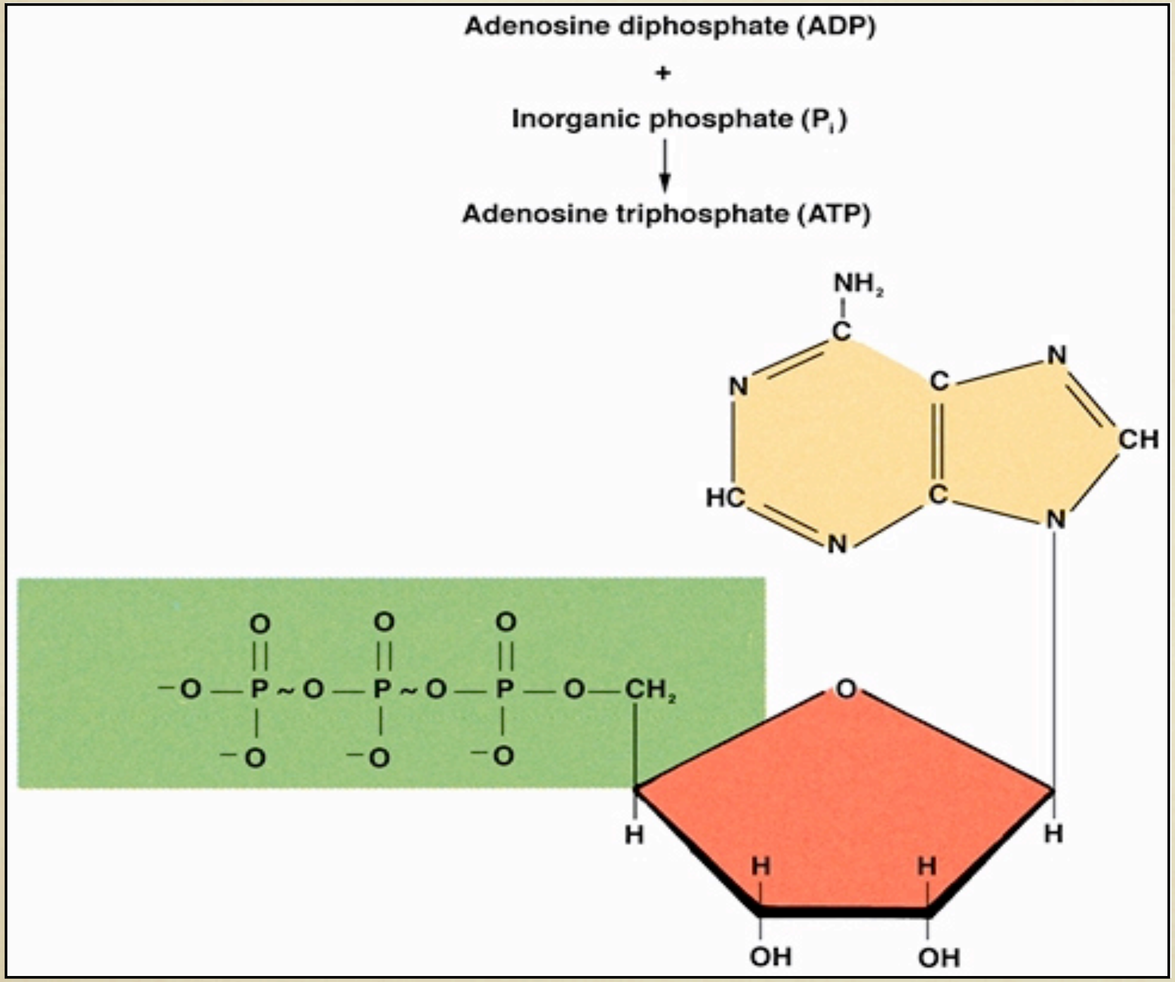
Bioenergetics: Energy for Exercise

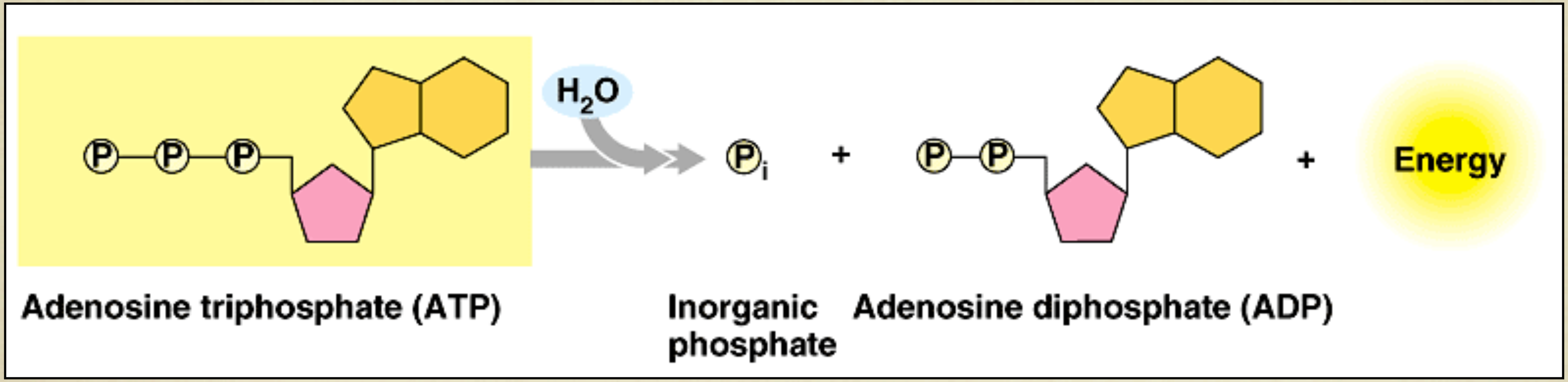
Chapter 3
pp 28-47

ATP



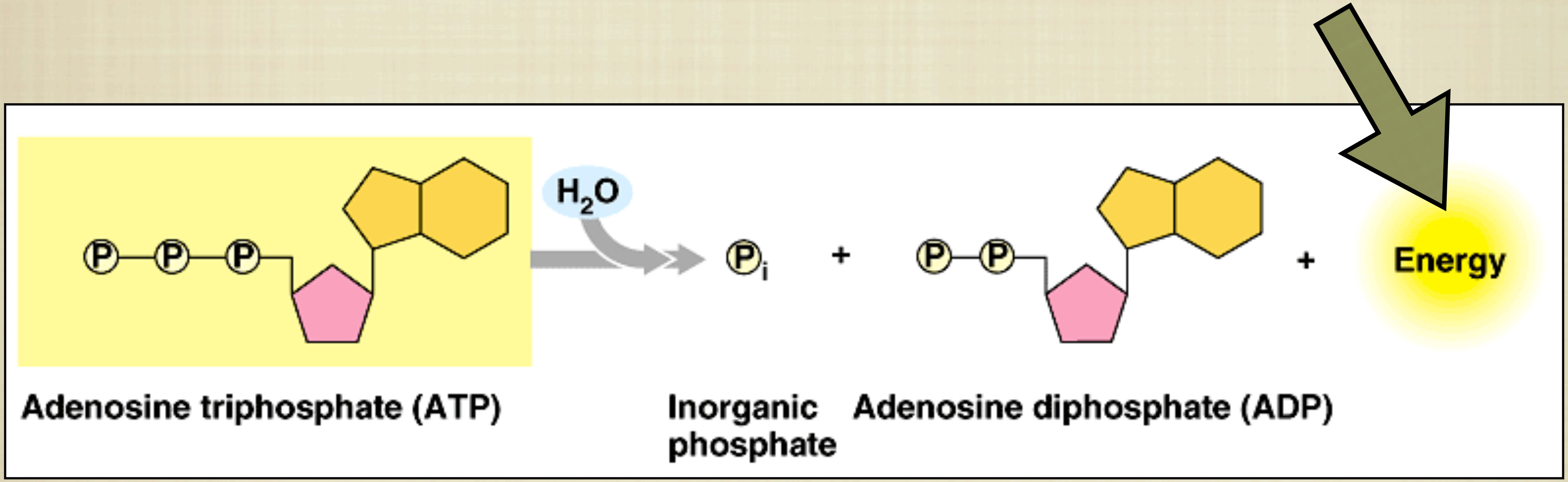
- ATP
  - Adenosine
  - Ribose
  - 3 Phosphates

ATP



H_2O
P_i
+
+
Energy
Adenosine triphosphate (ATP)
Inorganic phosphate
Adenosine diphosphate (ADP)

ATP



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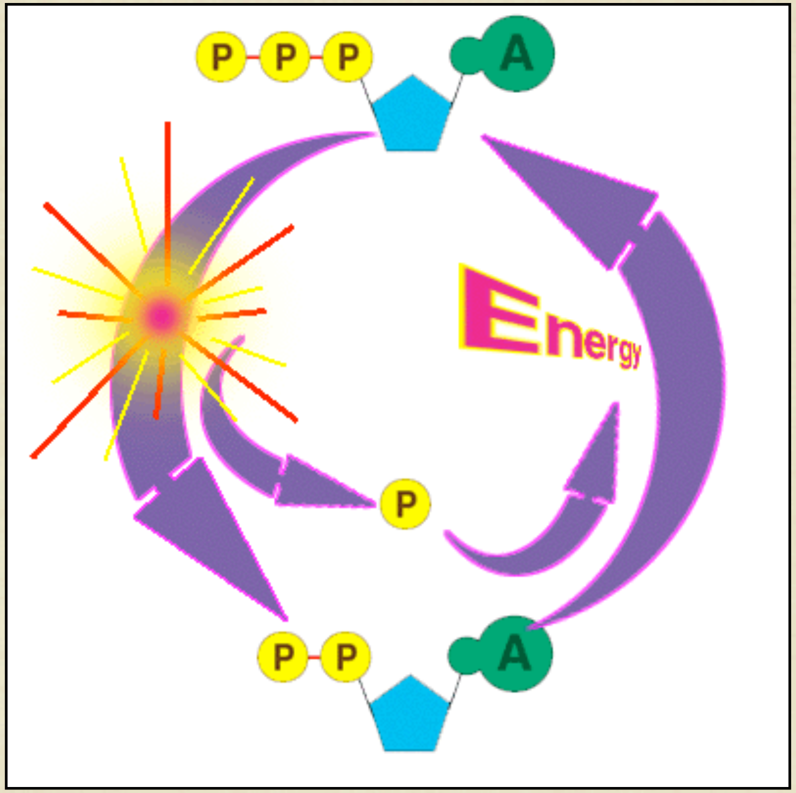
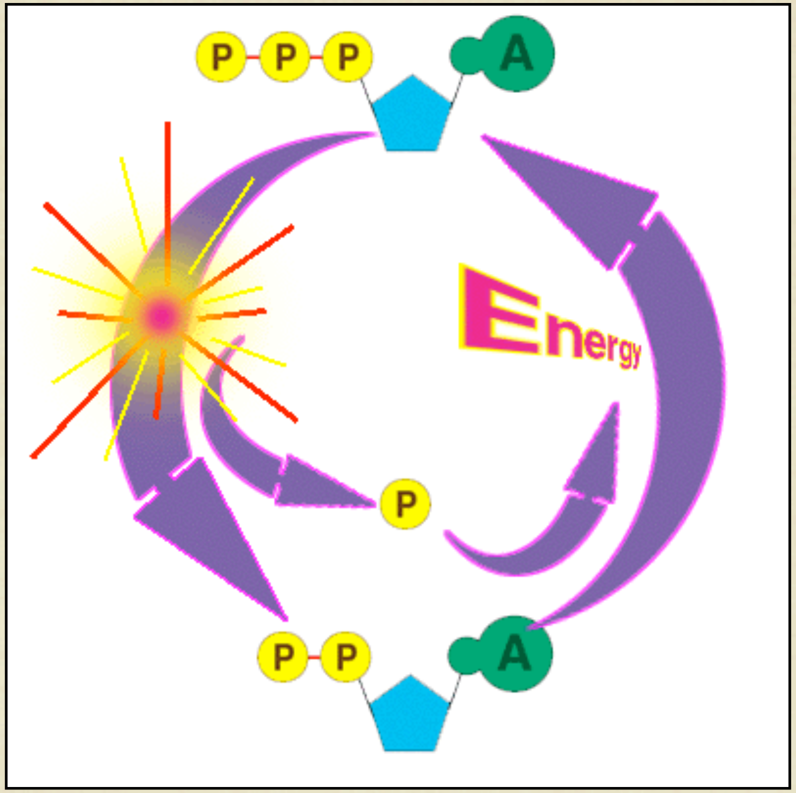


