATP
C C C
C C C
Pyruvate
Pyruvate


C
C
C
C
C
C
Glucose
2 ATP
2 ADP
Fructose
diphosphate
C C C Pi
C C C Pi
Glyceraldehyde 3-phosphate
Glyceraldehyde 3-phosphate
NAD+
NADH
2 ADP
2 ATP
NAD+
NADH
2 ADP
2 ATP
C C C
C C C
Pyruvate
Pyruvate


C
C
C
C
C
C
Glucose
2 ATP
2 ADP
Fructose
diphosphate
C C C Pi
C C C Pi
Glyceraldehyde 3-phosphate
Glyceraldehyde 3-phosphate
NAD+
NADH
2 ADP
2 ATP
NAD+
NADH
2 ADP
2 ATP
C C C
C C C
Pyruvate
Pyruvate

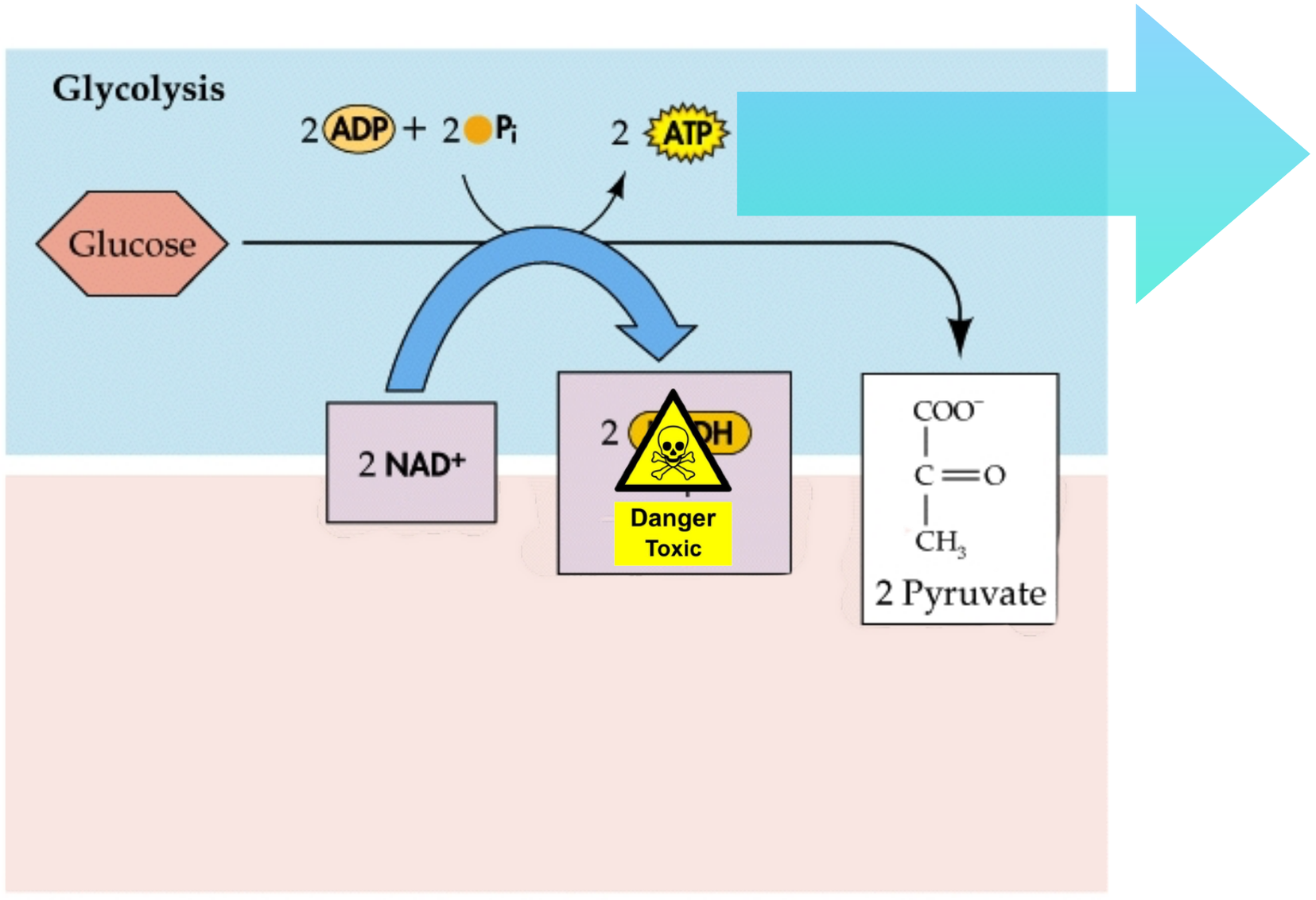

AUTOTROPHS AND HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP


AUTOTROPHS AND HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP


Glucose
2 ATP
2 ADP
Fructose diphosphate
Glyceraldehyde 3-phosphate
Glyceraldehyde 3-phosphate
In the ABSENCE of Oxygen
the reduced form of NAD+ (NADH + H+) builds up and becomes a cellular toxin...
Danger Toxic
NAD+
NADH
2 ADP
2 ATP
Pyruvate
Pyruvate
Danger Toxic
NAD+
NADH
2 ADP
2 ATP

Anaerobic Conditions

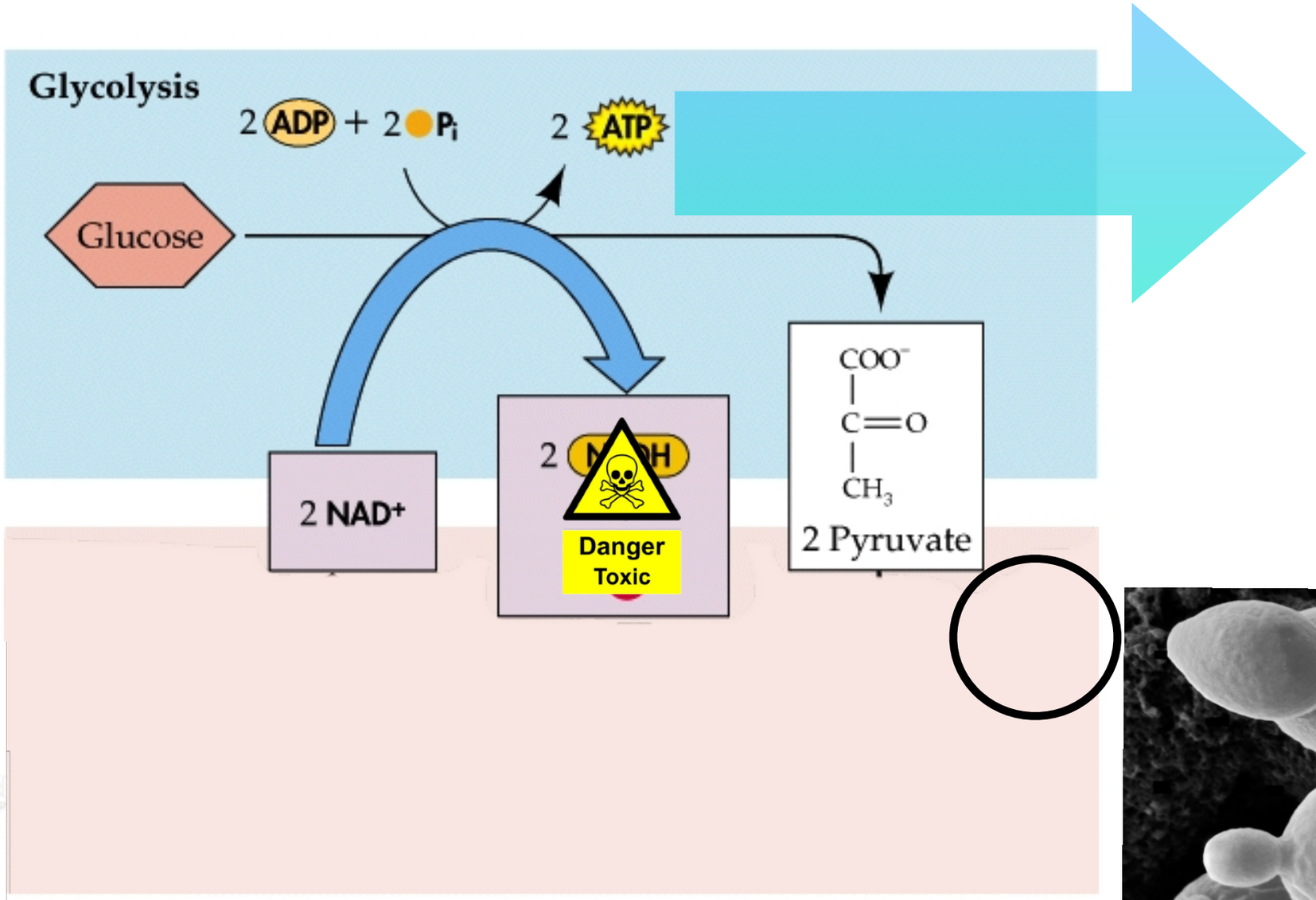
Fatigue

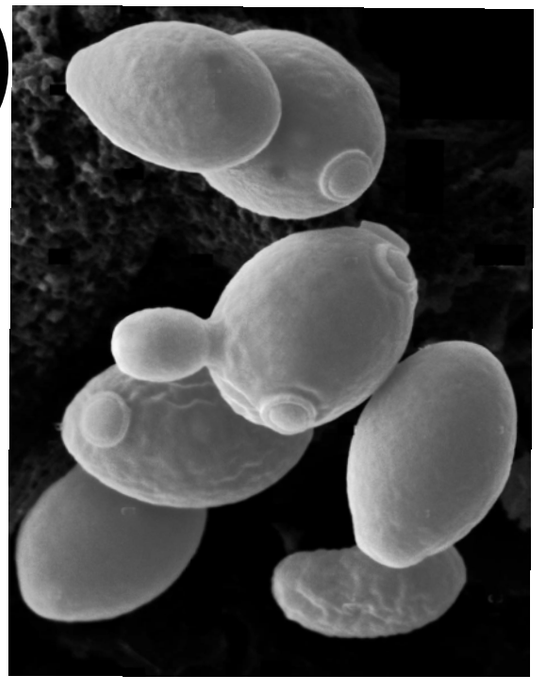


In the ABSENCE of oxygen the reduced form of **NAD^+** (**NADH + H^+**) builds up and becomes a cellular toxin...

It, therefore, needs to be **RECYCLED...**

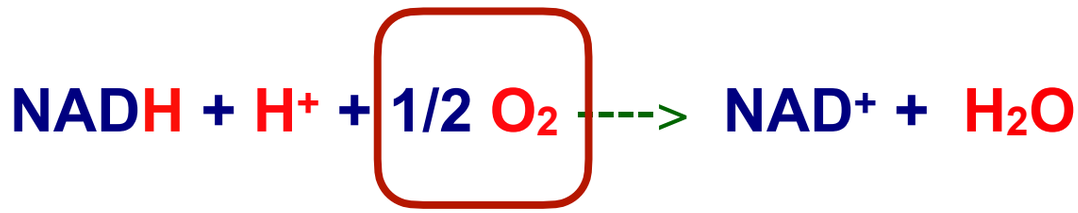
Anaerobic Conditions



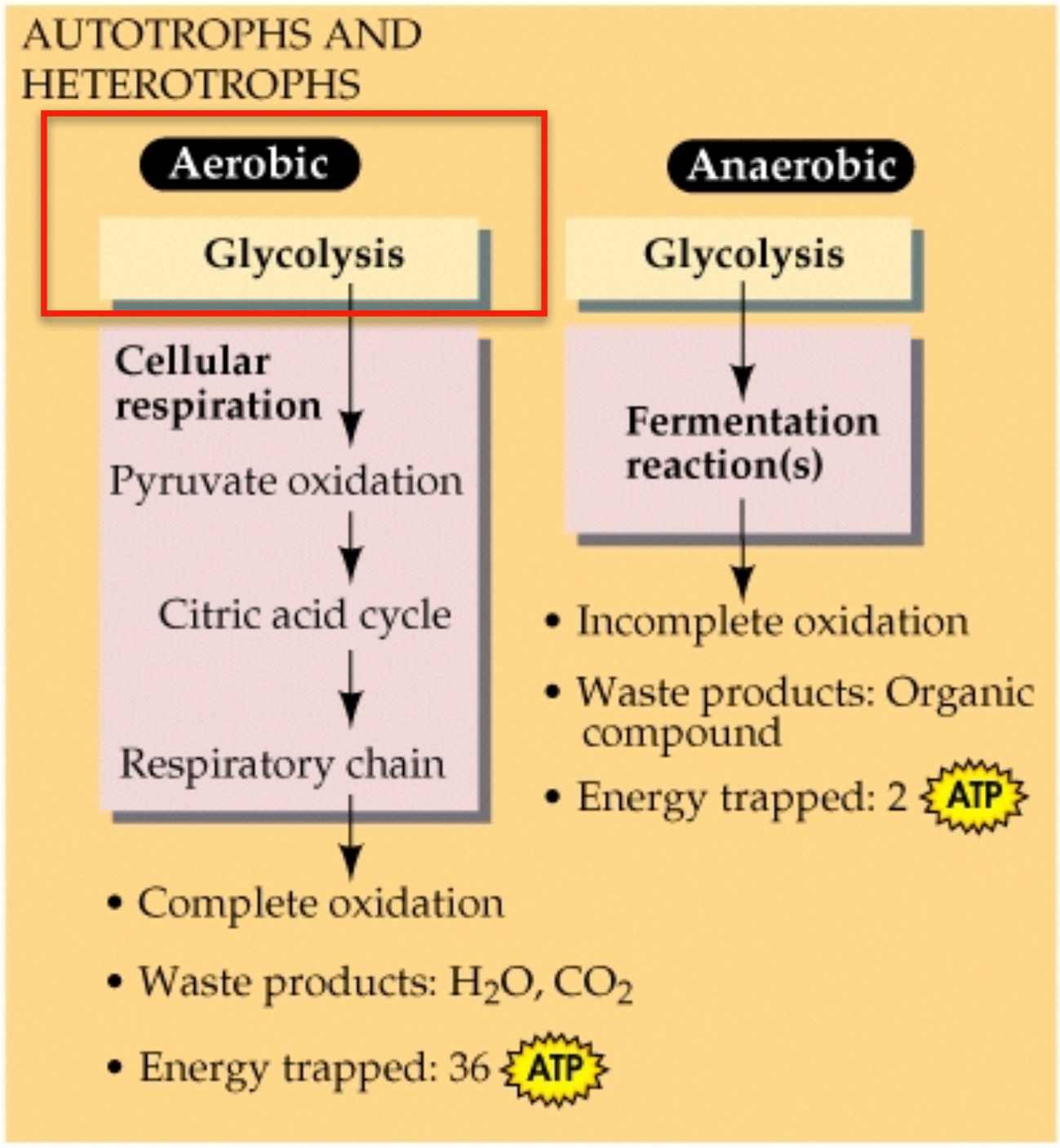


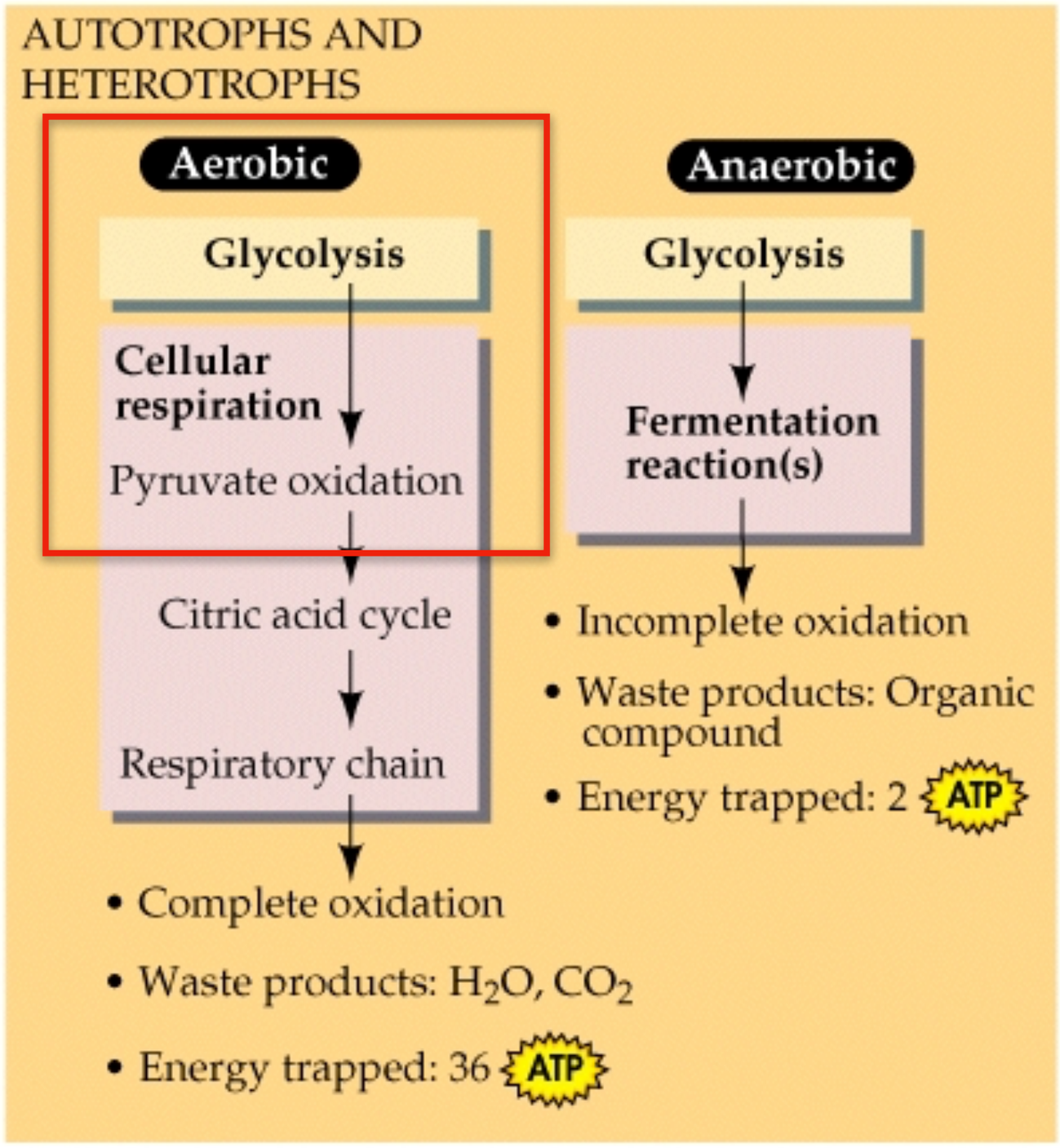
Aerobic Conditions

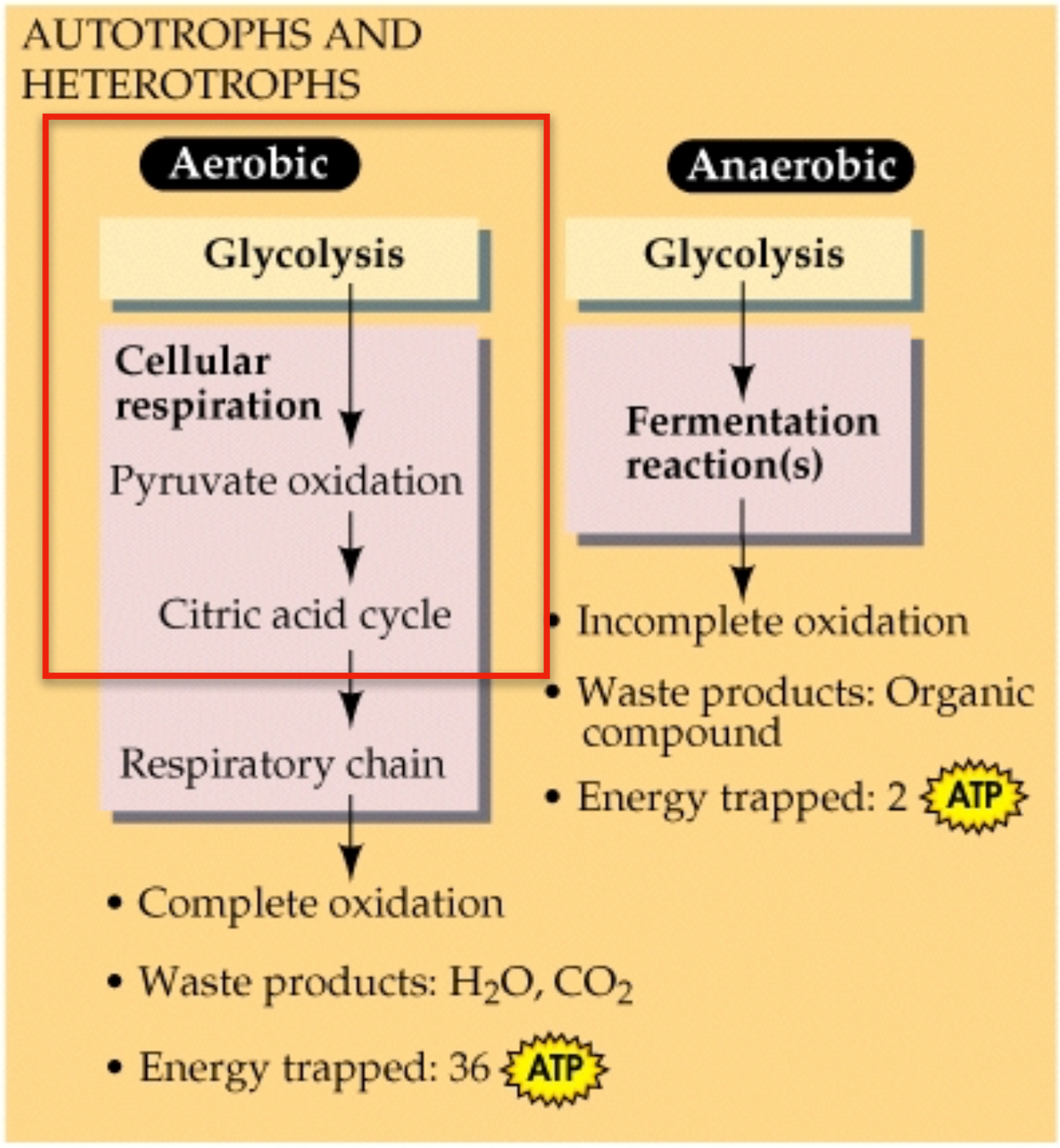
In the **presence of oxygen,** however, the reduced form of NAD^+ ($NADH + H^+$) can be converted back into the oxidized form…

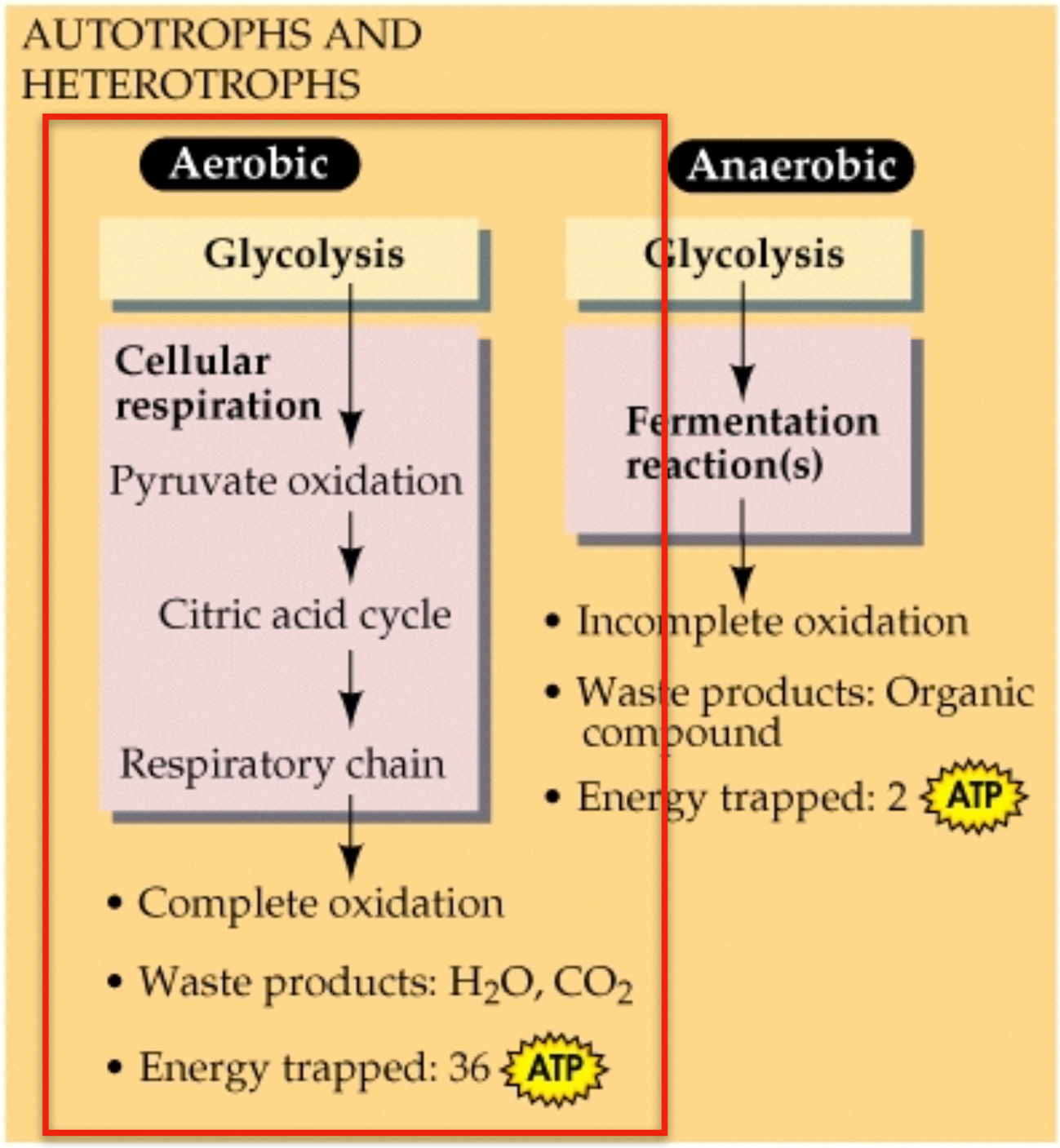


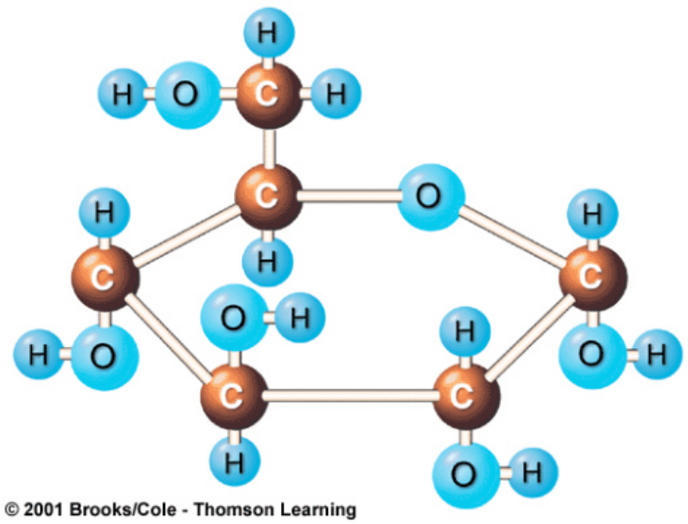
…and just like the normal reaction this is an **ENERGY yielding reaction**... with almost the same energy yield.


AUTOTROPHS AND HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP


AUTOTROPHS AND HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP

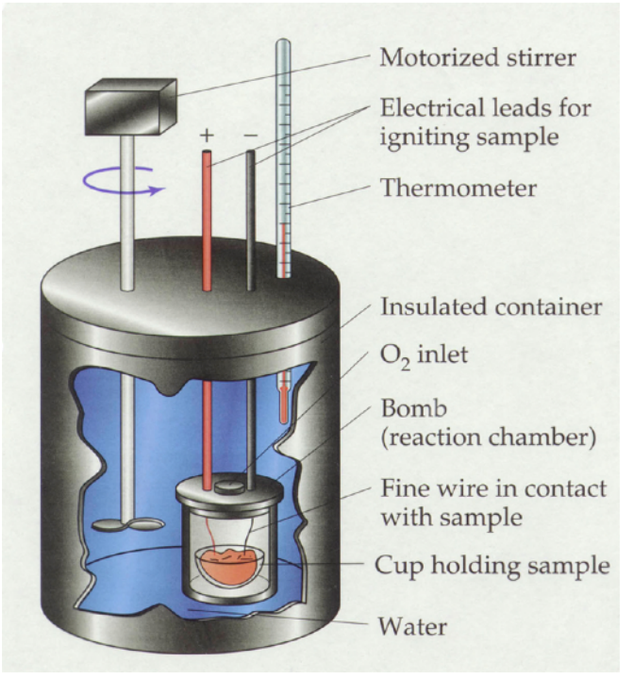

AUTOTROPHS AND HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP


AUTOTROPHS AND
HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP



© 2001 Brooks/Cole - Thomson Learning

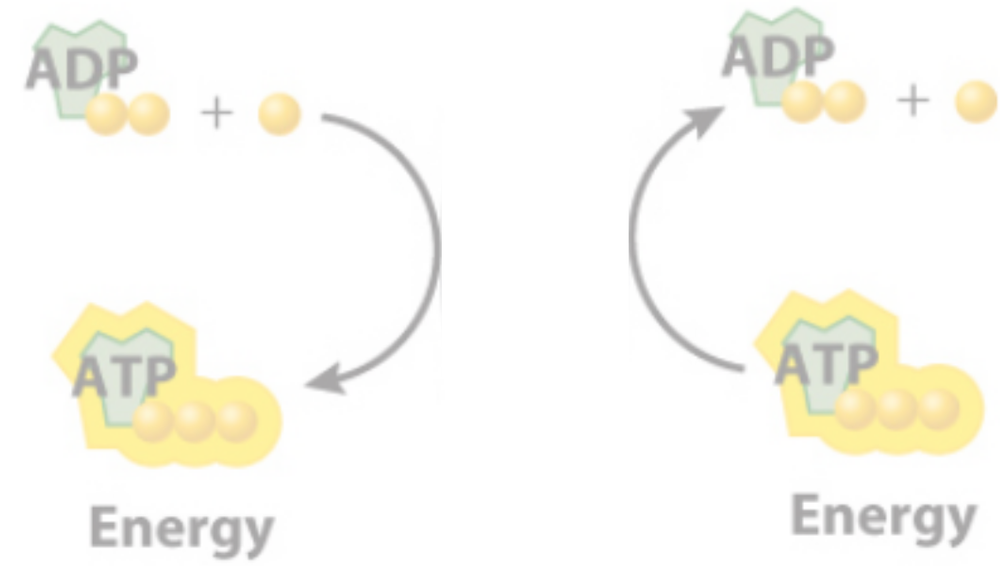
GLUCOSE



more than 1/3

- 686 kcal/mol.

1 mole of Glucose —> - 686 kcal/mol

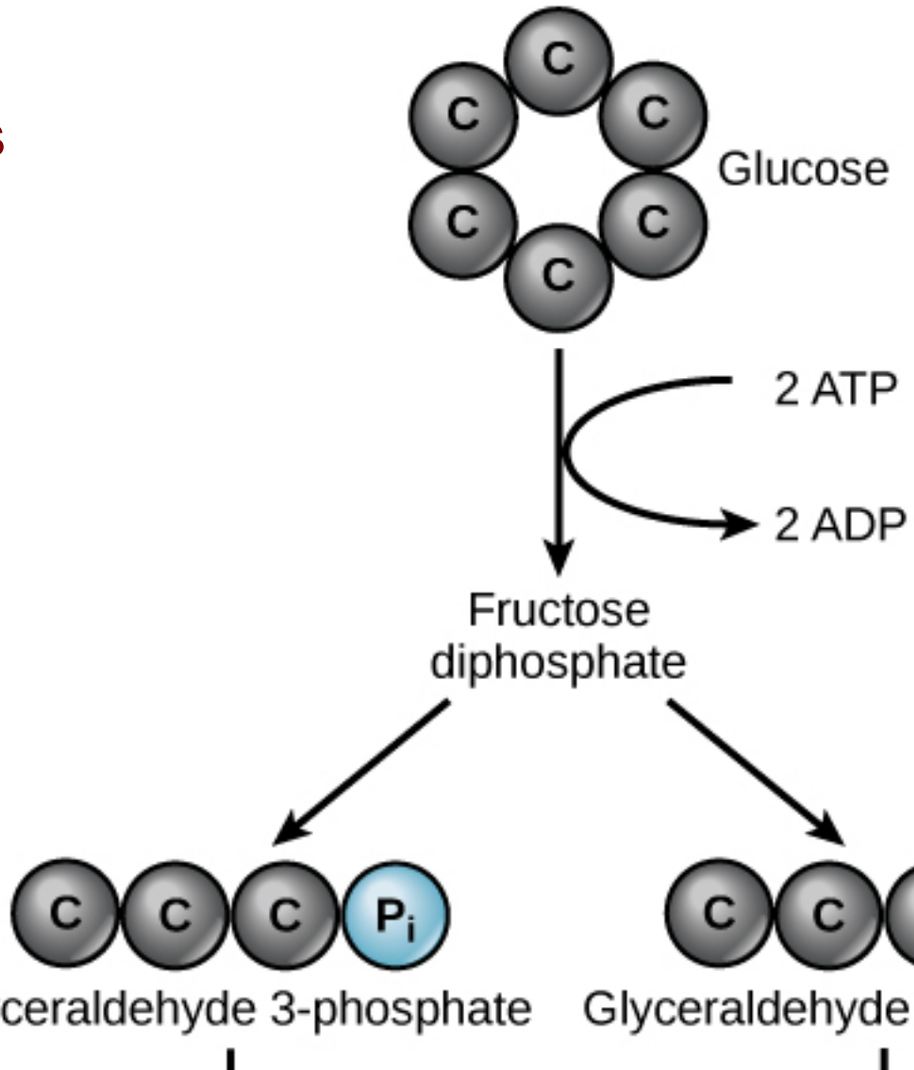


- 7.3 kcal/mol

1 mole of Glucose —> ~~~~94~~ ATP's worth of energy

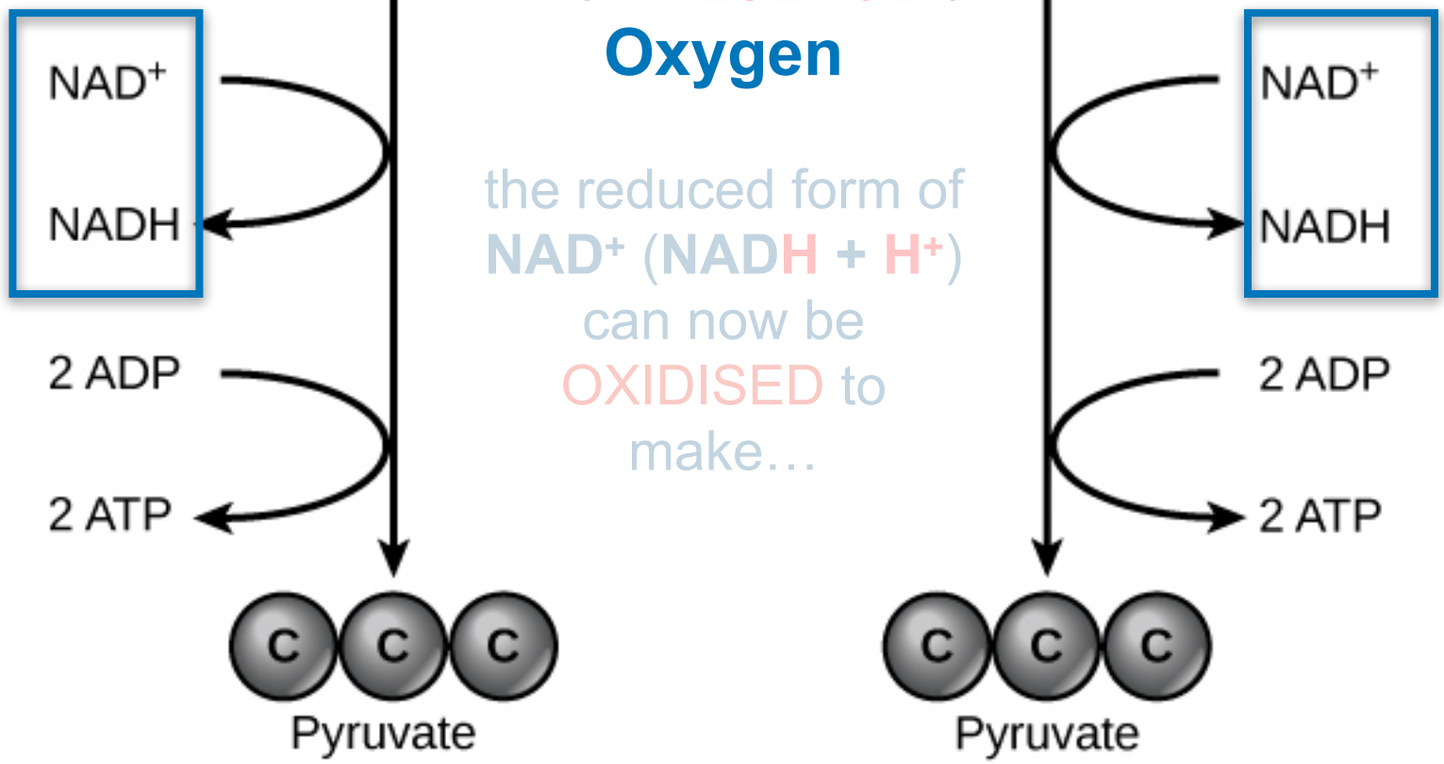
36 …not too bad!!