ATP

ATP



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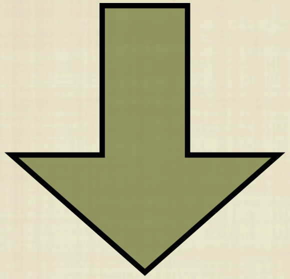
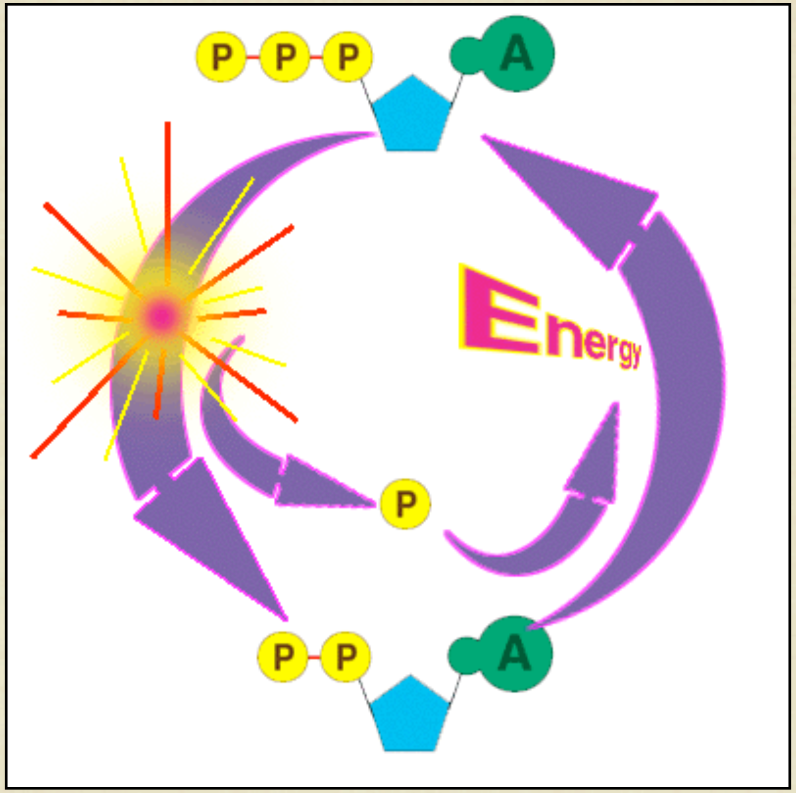
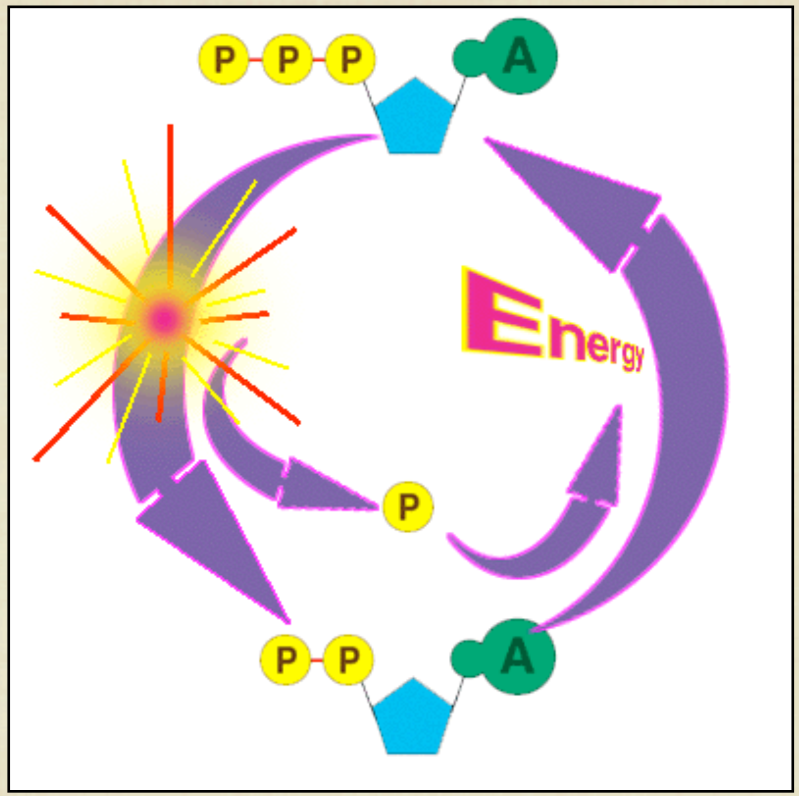




ATP

ATP

Energy
Out

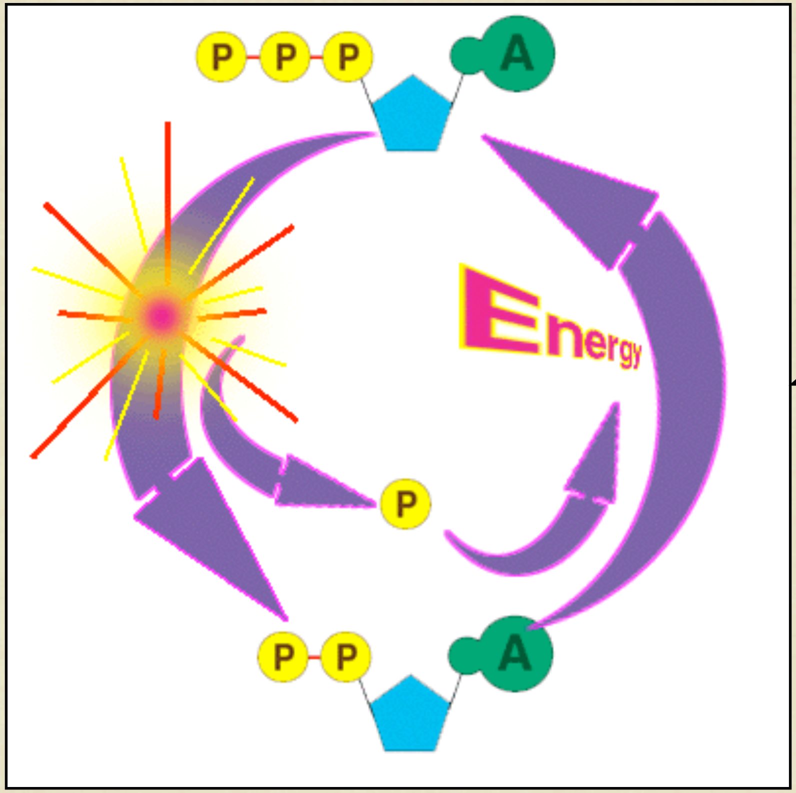


ADP + P

ATP

ATP

Energy Out

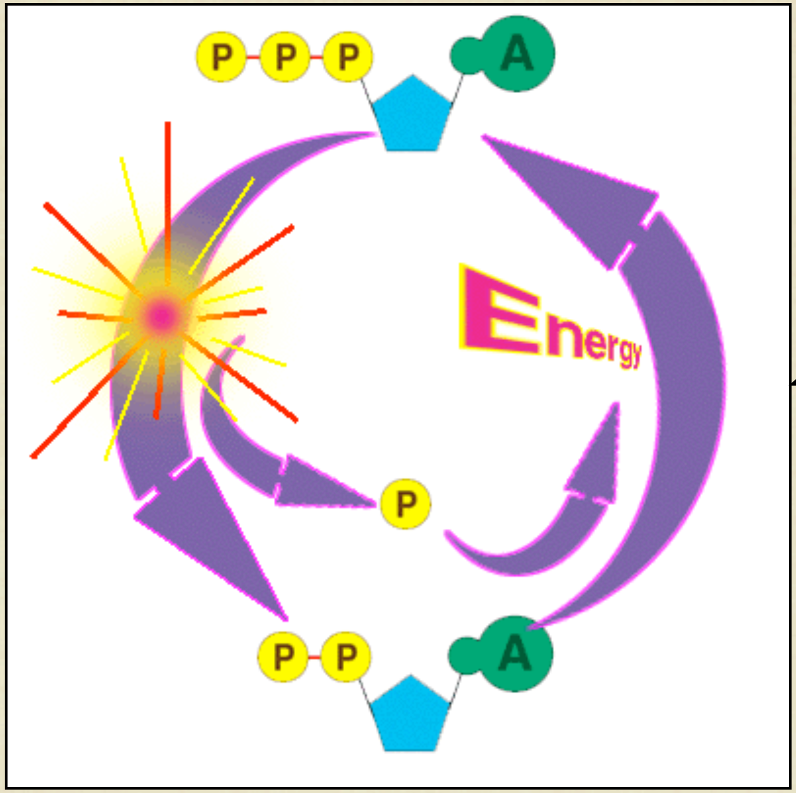


ADP + P

ATP

ATP

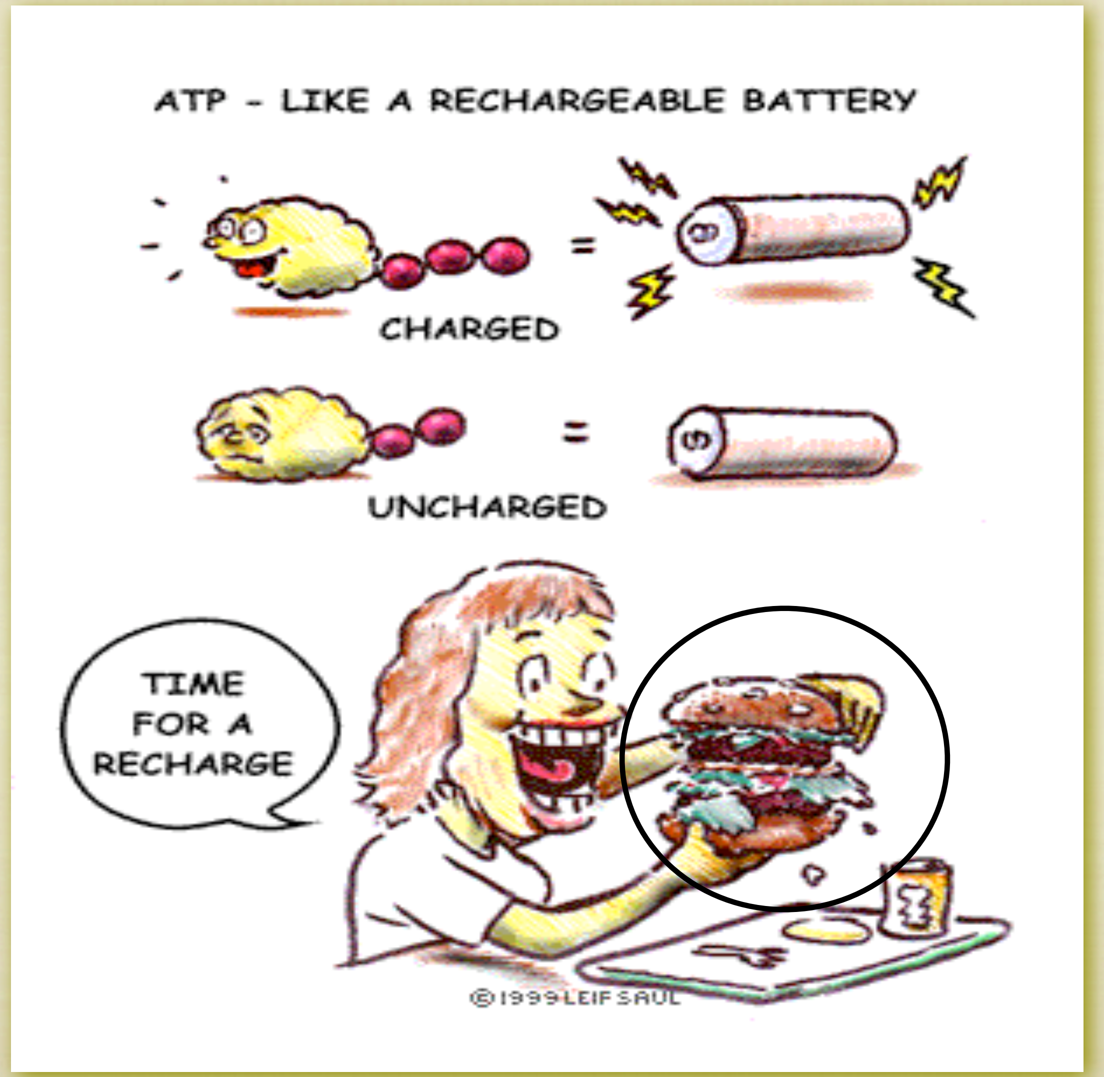
Energy Out



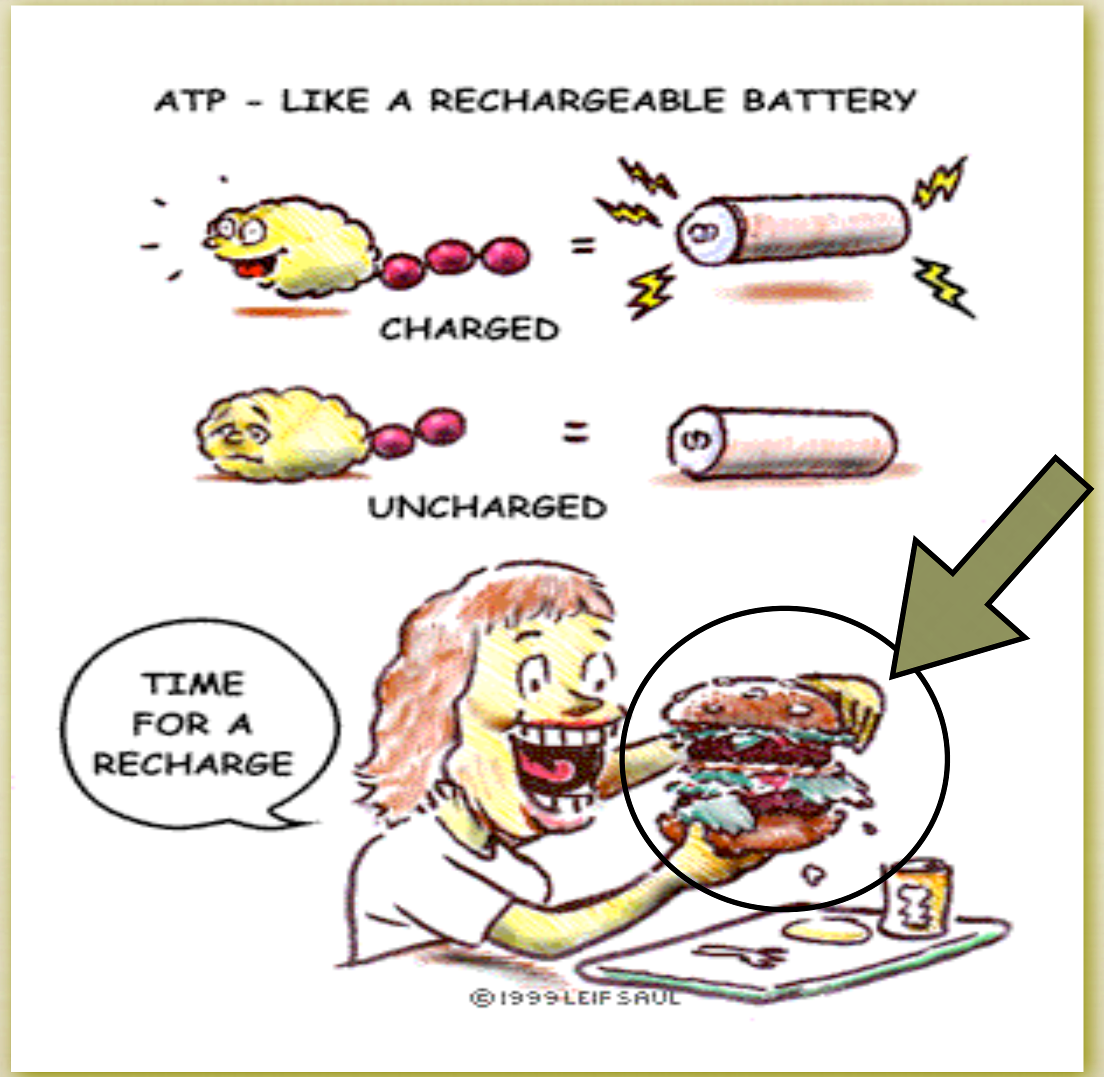
Energy In

ADP + P

ATP


ATP - LIKE A RECHARGEABLE BATTERY
CHARGED
UNCHARGED
TIME FOR A RECHARGE
©1999 LEIF SAUL

ATP


ATP - LIKE A RECHARGEABLE BATTERY
CHARGED
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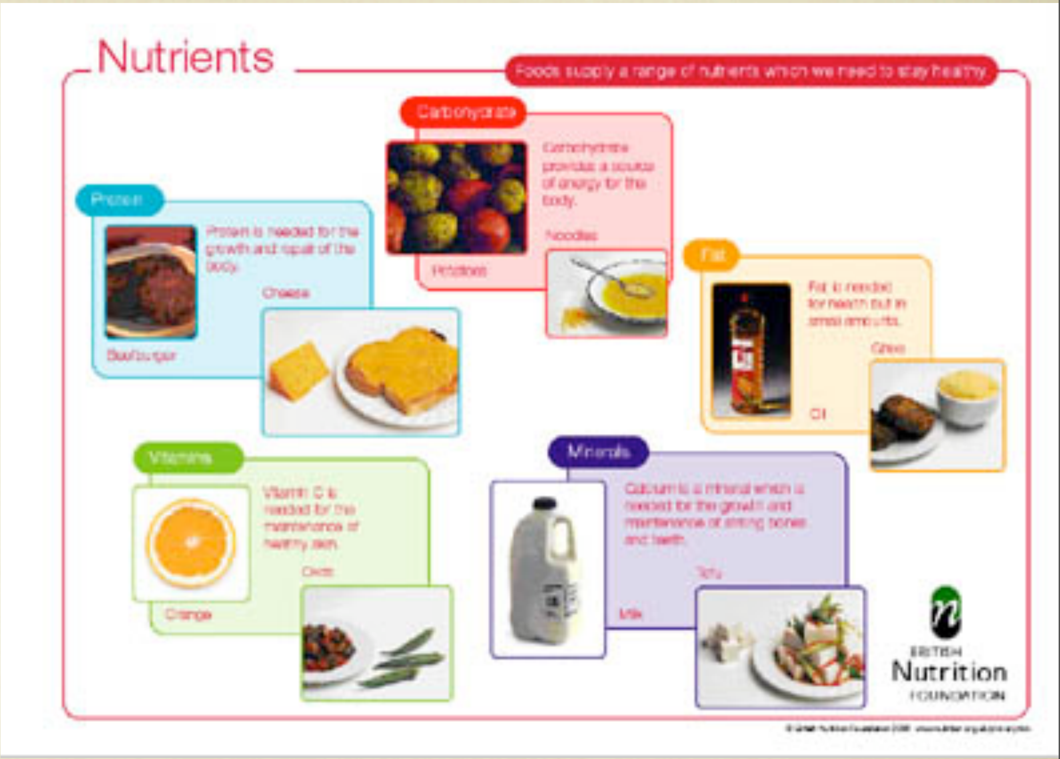
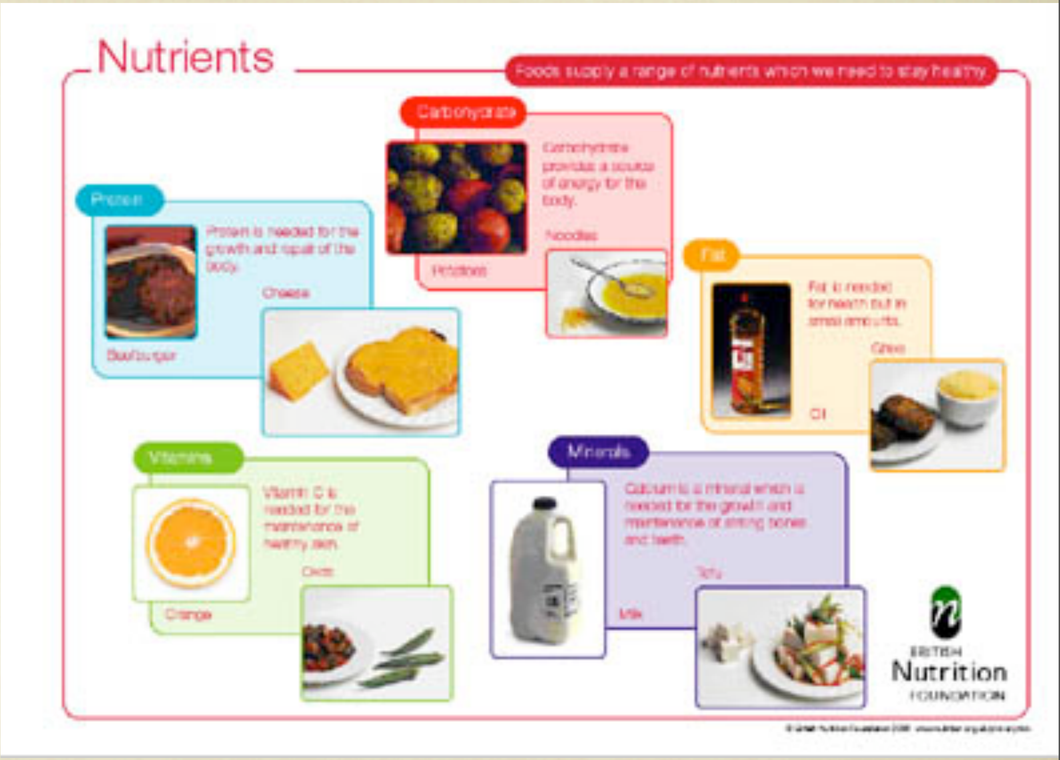
ENERGY