STAGE 1: Glycolysis



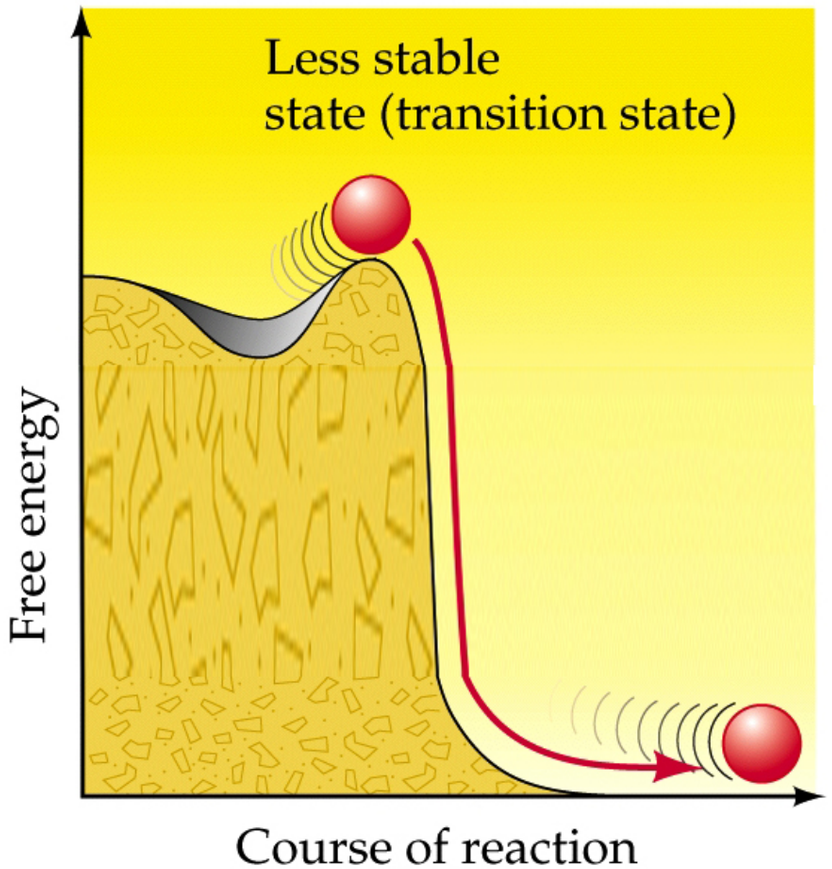
In the **PRESENCE** of **Oxygen**

the reduced form of **NAD⁺** (**NADH + H⁺**) can now be OXIDISED to make…



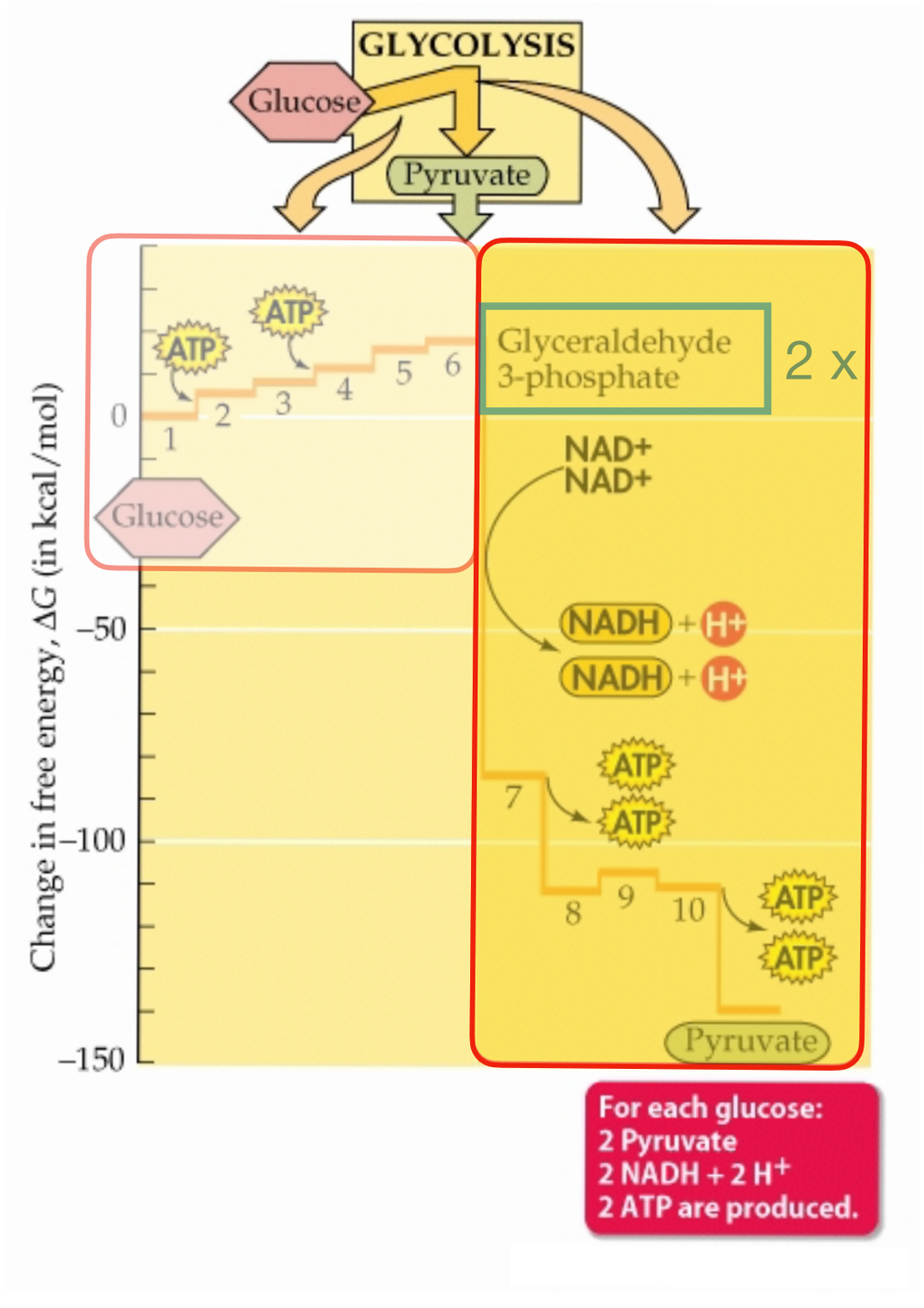
Water !!!

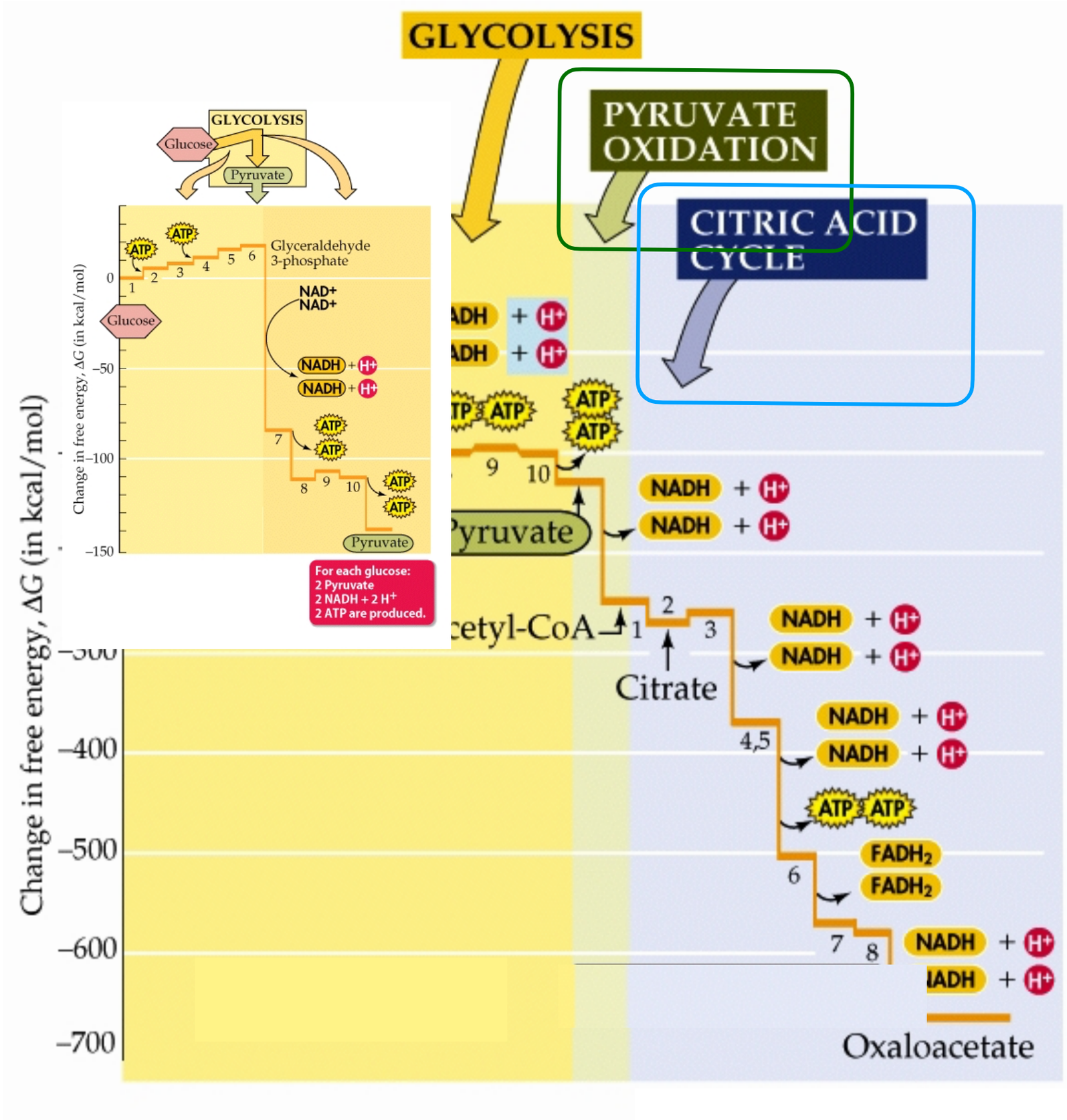
$$NADH + H^+ + 1/2\ O_2 \text{----->}\ NAD^+ + H_2O$$

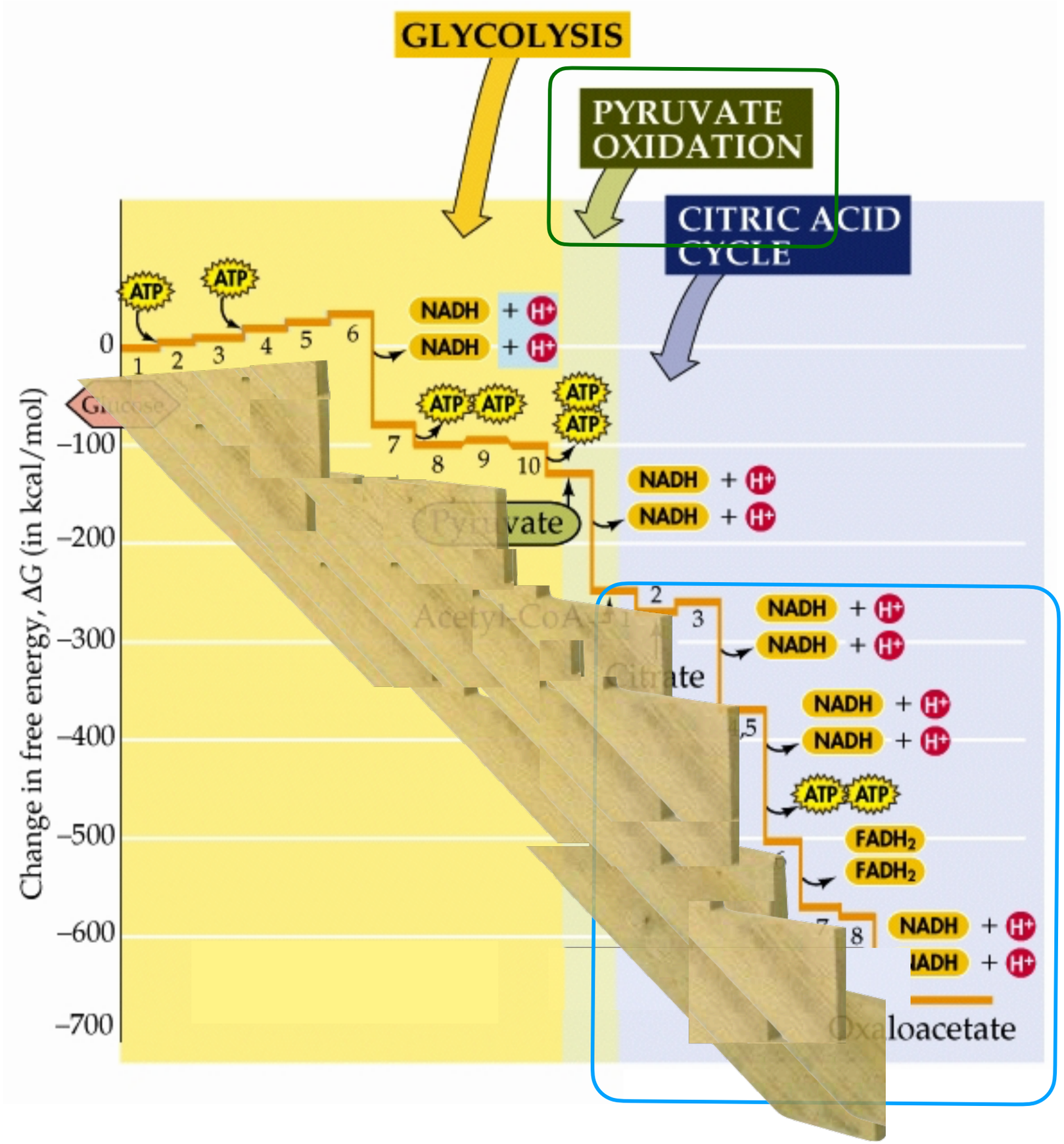


$$C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O + \text{energy (heat and light)}$$

- 686 kcal/mol

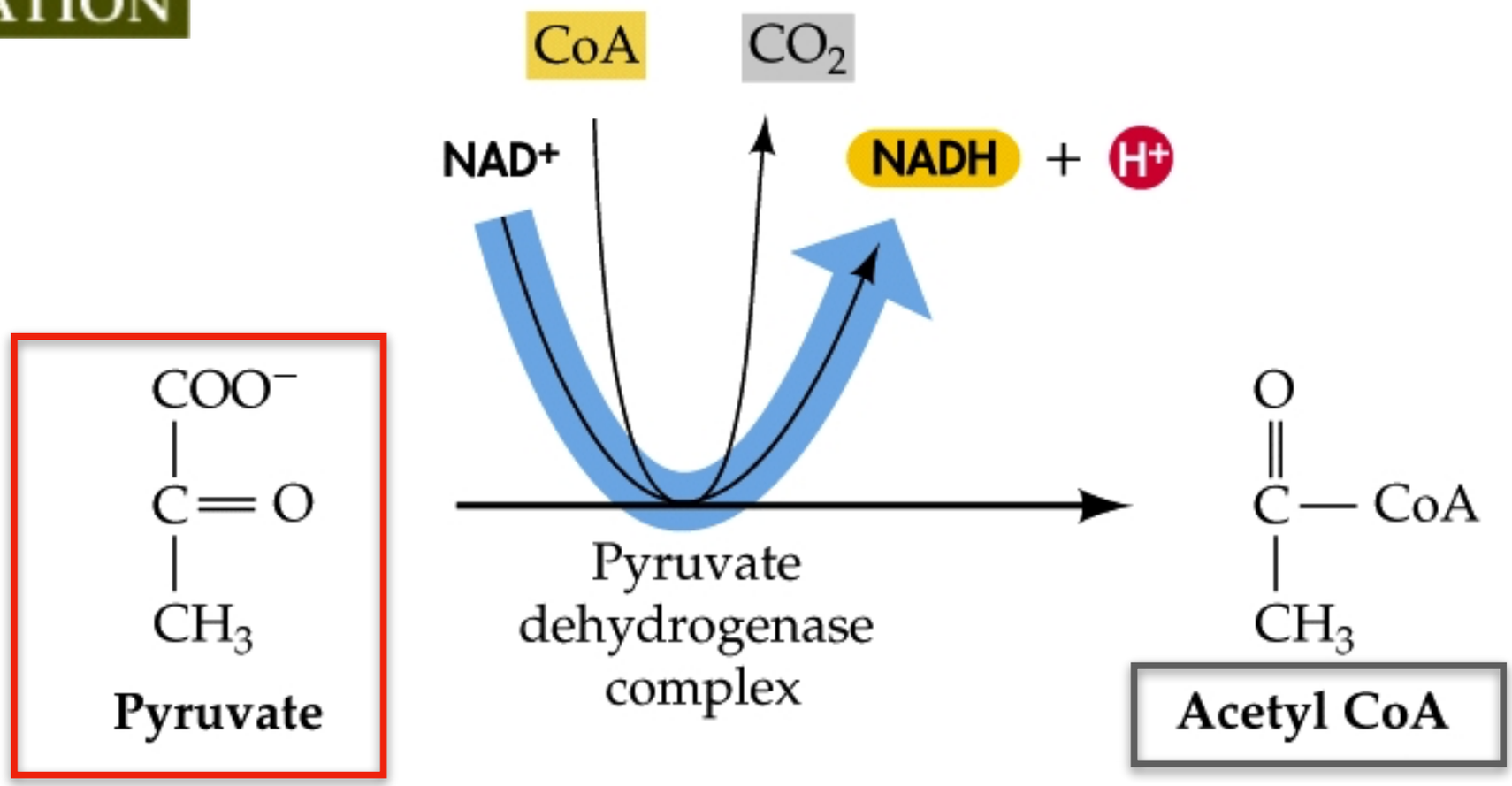

GLYCOLYSIS
Glucose
Pyruvate
ATP
ATP
0
1
2
3
4
5
6
Glucose
Glyceraldehyde 3-phosphate
2 x
NAD+
NAD+
NADH + H+
NADH + H+
ATP
ATP
7
8
9
10
ATP
ATP
Pyruvate
Change in free energy, ΔG (in kcal/mol)
–50
–100
–150
For each glucose:
2 Pyruvate
2 NADH + 2 H+
2 ATP are produced.


GLYCOLYSIS
PYRUVATE OXIDATION
CITRIC ACID CYCLE
Glucose
Pyruvate
Glyceraldehyde 3-phosphate
NAD+
NAD+
NADH + H+
ATP
Change in free energy, ΔG (in kcal/mol)
0
–50
–100
–150
–400
–500
–600
–700
1
2
3
4
5
6
7
8
9
10
4,5
For each glucose:
2 Pyruvate
2 NADH + 2 H+
2 ATP are produced.
Acetyl-CoA
Citrate
Oxaloacetate
FADH2


GLYCOLYSIS
PYRUVATE OXIDATION
CITRIC ACID CYCLE
Change in free energy, ΔG (in kcal/mol)
0
–100
–200
–300
–400
–500
–600
–700
ATP
NADH + H+
FADH2
Glucose
Pyruvate
Acetyl-CoA
Citrate
Oxaloacetate

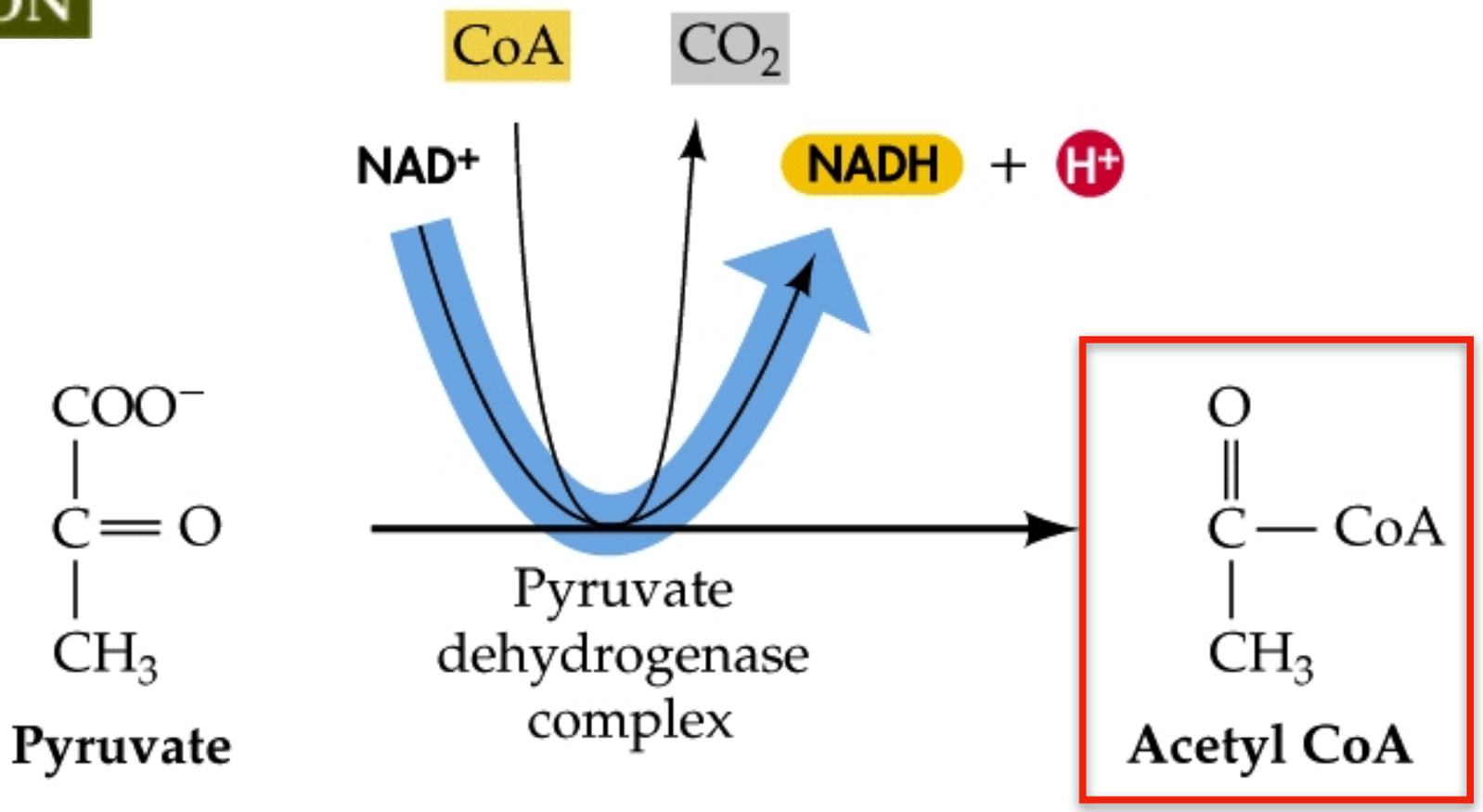
STAGE 2:

PYRUVATE OXIDATION



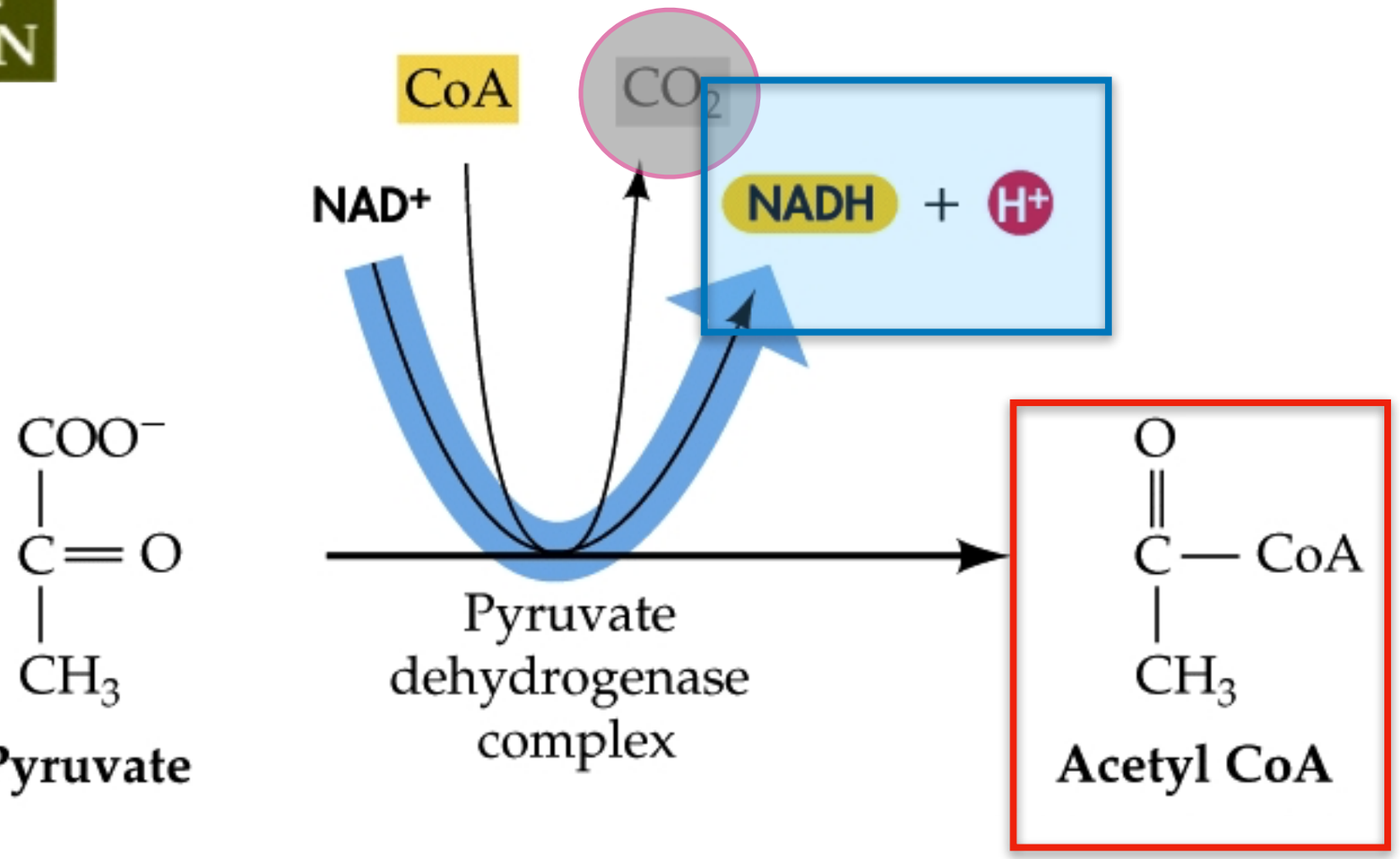
STAGE 2:

PYRUVATE OXIDATION



STAGE 2:

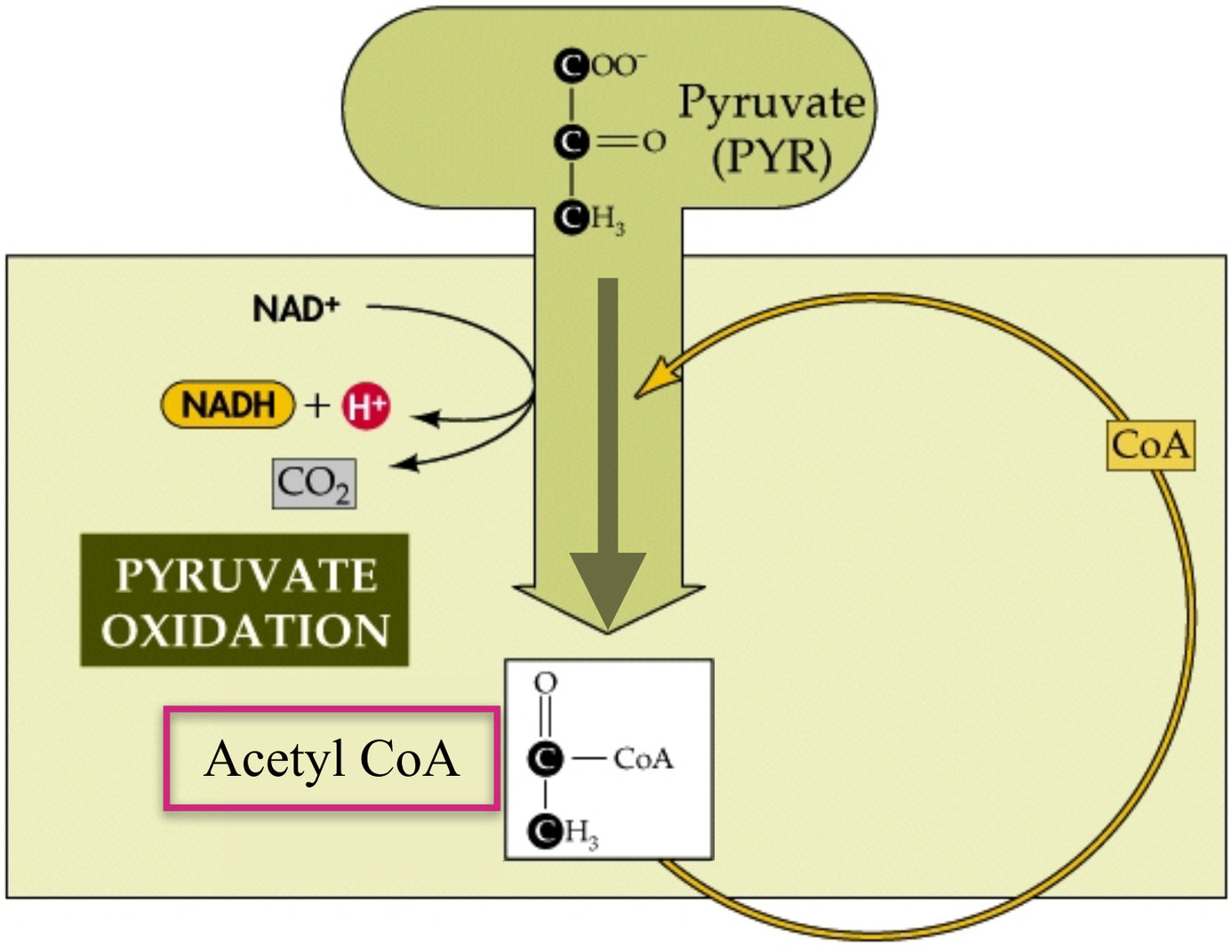
PYRUVATE OXIDATION

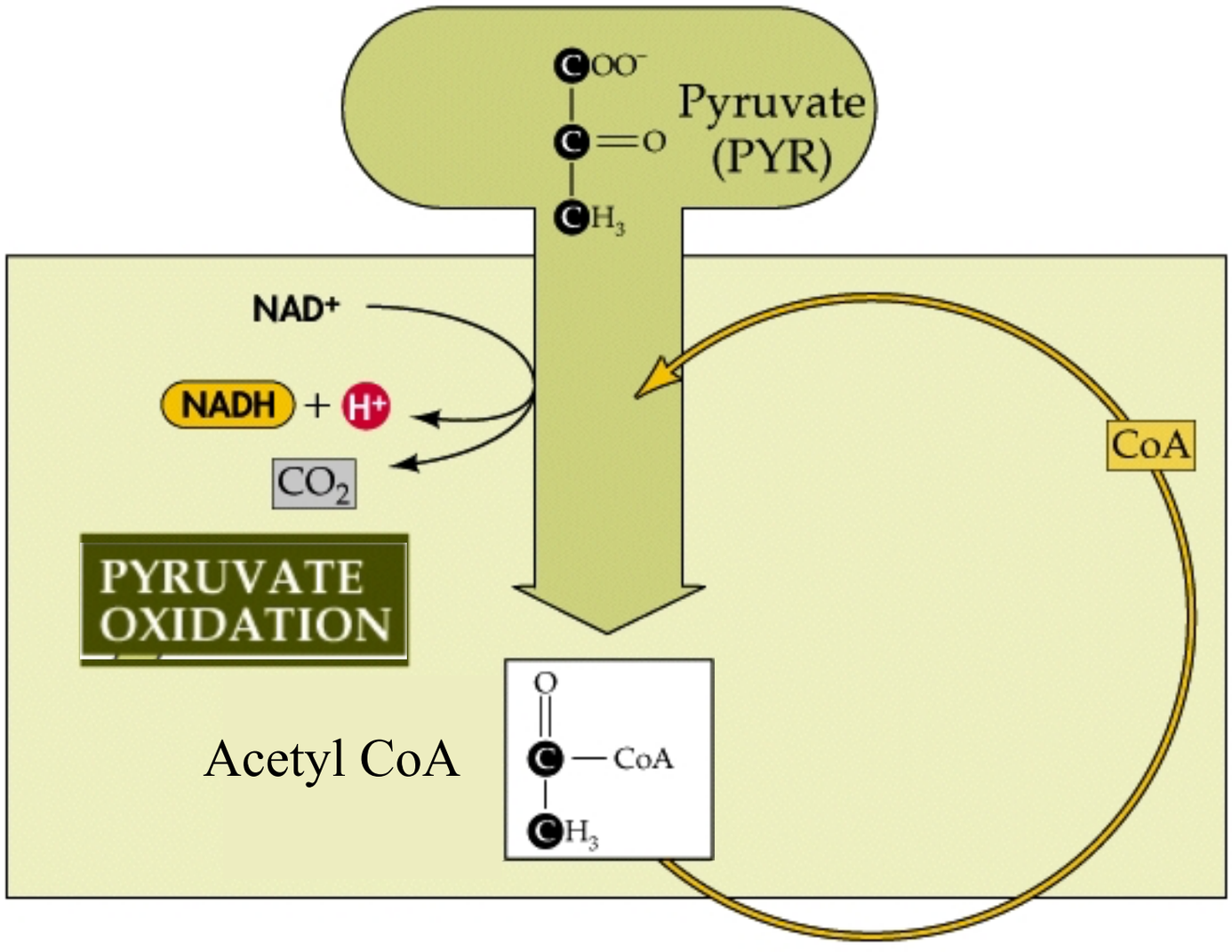


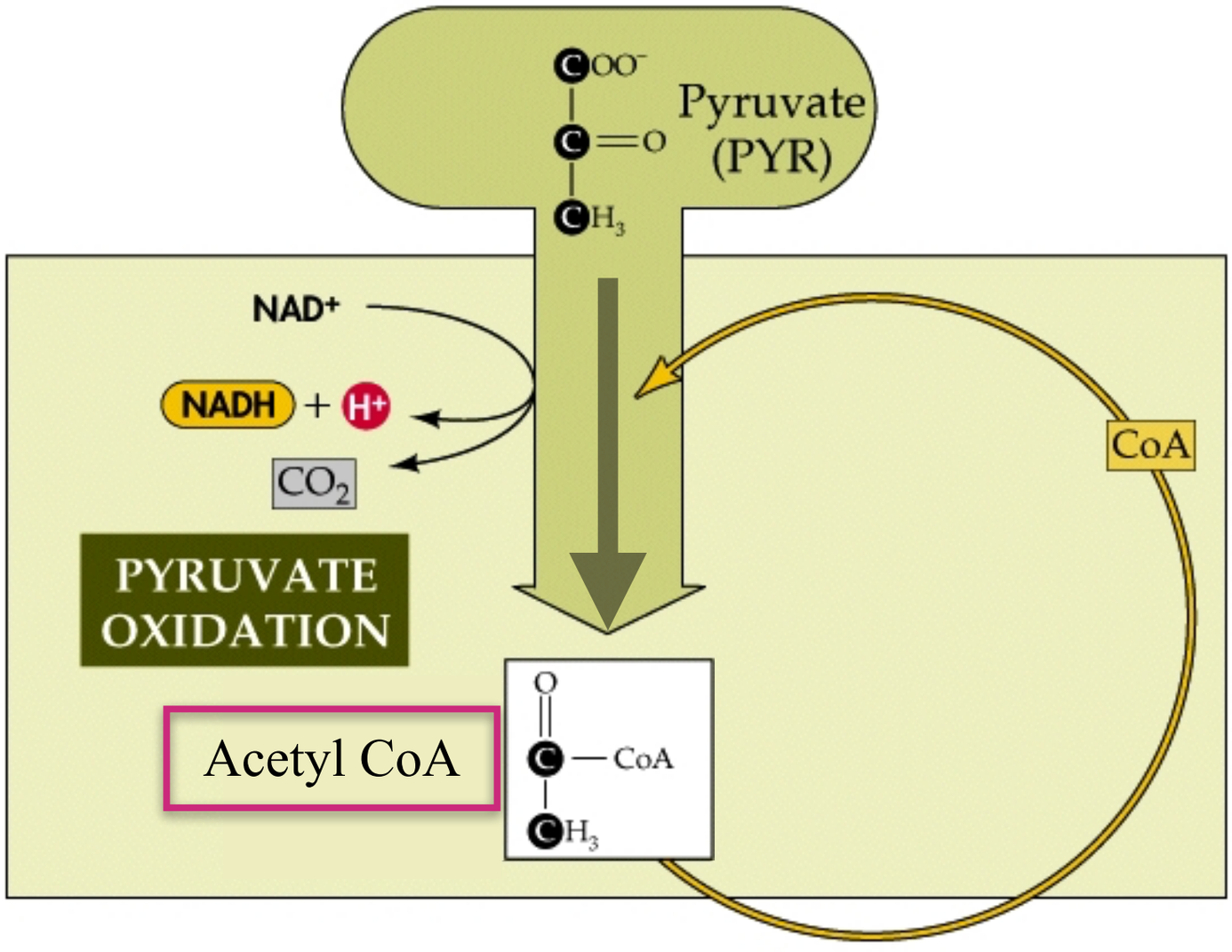
3 carbons **2 carbons**

Glucose **2 x Pyruvate** **2 x Acetyl CoA**

6 carbons 2 x **3 carbons** 2 x **2 carbons**


Pyruvate
(PYR)
NAD+
NADH + H+
CO2
CoA
PYRUVATE
OXIDATION
Acetyl CoA
CoA


Pyruvate
(PYR)
NAD+
NADH + H+
CO2
PYRUVATE
OXIDATION
CoA
Acetyl CoA
CoA

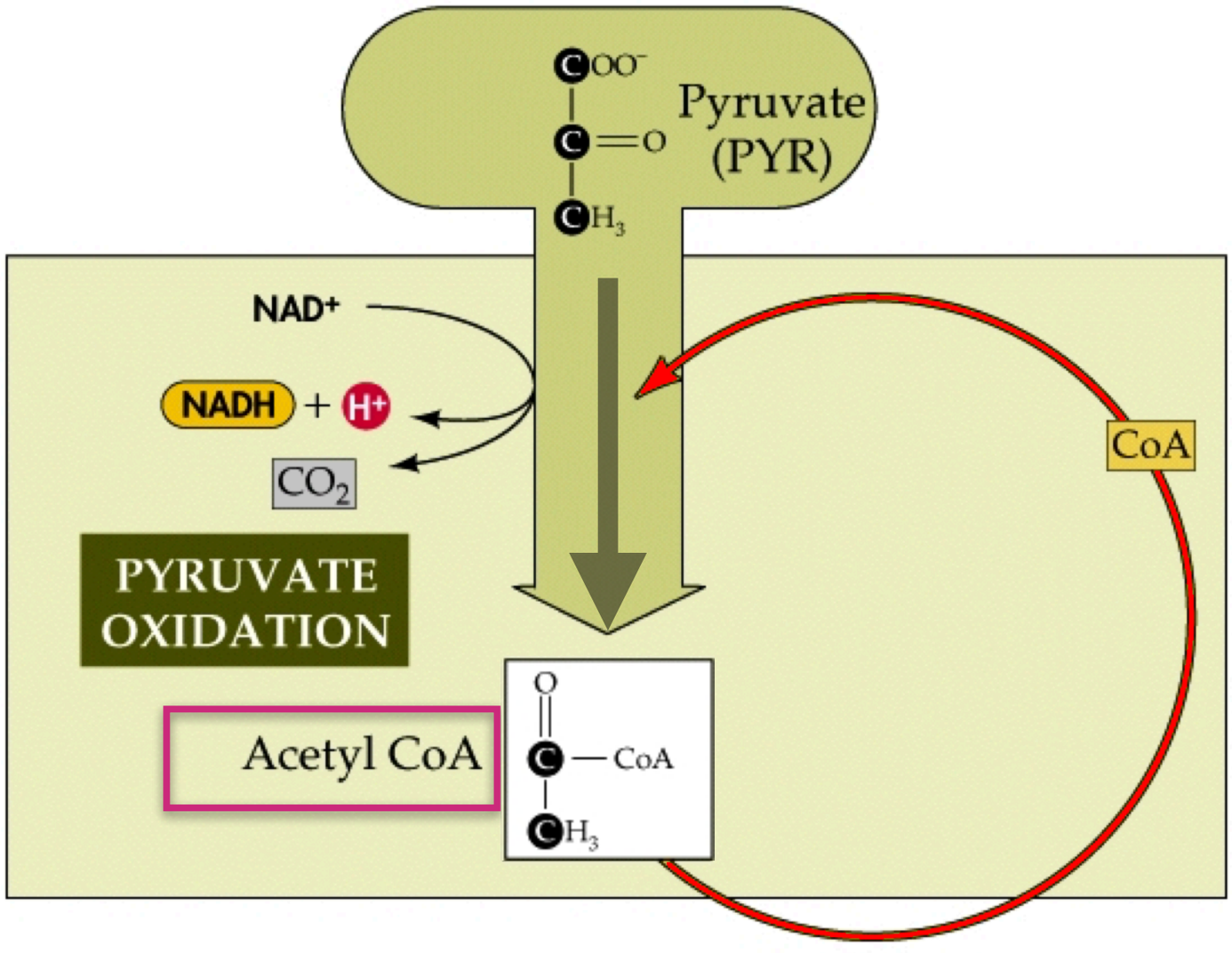

Pyruvate
(PYR)
NAD+
NADH + H+
CO2
CoA
PYRUVATE
OXIDATION
Acetyl CoA
CoA

6.1 A Few Examples of Nonprotein Molecular "Partners" of Enzymes

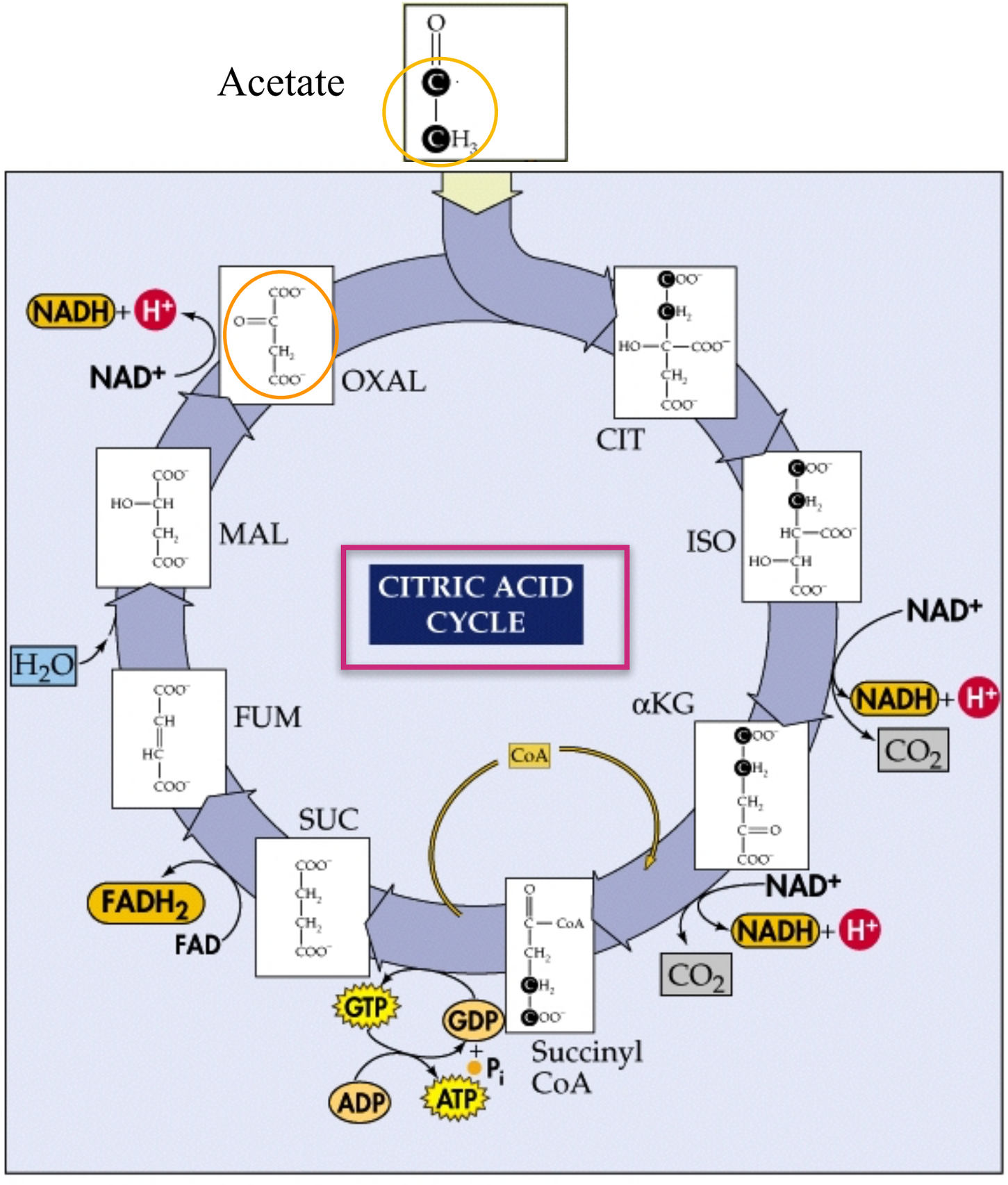
TYPE OF MOLECULE	ROLE IN CATALYZED REACTIONS
Cofactors	
Iron	Oxidation/reduction
Copper	Oxidation/reduction
Zinc	Helps bind NAD
Coenzymes	
Biotin	Carries $—COO^-$
Coenzyme A	Carries $—CH_2—CH_3$
NAD	Carries electrons
FAD	Carries electrons
Prosthetic groups	
Heme	Binds ions, O_2, and electrons; contains iron cofactor
Flavin	Binds electrons
Retinal	Converts light energy