Fuels for Exercise



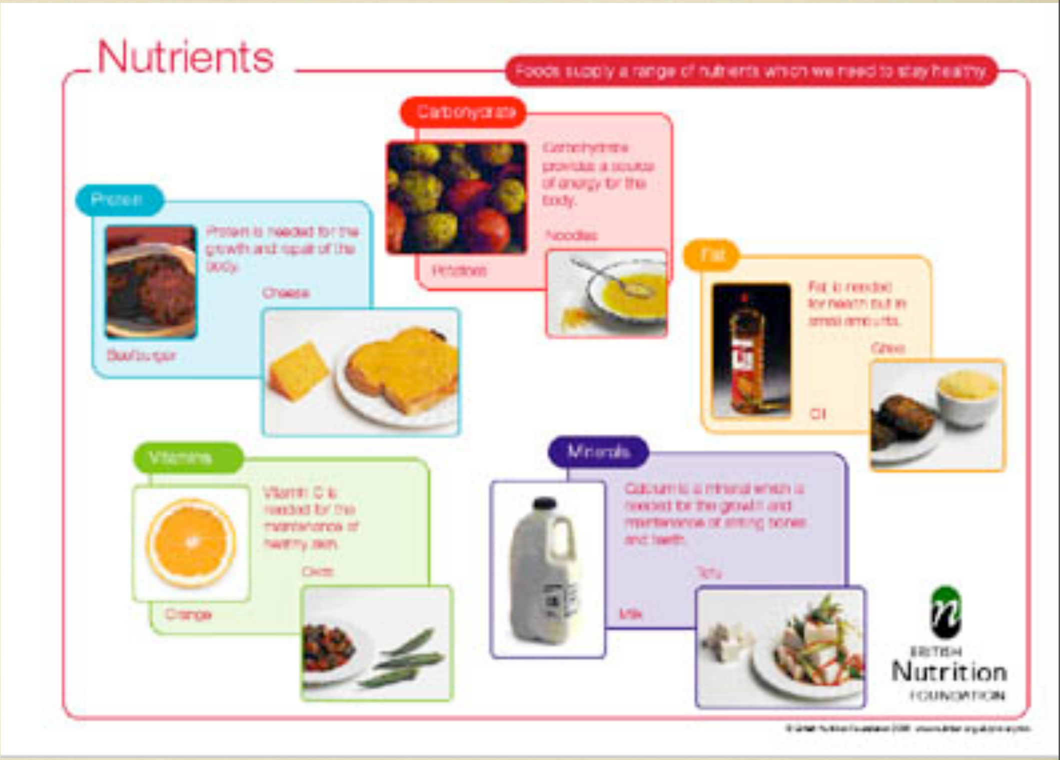
Fuels for Exercise

- carbohydrates



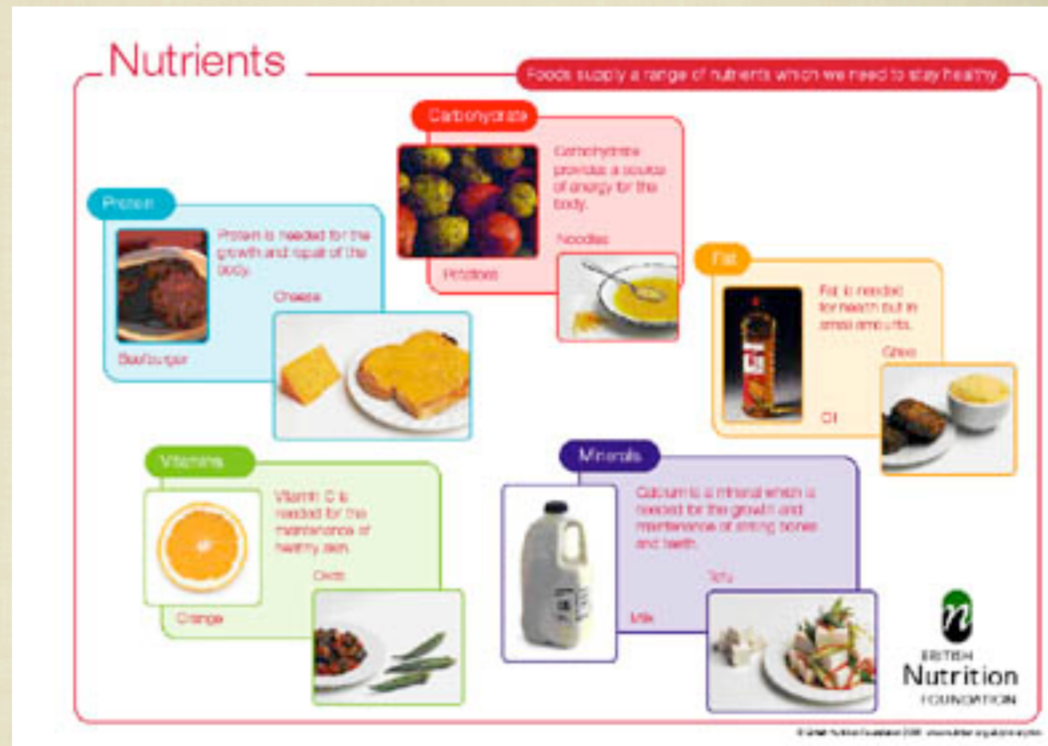
Fuels for Exercise

- carbohydrates
- Fats



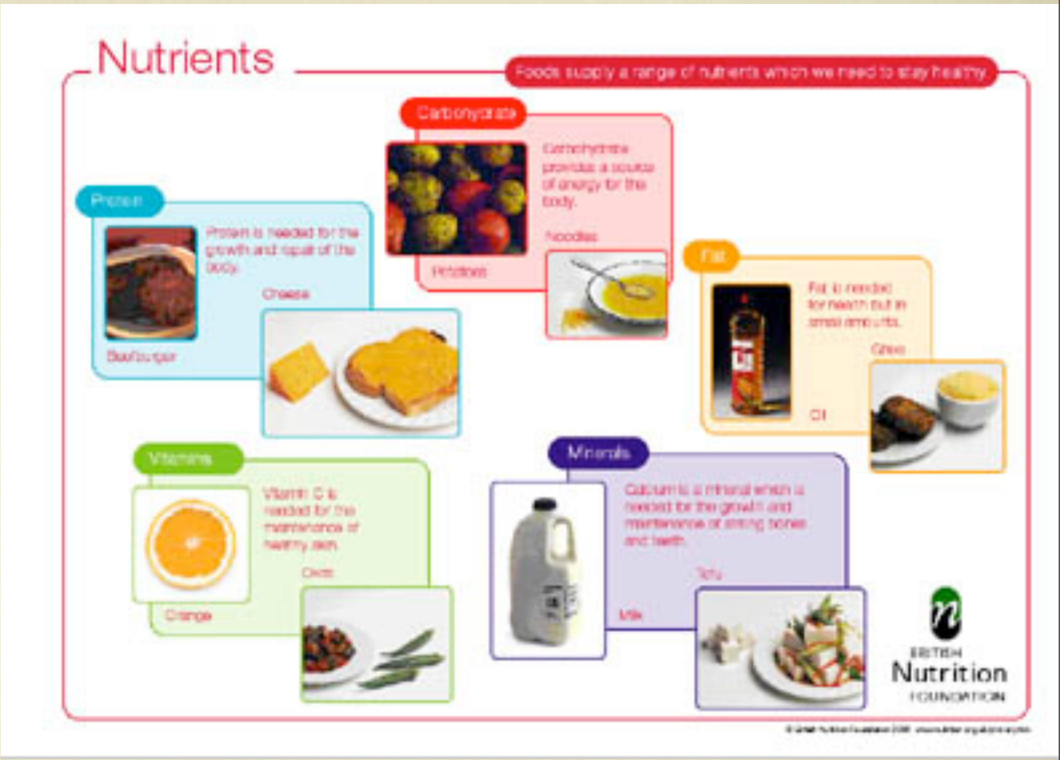
Fuels for Exercise

- carbohydrates
- Fats
- Proteins



Fuels for Exercise

- carbohydrates
- Fats
- Proteins
- Phoshocreatine

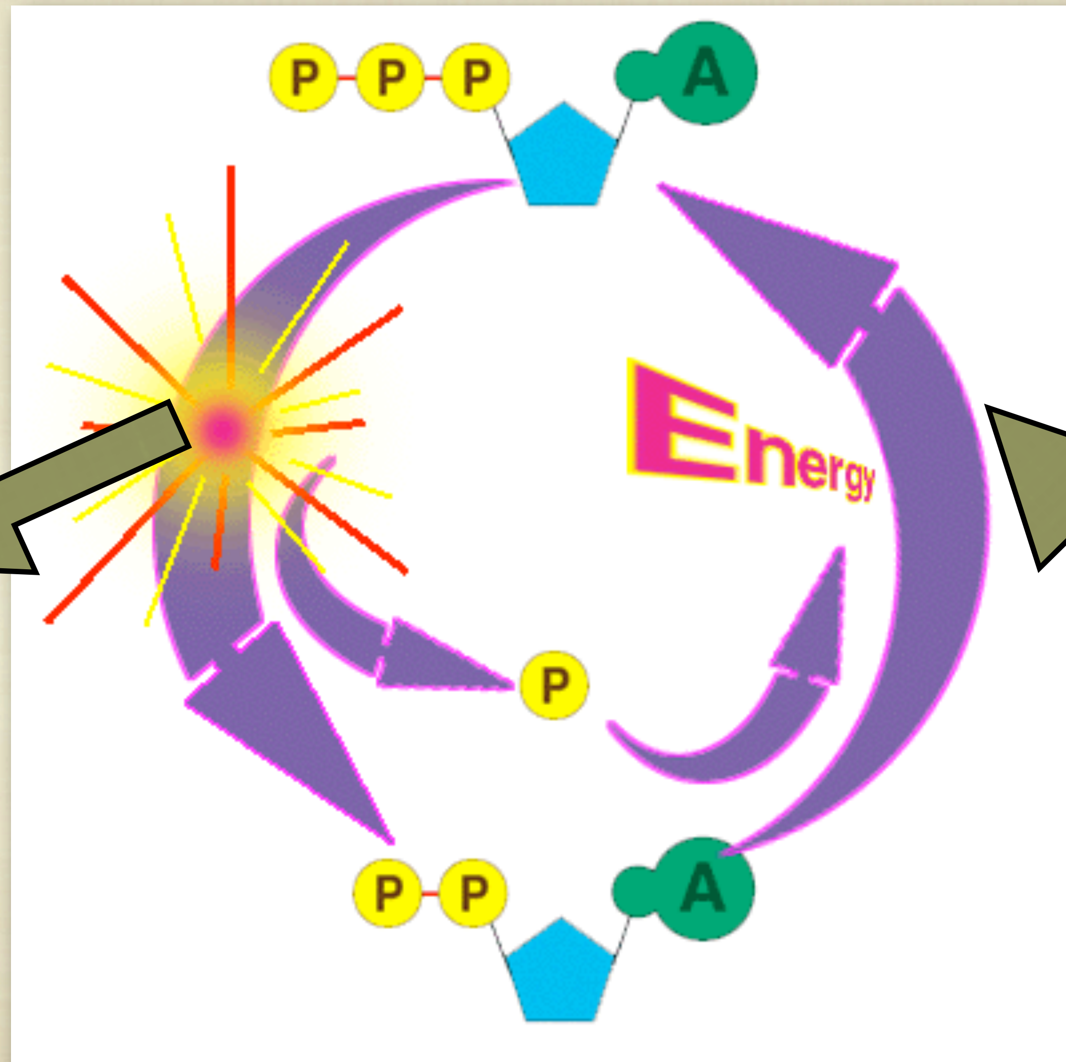


Bioenergetics

- ATP is the only source of energy recognized by the cells
- Only a small amount of ATP is stored inside the muscle cells

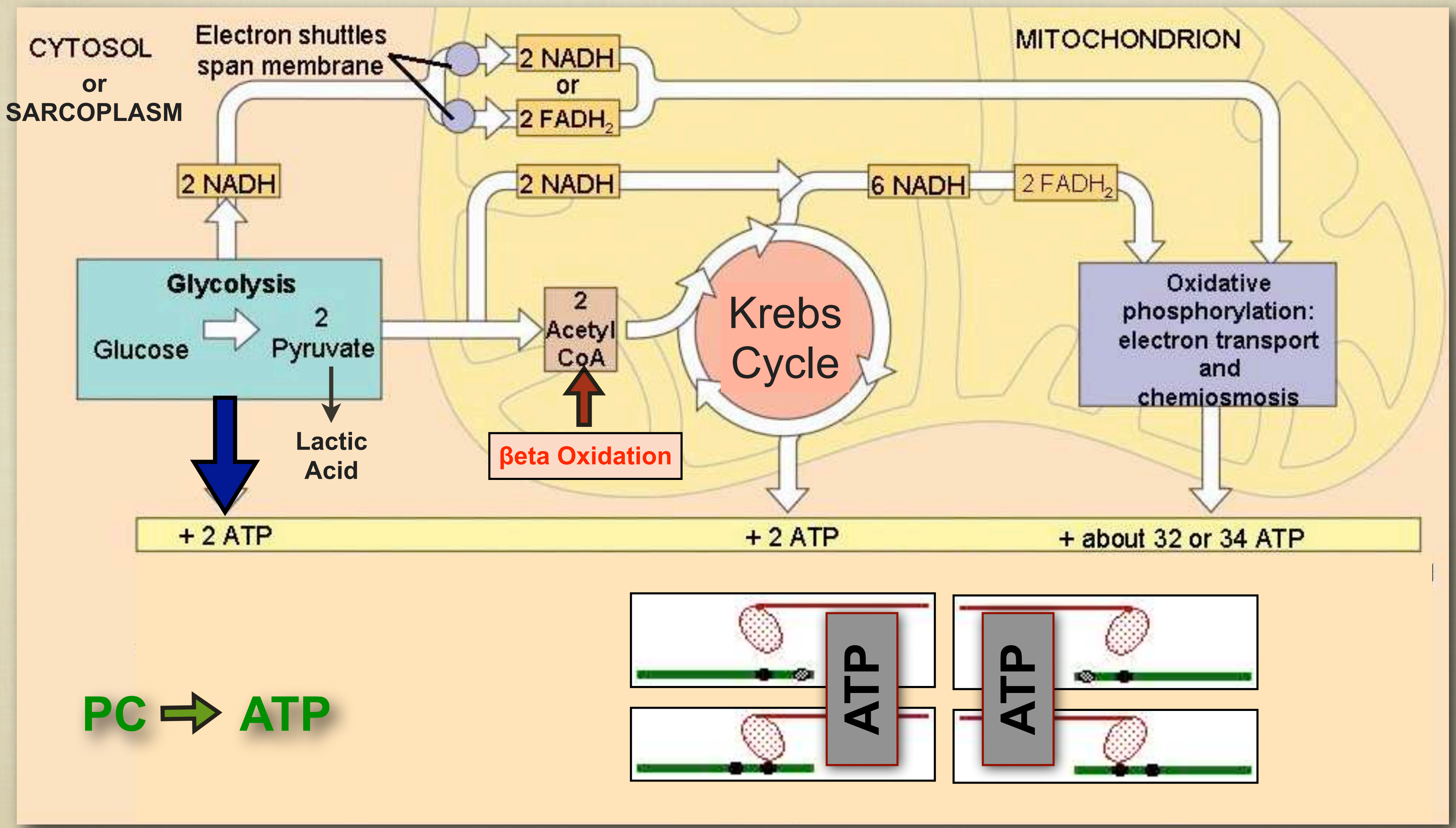
Bioenergetics

Energy "Out" (muscle contraction)



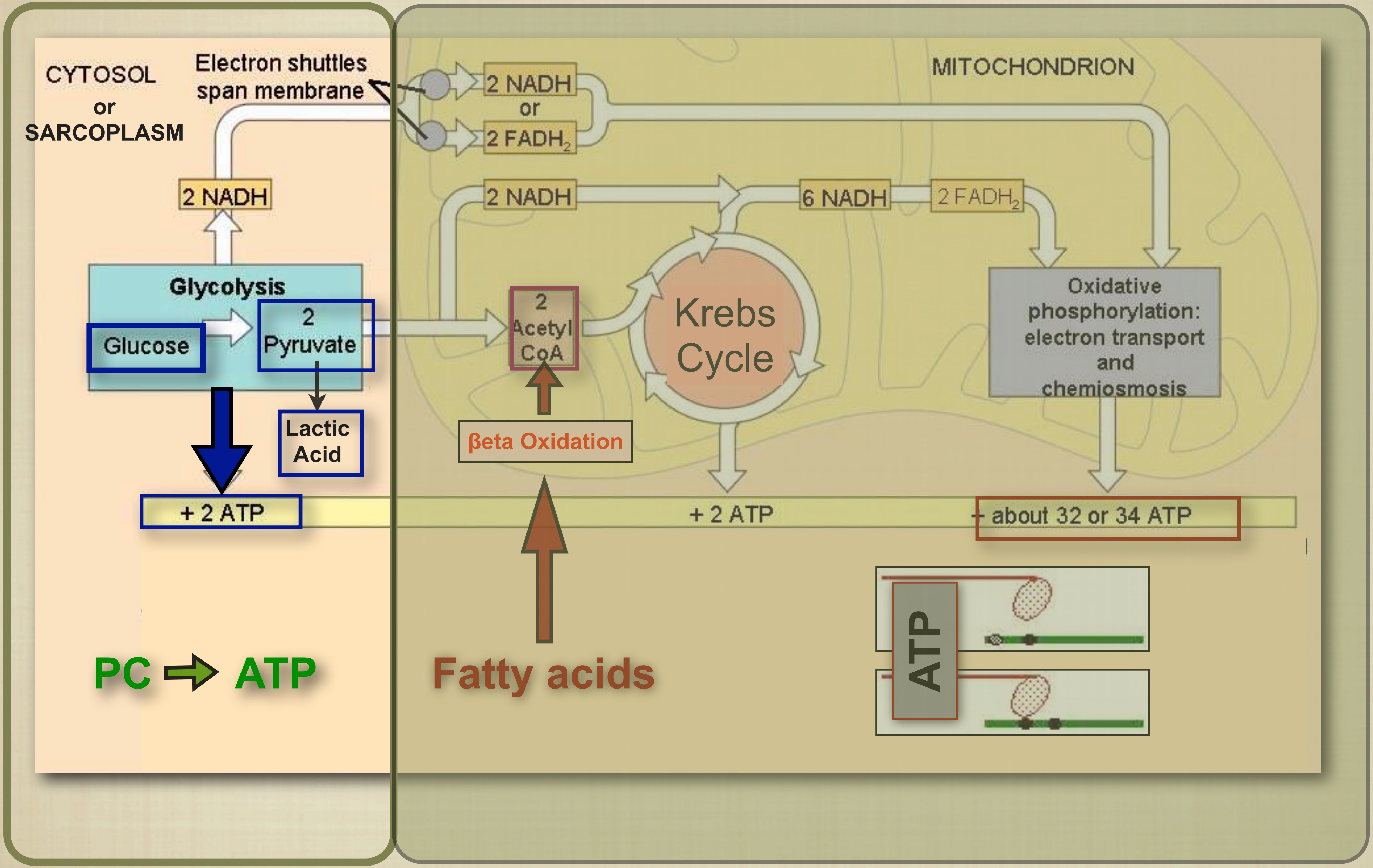
Energy "In" (food sources)