6.1 A Few Examples of Nonprotein Molecular "Partners" of Enzymes

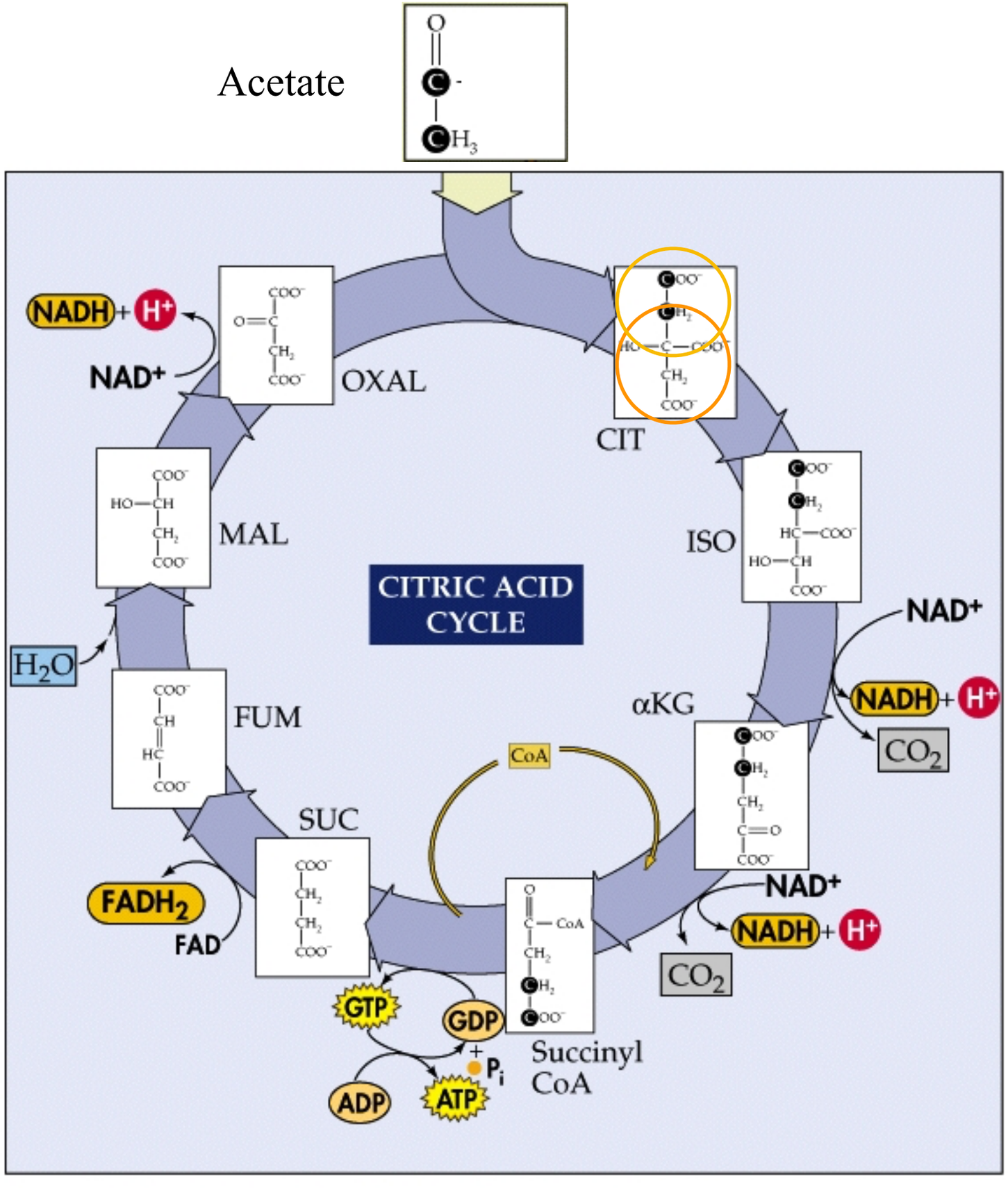
TYPE OF MOLECULE	ROLE IN CATALYZED REACTIONS
Cofactors	
Iron	Oxidation/reduction
Copper	Oxidation/reduction
Zinc	Helps bind NAD
Coenzymes	
Biotin	Carries $—COO^-$
Coenzyme A	Carries $—CH_2—CH_3$
NAD	Carries electrons
FAD	Carries electrons
Prosthetic groups	
Heme	Binds ions, O_2, and electrons; contains iron cofactor
Flavin	Binds electrons
Retinal	Converts light energy


Pyruvate
(PYR)
NAD+
NADH + H+
CO2
PYRUVATE
OXIDATION
Acetyl CoA
CoA
CoA

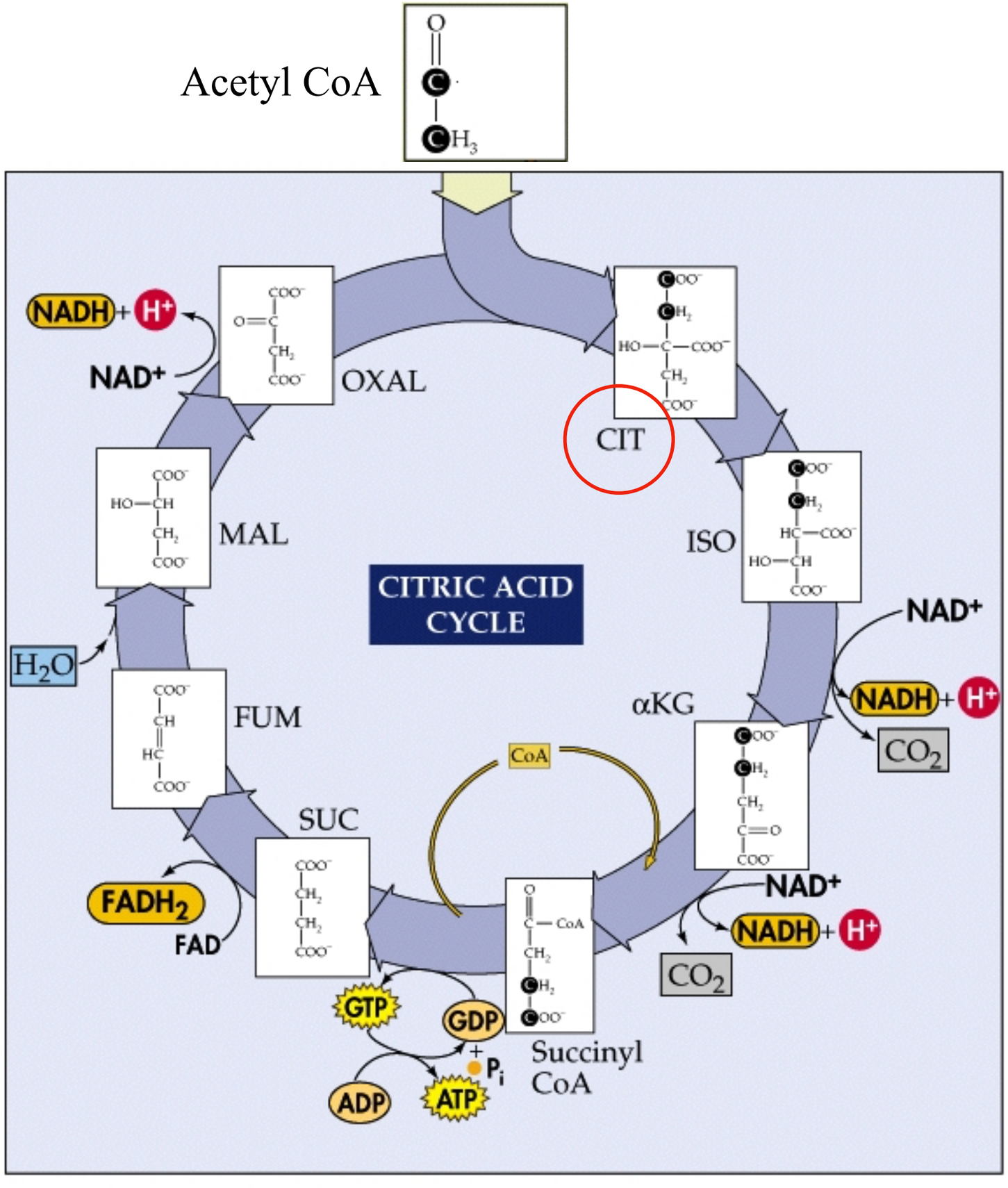
STAGE 3:

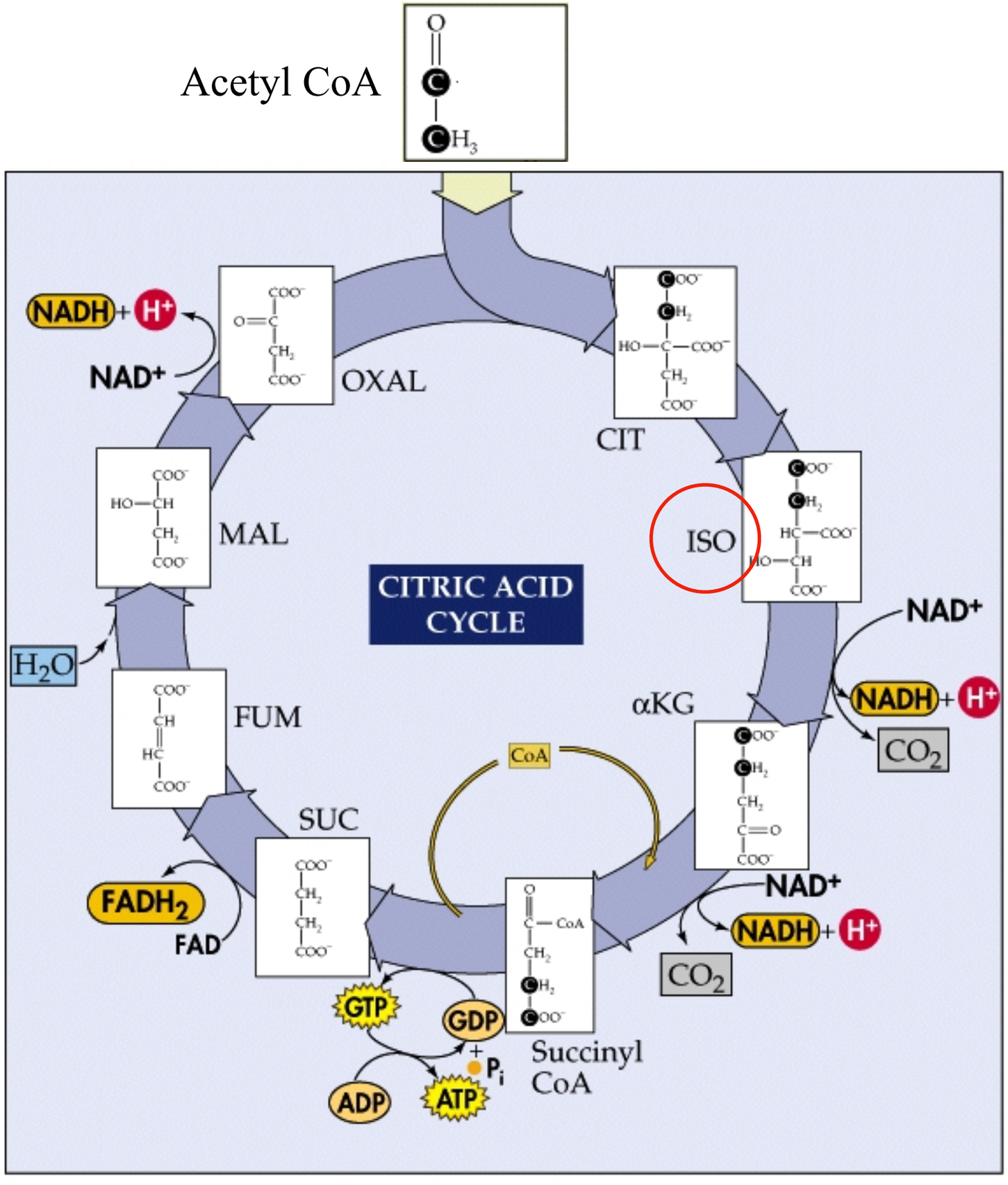

Acetate
NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

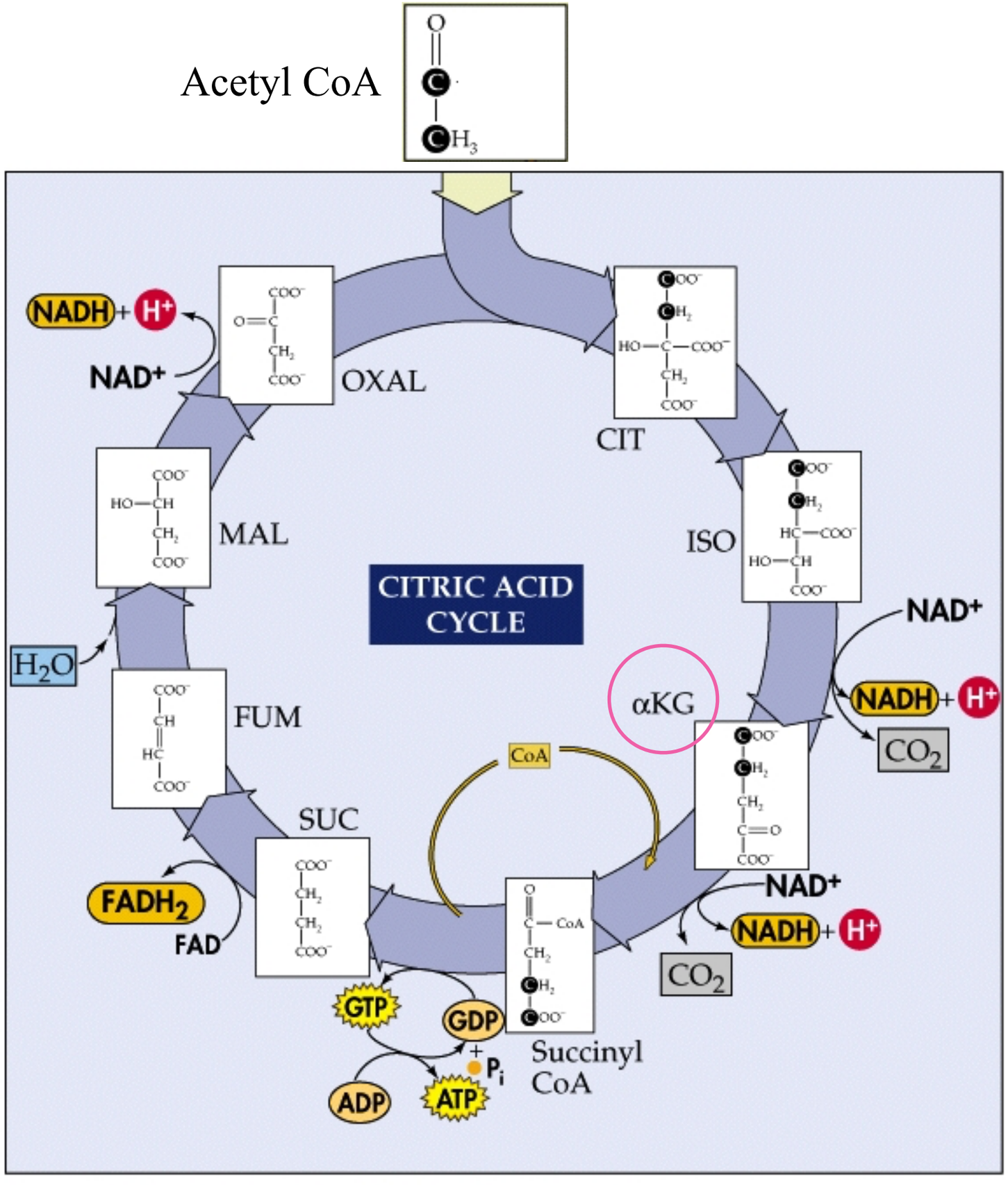
Acetate


NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

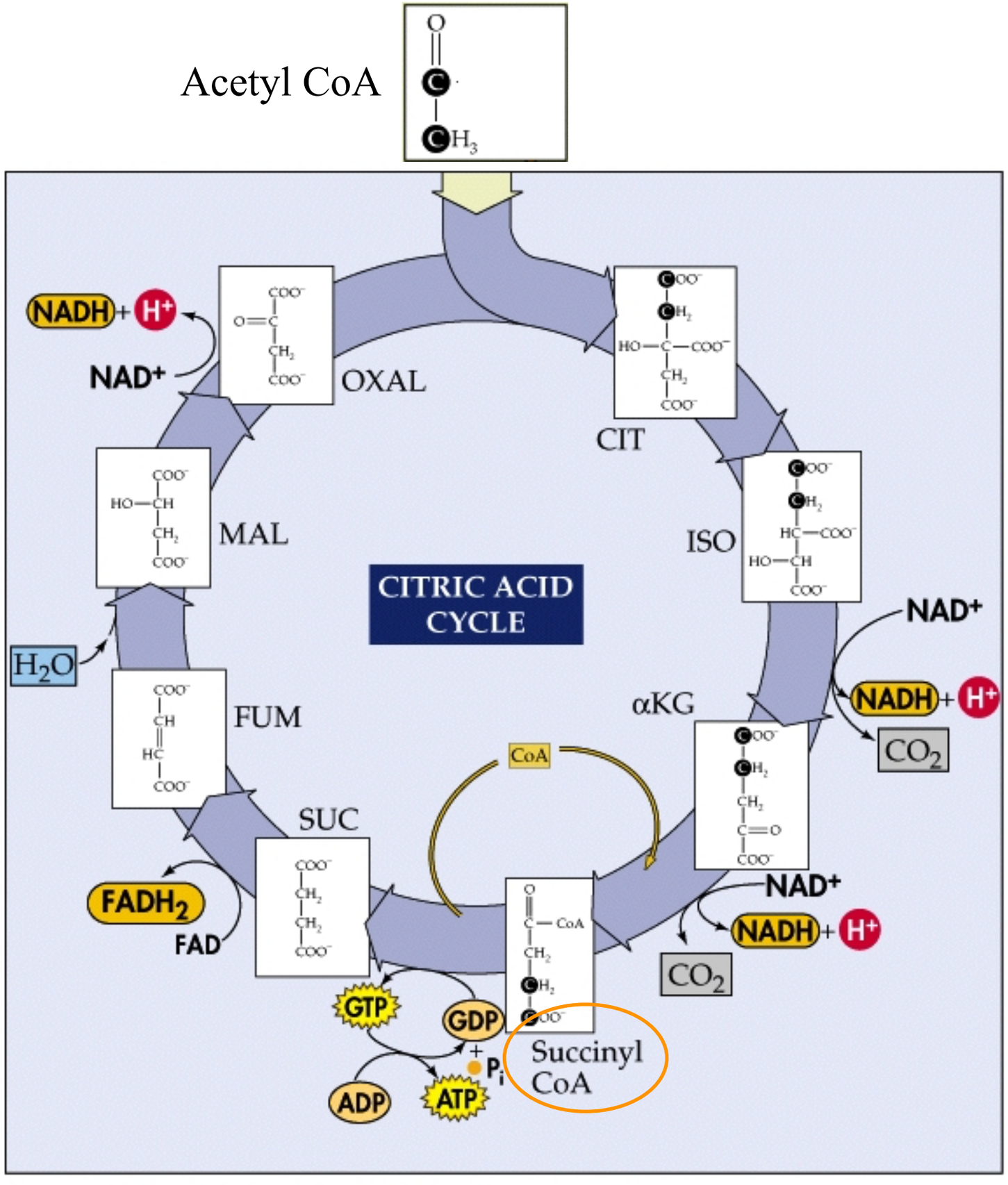
Acetyl CoA


NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

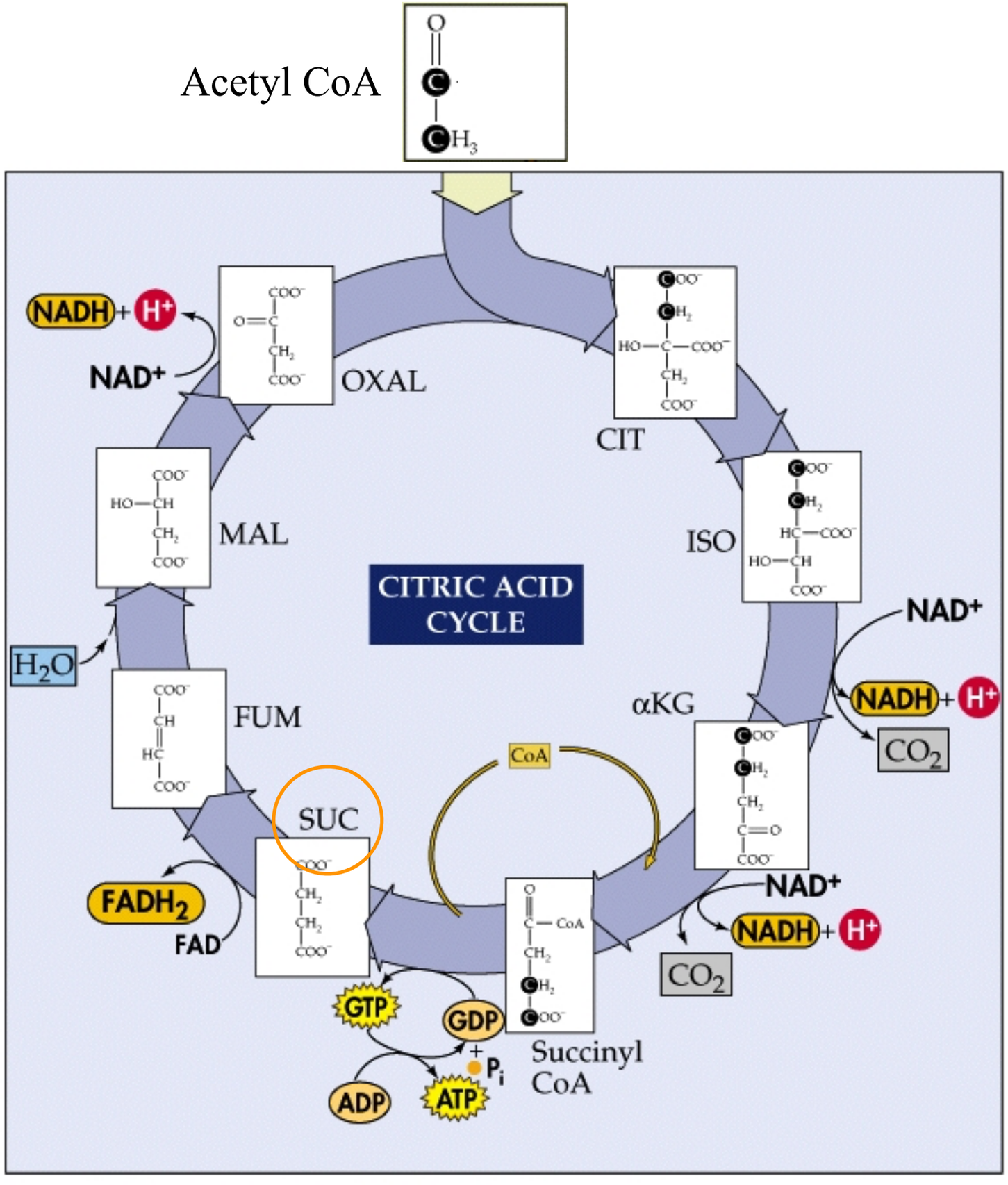

Acetyl CoA
NADH
H+
NAD+
OXAL
CIT
ISO
MAL
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH
H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH
H+
CO2
GTP
GDP
Pi
Succinyl CoA
ADP
ATP


Acetyl CoA
NADH
H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
αKG
NADH
H+
CO2
FUM
CoA
SUC
FADH2
FAD
NAD+
NADH
H+
CO2
GTP
GDP
+
Pi
Succinyl CoA
ADP
ATP

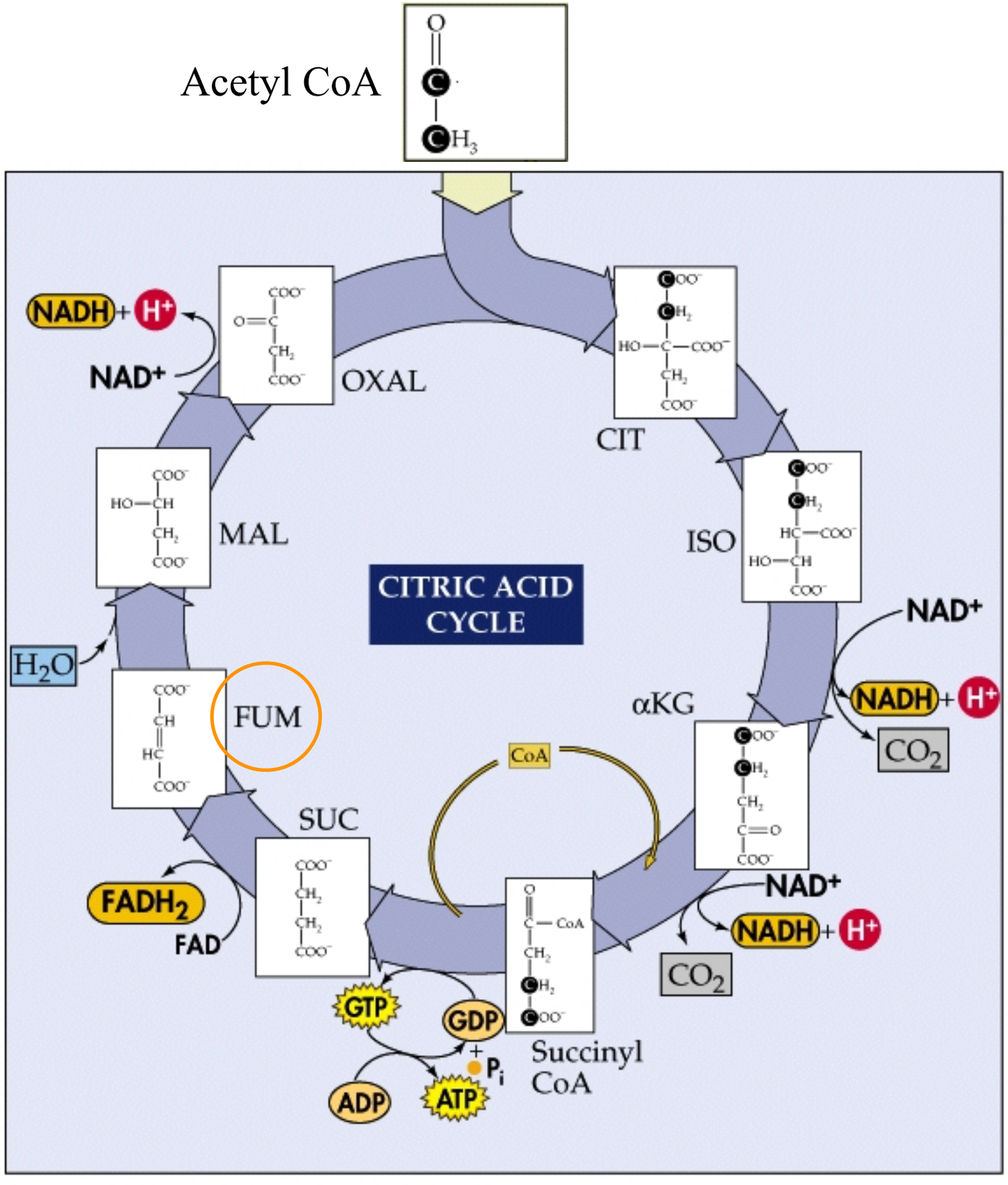
Acetyl CoA


NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

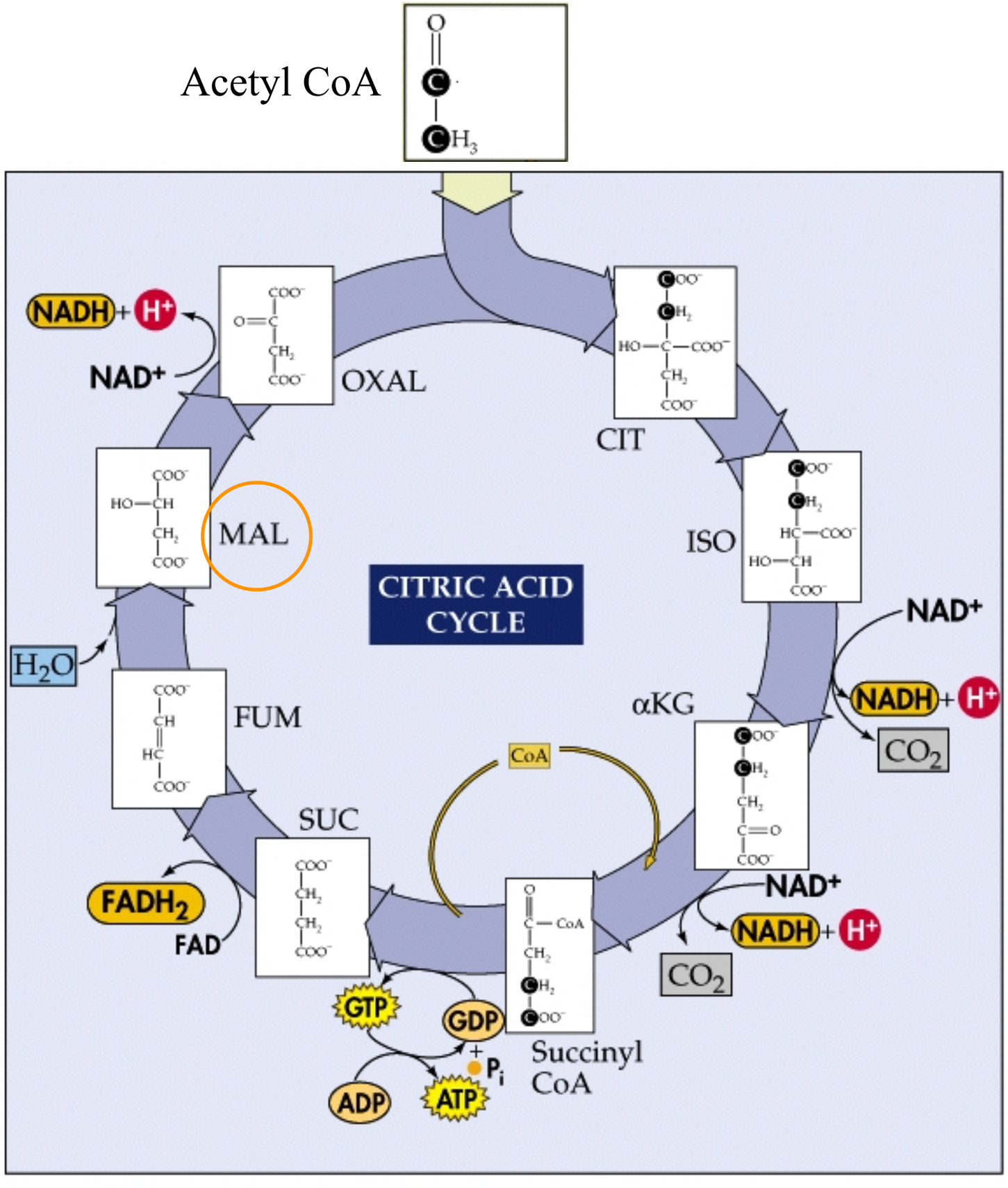
Acetyl CoA


NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

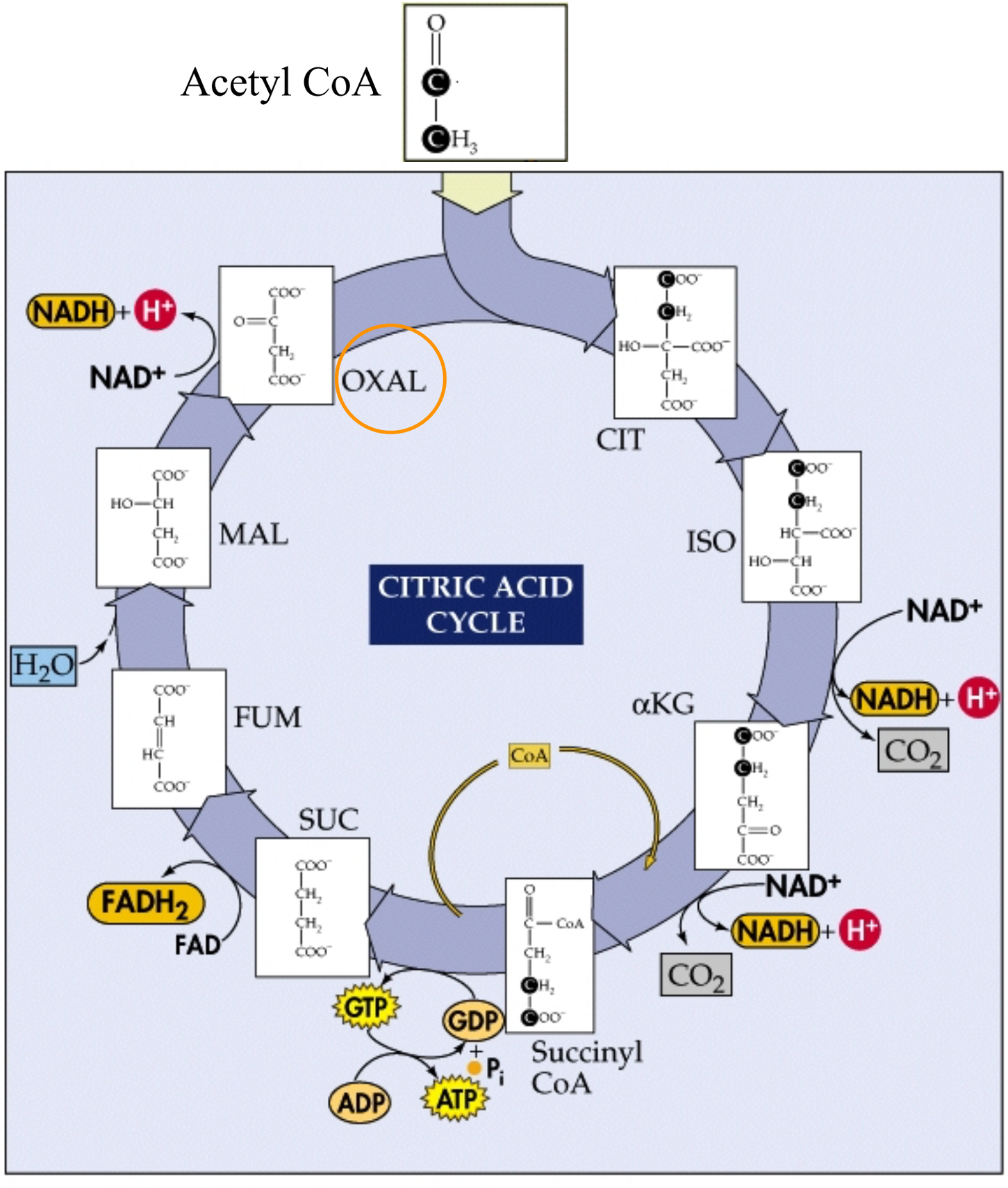
Acetyl CoA


NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

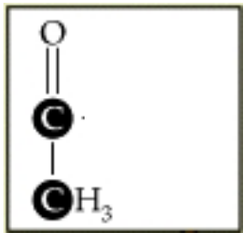
Acetyl CoA

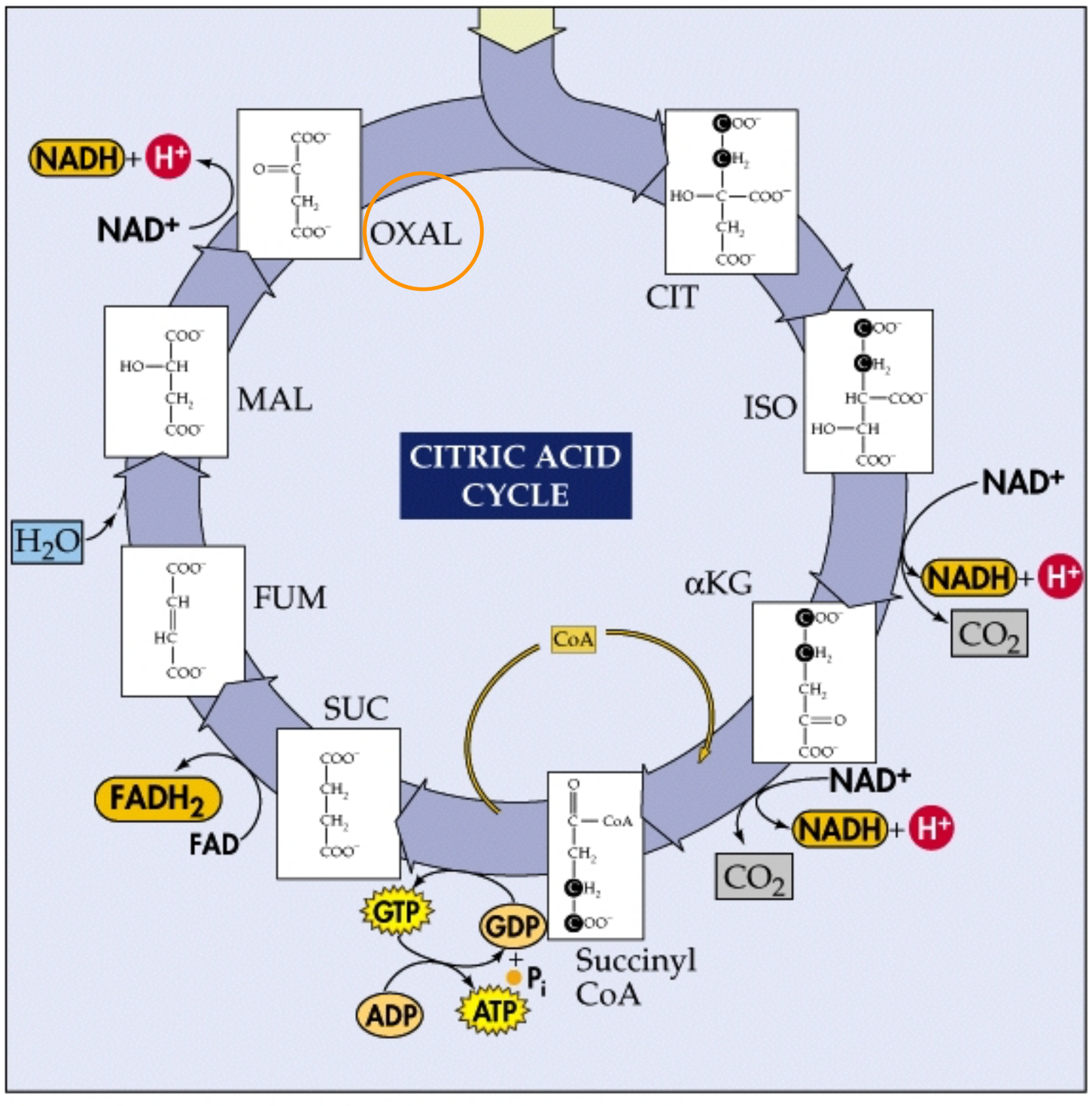

NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

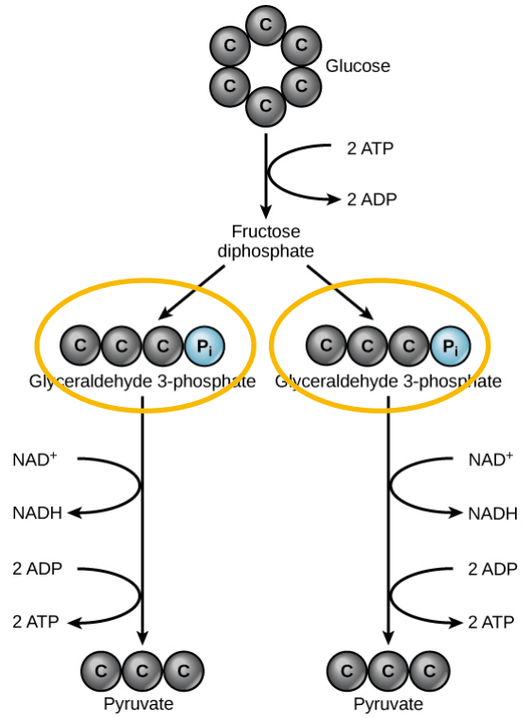
Acetyl CoA


NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

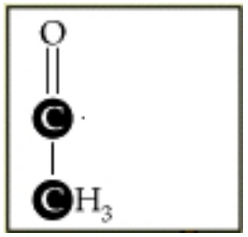
Acetyl CoA

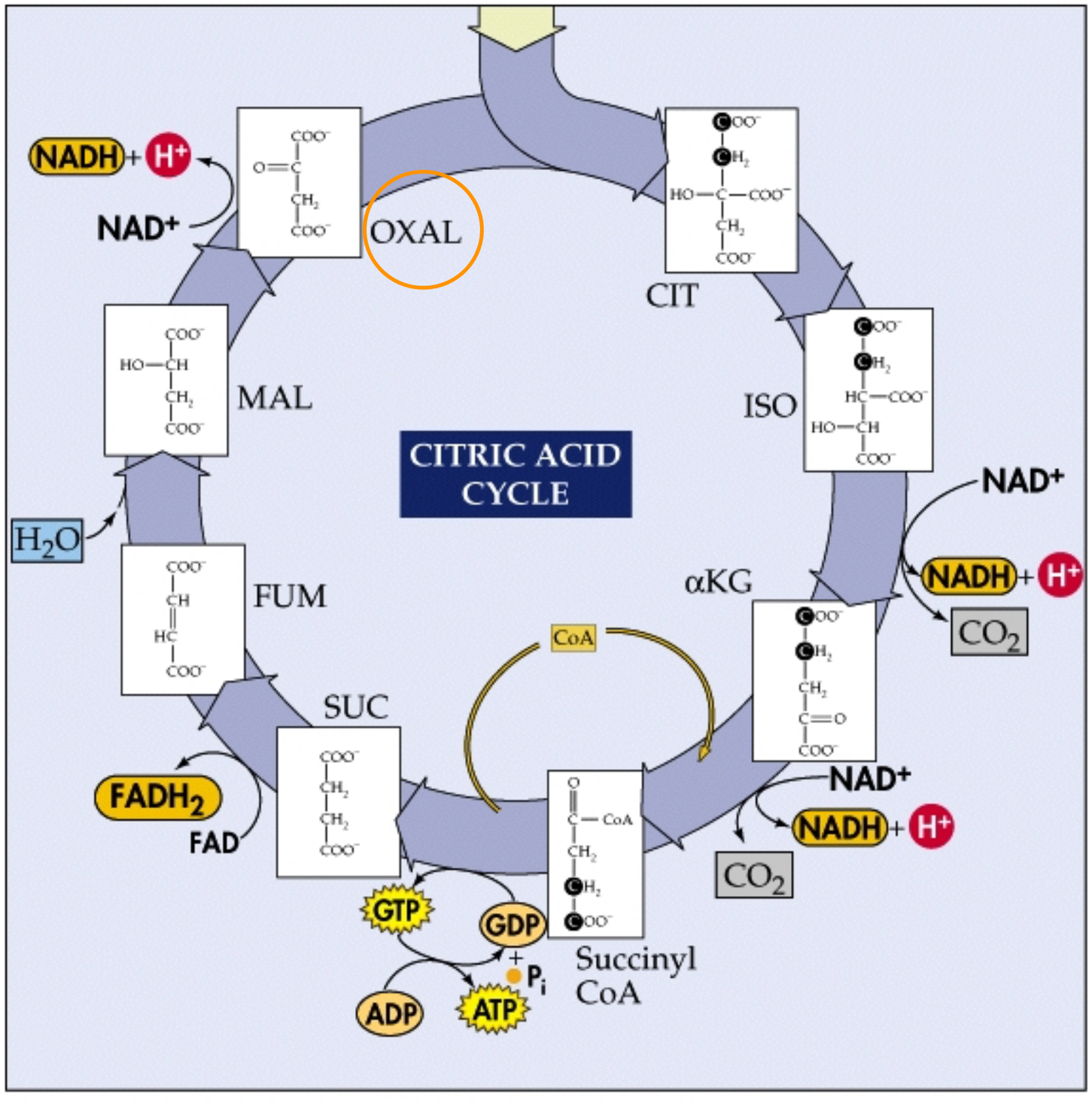

O
C
CH3

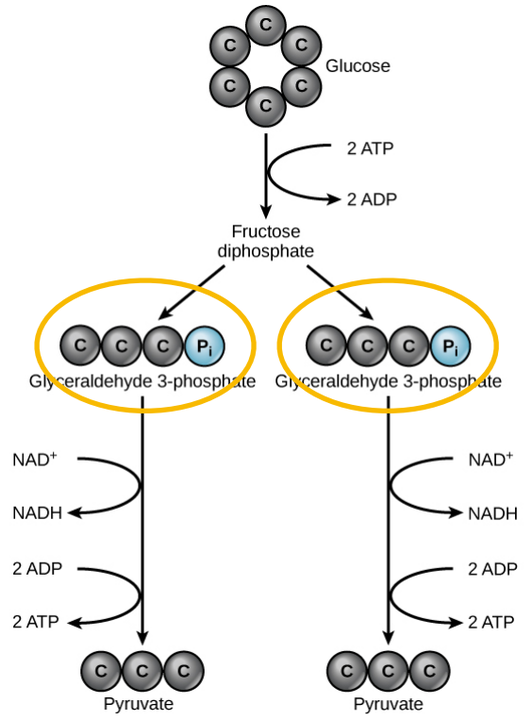

NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
NADH + H+
FUM
αKG
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP


Glucose
2 ATP
2 ADP
Fructose diphosphate
Glyceraldehyde 3-phosphate
Glyceraldehyde 3-phosphate
NAD+
NADH
2 ADP
2 ATP
NAD+
NADH
2 ADP
2 ATP
Pyruvate
Pyruvate

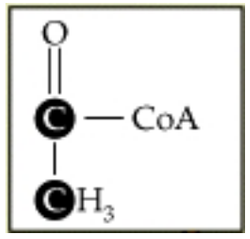
Acetyl CoA



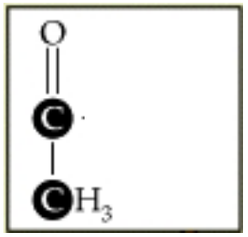


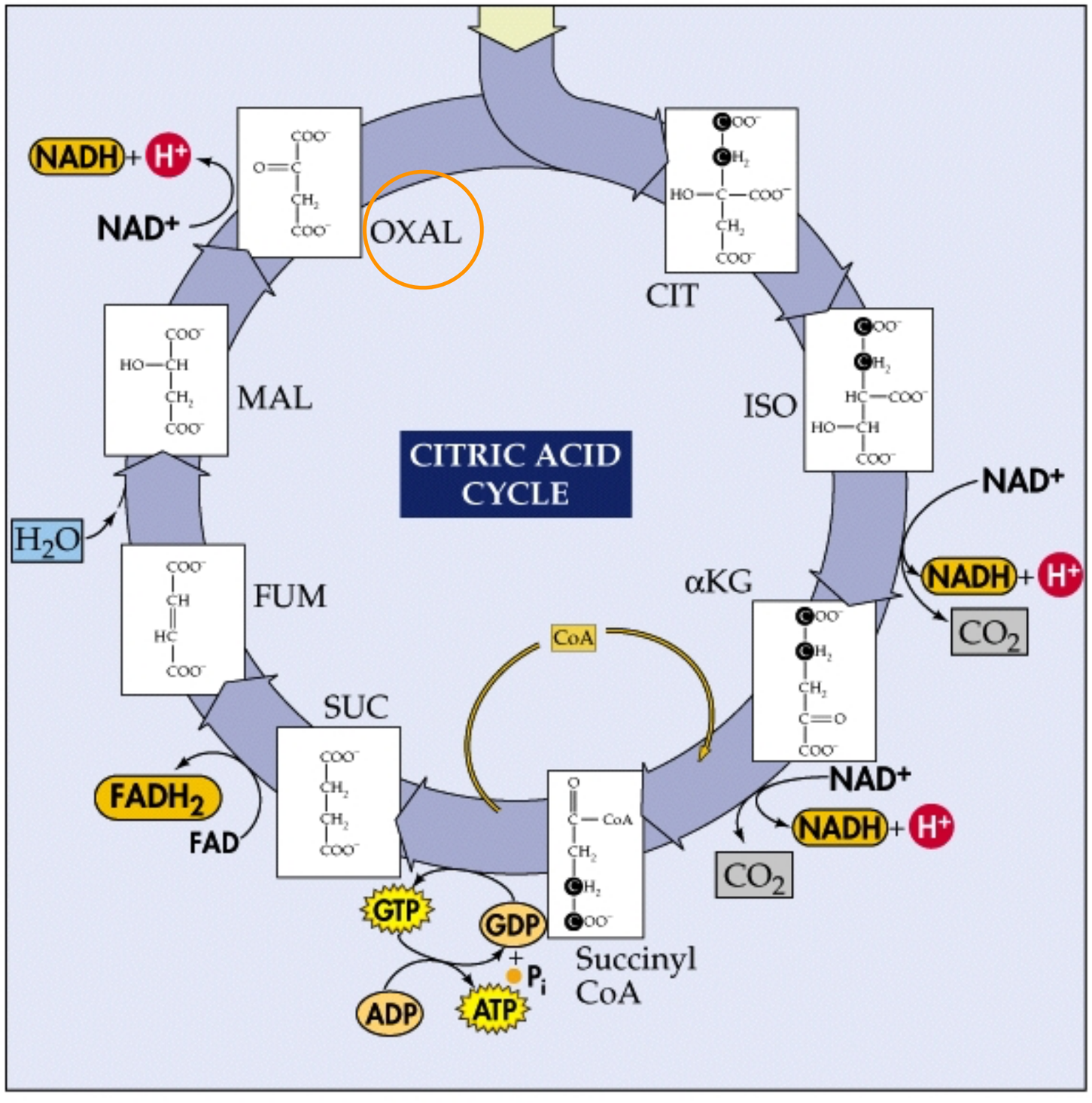


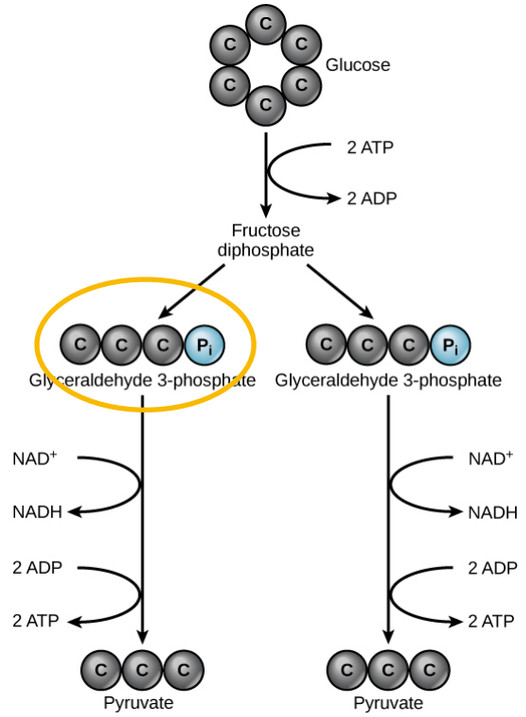
2 x

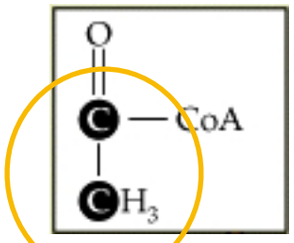


Acetyl CoA

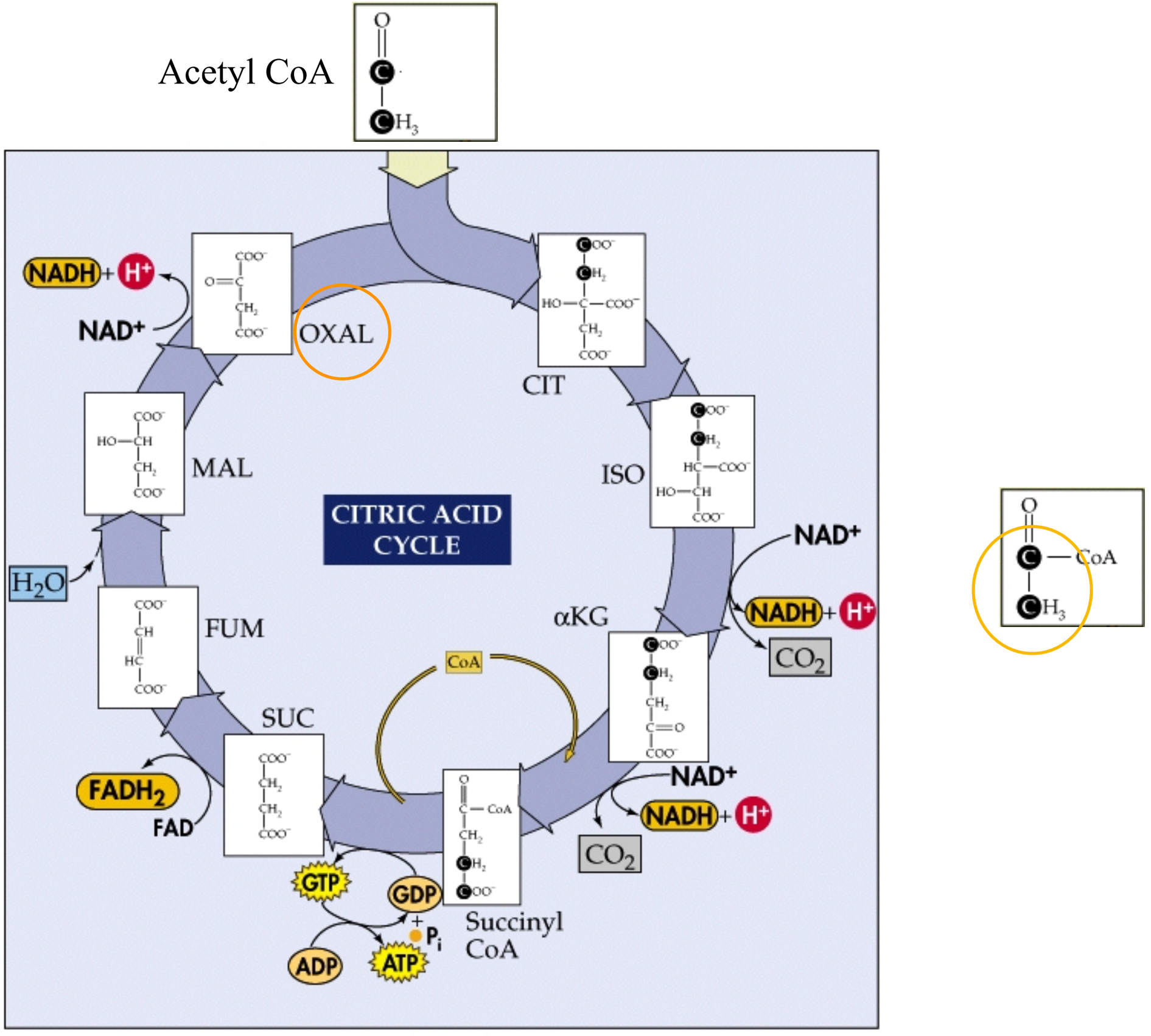



NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
H2O
FUM
αKG
NAD+
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP + Pi
ADP
ATP
Succinyl CoA

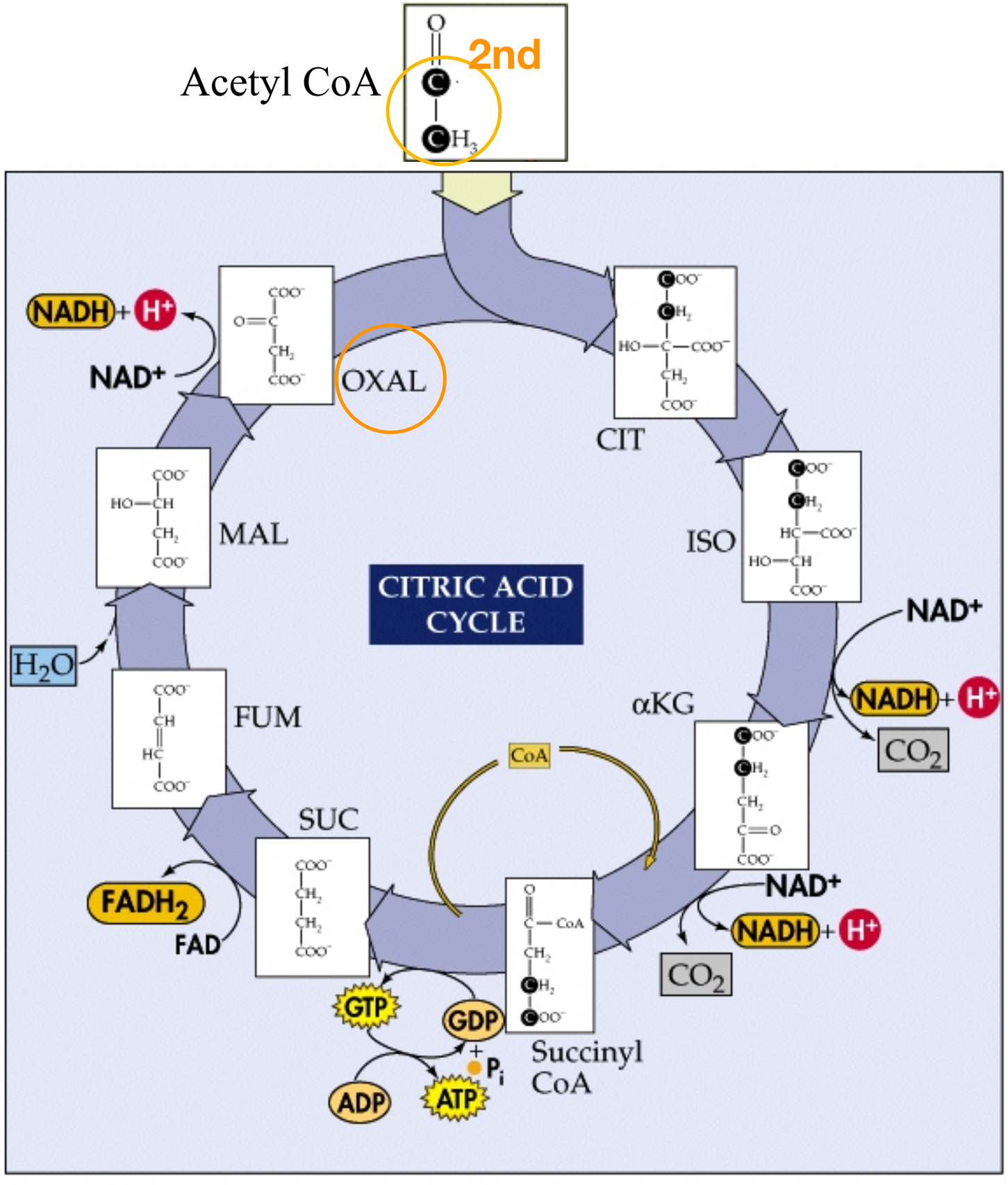

Glucose
2 ATP
2 ADP
Fructose diphosphate
Glyceraldehyde 3-phosphate
Glyceraldehyde 3-phosphate
NAD+
NADH
2 ADP
2 ATP
NAD+
NADH
2 ADP
2 ATP
Pyruvate
Pyruvate


CoA

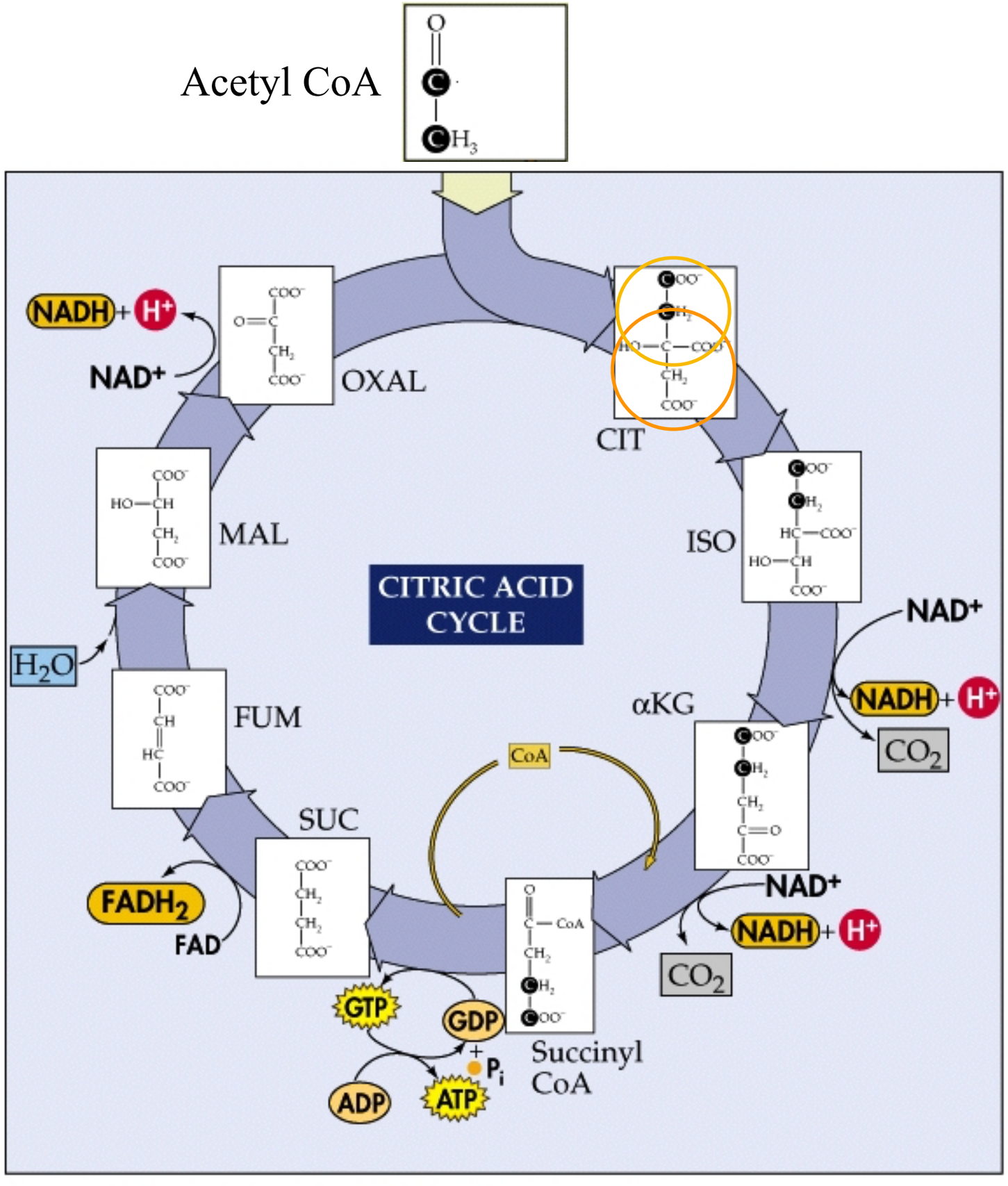
Acetyl CoA

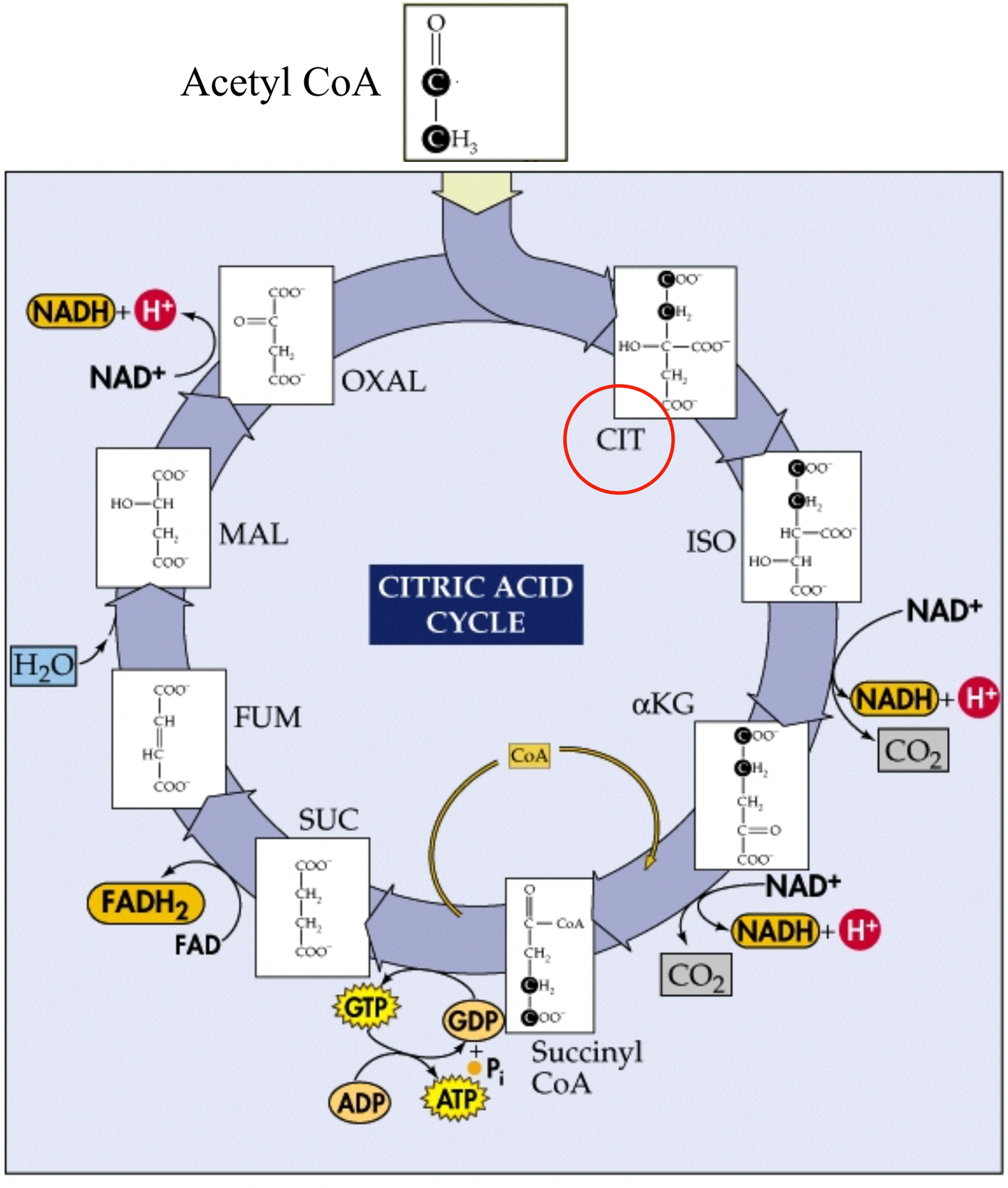

NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
ADP
ATP
Succinyl CoA

CoA

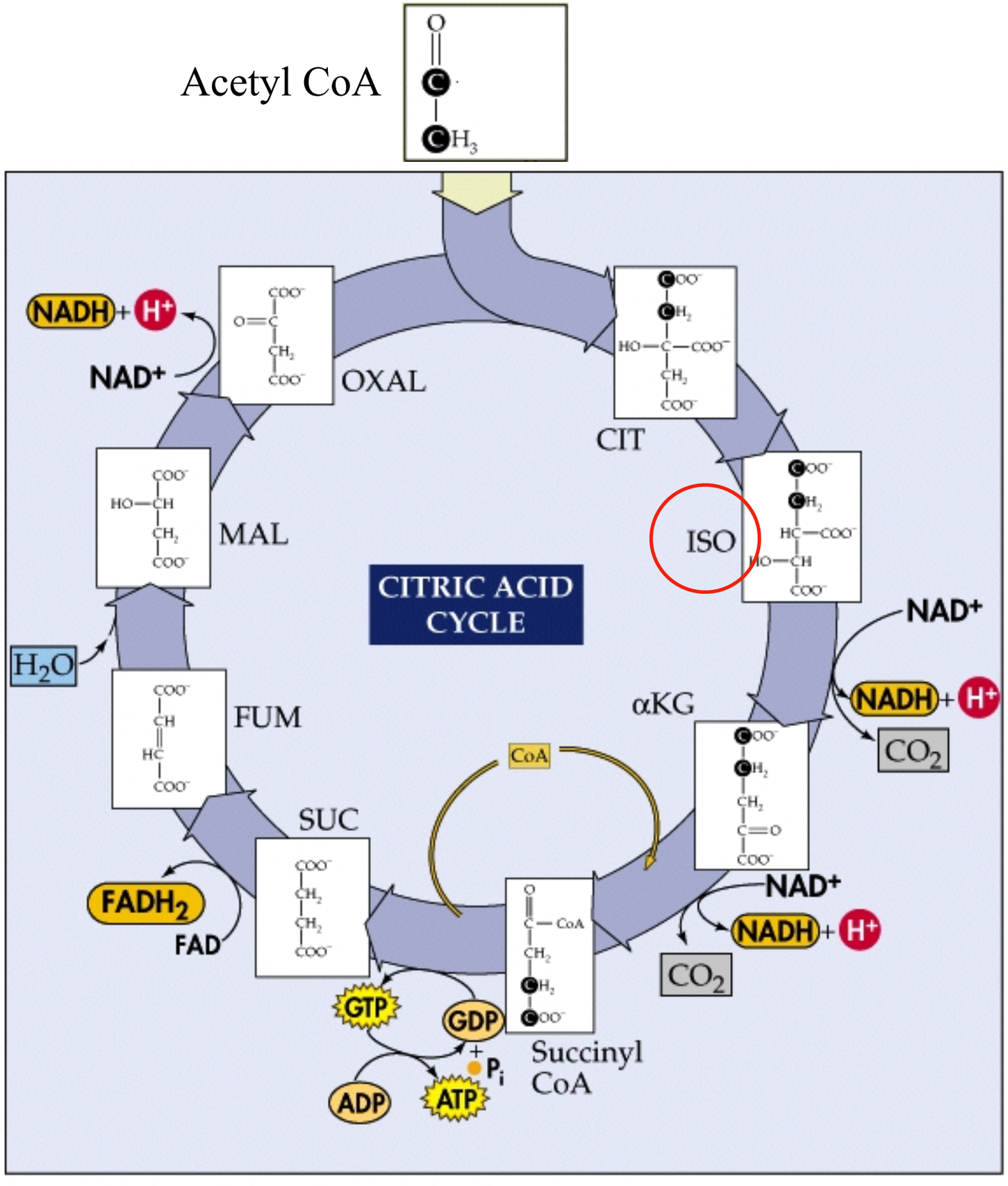

Acetyl CoA
2nd
NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

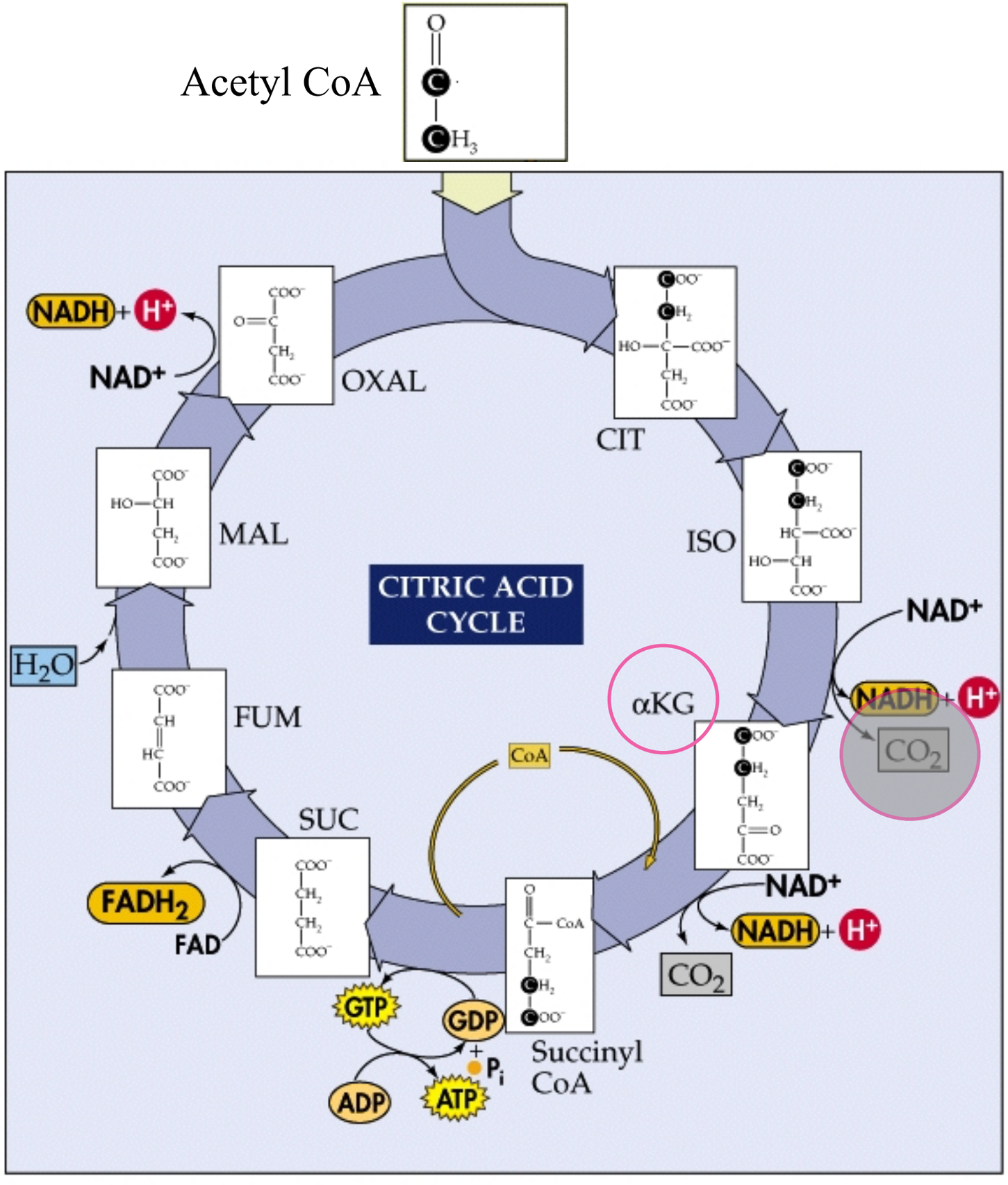
2nd


Acetyl CoA
NADH
H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH
H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH
H+
CO2
GTP
GDP
+
Pi
Succinyl CoA
ADP
ATP

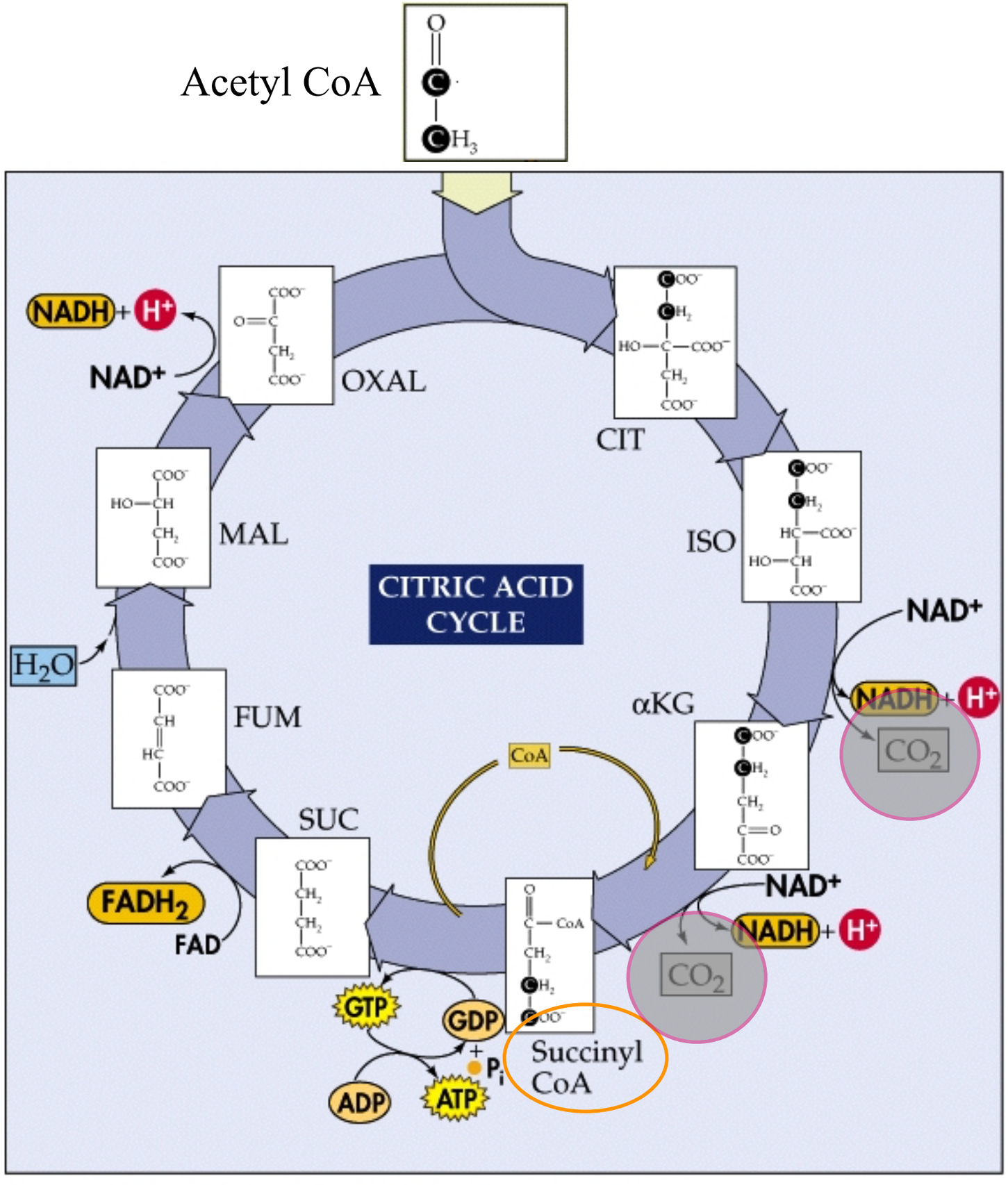

Acetyl CoA
CITRIC ACID CYCLE
OXAL
CIT
ISO
αKG
Succinyl CoA
SUC
FUM
MAL
NADH + H+
NAD+
CO2
CoA
FADH2
FAD
GTP
GDP
Pi
ADP
ATP
H2O