Energy Systems



Anaerobic

Aerobic



Bioenergetics

Bioenergetics

- "Making or Recycling" ATP

Bioenergetics

- "Making or Recycling" ATP
- Fuels/Systems

Bioenergetics

- "Making or Recycling" ATP
- Fuels/Systems

1. Phosphocreatine /ATP-PC (phosphagen system)

Bioenergetics

- "Making or Recycling" ATP
- Fuels/Systems

1. Phosphocreatine /ATP-PC (phosphagen system)

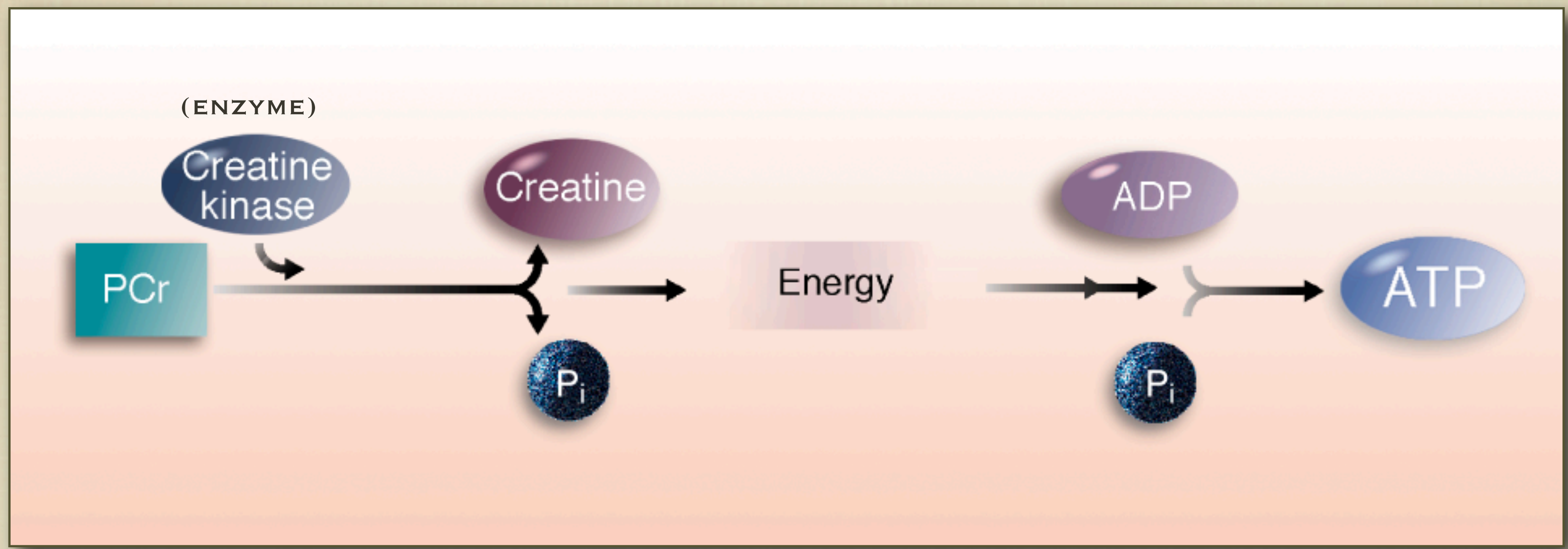
2. Carbohydrates/Glycolysis (lactic acid system)

Bioenergetics

- "Making or Recycling" ATP
- Fuels/Systems

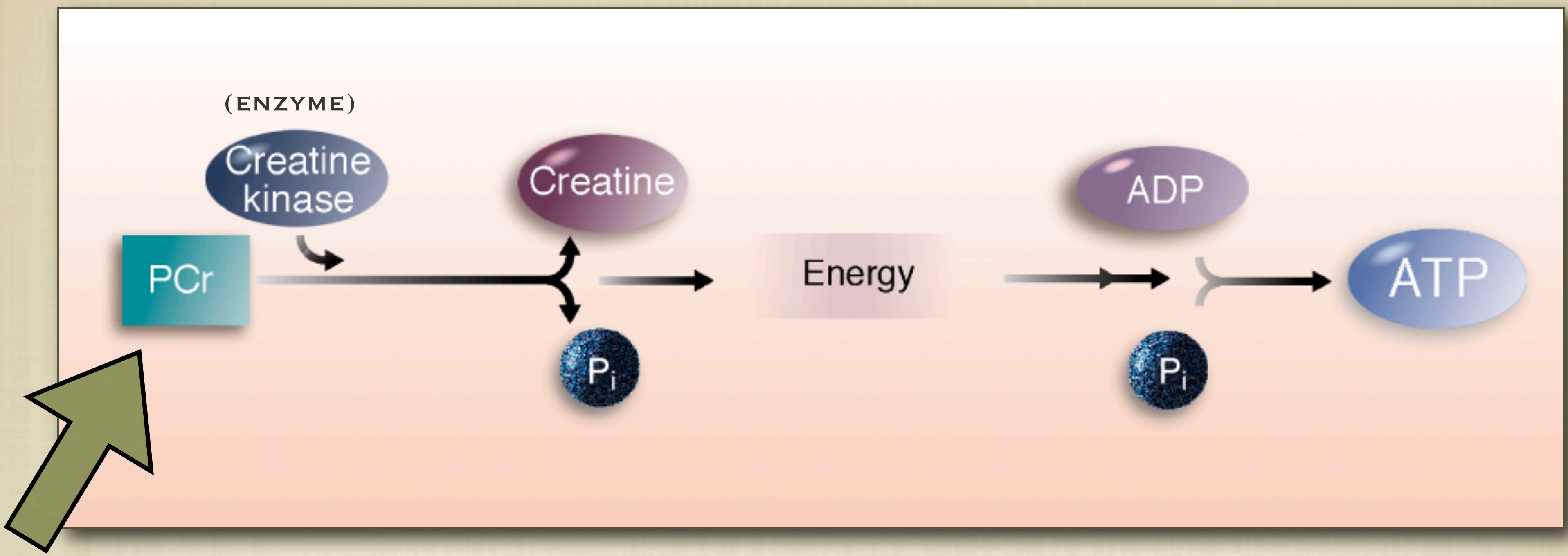
1. Phosphocreatine /ATP-PC (phosphagen system)
2. Carbohydrates/Glycolysis (lactic acid system)
3. Carbohydrates, Fats and Proteins / Aerobic (oxidation)

ATP-PC System



- How does it work?

ATP-PC System



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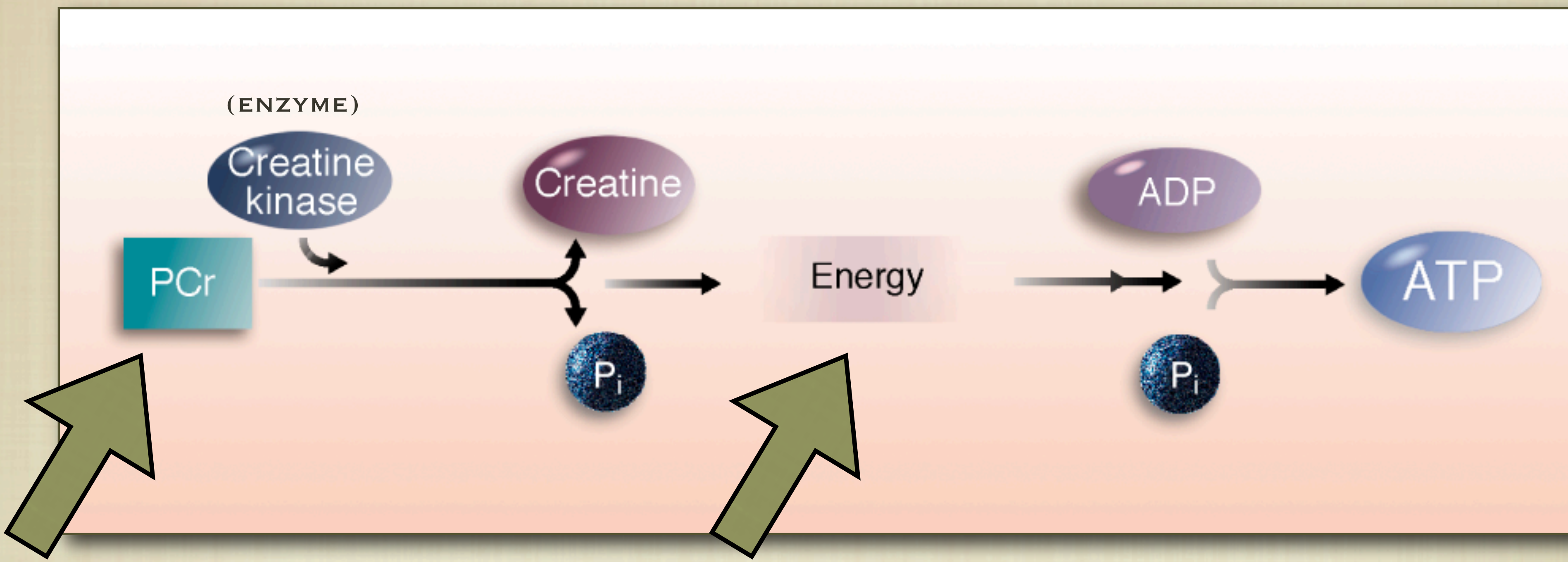
ATP-PC System



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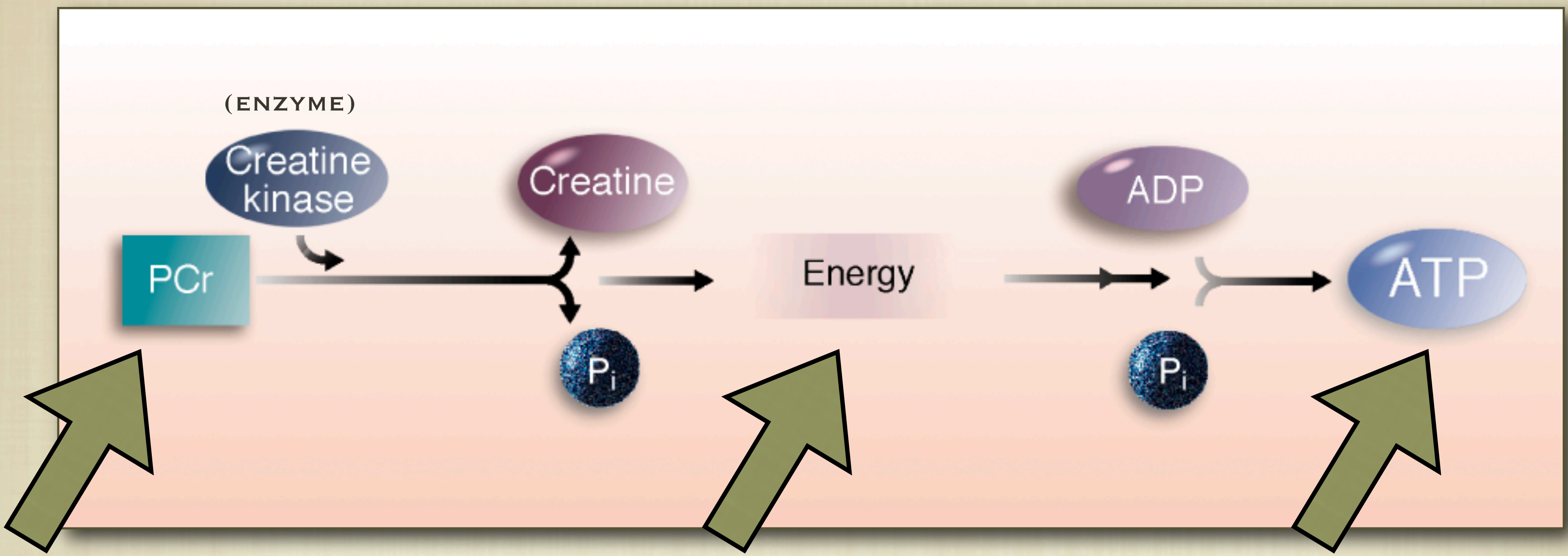
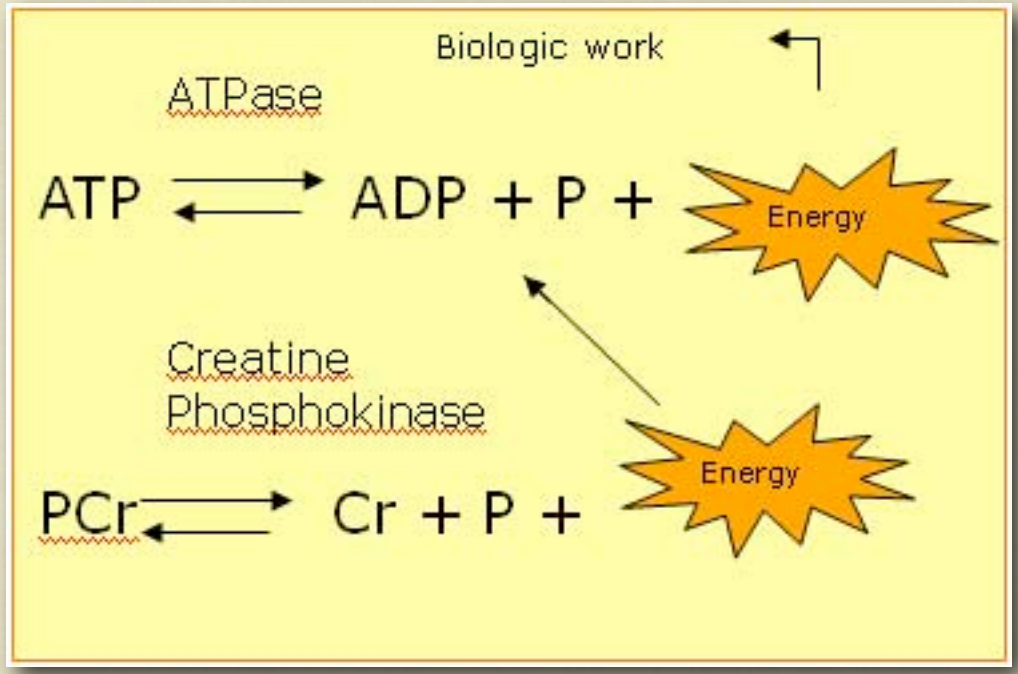
ATP-PC System