2nd

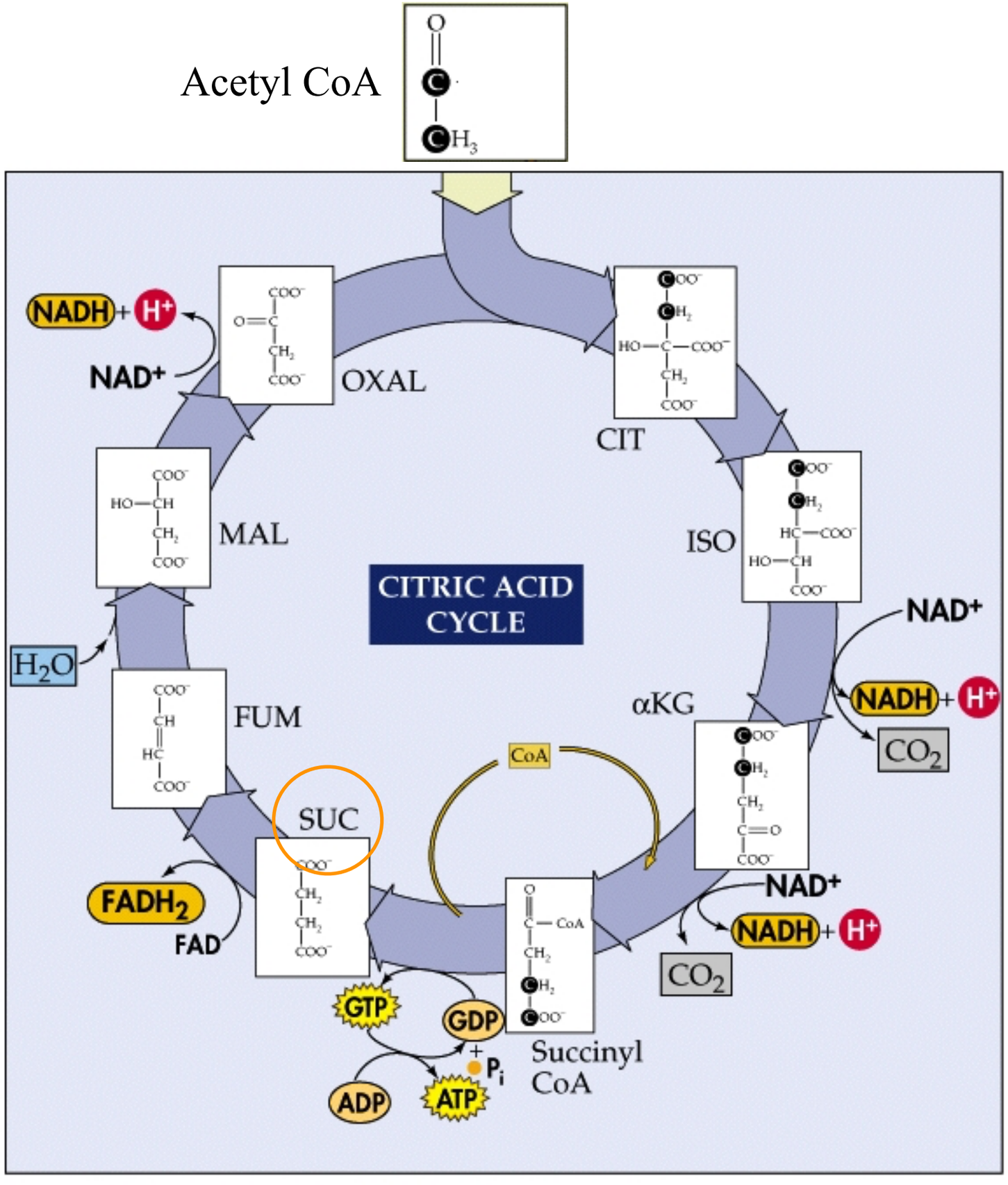

Acetyl CoA
NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP


Acetyl CoA
NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
αKG
NADH + H+
CO2
FUM
CoA
SUC
NAD+
FADH2
FAD
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

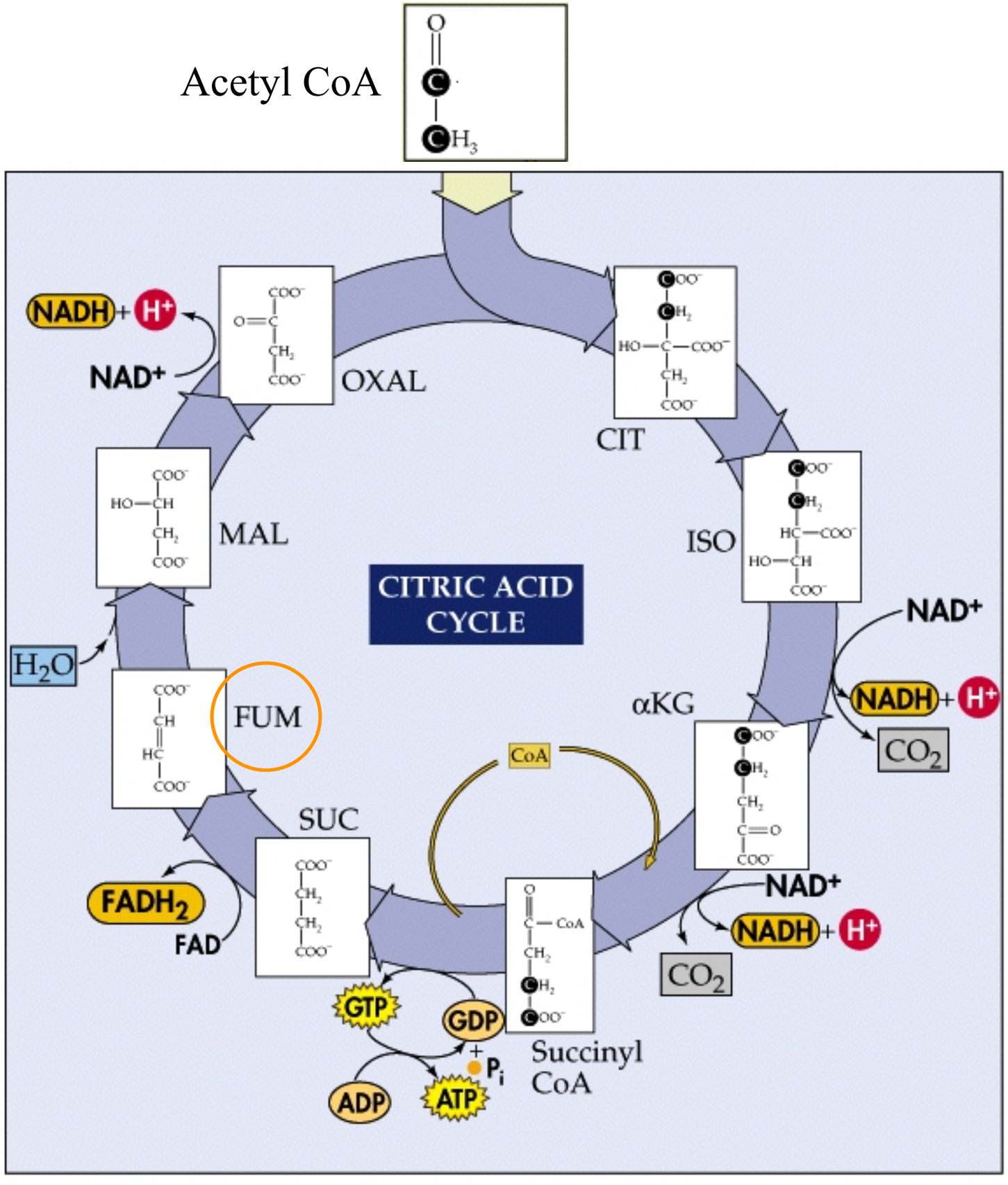
2nd


Acetyl CoA
CITRIC ACID CYCLE
OXAL
CIT
ISO
αKG
Succinyl CoA
SUC
FUM
MAL
NADH + H+
NAD+
CO2
CoA
FADH2
FAD
GTP
GDP
+ Pi
ADP
ATP
H2O

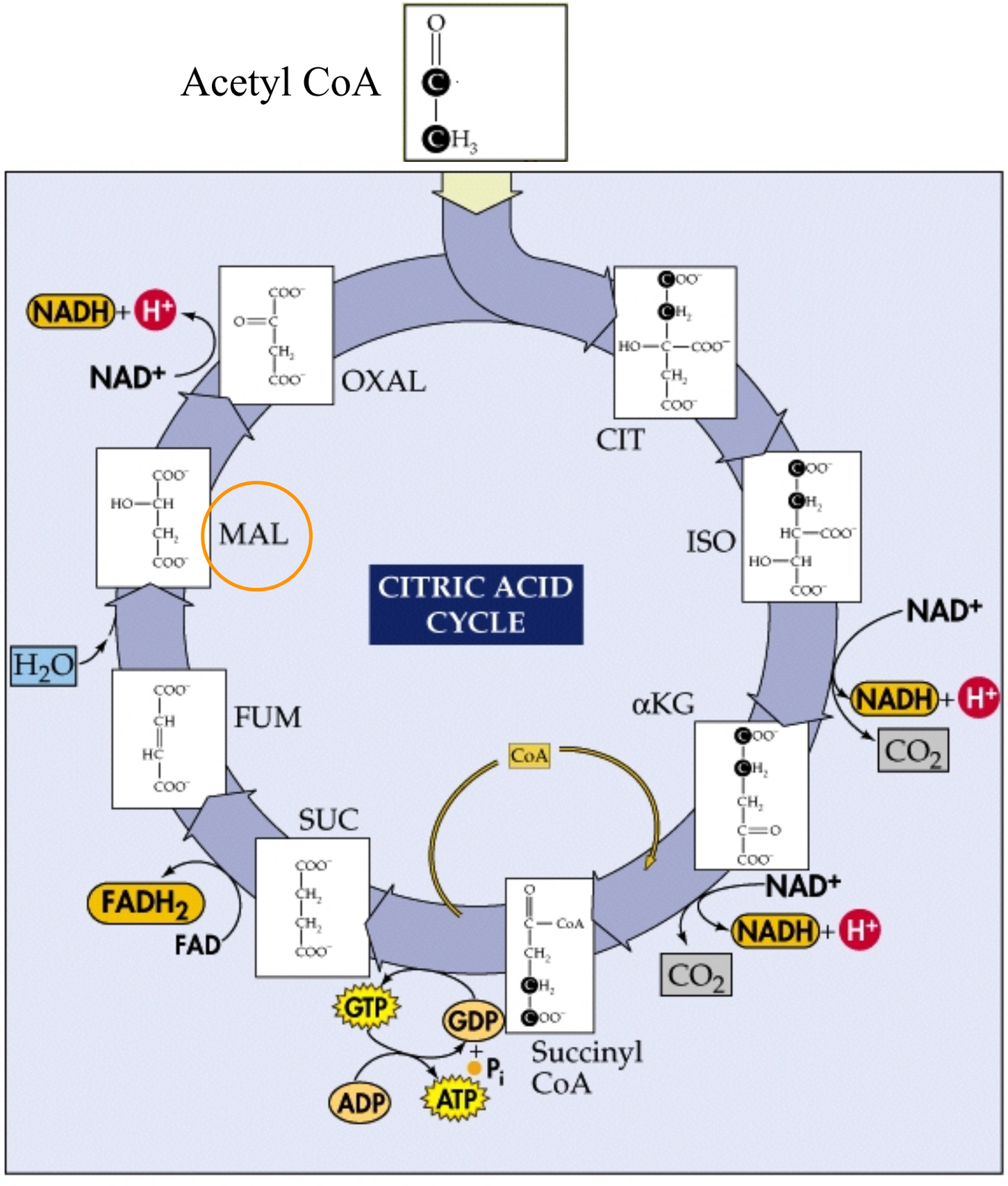
Acetyl CoA


NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

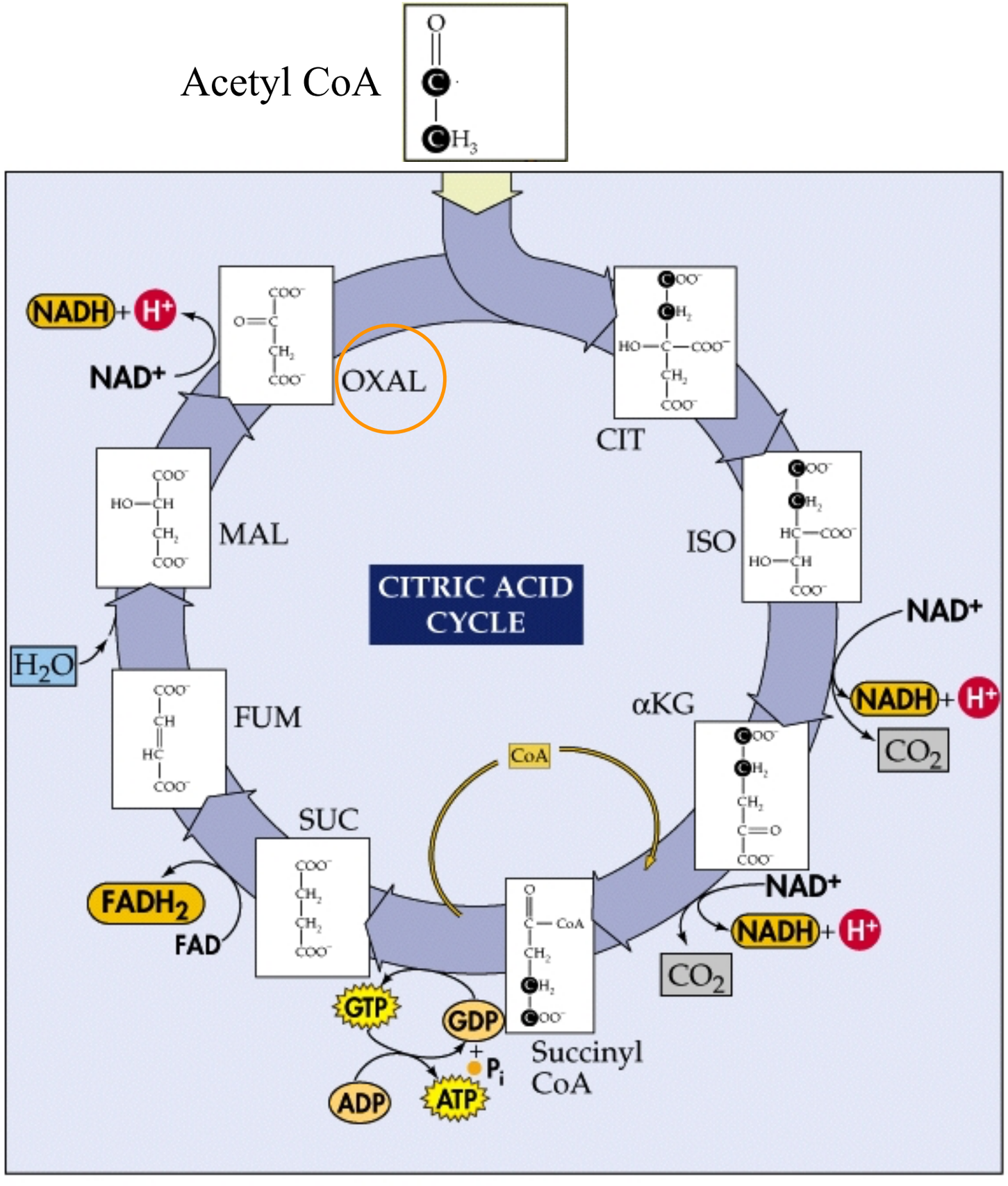
2nd


Acetyl CoA
NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

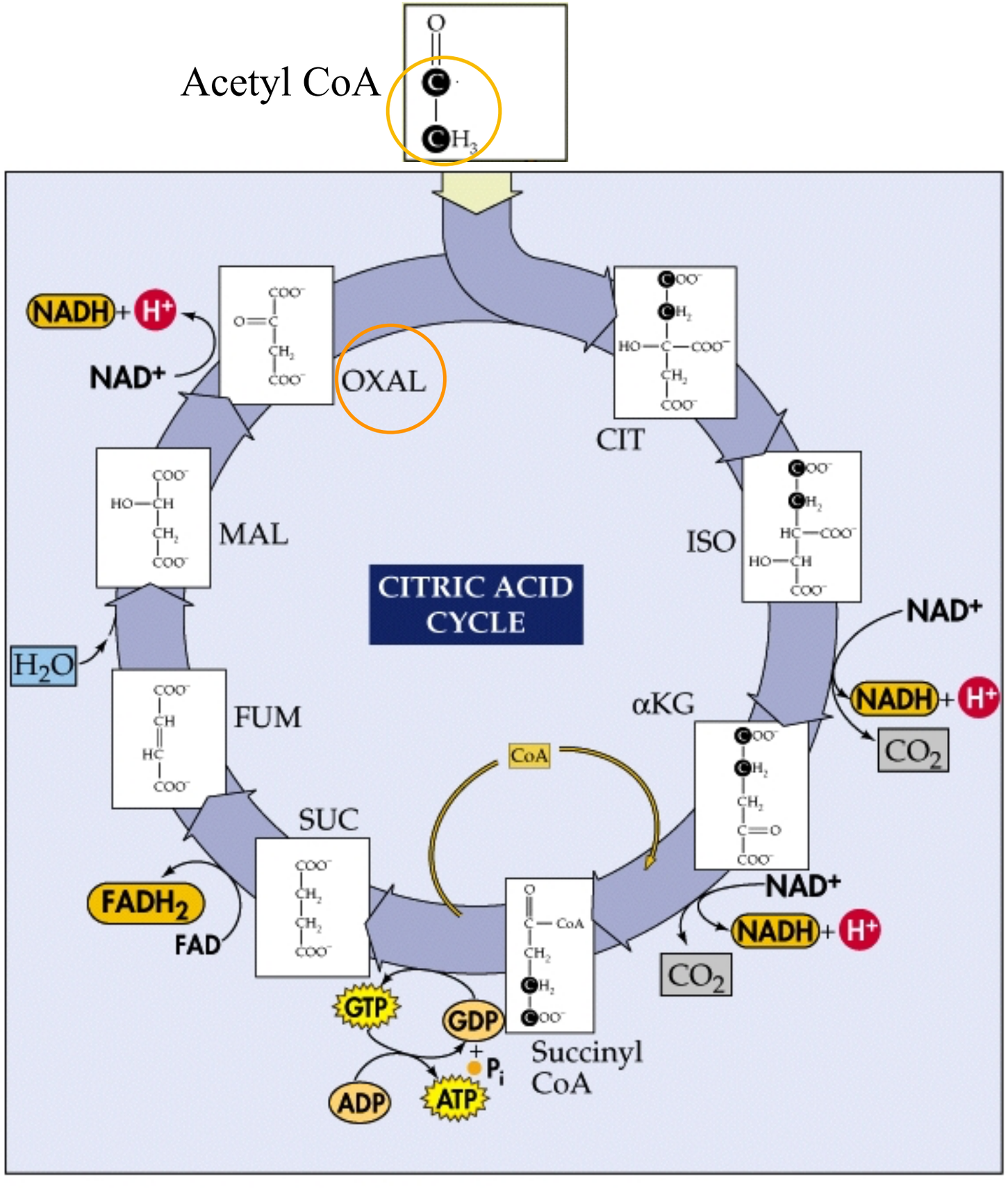
2nd


Acetyl CoA
NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

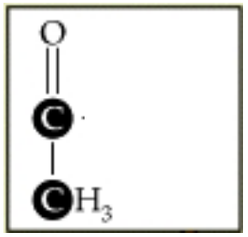
2nd


Acetyl CoA
NADH + H+
NAD+
OXAL
CIT
MAL
ISO
CITRIC ACID CYCLE
NAD+
H2O
FUM
αKG
NADH + H+
CO2
CoA
SUC
FADH2
FAD
NAD+
NADH + H+
CO2
GTP
GDP
+ Pi
Succinyl CoA
ADP
ATP