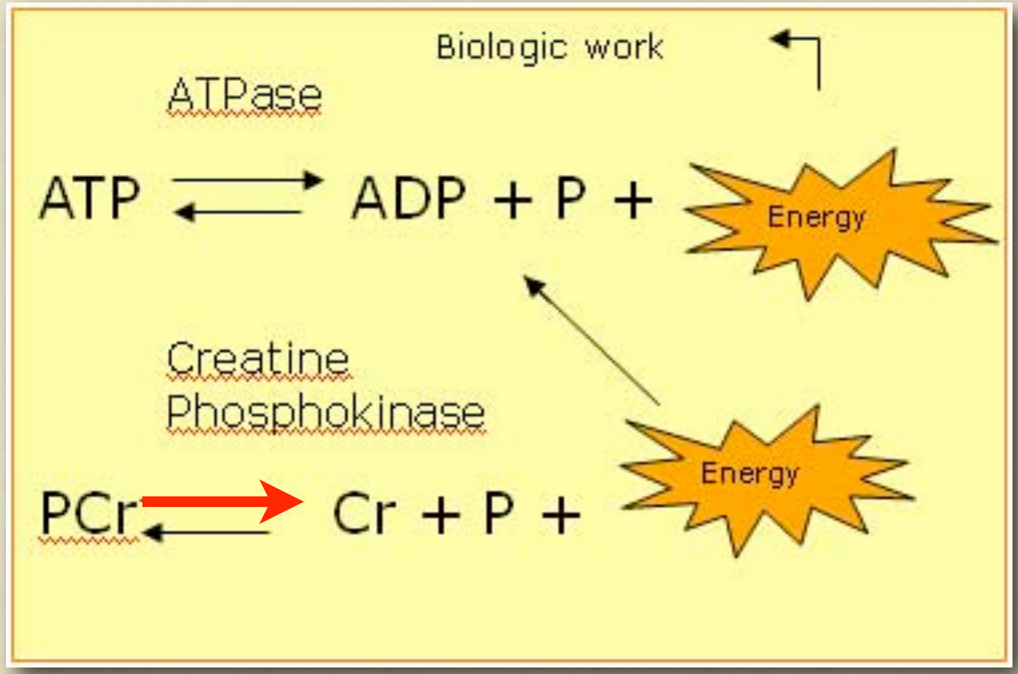


- How does it work?

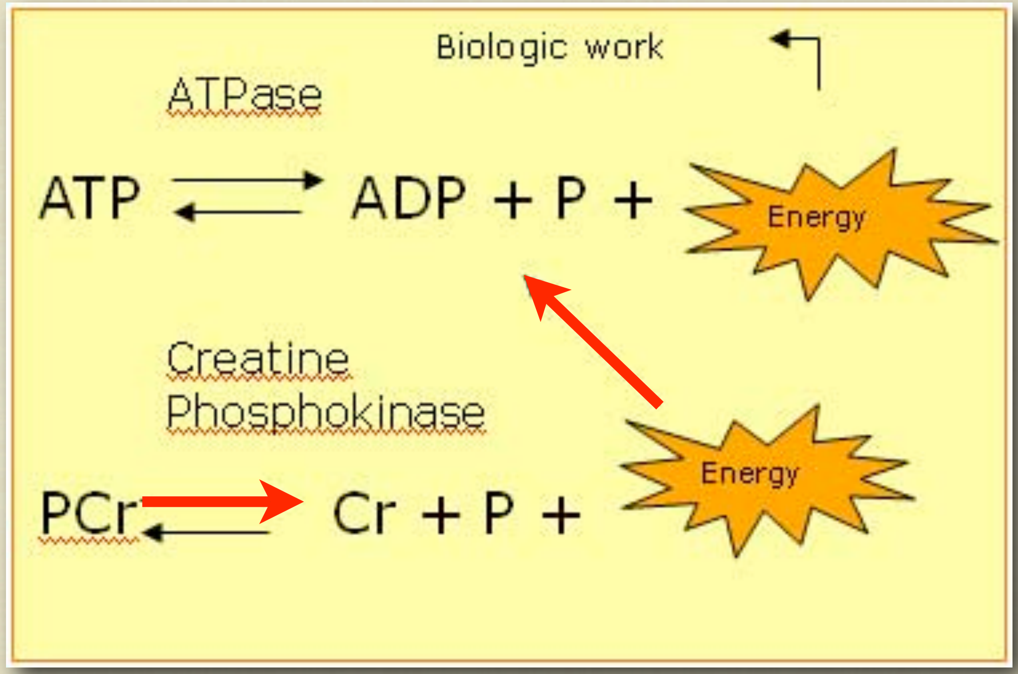
ATP-PC System



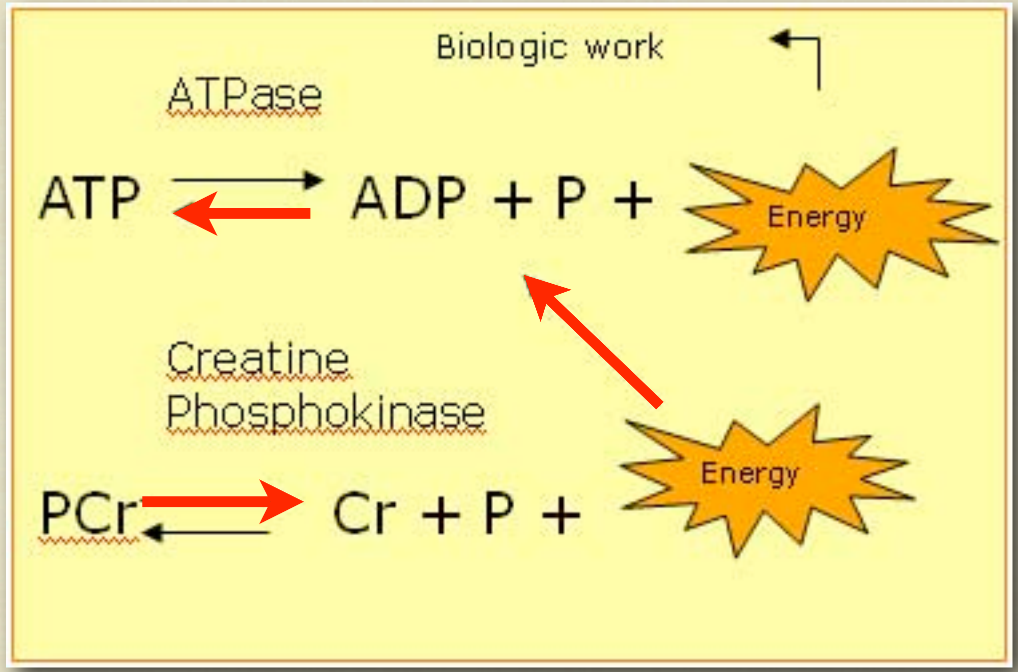
ATP-PC System



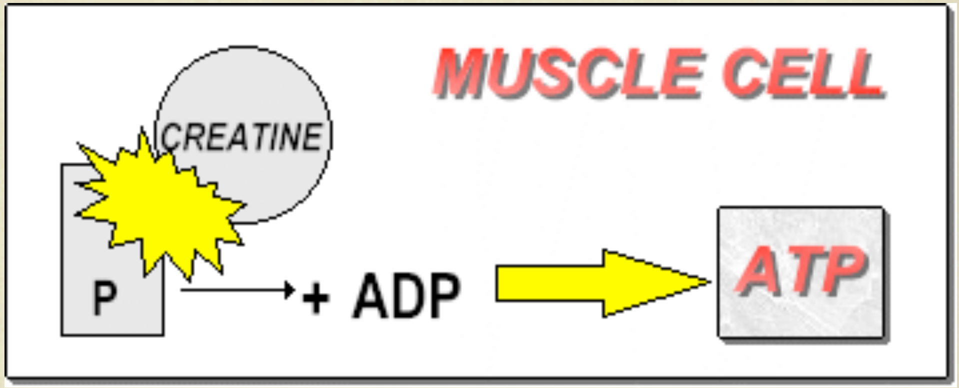
ATP-PC System



ATP-PC System

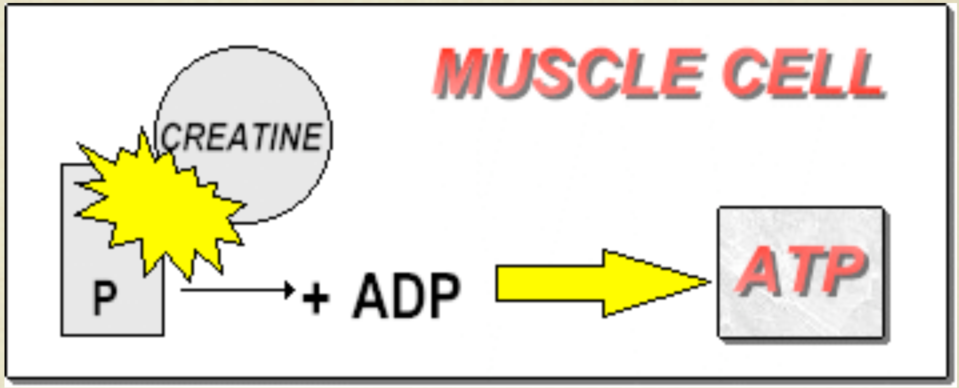


ATP-PC System



ATP-PC System

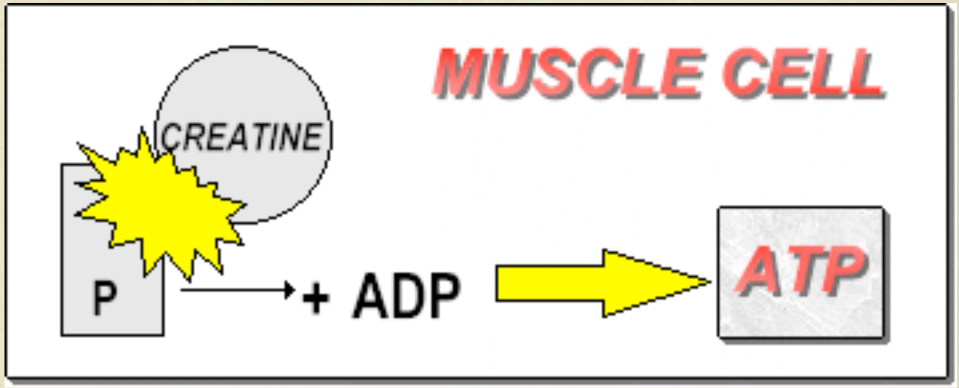
Advantages?



ATP-PC System

Advantages?

Disadvantages?



Creatine Supplement

Creatine Supplement

- Does it work?