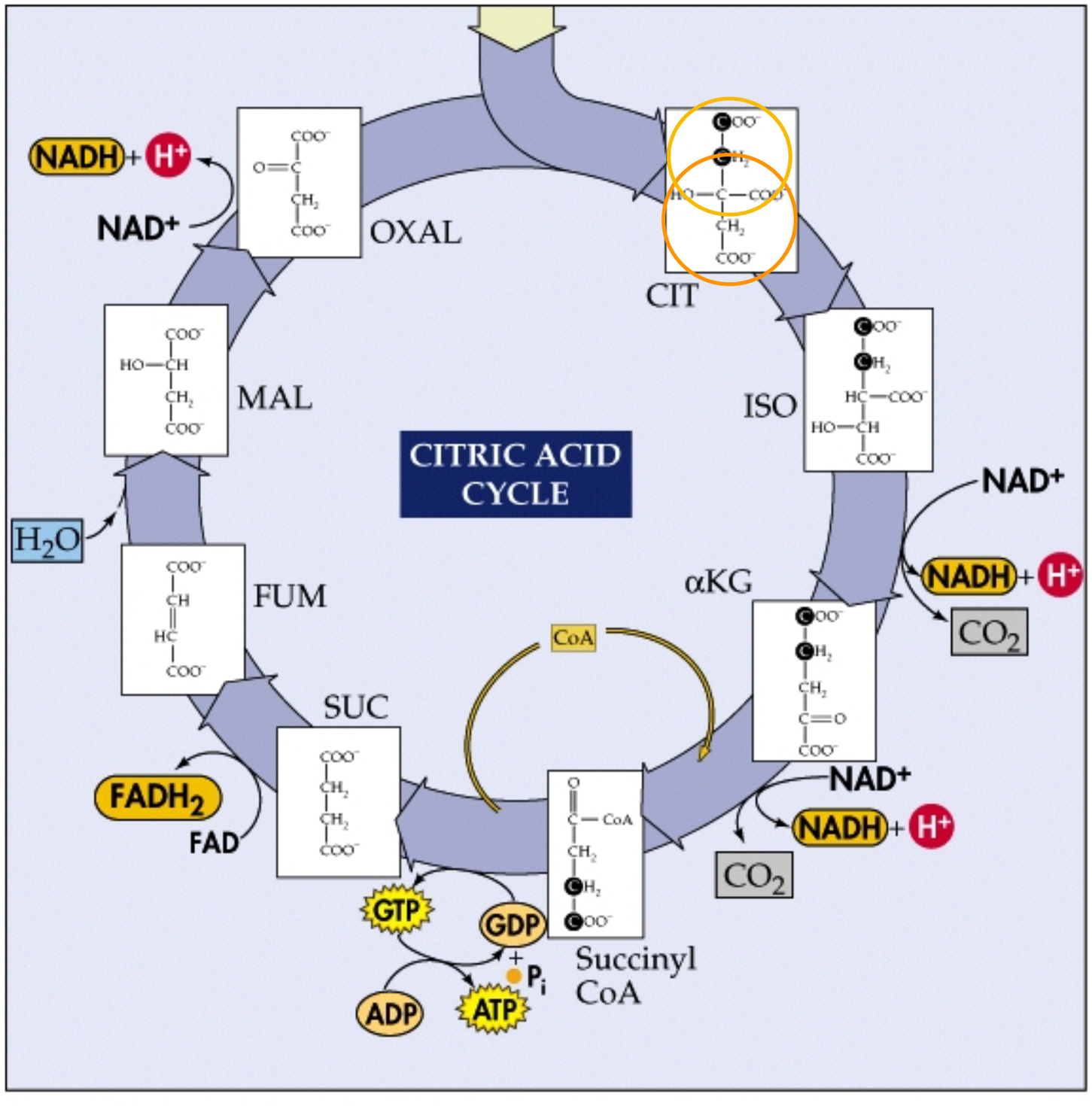
Energy Yield



Acetyl CoA

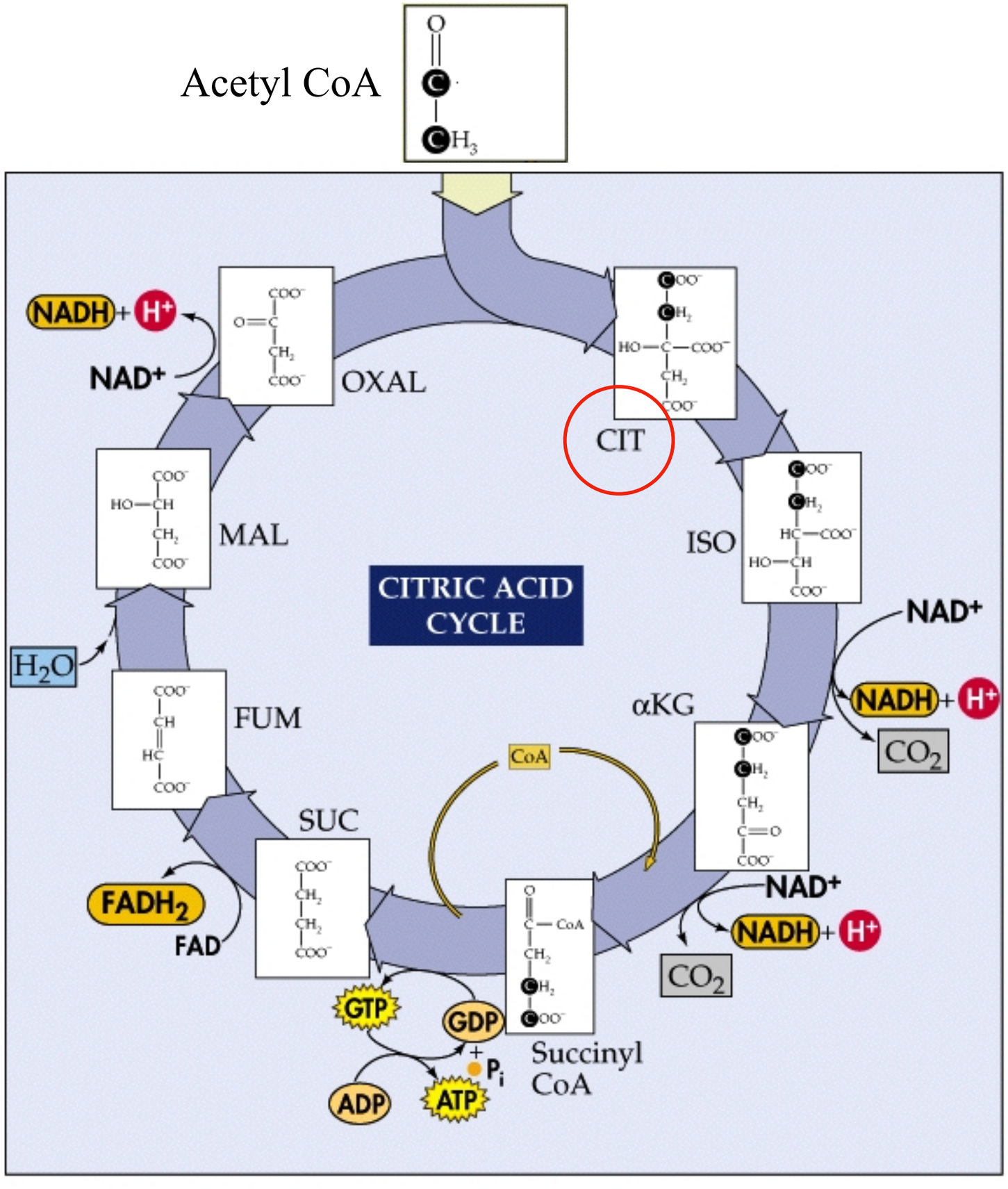


Energy Yield

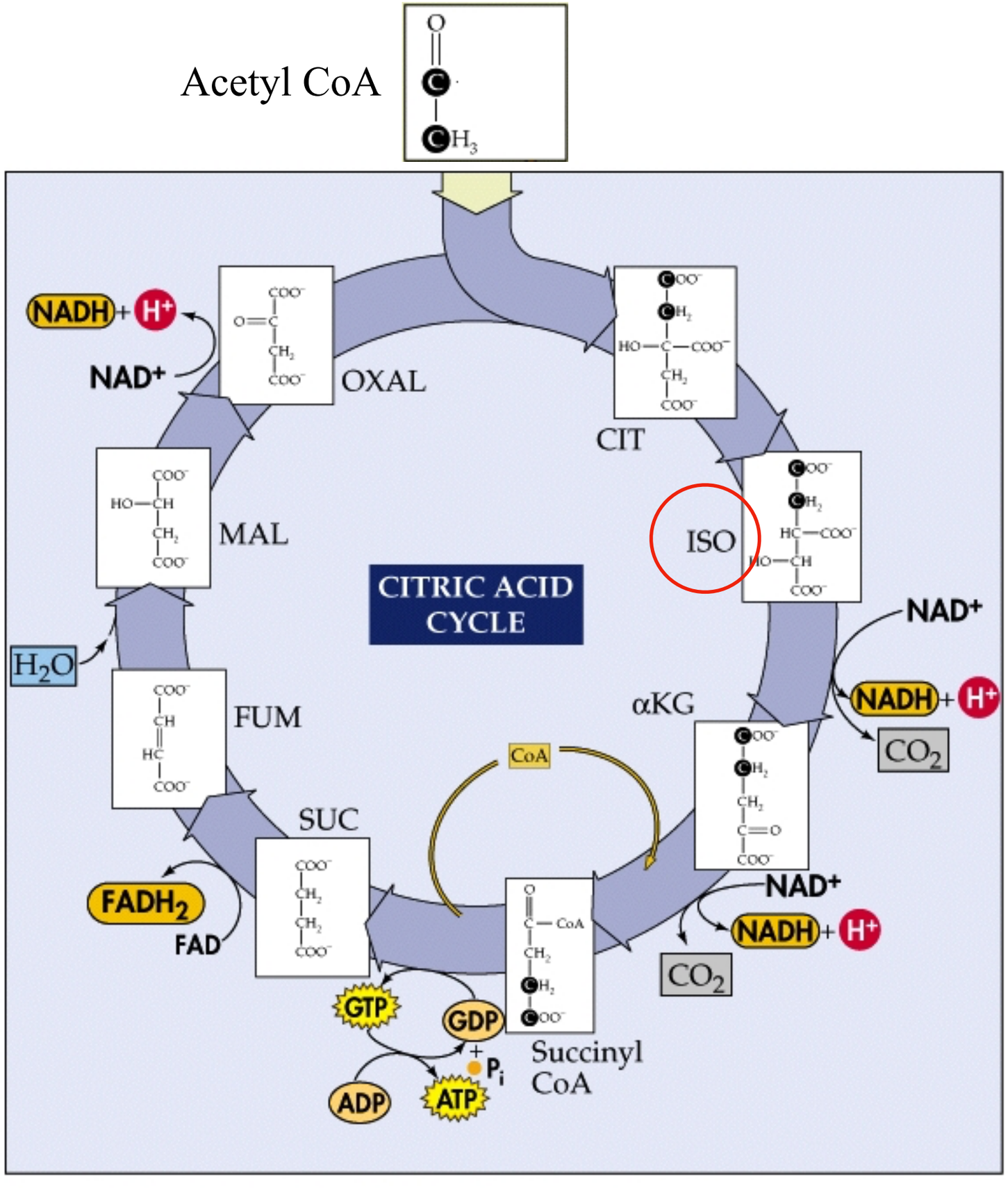


Energy Yield

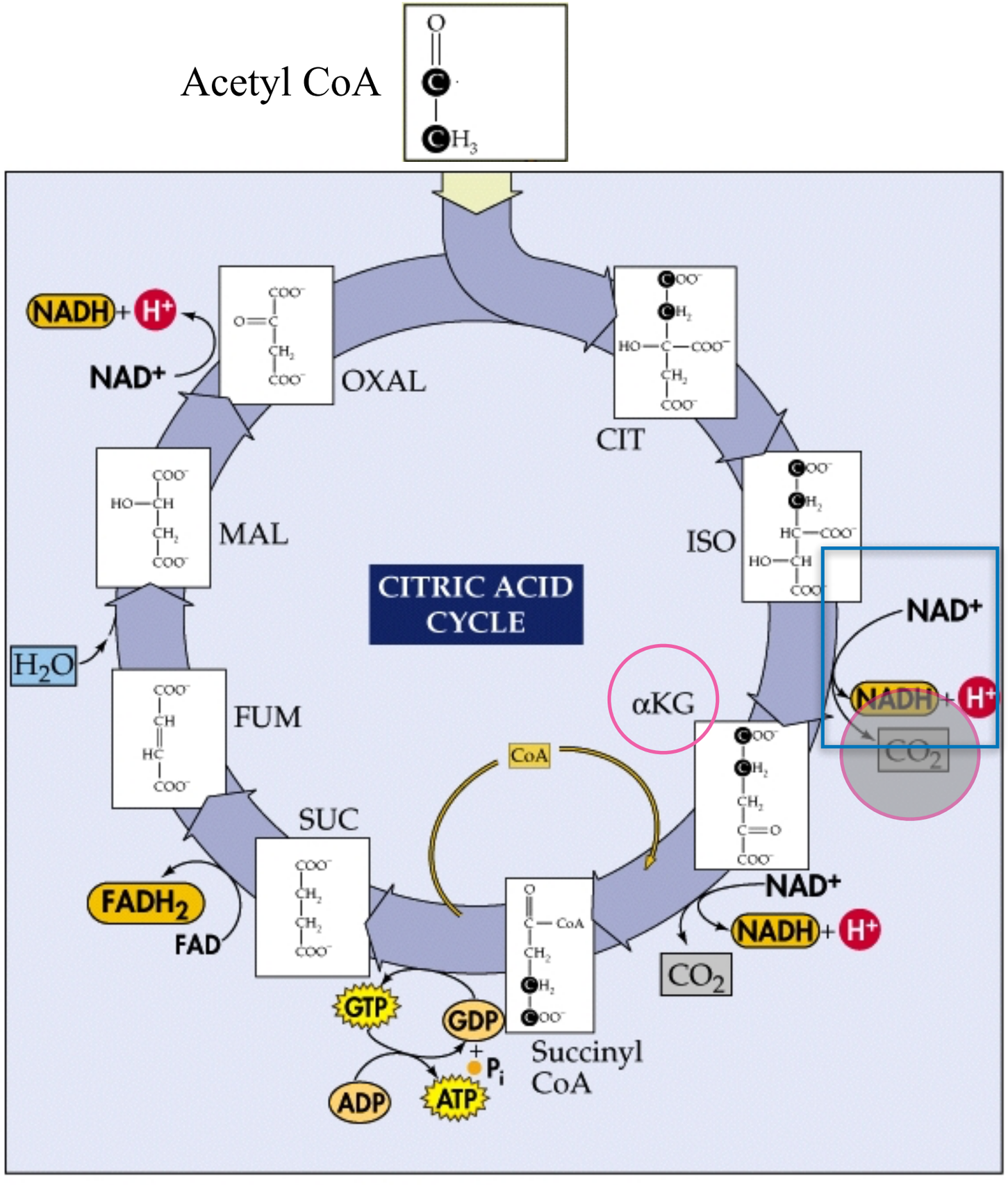
Acetyl CoA



Energy Yield

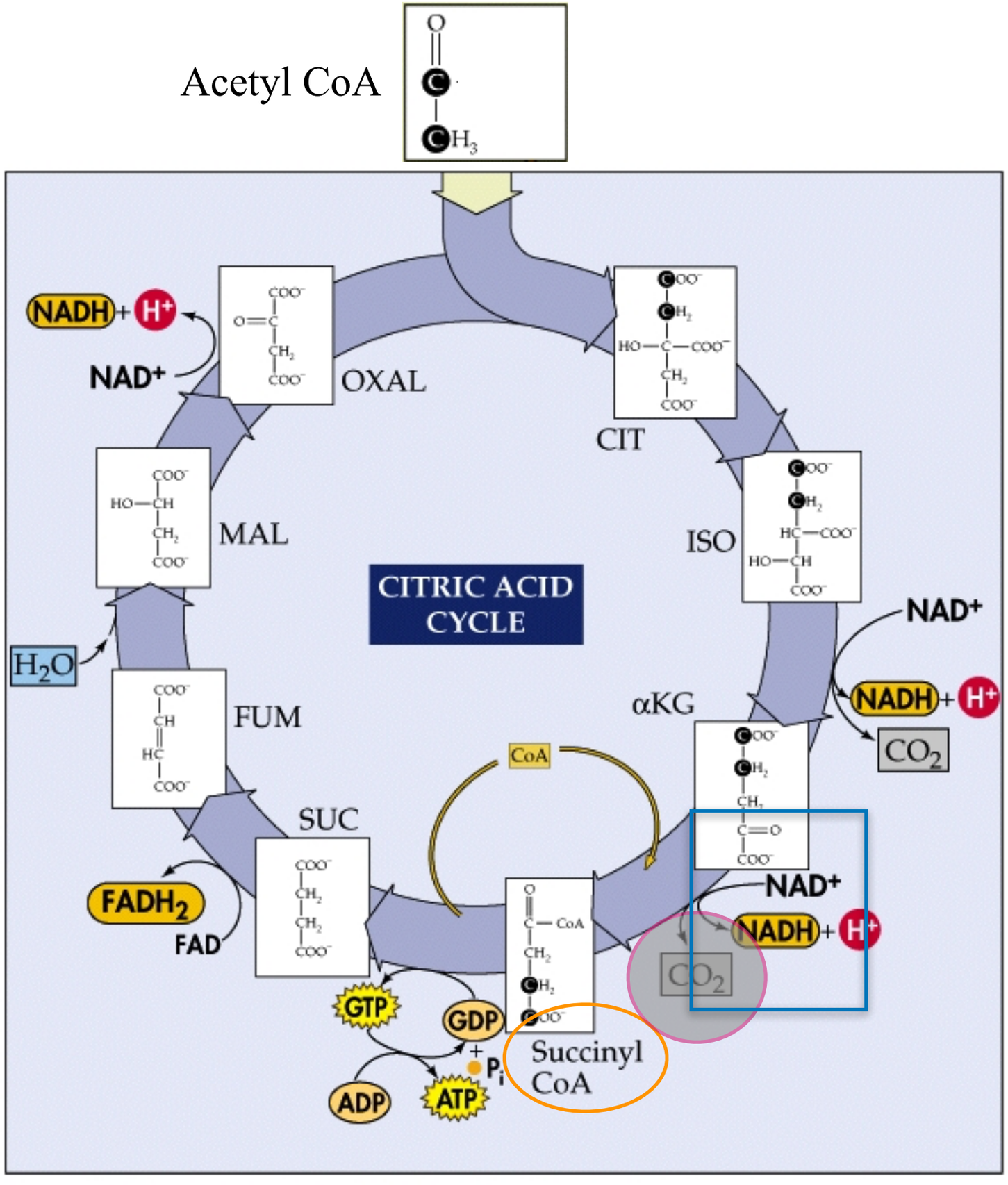


Acetyl CoA

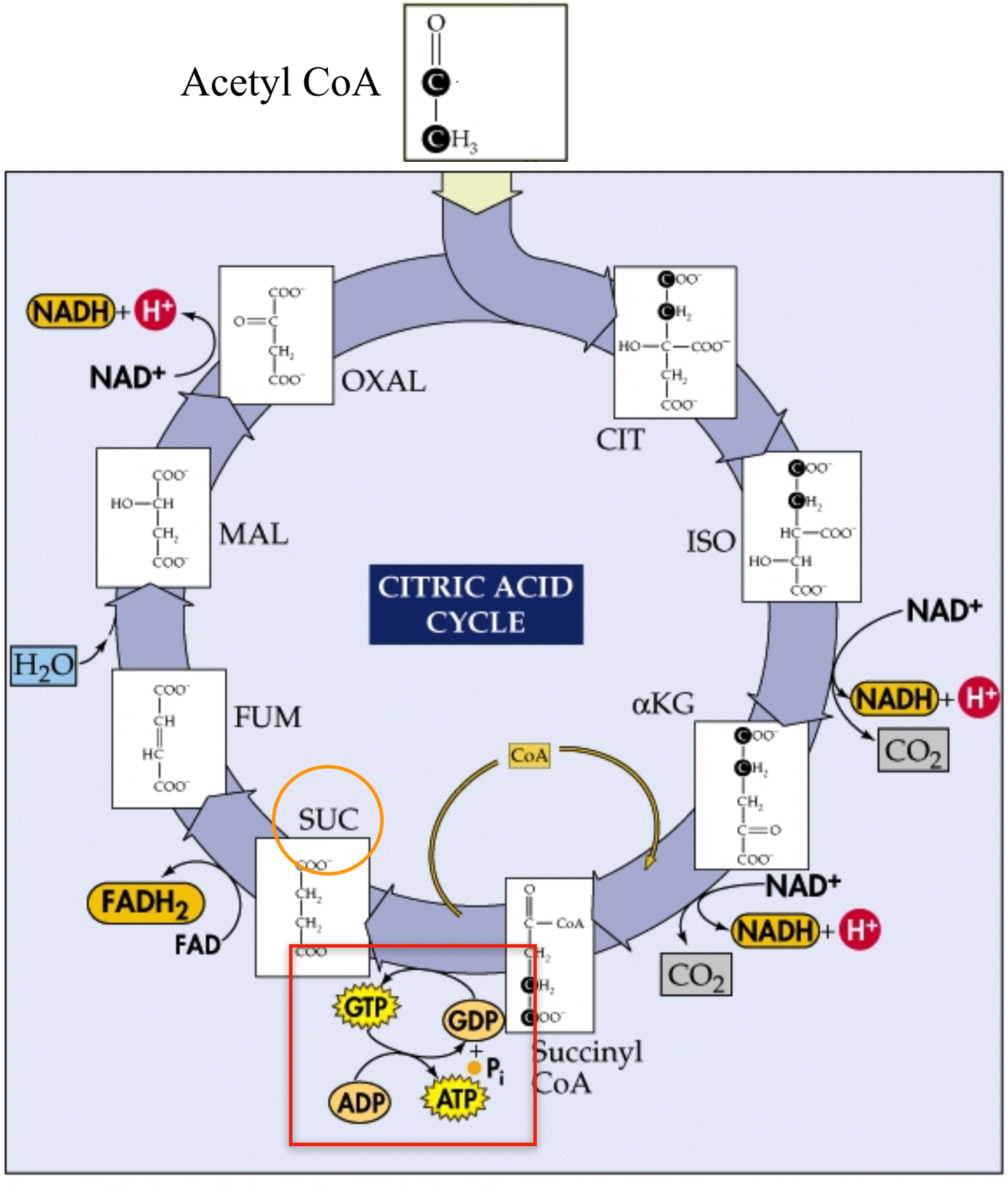


Energy Yield

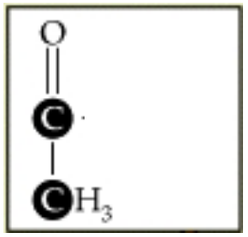
Energy Yield



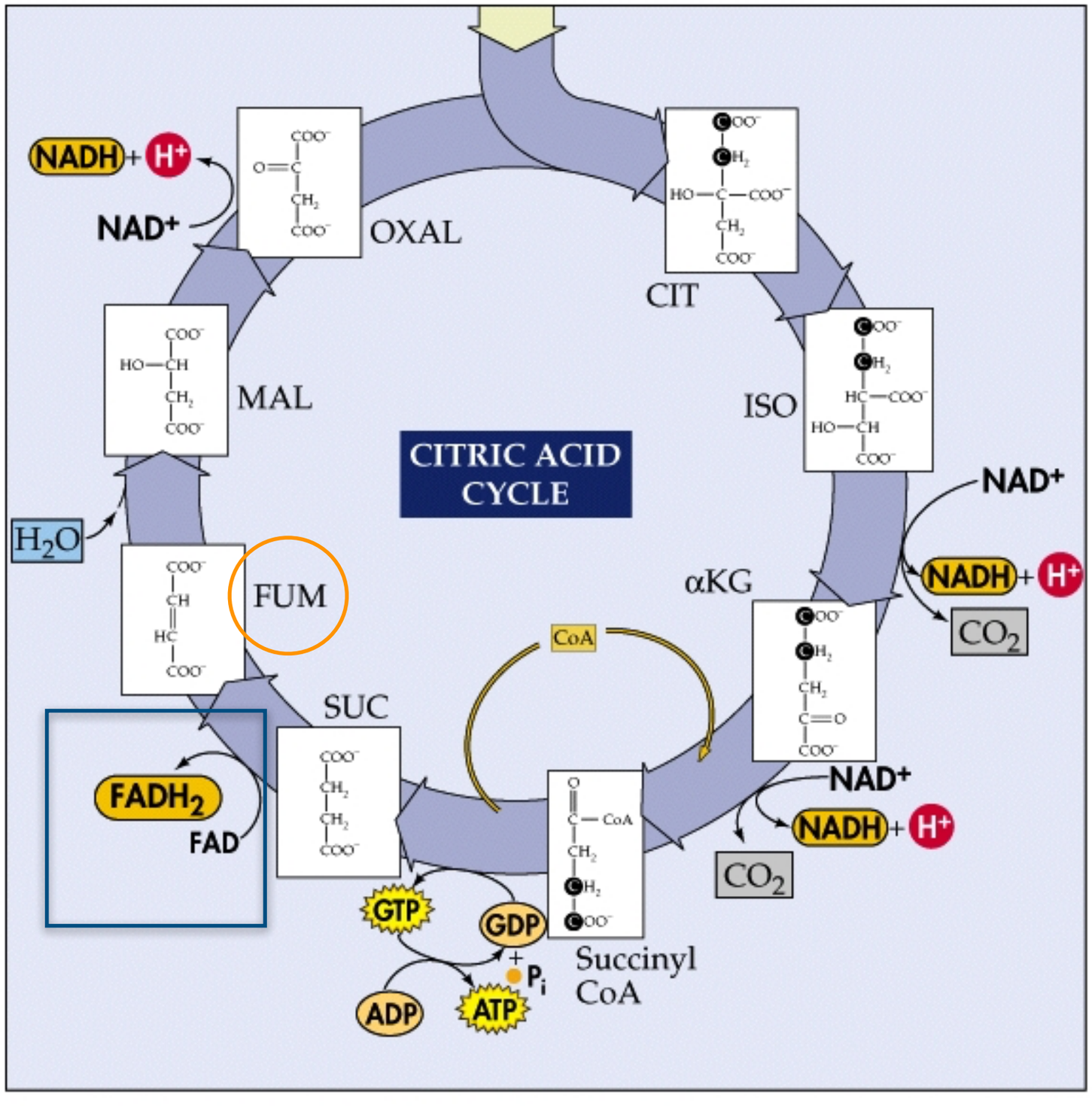
Energy Yield



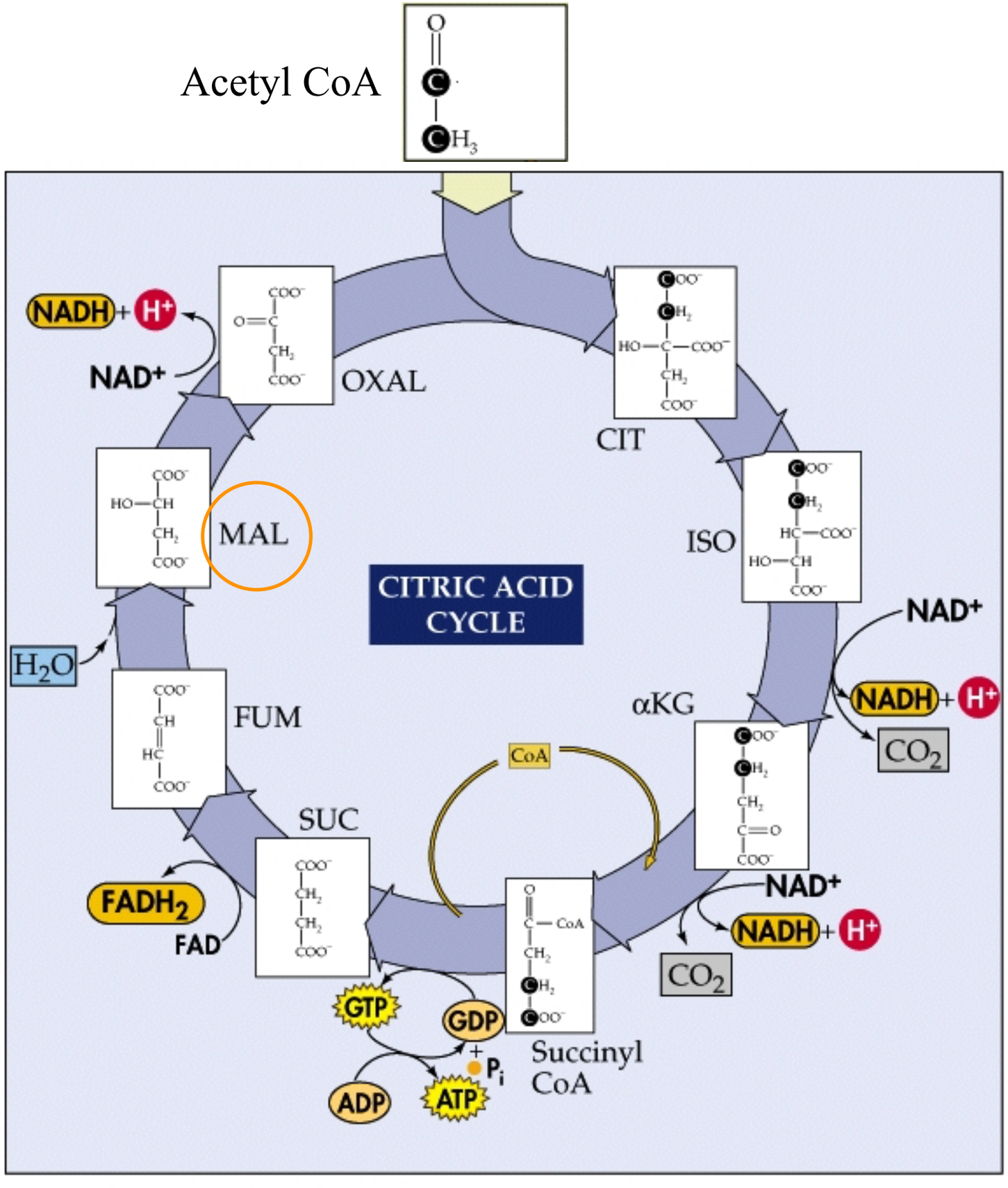
Acetyl CoA



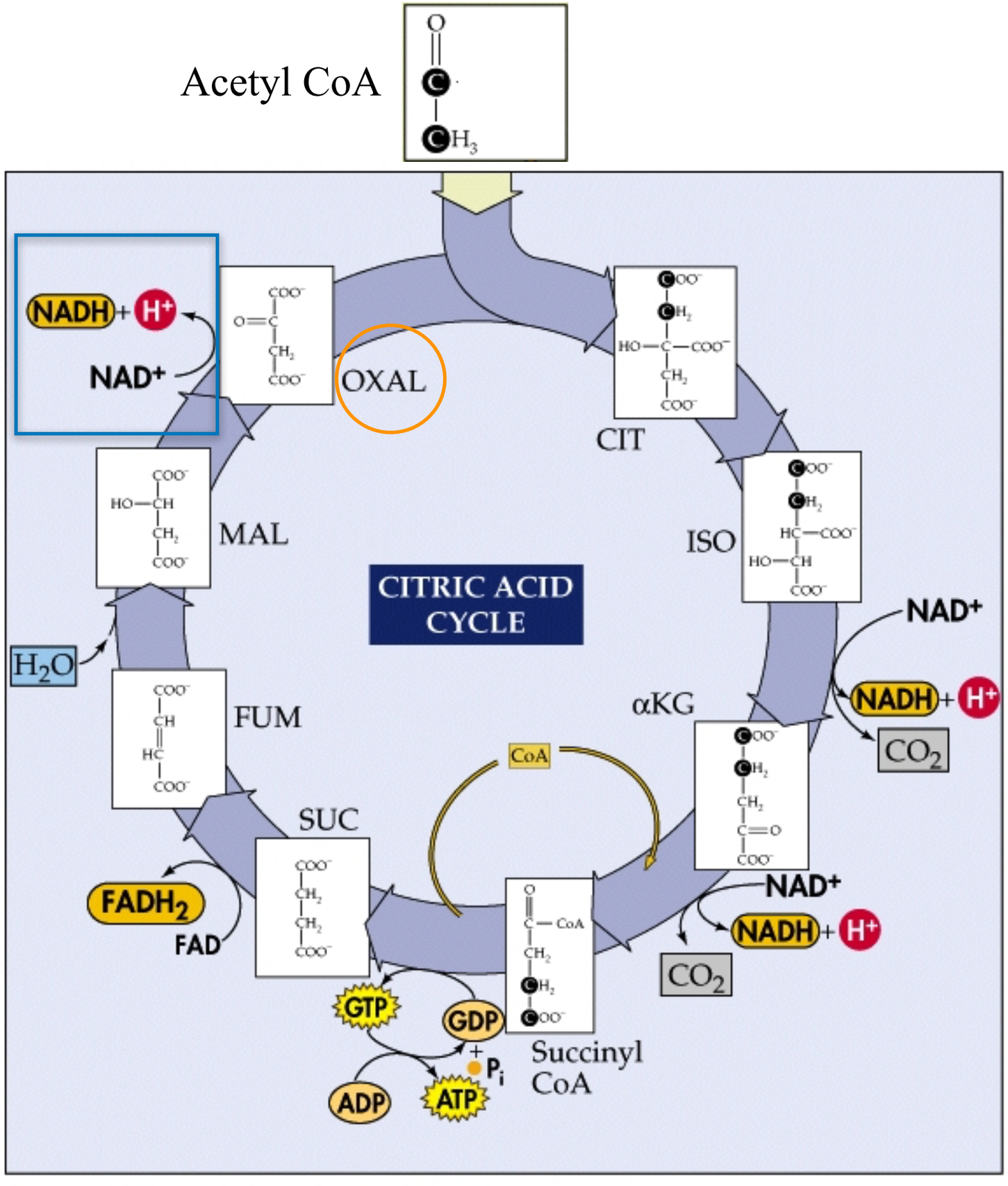
Energy Yield



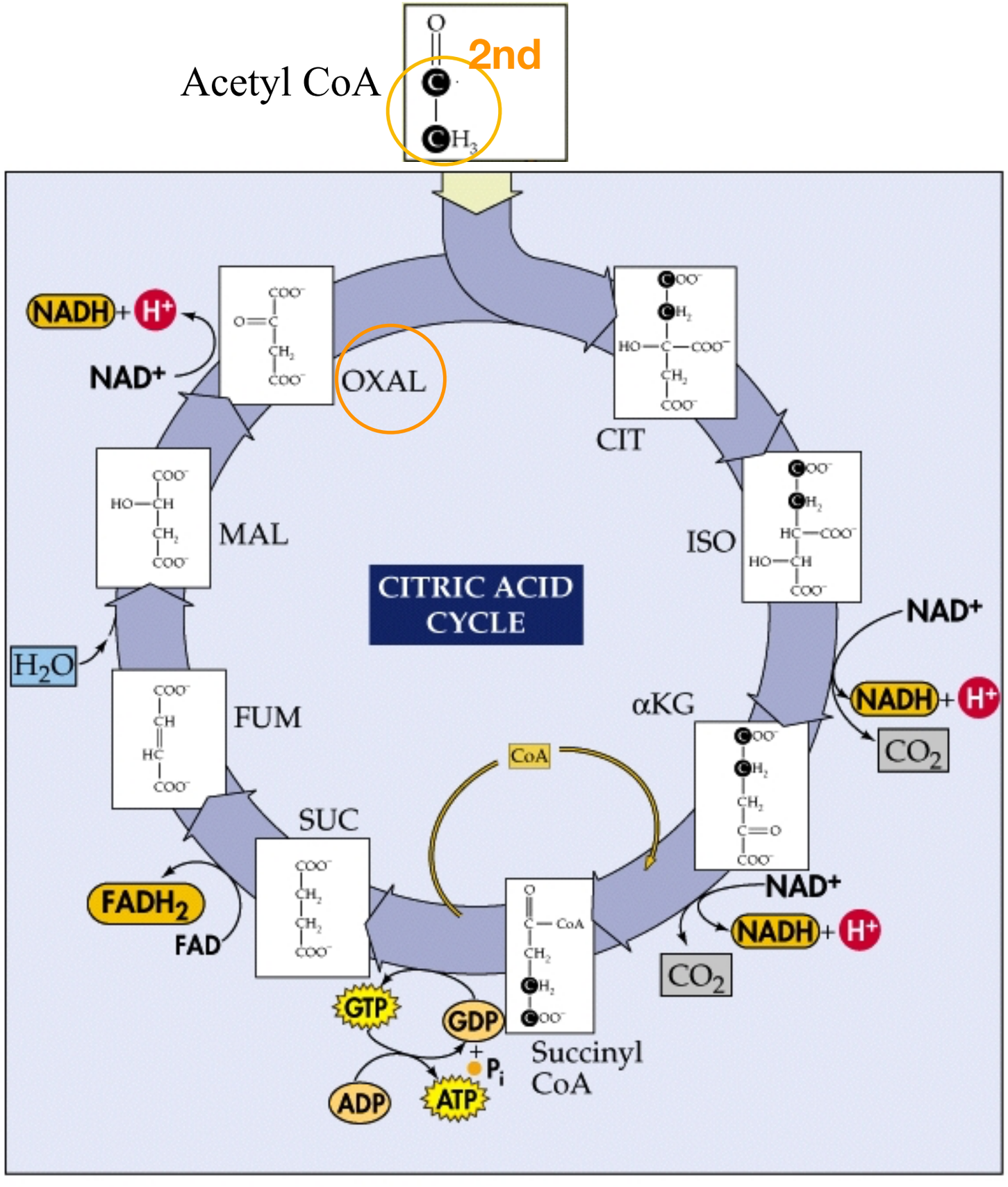
Energy Yield



Energy Yield

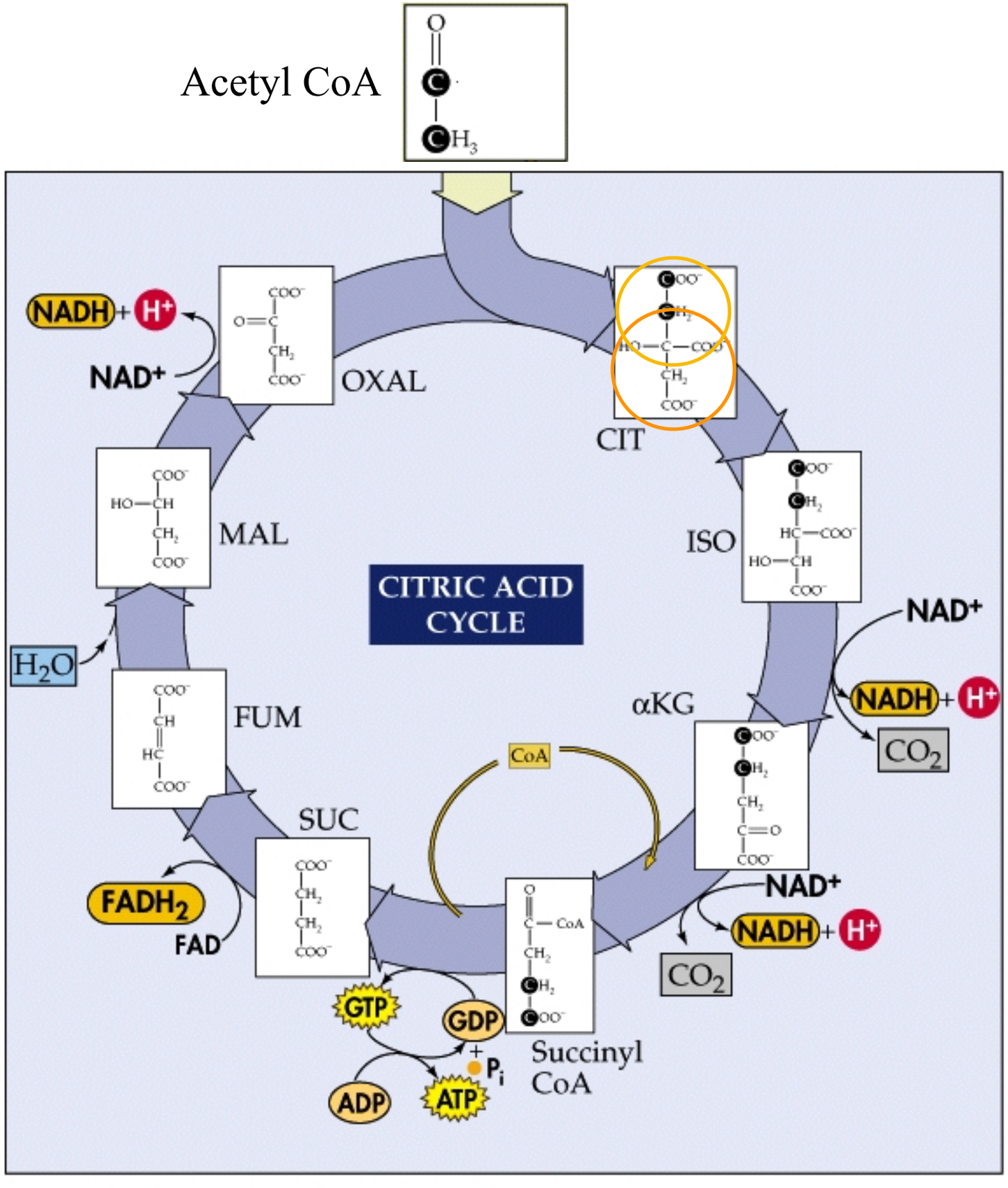


Acetyl CoA



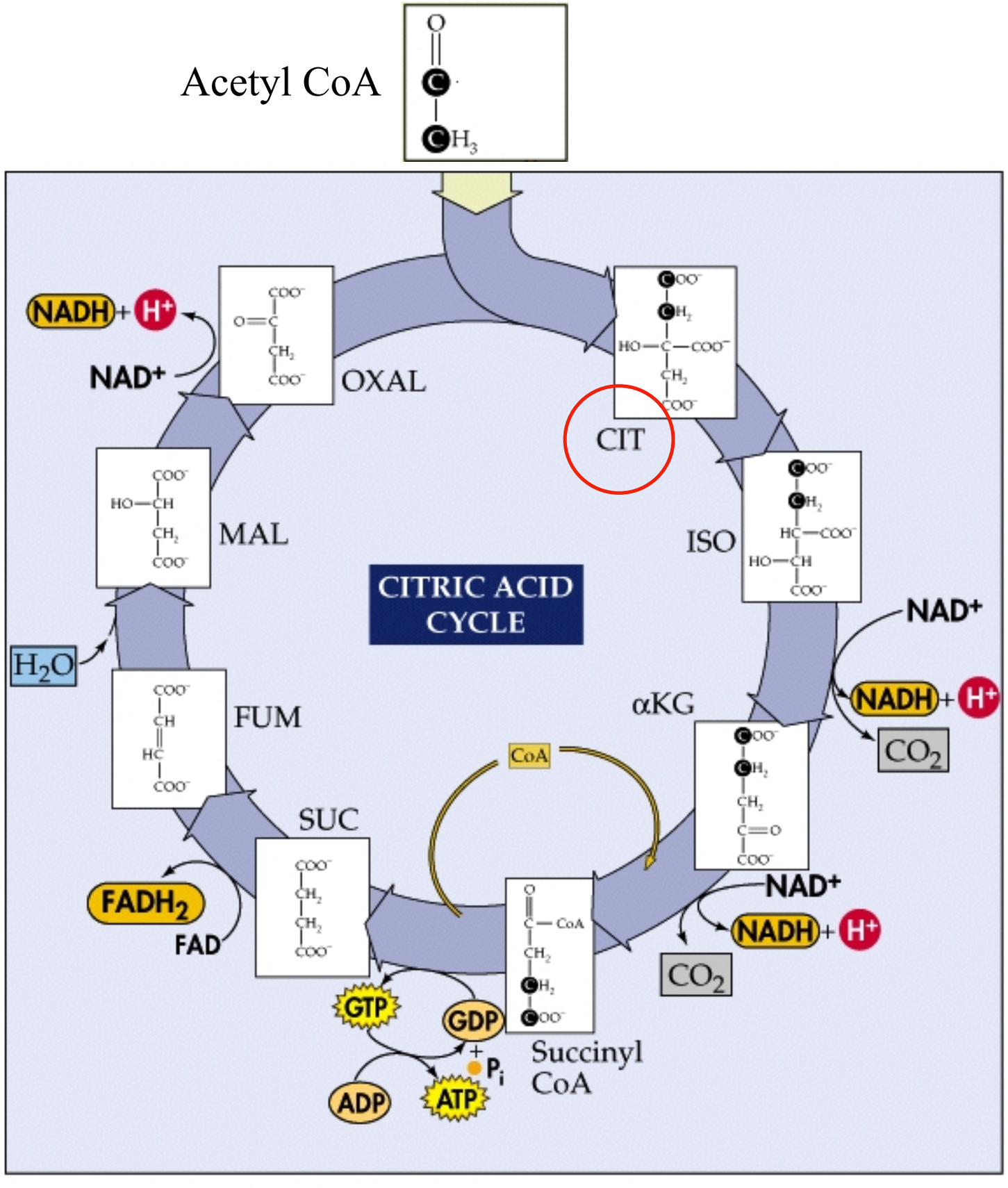
Energy Yield
2 x

Acetyl CoA

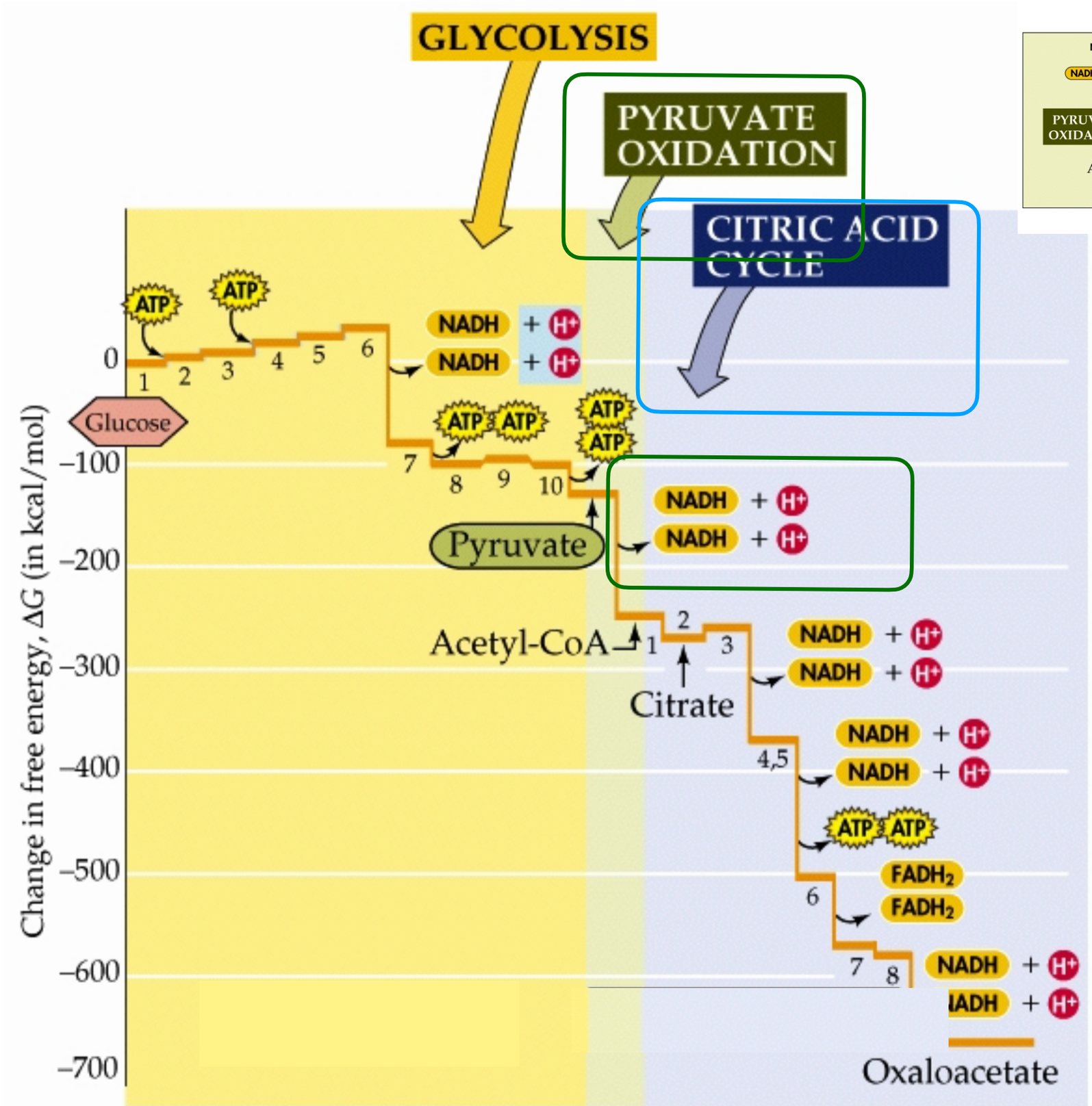


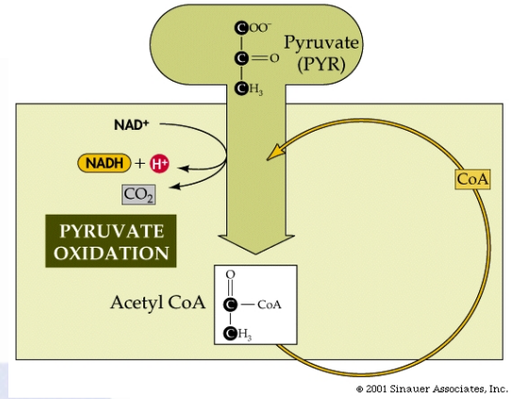
Energy Yield
2 x

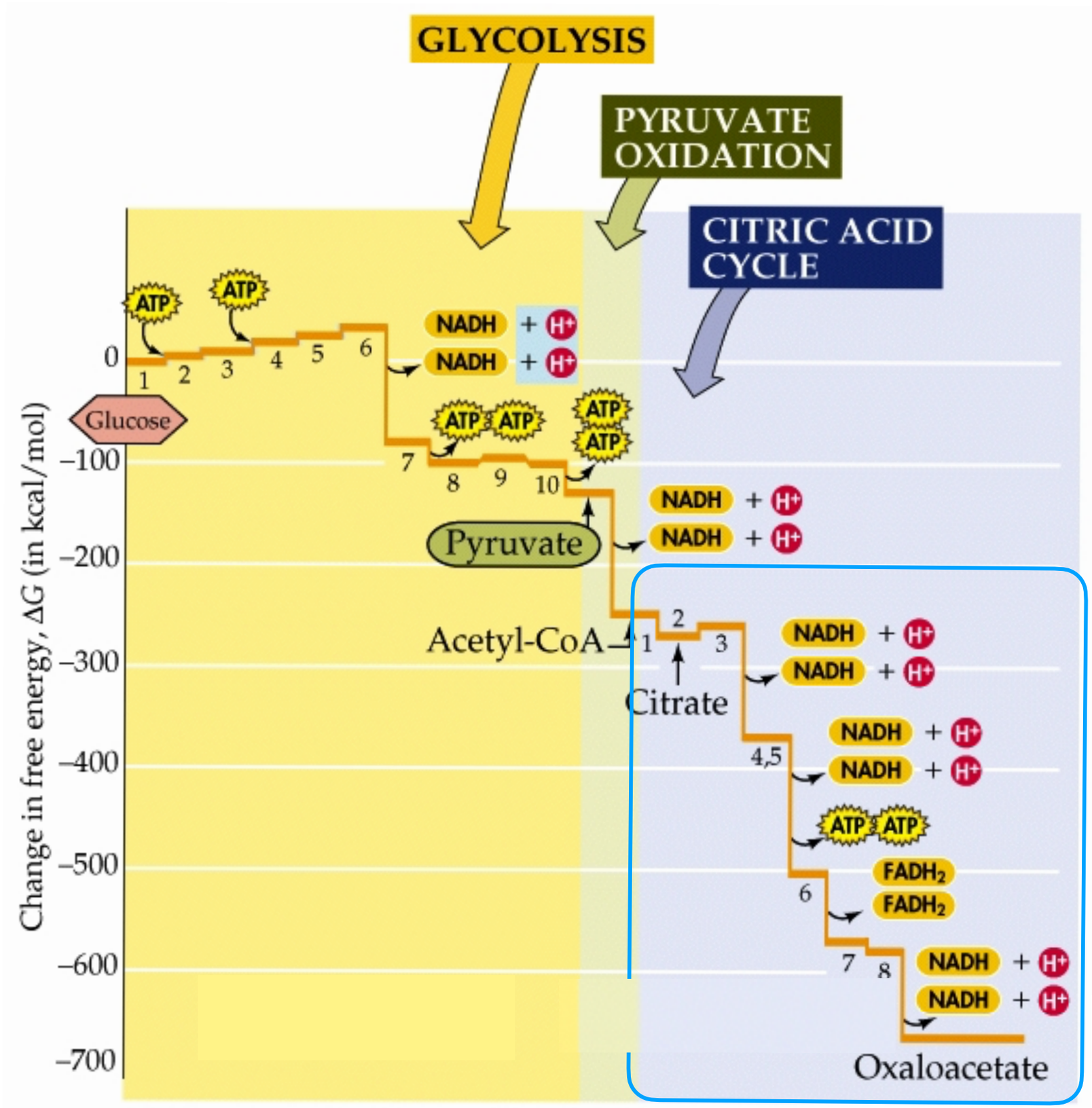
Acetyl CoA



Energy Yield
2 x


GLYCOLYSIS
PYRUVATE OXIDATION
CITRIC ACID CYCLE
Change in free energy, ΔG (in kcal/mol)
0
–100
–200
–300
–400
–500
–600
–700
Glucose
Pyruvate
Acetyl-CoA
Citrate
Oxaloacetate
ATP
NADH + H+
FADH2
1
2
3
4
5
6
7
8
9
10
4,5


Pyruvate (PYR)
NAD+
NADH + H+
CO2
PYRUVATE OXIDATION
CoA
Acetyl CoA
© 2001 Sinauer Associates, Inc.