Creatine Supplement

- Does it work?
- THE WINNING EDGE 3.1 p.32

Creatine Supplement

- Does it work?
- THE WINNING EDGE 3.1 p.32
  - Can increase creatine levels inside muscle

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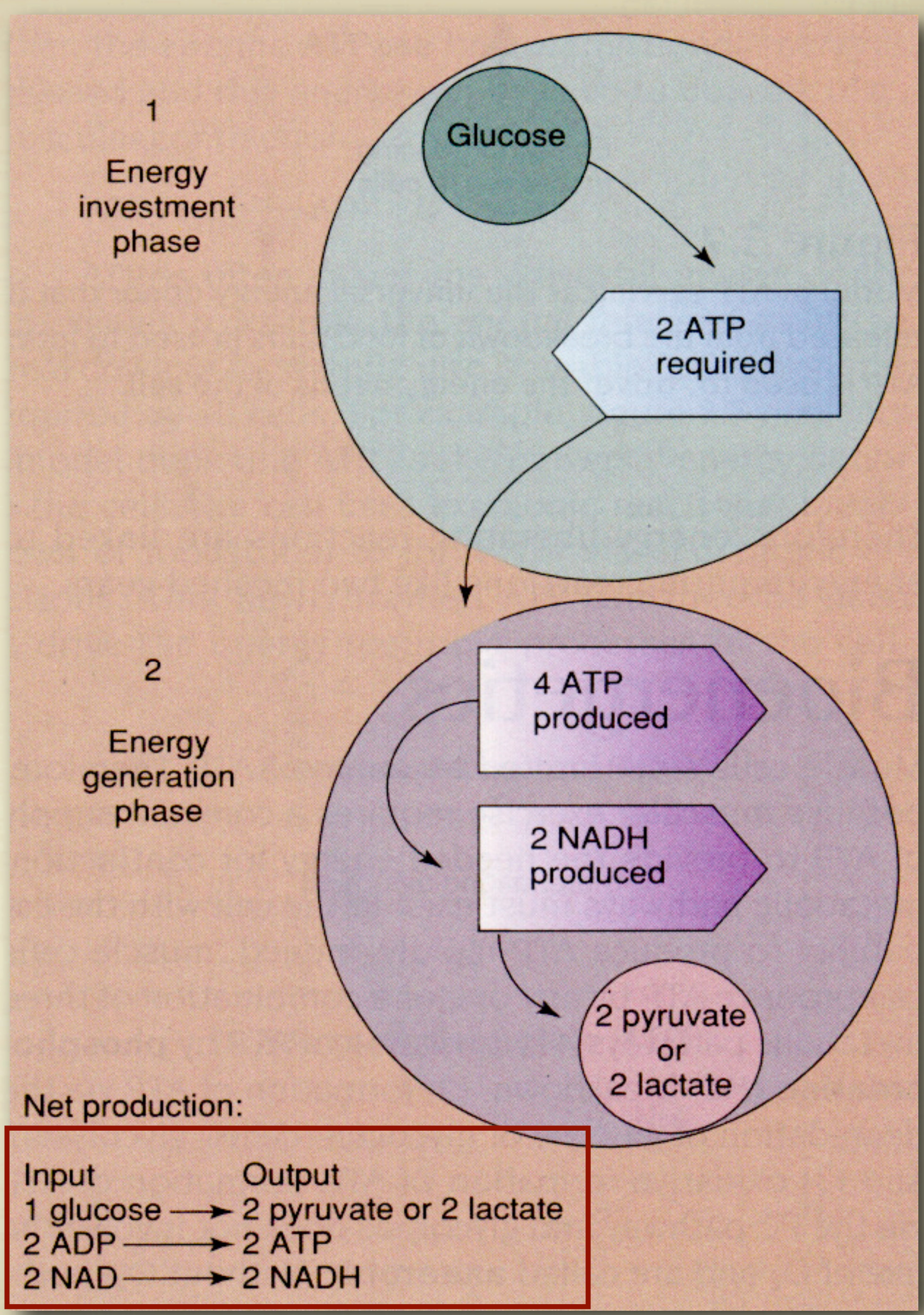
  - Can increase creatine levels inside muscle
  - Improve short, high intensity performance

Creatine Supplement

- Does it work?
- THE WINNING EDGE 3.1 p.32
  - Can increase creatine levels inside muscle
  - Improve short, high intensity performance
  - Small increase in muscle strength

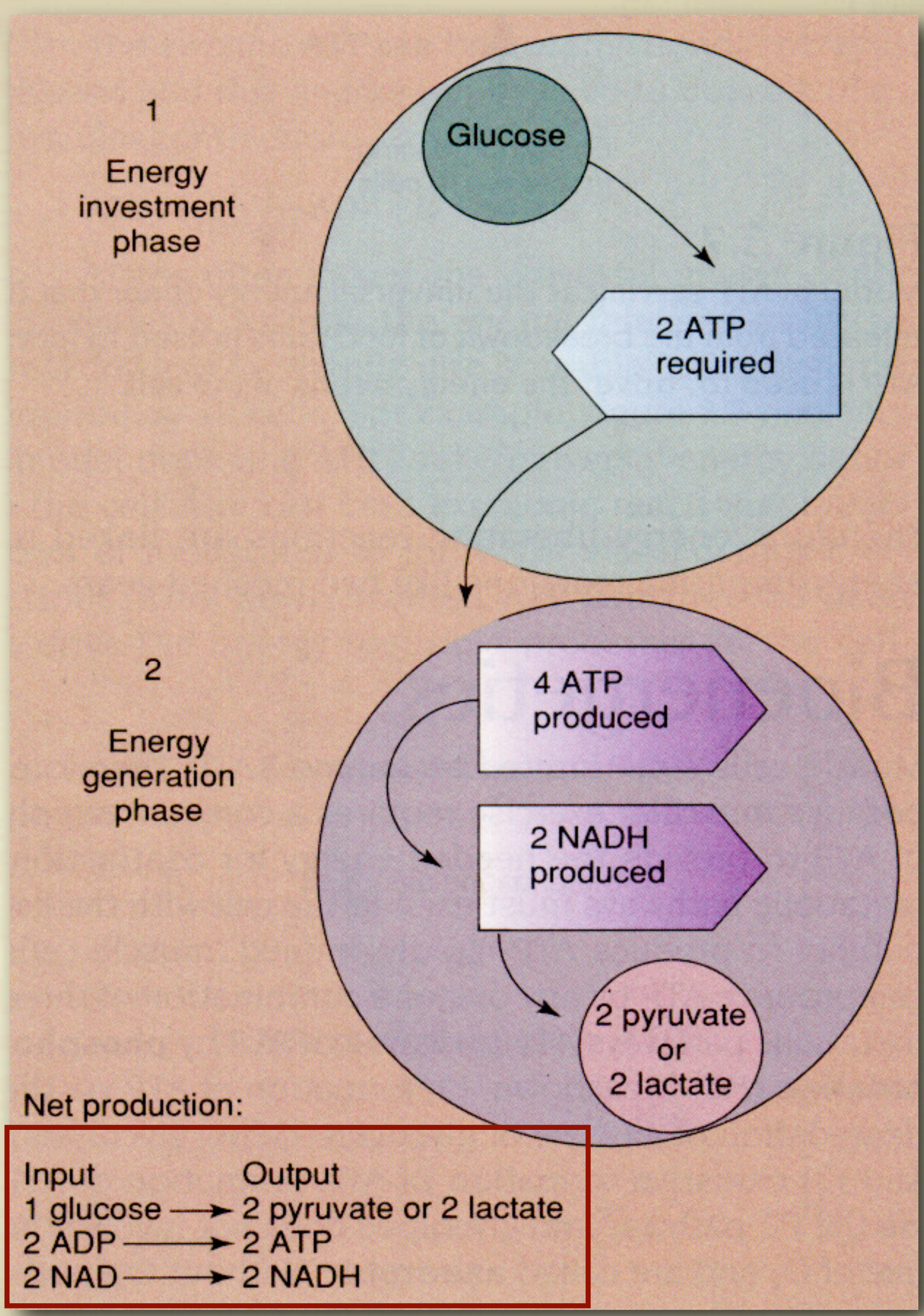
Glycolysis

GLYCOLYSIS


1
Energy investment phase
Glucose
2 ATP required
2
Energy generation phase
4 ATP produced
2 NADH produced
2 pyruvate or 2 lactate
Net production:
Input
Output
1 glucose → 2 pyruvate or 2 lactate
2 ADP → 2 ATP
2 NAD → 2 NADH

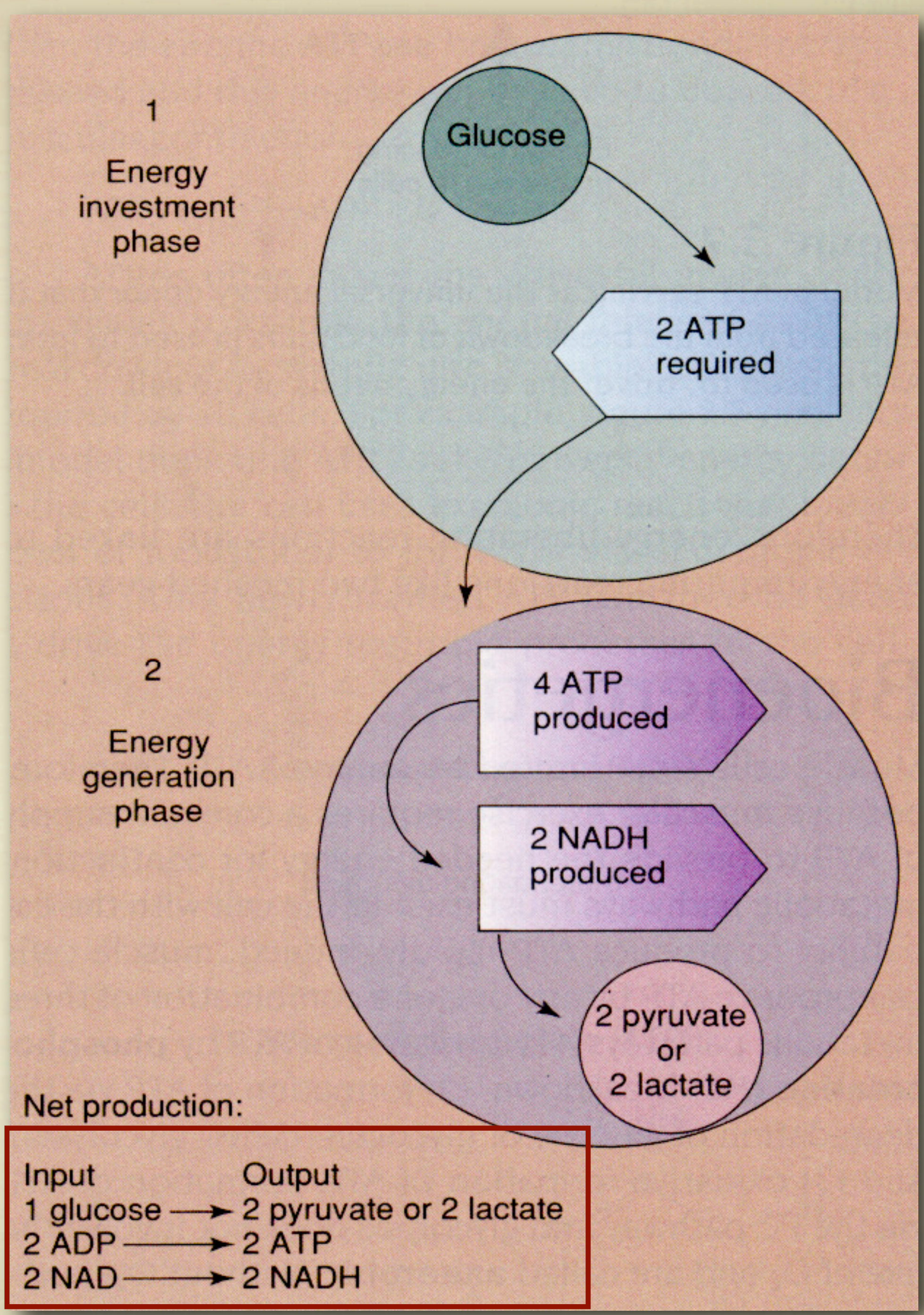
GLYCOLYSIS

- Where?