GLYCOLYSIS
PYRUVATE OXIDATION
CITRIC ACID CYCLE
Change in free energy, ΔG (in kcal/mol)
0
–100
–200
–300
–400
–500
–600
–700
Glucose
Pyruvate
Acetyl-CoA
Citrate
Oxaloacetate
ATP
NADH + H+
FADH2
1
2
3
4
5
6
7
8
9
10
4,5

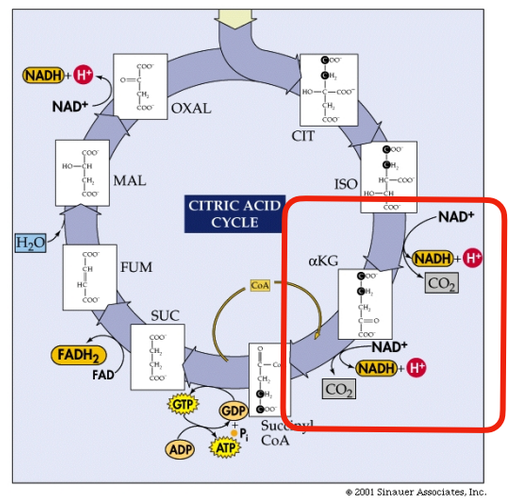
$NADH + H^+ + 1/2\ O_2 \text{----->}\ NAD^+ + H_2O$

The $\Delta G^{o\prime}$ of this oxidation reaction is **-52.4 kcal/mol**.
(For comparisons sake, remember that the $\Delta G^{o\prime}$ of the ATP to ADP reaction is **~7.3 kcal/mol**)

Think of **NADH + H^+**, therefore, as a pre-packaged form of available "potential" energy source, that can eventually be turned into ATP (approximately 3 ATP's)

$C_6H_{12}O_6 + 6\ O_2$ ---> $6\ CO_2$ + 6 H_2O + energy (heat and light)

Total Net yield = 4 ATP, 2 $FADH_2$ and 10 NADH + H^+



$$\mathbf{NADH + H^+ + 1/2\ O_2 ----> \ NAD^+ + \ H_2O}$$

The $\Delta G^{o\prime}$ of this oxidation reaction is **-52.4 kcal/mol**.
(For comparisons sake, remember that the $\Delta G^{o\prime}$ of the ATP to ADP reaction is **~7.3 kcal/mol**)

Think of **NADH + H⁺**, therefore, as a pre-packaged form of available "potential" energy source, that can eventually be turned into ATP (approximately 3 ATP's)

$$\mathbf{C_6H_{12}O_6 + 6\ O_2 \text{ ---> } 6\ CO_2 + \boxed{6\ H_2O} + \text{energy (heat and light)}}$$

Total Net yield = 4 ATP, 2 $FADH_2$ and 10 NADH + H^+

$$\mathbf{NADH + H^+ + 1/2\ O_2 ----> \ NAD^+ + \ H_2O}$$

The $\Delta G^{o\prime}$ of this oxidation reaction is **-52.4 kcal/mol**.
(For comparisons sake, remember that the $\Delta G^{o\prime}$ of the ATP to ADP reaction is **~7.3 kcal/mol**)

Think of **NADH + H^+**, therefore, as a pre-packaged form of available "potential" energy source, that can eventually be turned into ATP (approximately 3 ATP's)

$$\mathbf{C_6H_{12}O_6 + 6\ O_2 \text{ ---> } 6\ CO_2 + 6\ H_2O + \text{energy (heat and light)}}$$

Total Net yield = 4 ATP, ***2 $FADH_2$ and 10 NADH + H^+***

$$NADH + H^+ + 1/2\ O_2 \text{----->}\ NAD^+ + H_2O$$

The $\Delta G^{o\prime}$ of this oxidation reaction is **-52.4 kcal/mol**.
(For comparisons sake, remember that the $\Delta G^{o\prime}$ of the ATP to ADP reaction is **~7.3 kcal/mol**)

Think of **NADH + H^+**, therefore, as a pre-packaged form of available "potential" energy source, that can eventually be turned into ATP (approximately 3 ATP's)

$$C_6H_{12}O_6 + 6\ O_2 \text{ ---> } 6\ CO_2 + 6\ H_2O + \text{energy (heat and light)}$$

Total Net yield = 4 ATP, 2 $FADH_2$ and 10 NADH + H^+

$NADH + H^+ + 1/2\ O_2 \text{----}> NAD^+ + H_2O$

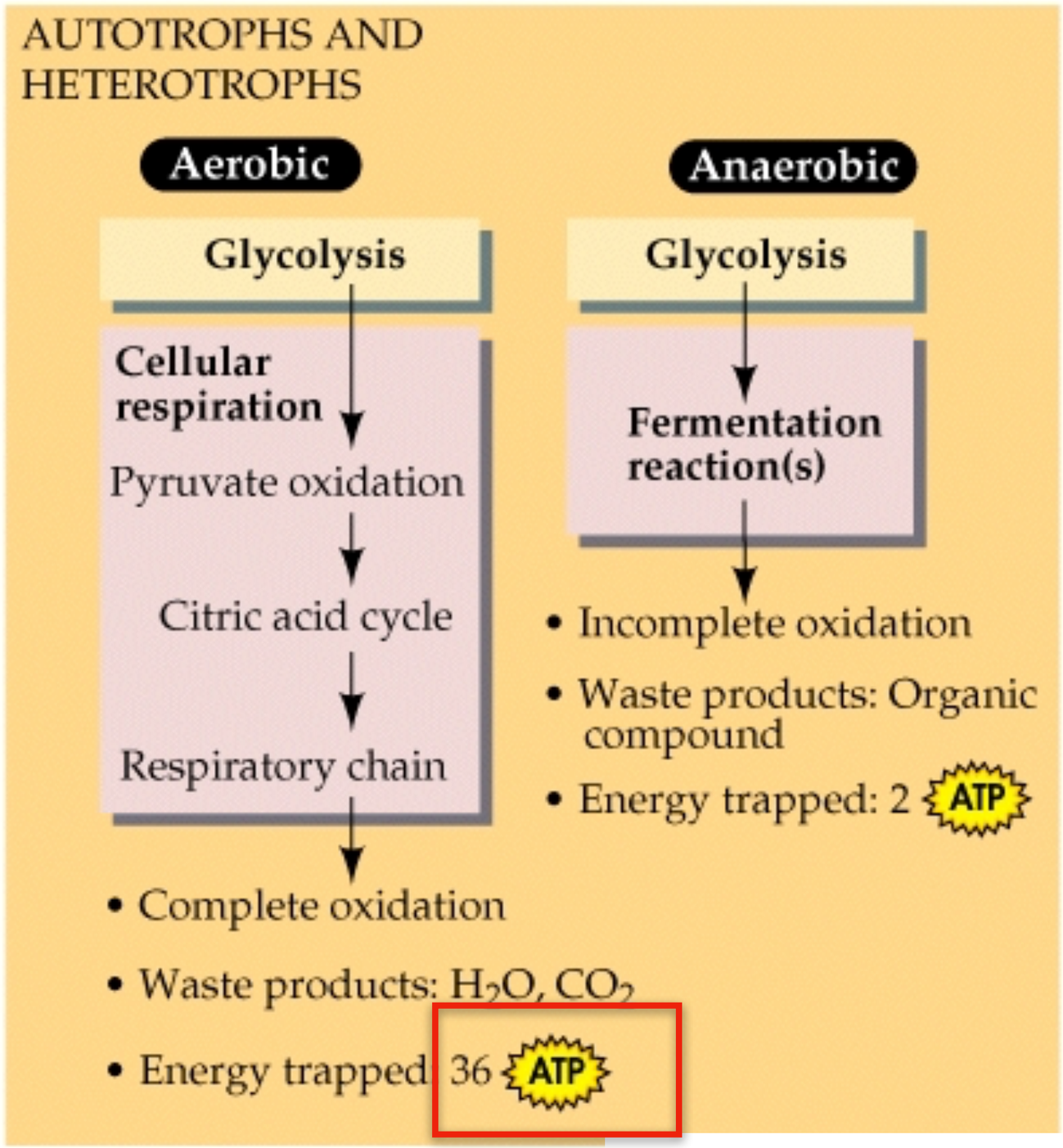
The $\Delta G^{o\prime}$ of this oxidation reaction is **-52.4 kcal/mol**.
(For comparisons sake, remember that the $\Delta G^{o\prime}$ of the ATP to ADP reaction is **~7.3 kcal/mol**)

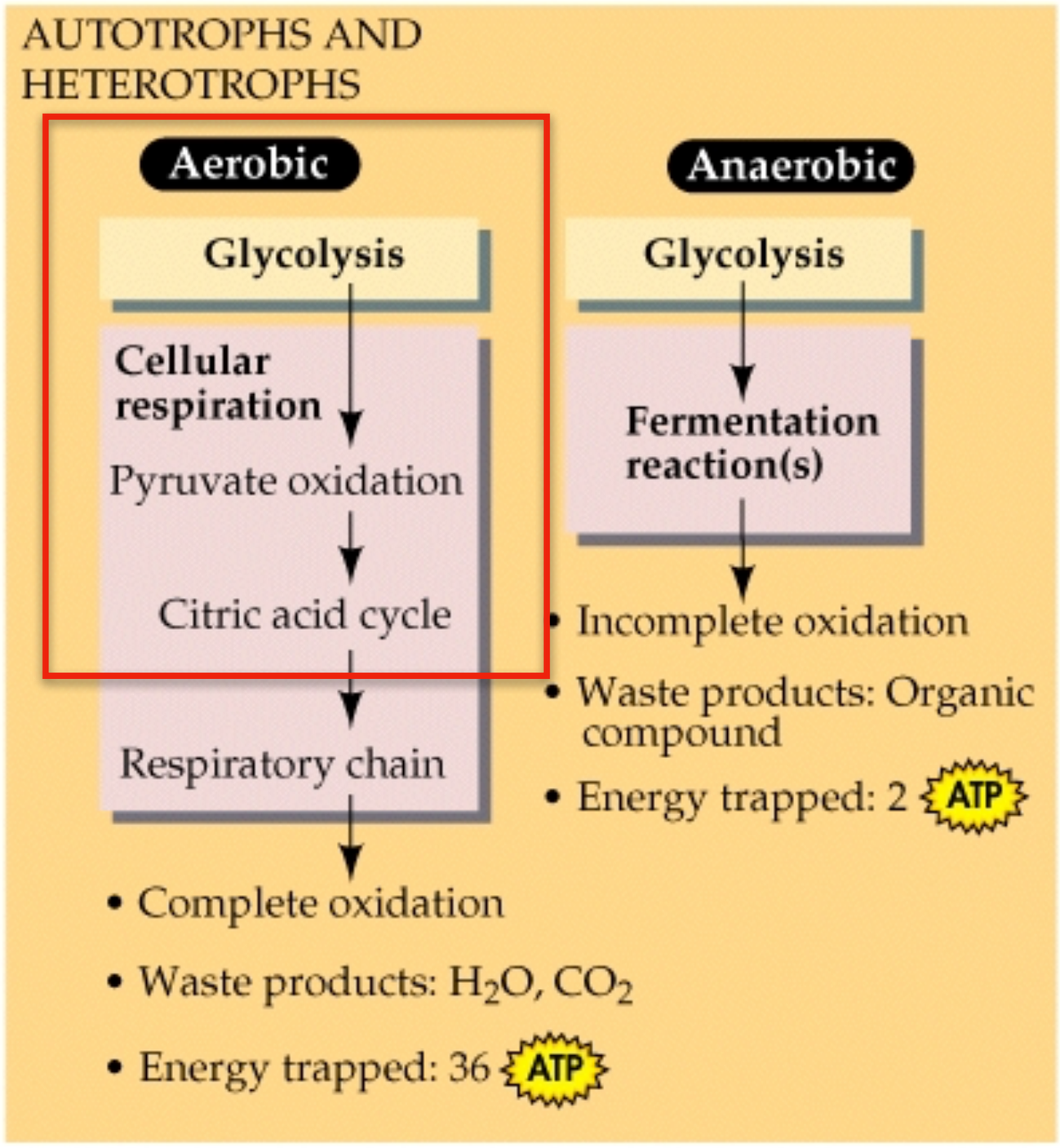
Think of **NADH + H^+**, therefore, as a pre-packaged form of available "potential" energy source, that can eventually be turned into ATP (approximately 3 ATP's)

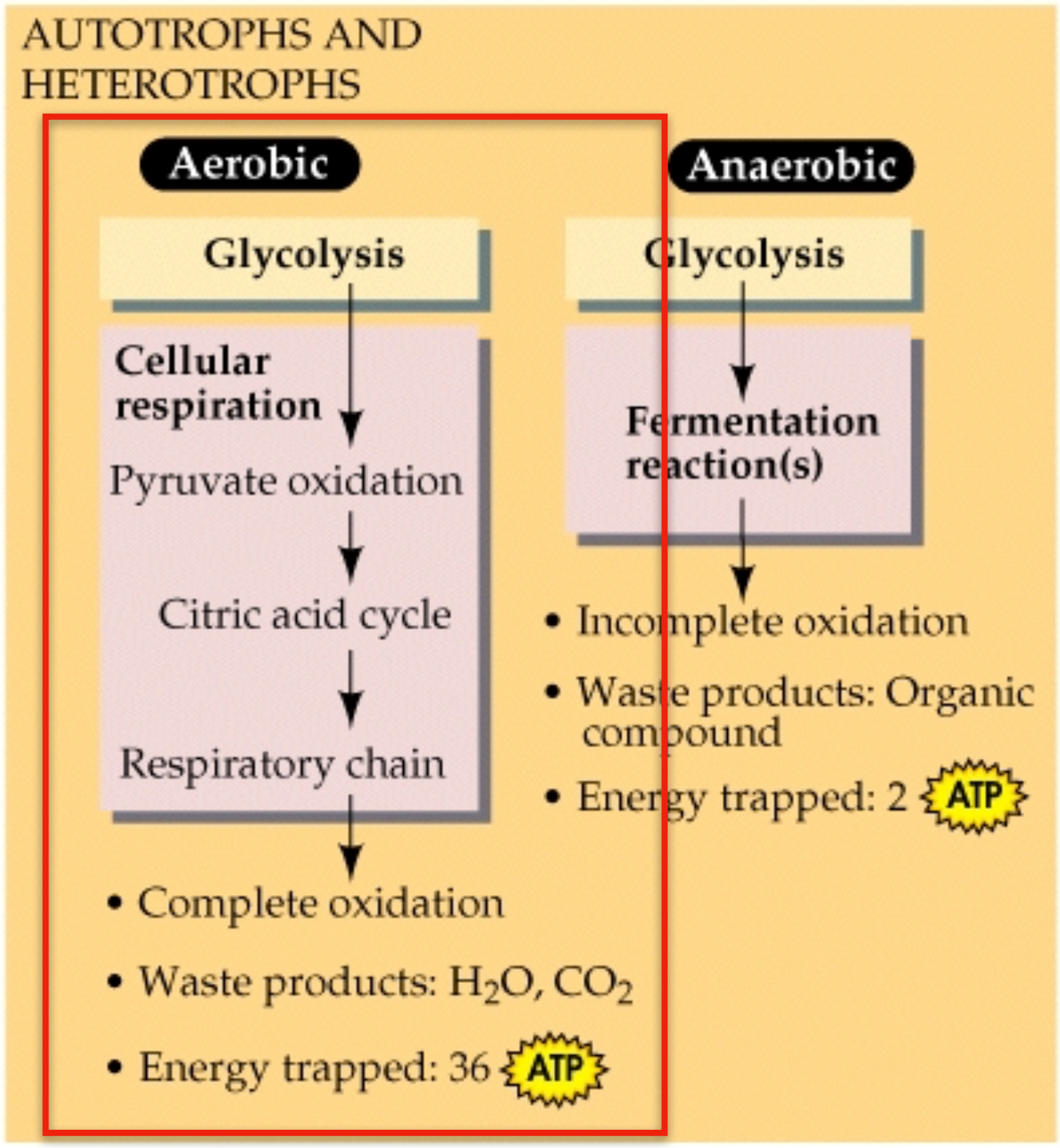
$C_6H_{12}O_6 + 6\ O_2$ ---> $6\ CO_2 + 6\ H_2O$ + energy (heat and light)

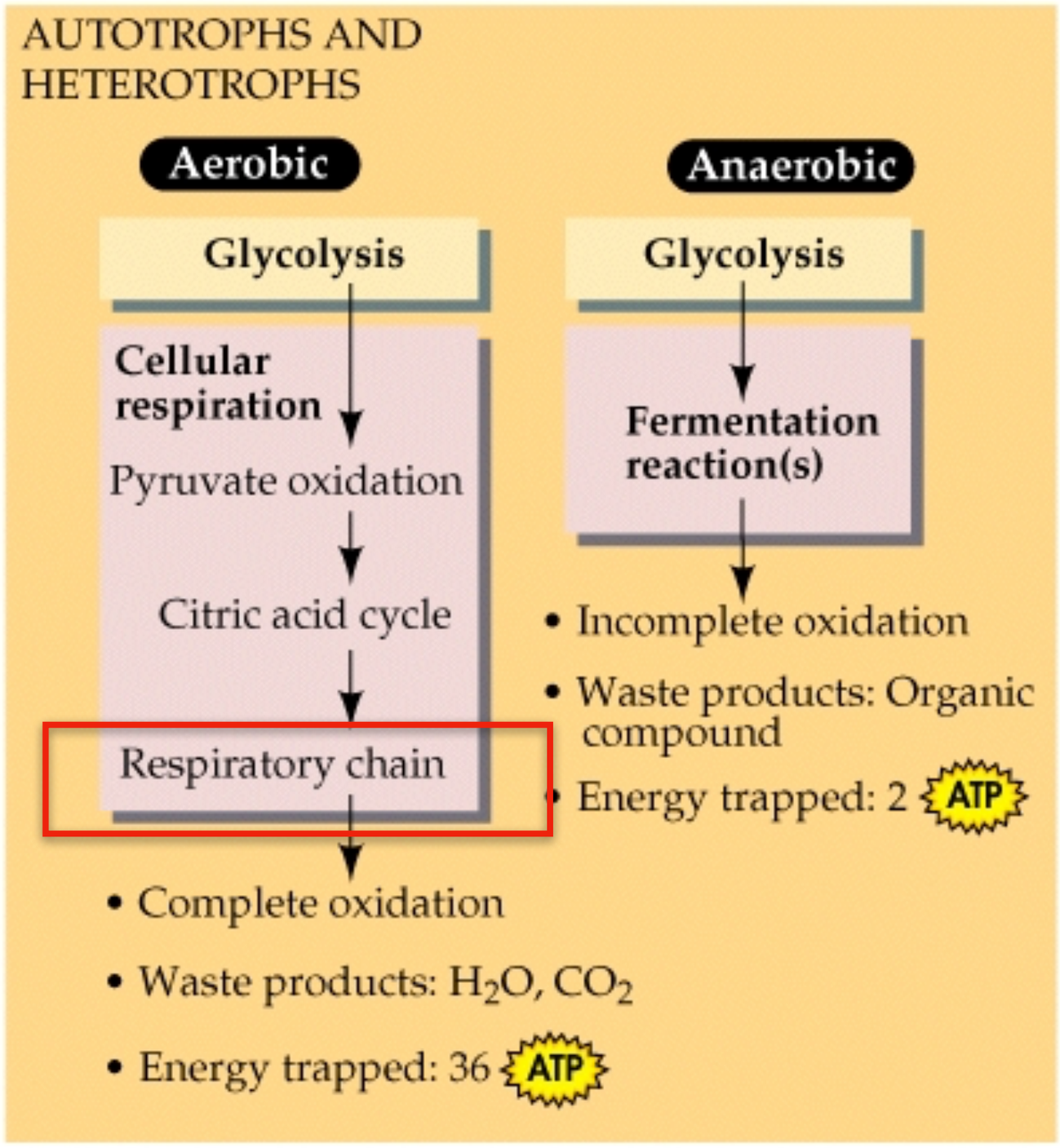
Total Net yield = 4 ATP, 2 $FADH_2$ and 10 NADH + H^+

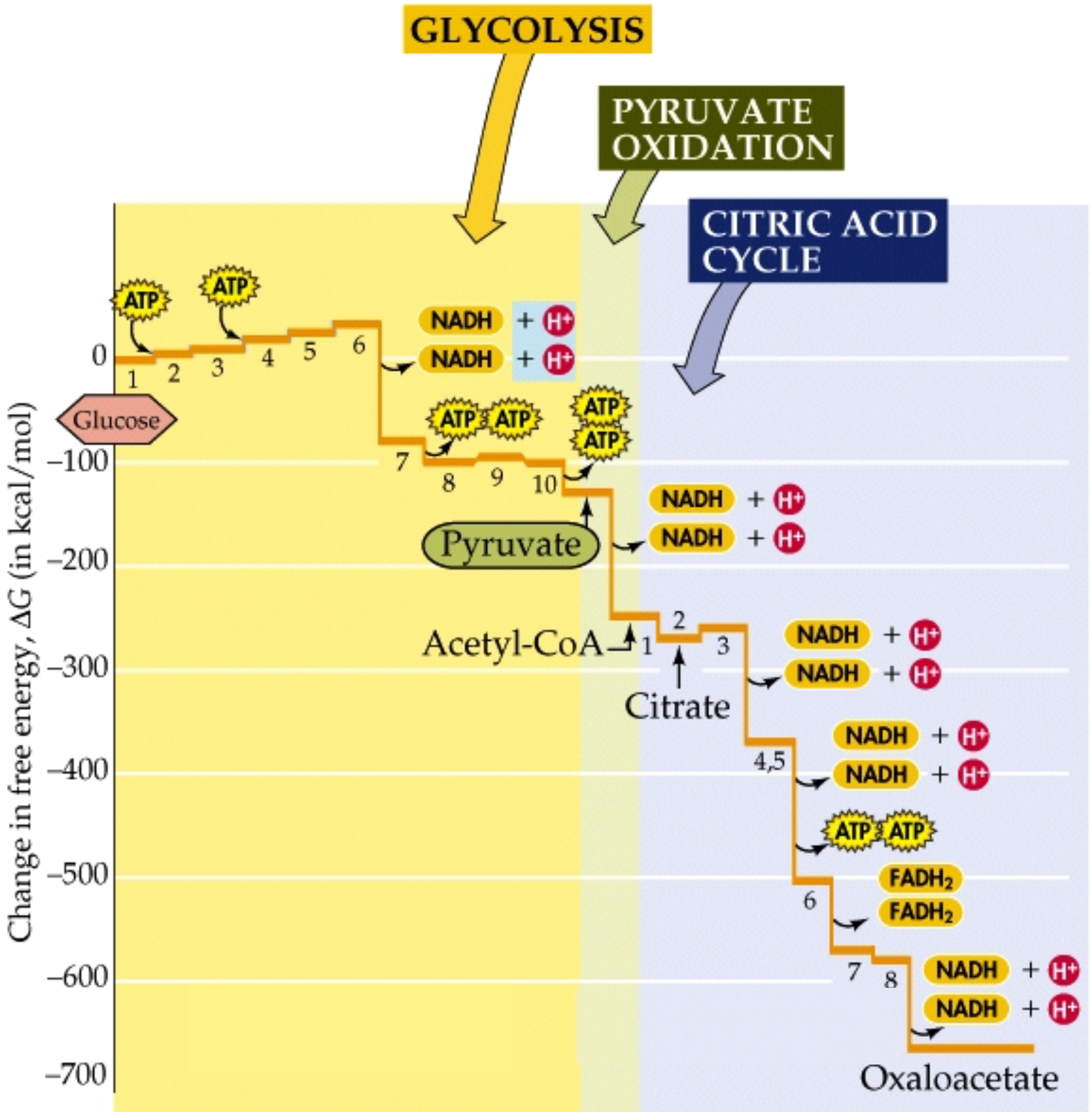
4 2 x 2 and 10 x 3 = 38 ATP

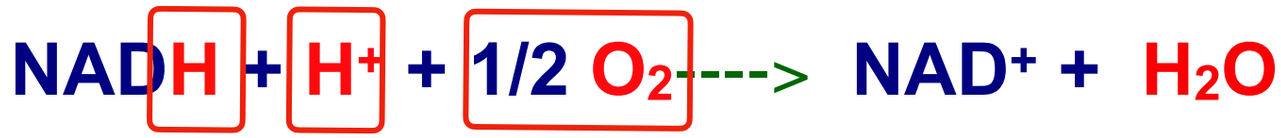

AUTOTROPHS AND HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP


AUTOTROPHS AND HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP


AUTOTROPHS AND
HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP

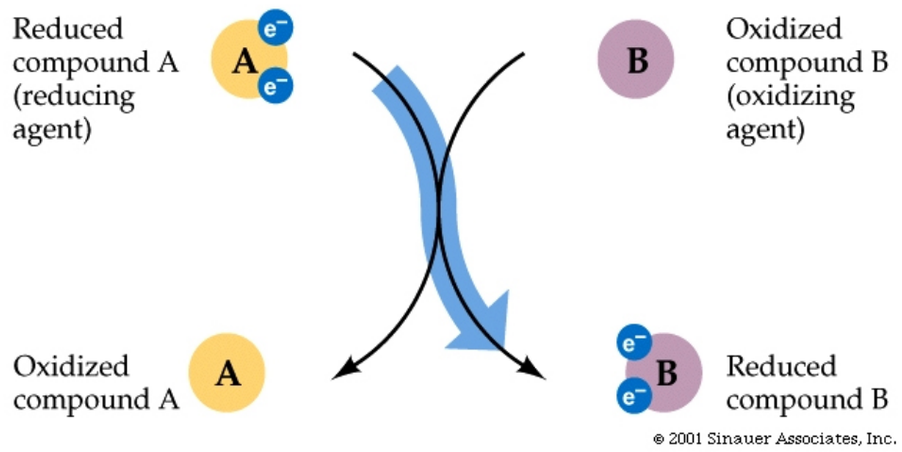

AUTOTROPHS AND HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP


GLYCOLYSIS
PYRUVATE OXIDATION
CITRIC ACID CYCLE
Change in free energy, ΔG (in kcal/mol)
0
–100
–200
–300
–400
–500
–600
–700
Glucose
Pyruvate
Acetyl-CoA
Citrate
Oxaloacetate
ATP
NADH + H+
FADH2
1
2
3
4
5
6
7
8
9
10
4,5


NADH + H+ + 1/2 O2 ---> NAD+ + H2O

$$NADH + H^+ + 1/2\ O_2 \text{----}> NAD^+ + \boxed{H_2O}$$

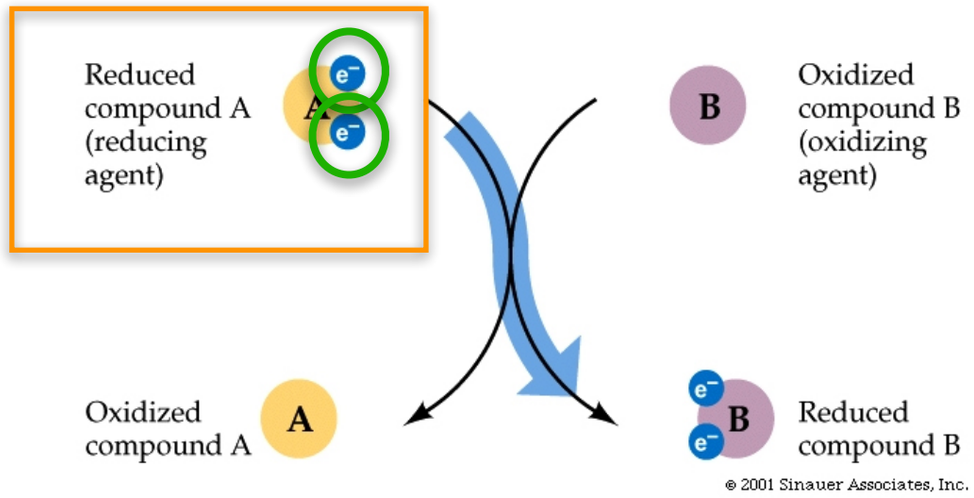
Respiratory Chain:



© 2001 Sinauer Associates, Inc.

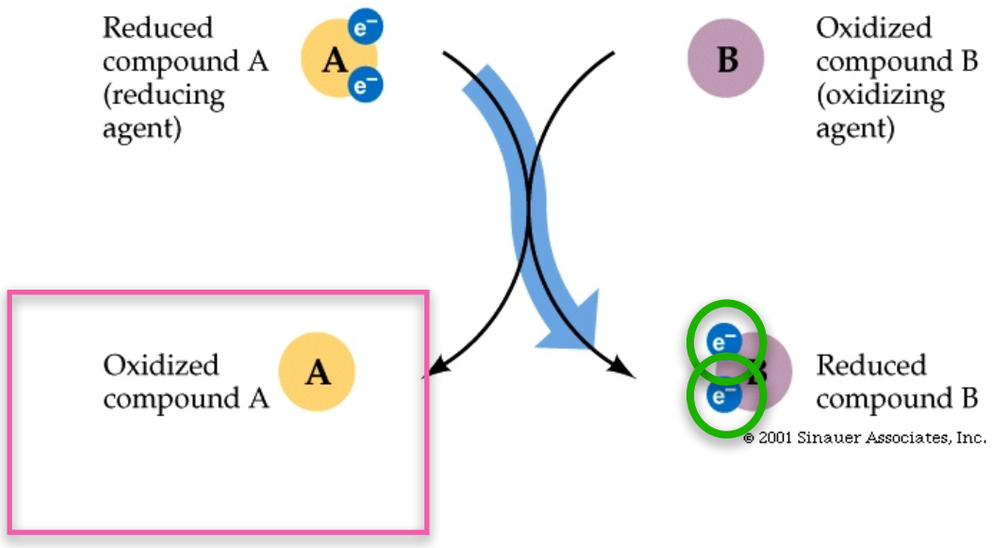
$$NADH + H^+ + 1/2\ O_2 \text{----}> NAD^+ + H_2O$$

REDOX REACTIONS



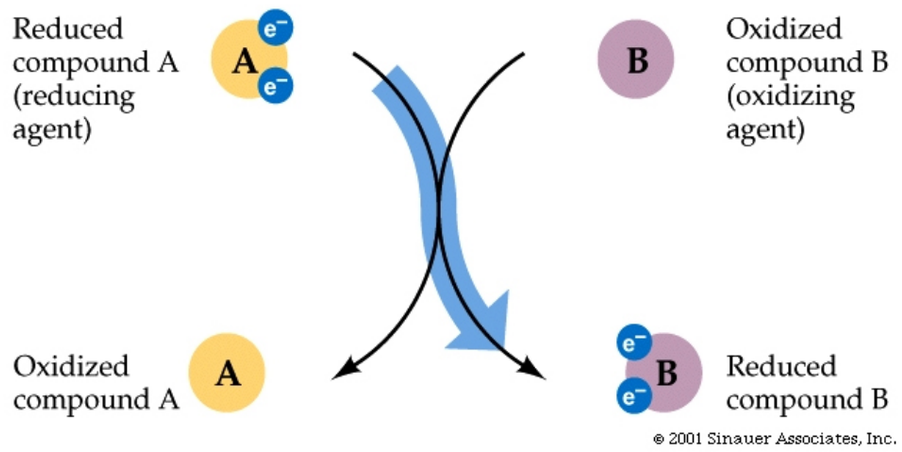
$$NADH + H^+ + 1/2\ O_2 \dashrightarrow NAD^+ + H_2O$$

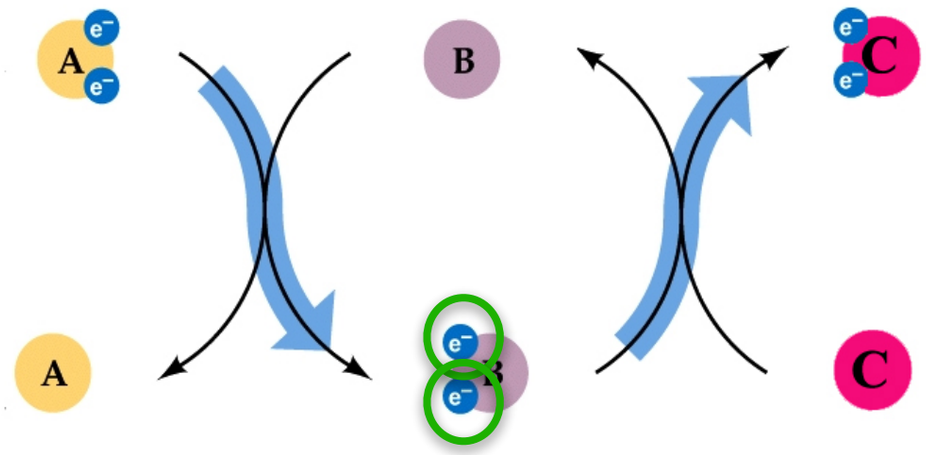
REDOX REACTIONS



$$NADH + H^+ + 1/2\ O_2 \dashrightarrow NAD^+ + H_2O$$

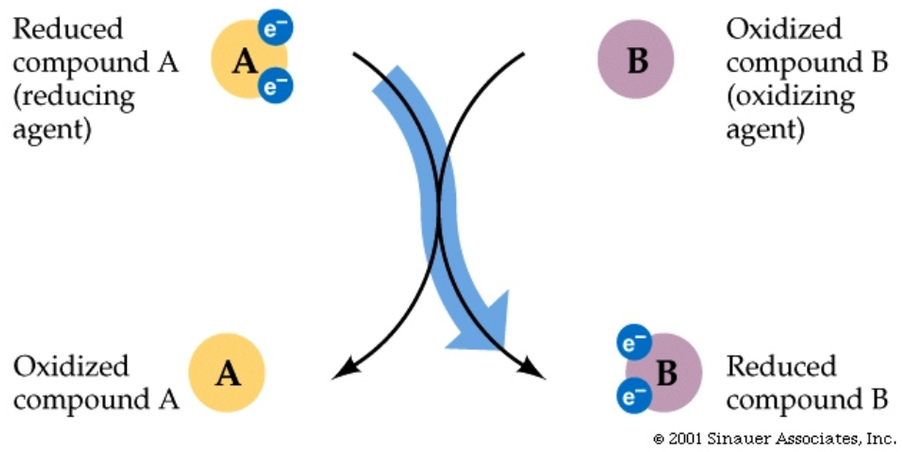
REDOX REACTIONS

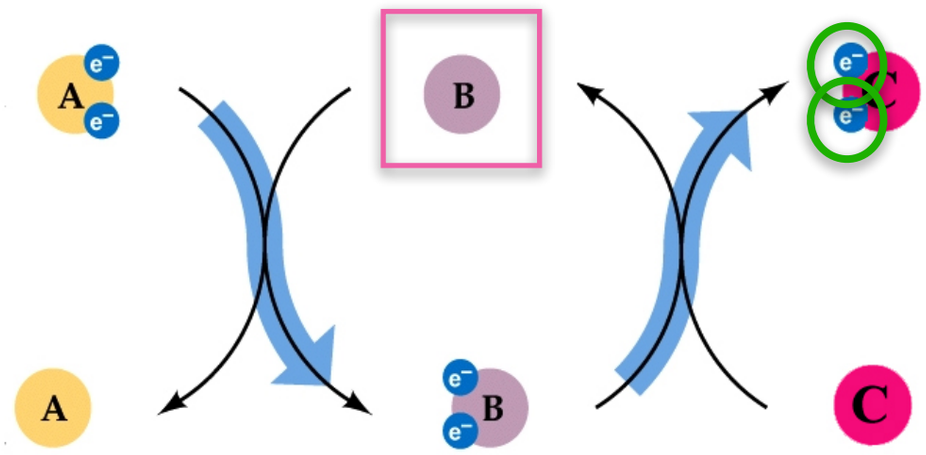




$$NADH + H^+ + 1/2\ O_2 \dashrightarrow NAD^+ + H_2O$$

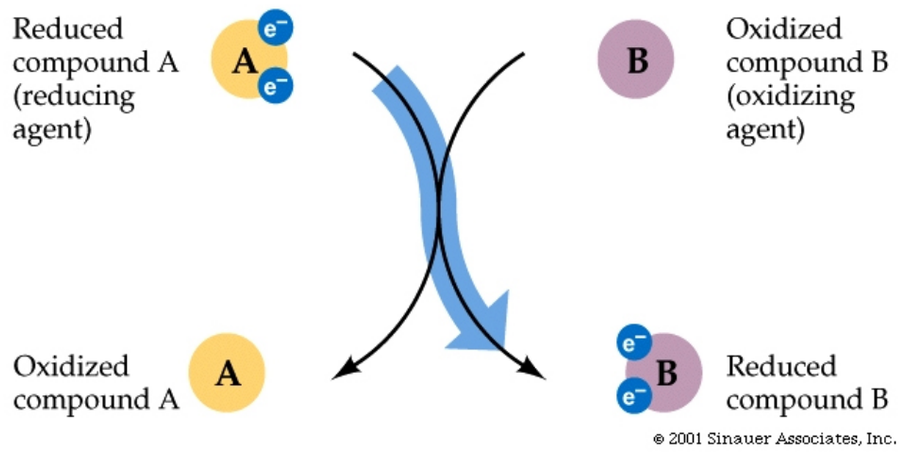
REDOX REACTIONS

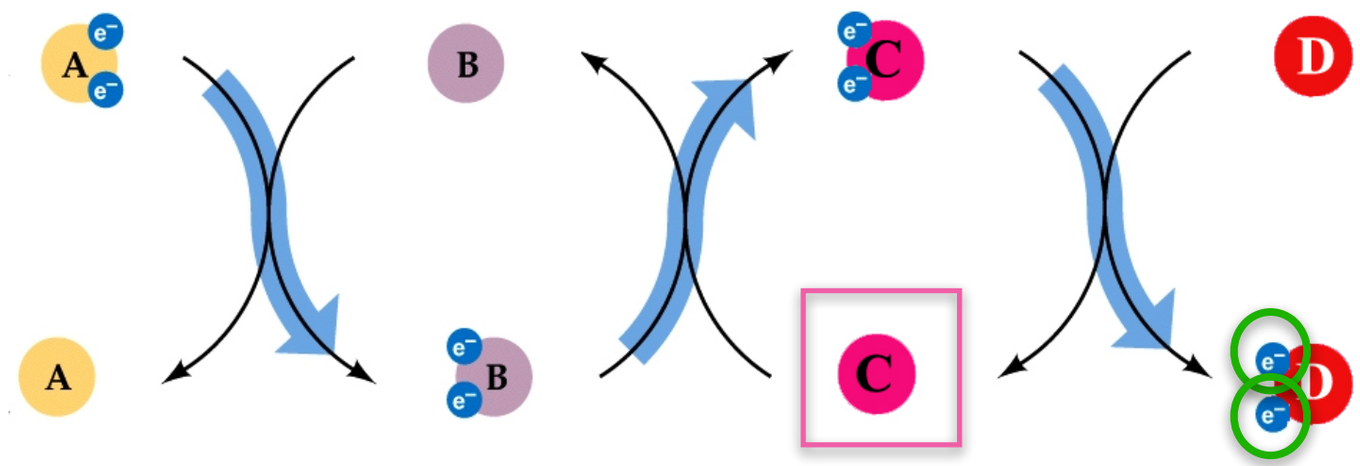




$$NADH + H^+ + 1/2\ O_2 \dashrightarrow NAD^+ + H_2O$$

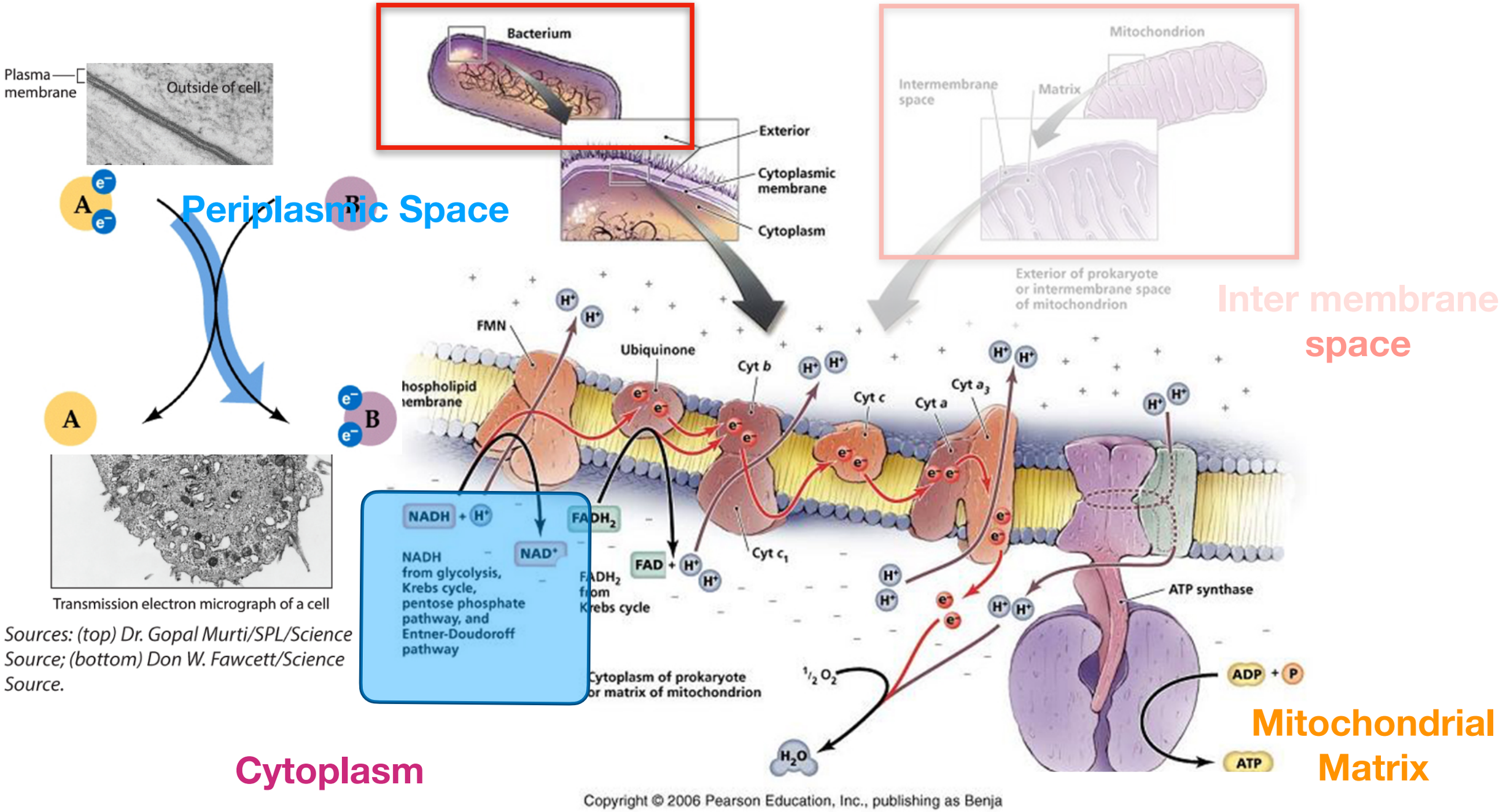
REDOX REACTIONS





$$NADH + H^+ + 1/2\ O_2 \text{----}> NAD^+ + H_2O$$

Respiratory Chain:



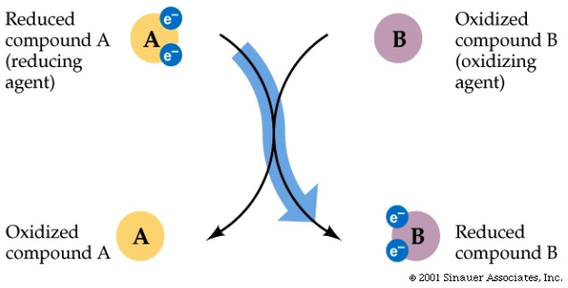
Transmission electron micrograph of a cell

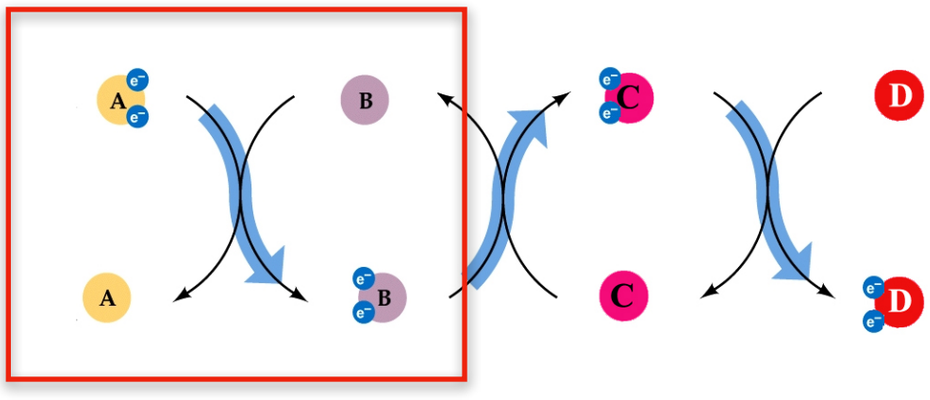
Sources: (top) Dr. Gopal Murti/SPL/Science Source; (bottom) Don W. Fawcett/Science Source.

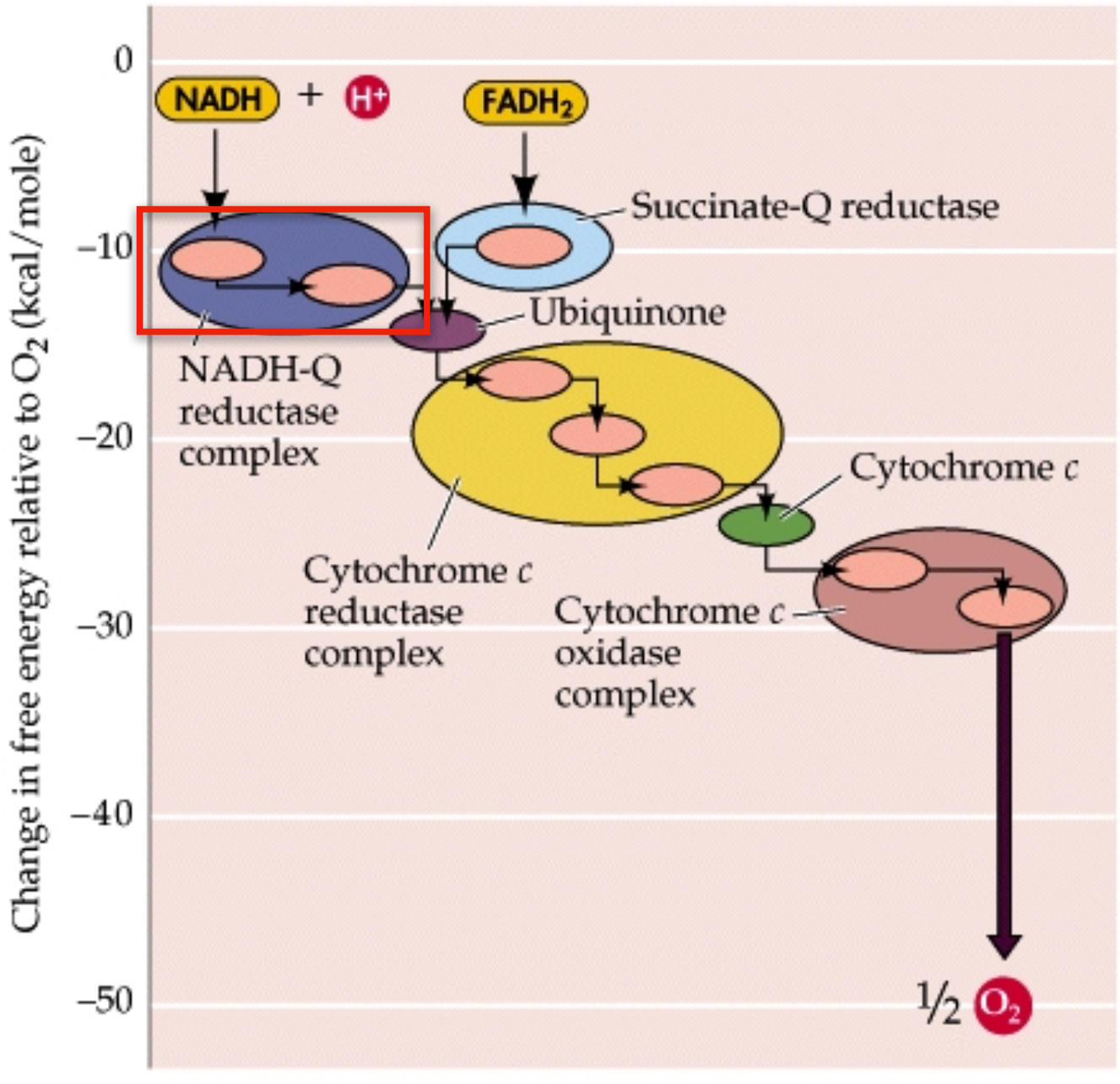
Copyright © 2006 Pearson Education, Inc., publishing as Benja

$$NADH + H^+ + 1/2\ O_2 \text{----->}\ NAD^+ + H_2O$$

Respiratory Chain:

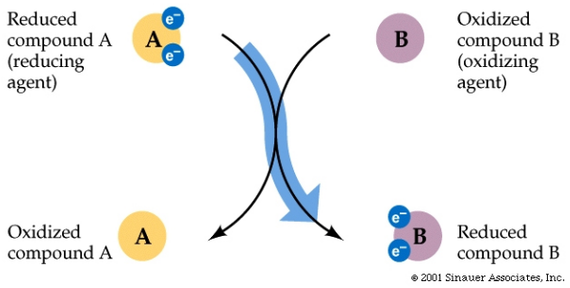


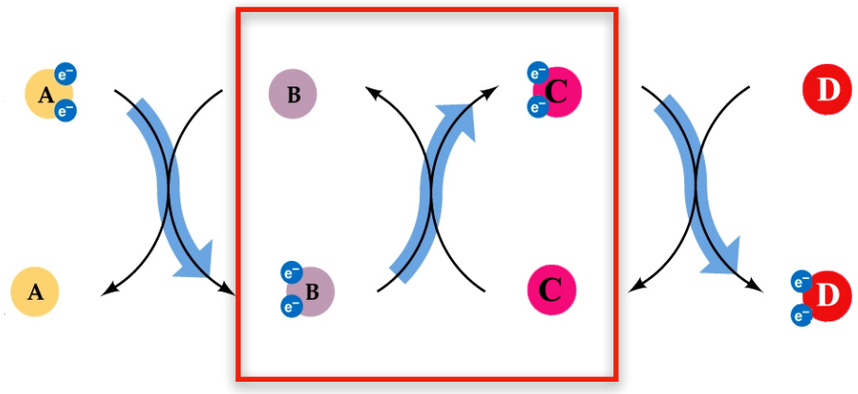


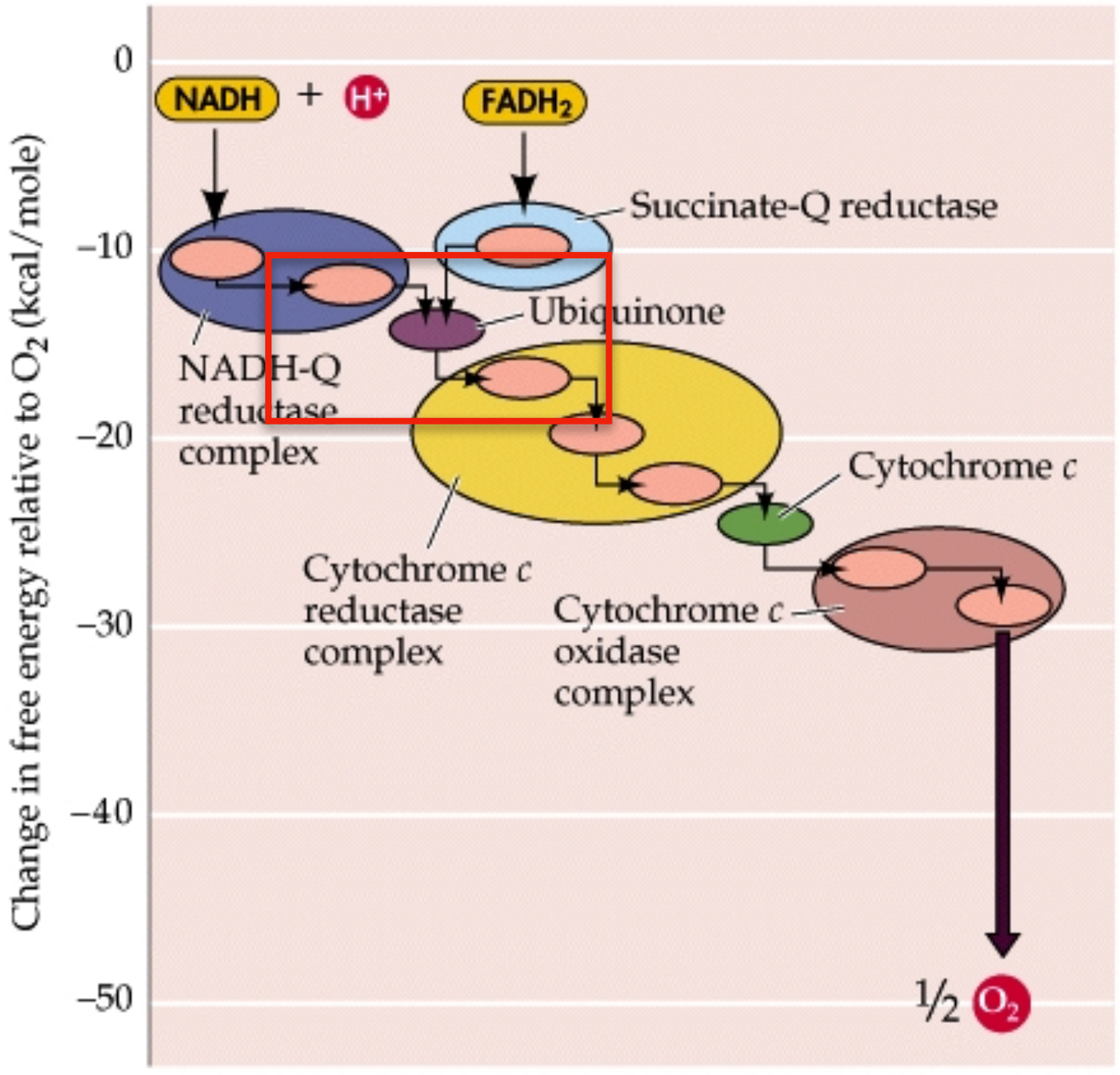


$$NADH + H^+ + 1/2\ O_2 \text{----}> NAD^+ + H_2O$$

Respiratory Chain:



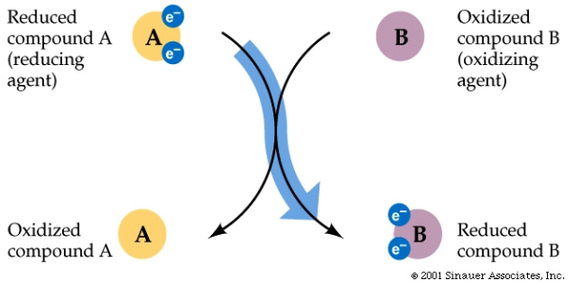


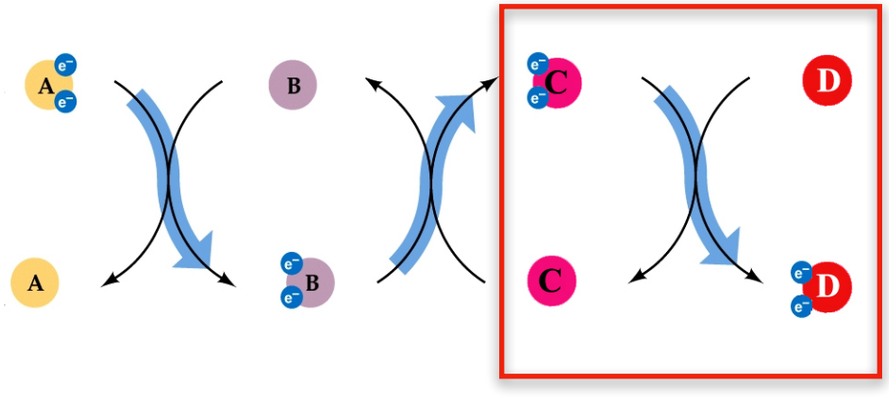


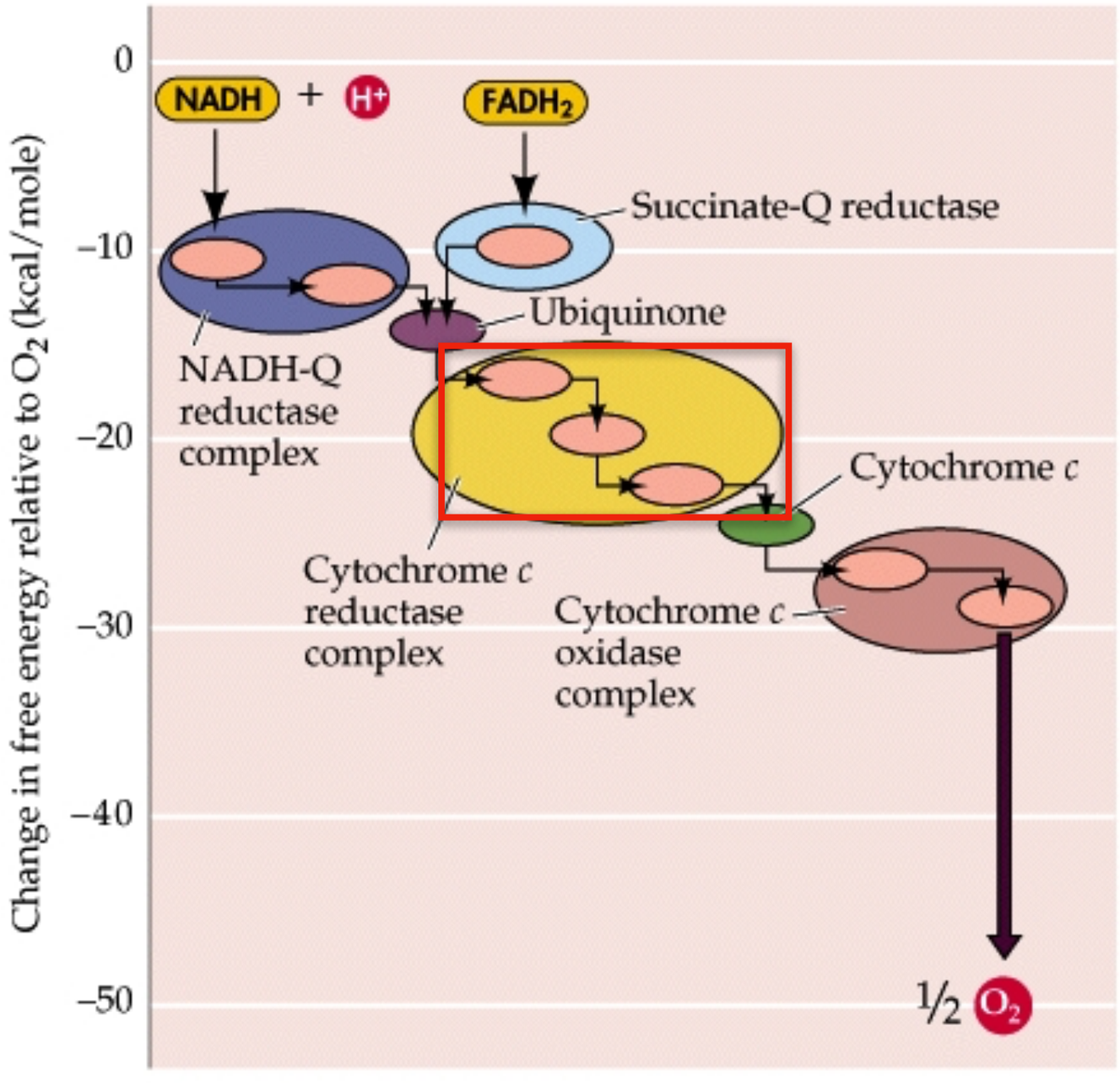
© 2001 Sinauer Associates, Inc.

$$NADH + H^+ + 1/2\ O_2 \text{----->}\ NAD^+ + H_2O$$

Respiratory Chain:

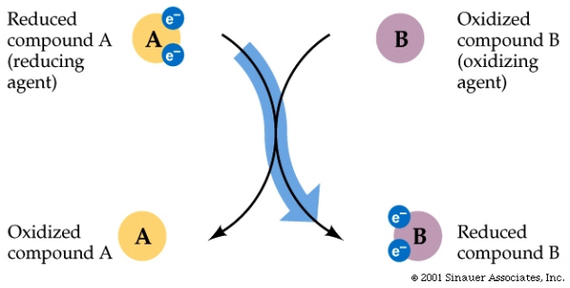


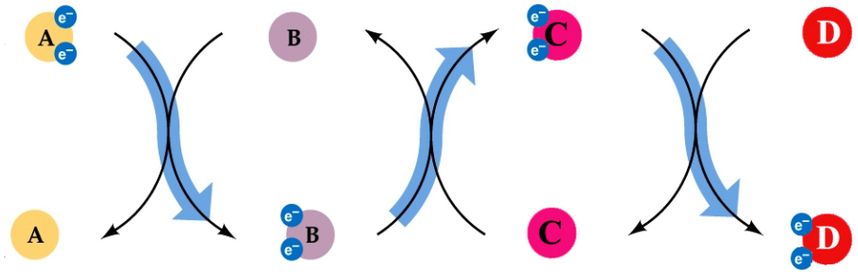


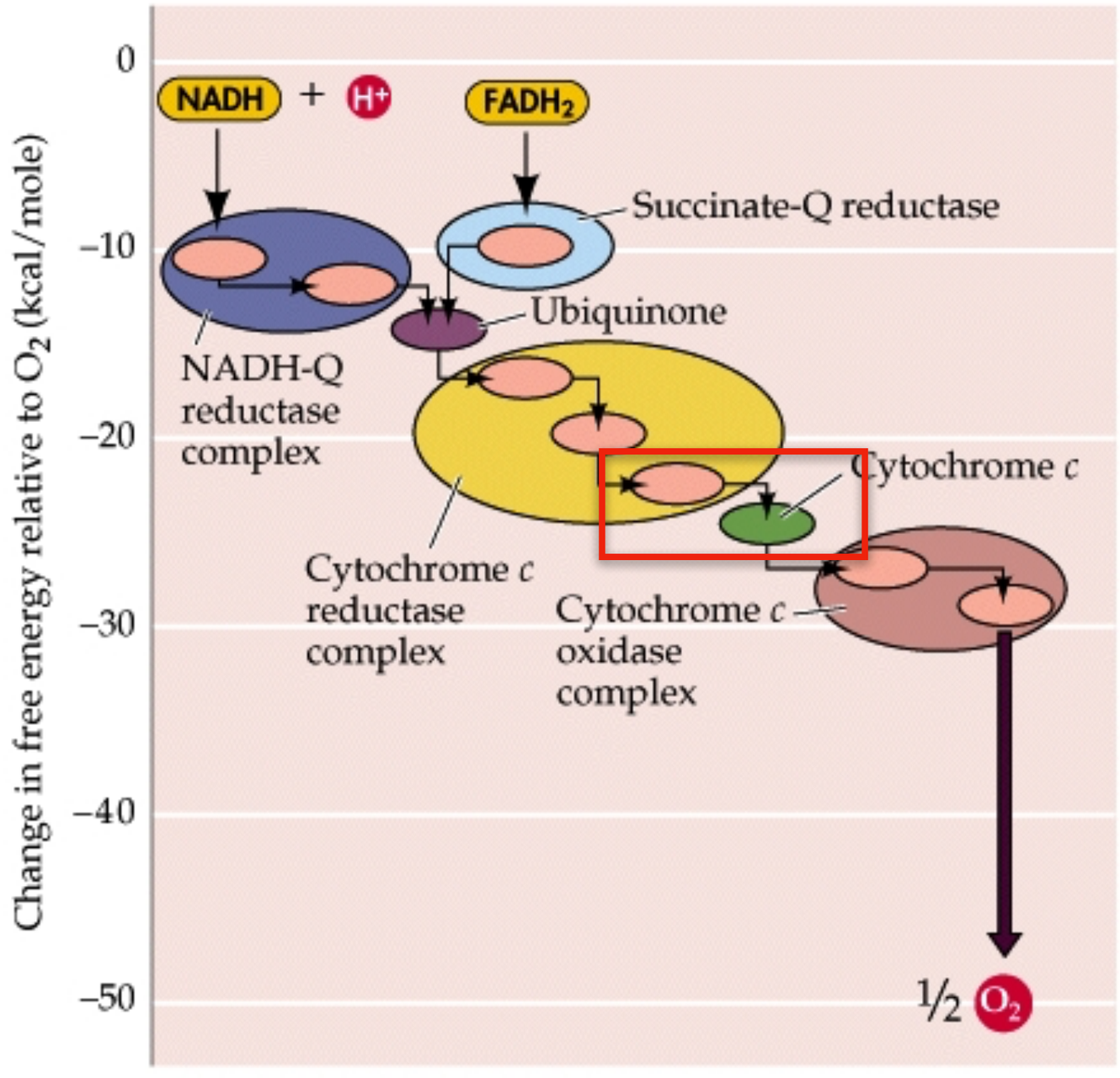


$$NADH + H^+ + 1/2\ O_2 \text{----->}\ NAD^+ + H_2O$$

Respiratory Chain:

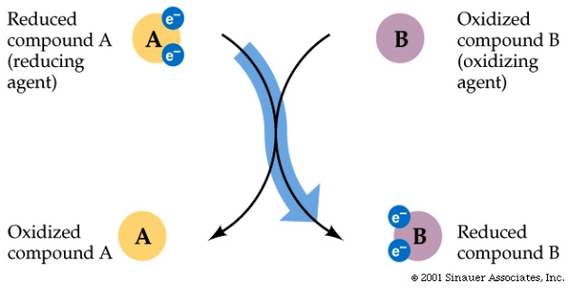


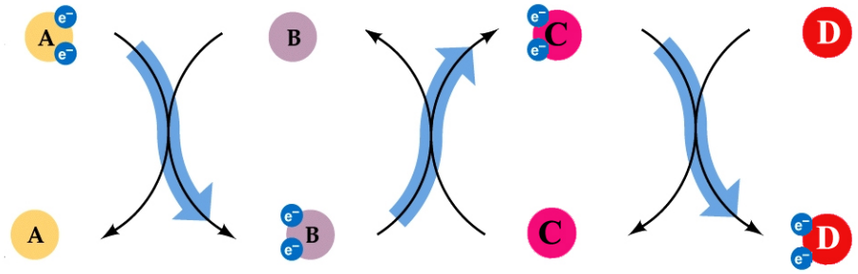


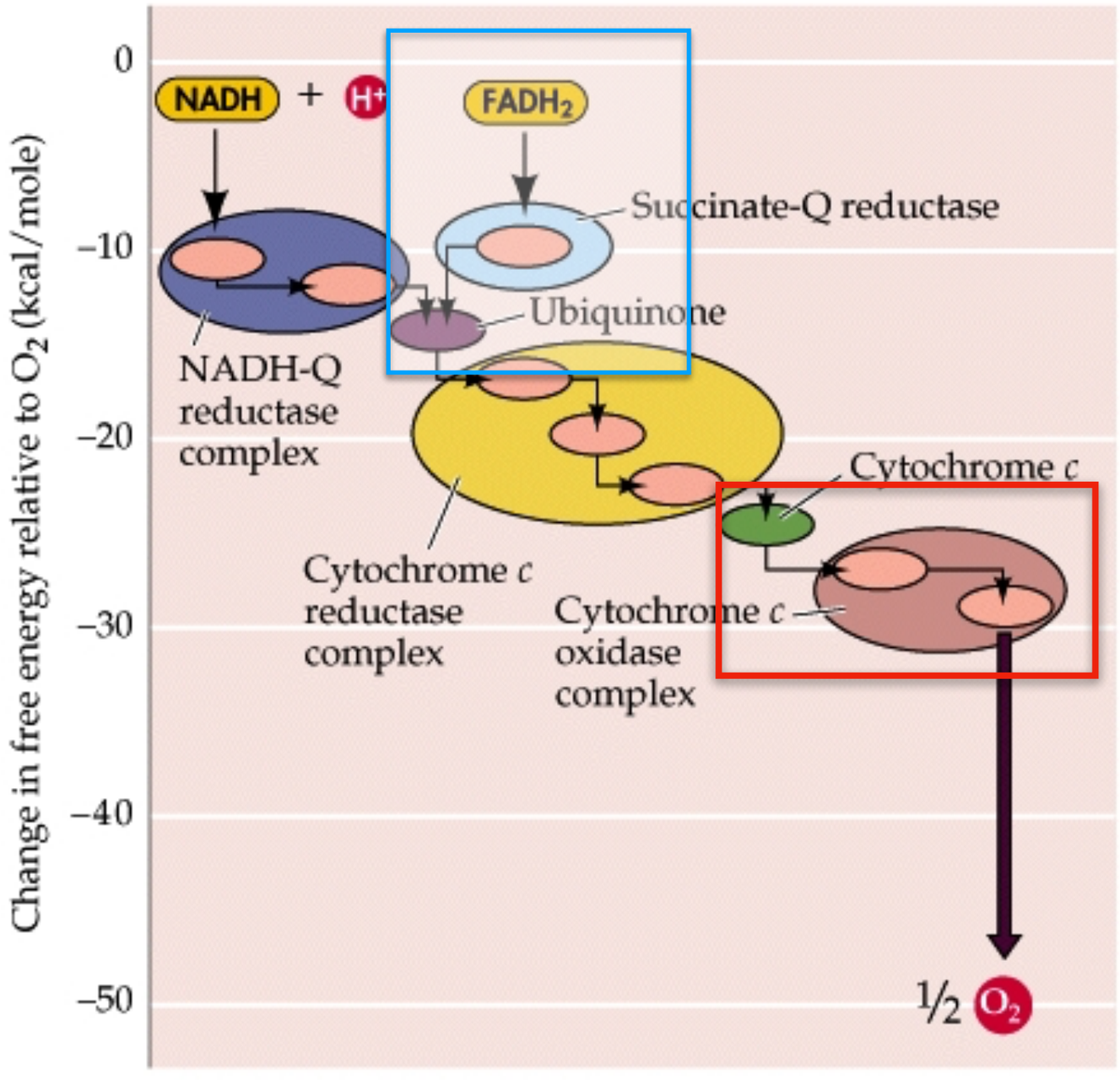


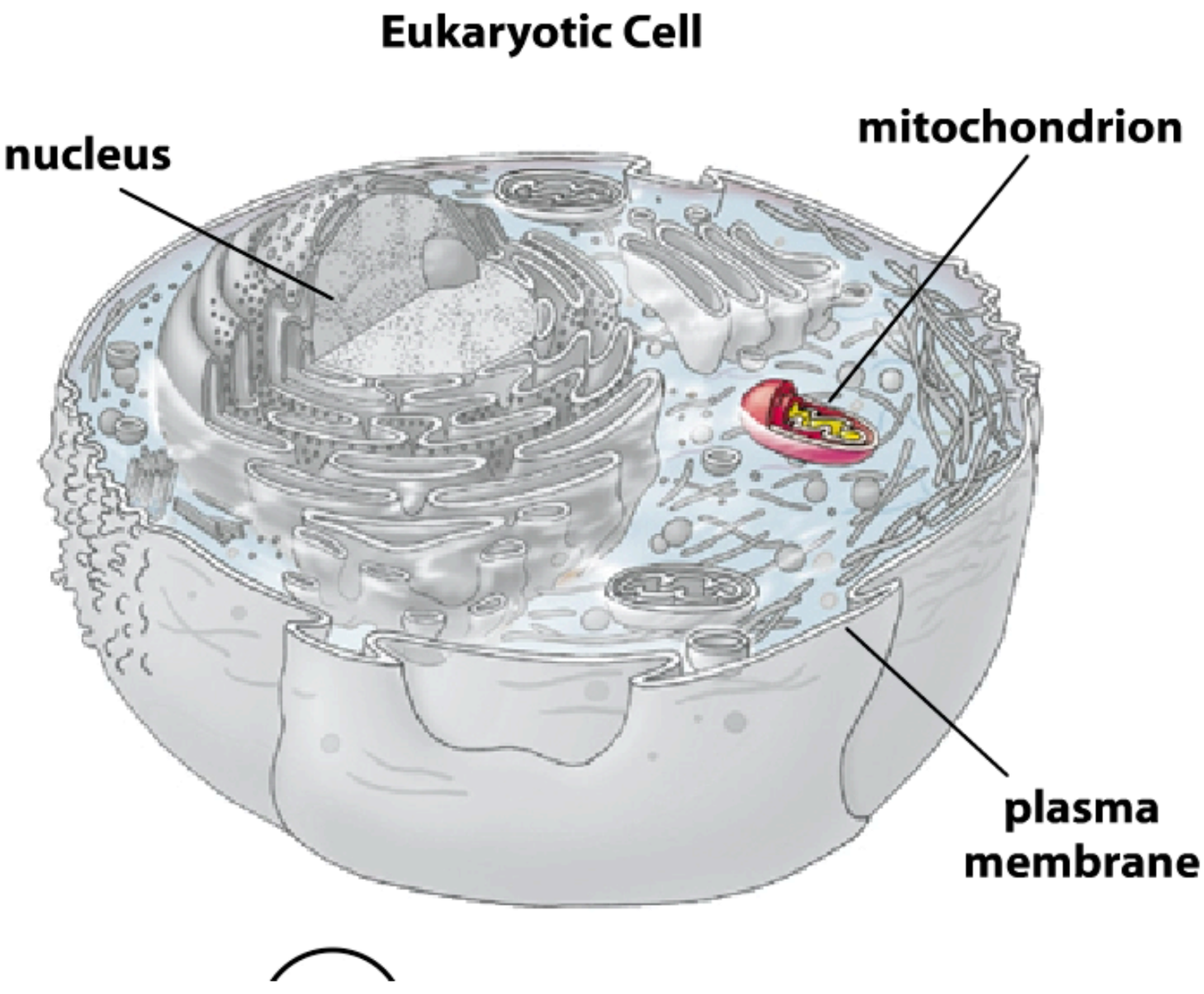
$$NADH + H^+ + 1/2\ O_2 \longrightarrow NAD^+ + H_2O$$

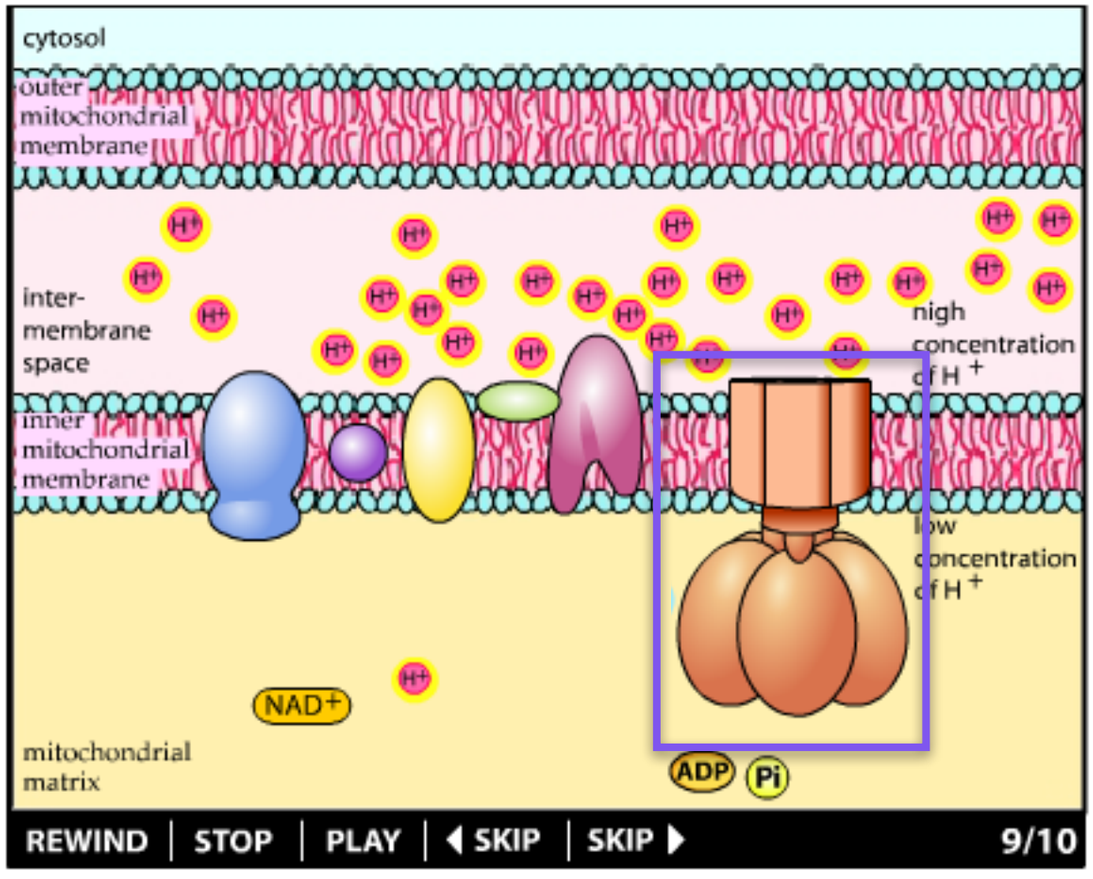
Respiratory Chain:

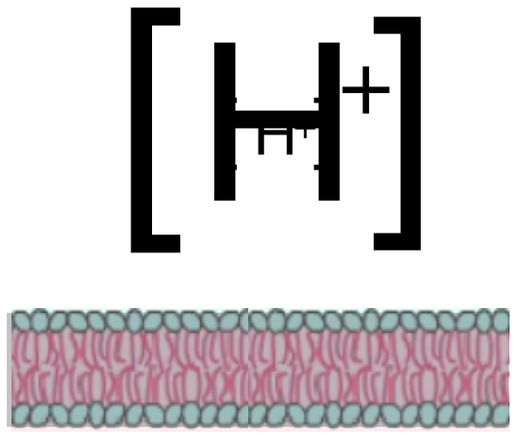







Eukaryotic Cell
nucleus
mitochondrion
plasma
membrane

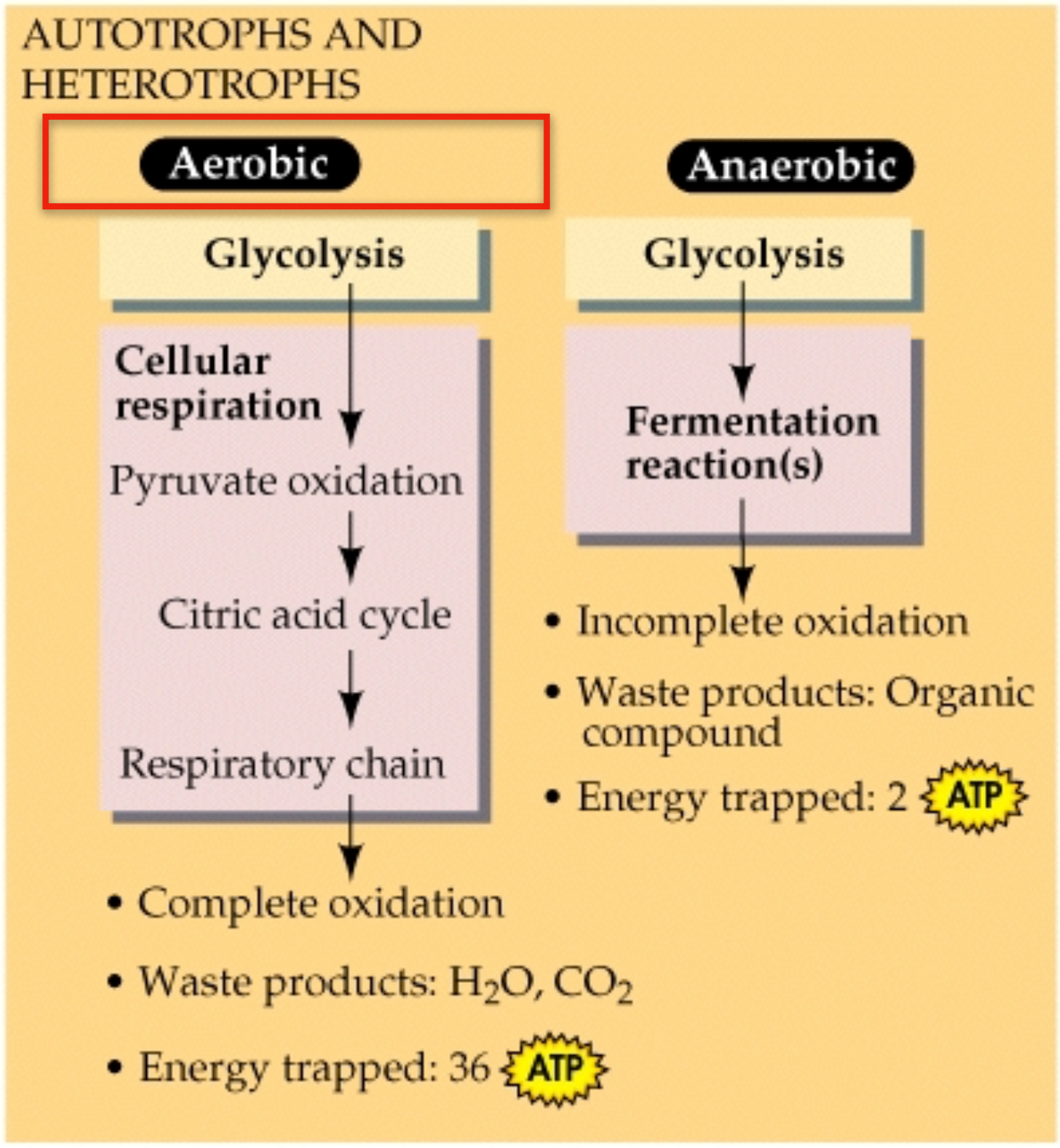


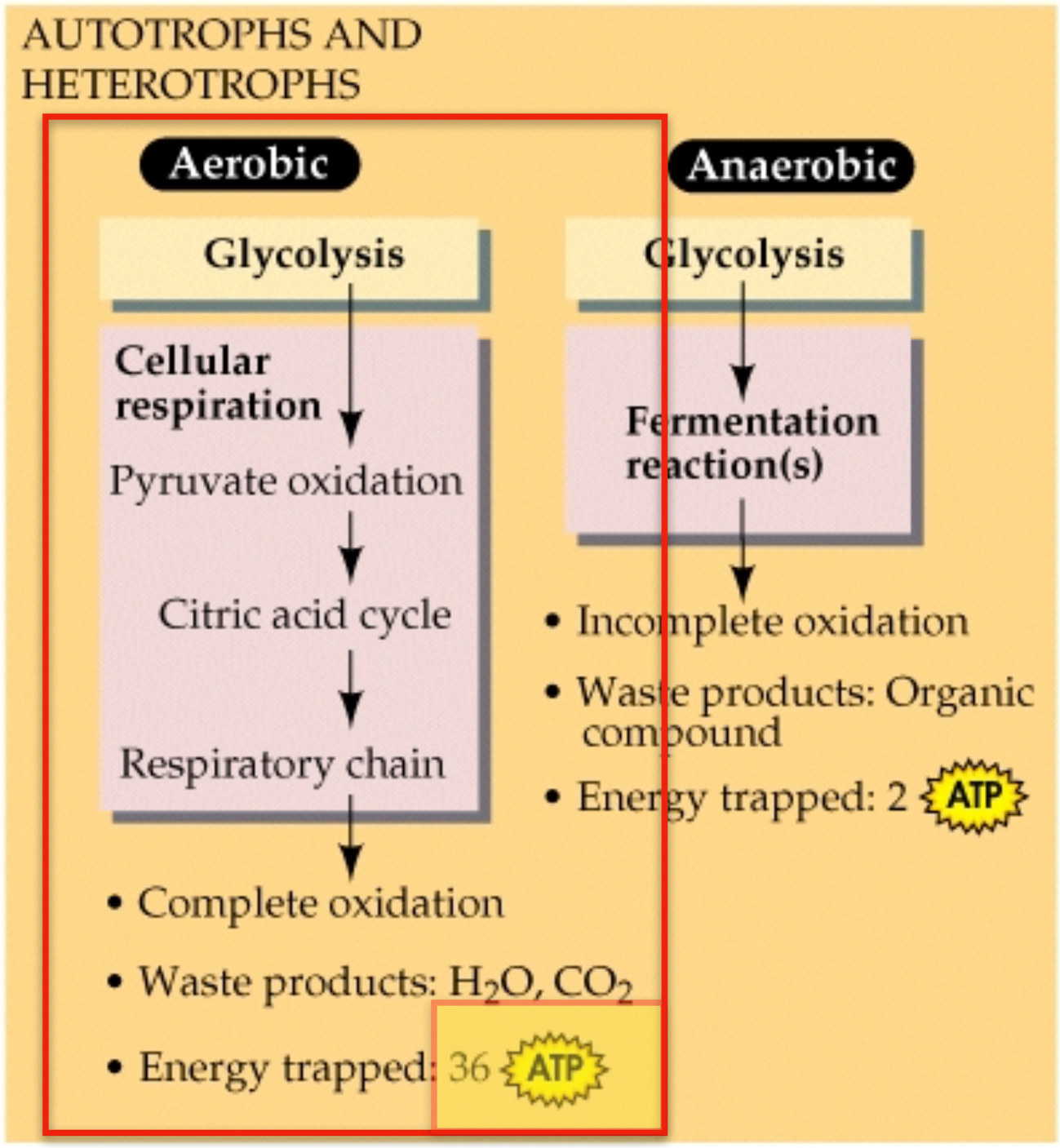


[H+]

$C_6H_{12}O_6$ + 6 O_2 ---> 6 CO_2 + 6 H_2O + energy (heat and light)

ATP


AUTOTROPHS AND HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP


AUTOTROPHS AND
HETEROTROPHS
Aerobic
Glycolysis
Cellular respiration
Pyruvate oxidation
Citric acid cycle
Respiratory chain
• Complete oxidation
• Waste products: H_2O, CO_2
• Energy trapped: 36 ATP
Anaerobic
Glycolysis
Fermentation reaction(s)
• Incomplete oxidation
• Waste products: Organic compound
• Energy trapped: 2 ATP