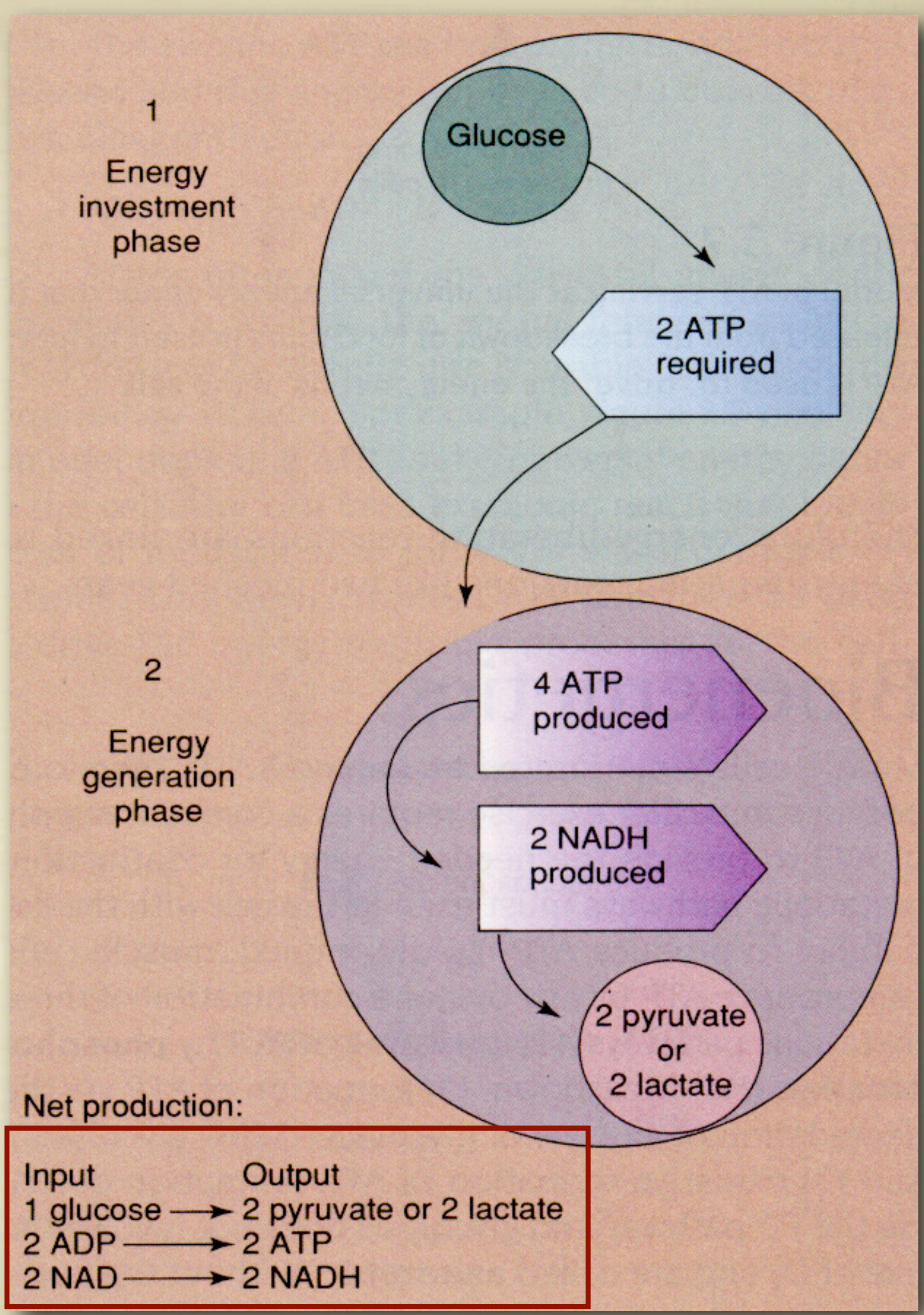
GLYCOLYSIS

- Where?
- What fuel?



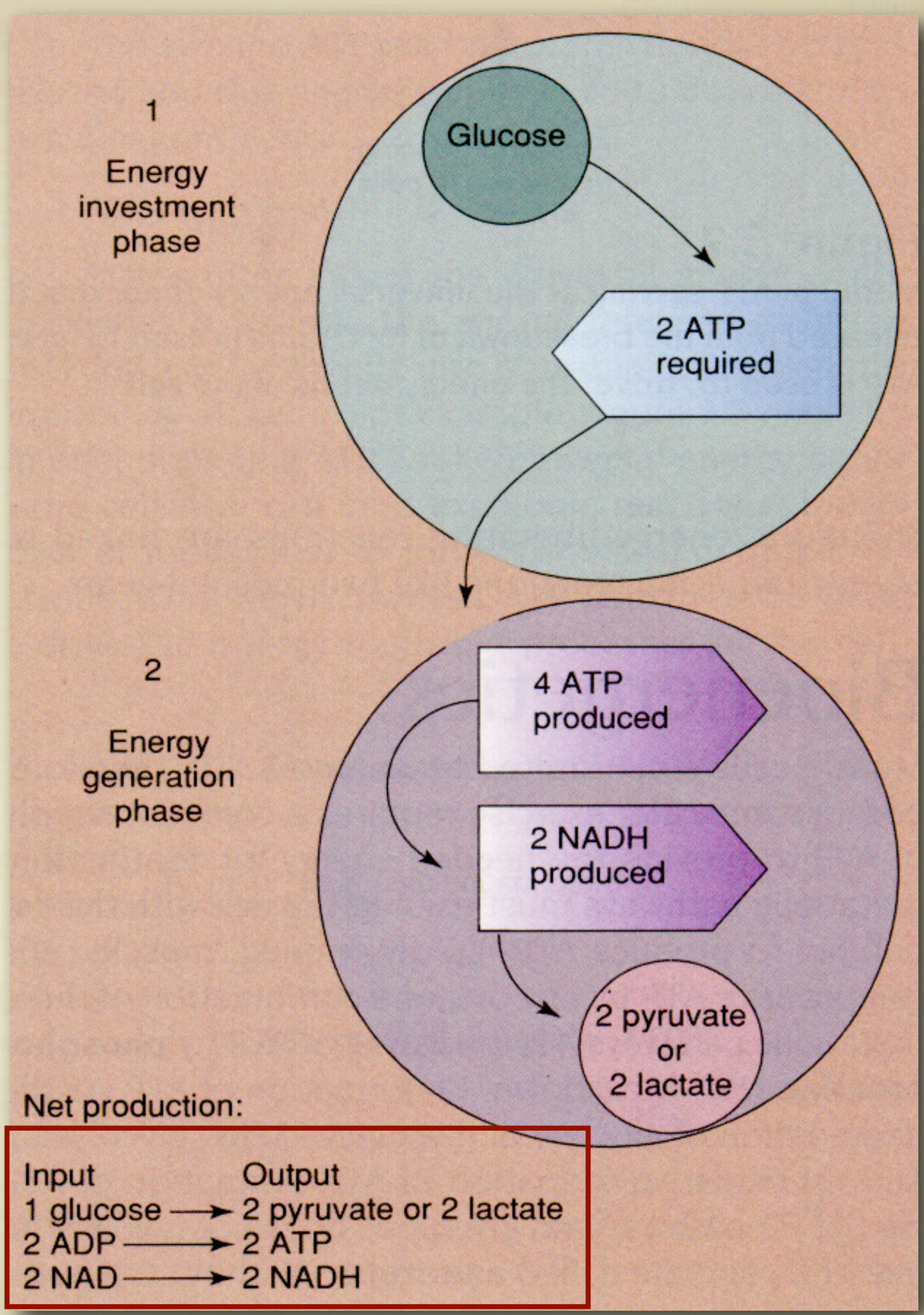
GLYCOLYSIS

- Where?
- What fuel?
- How? reactions, Enzymes



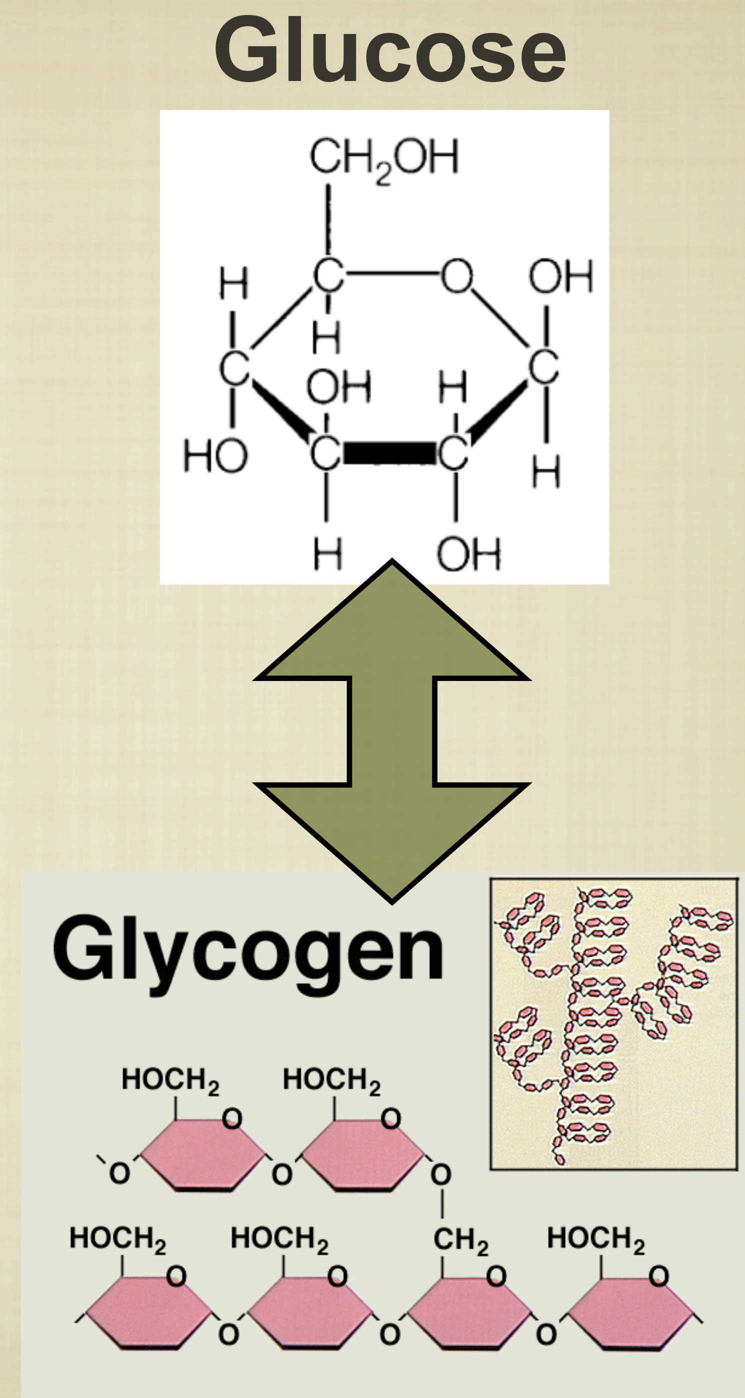
GLYCOLYSIS

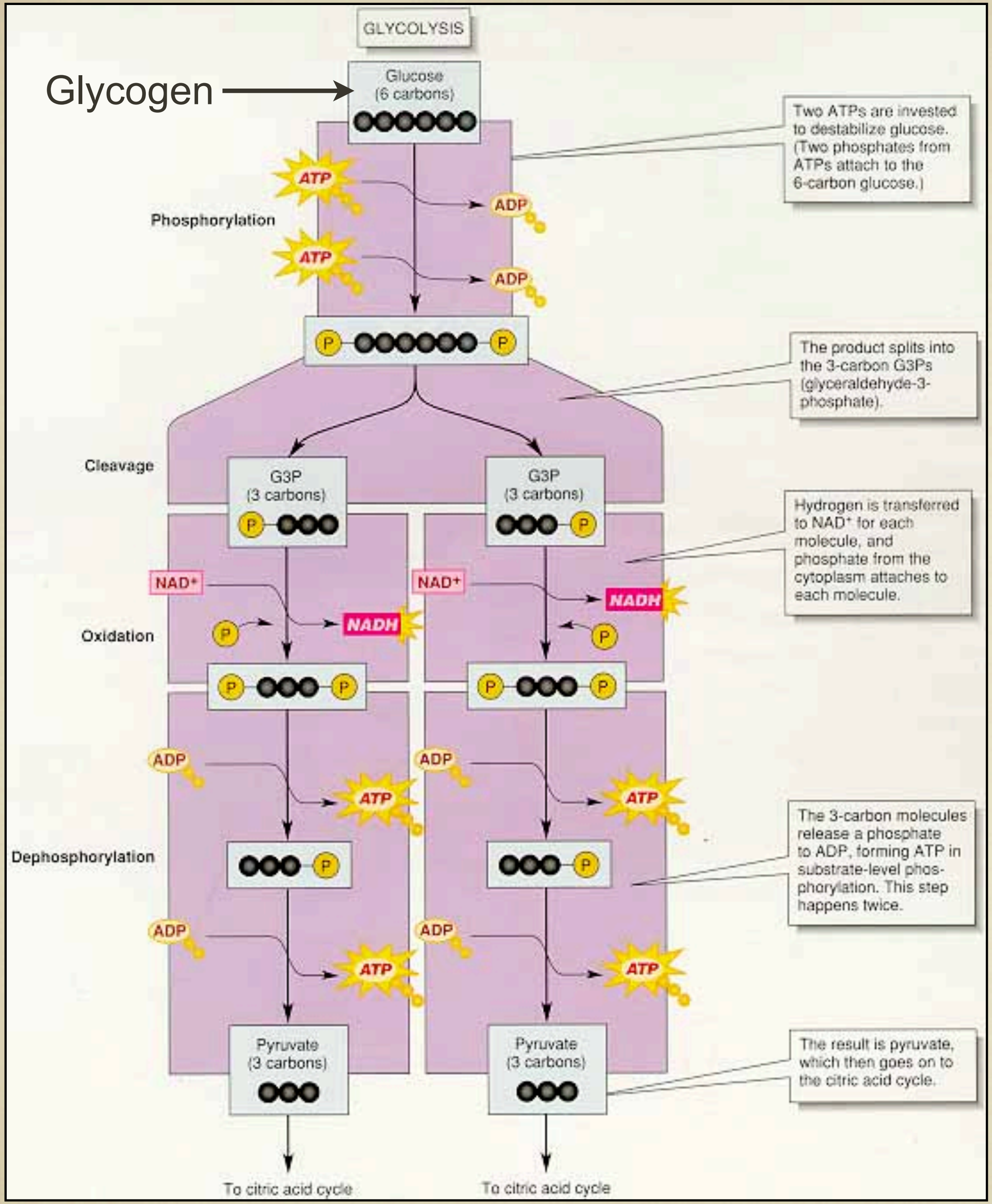
- Where?
- What fuel?
- How? reactions, Enzymes
- What is produced?
    1. ATP
    2. Hydrogens (NADH)
    3. Pyruvate or Lactate



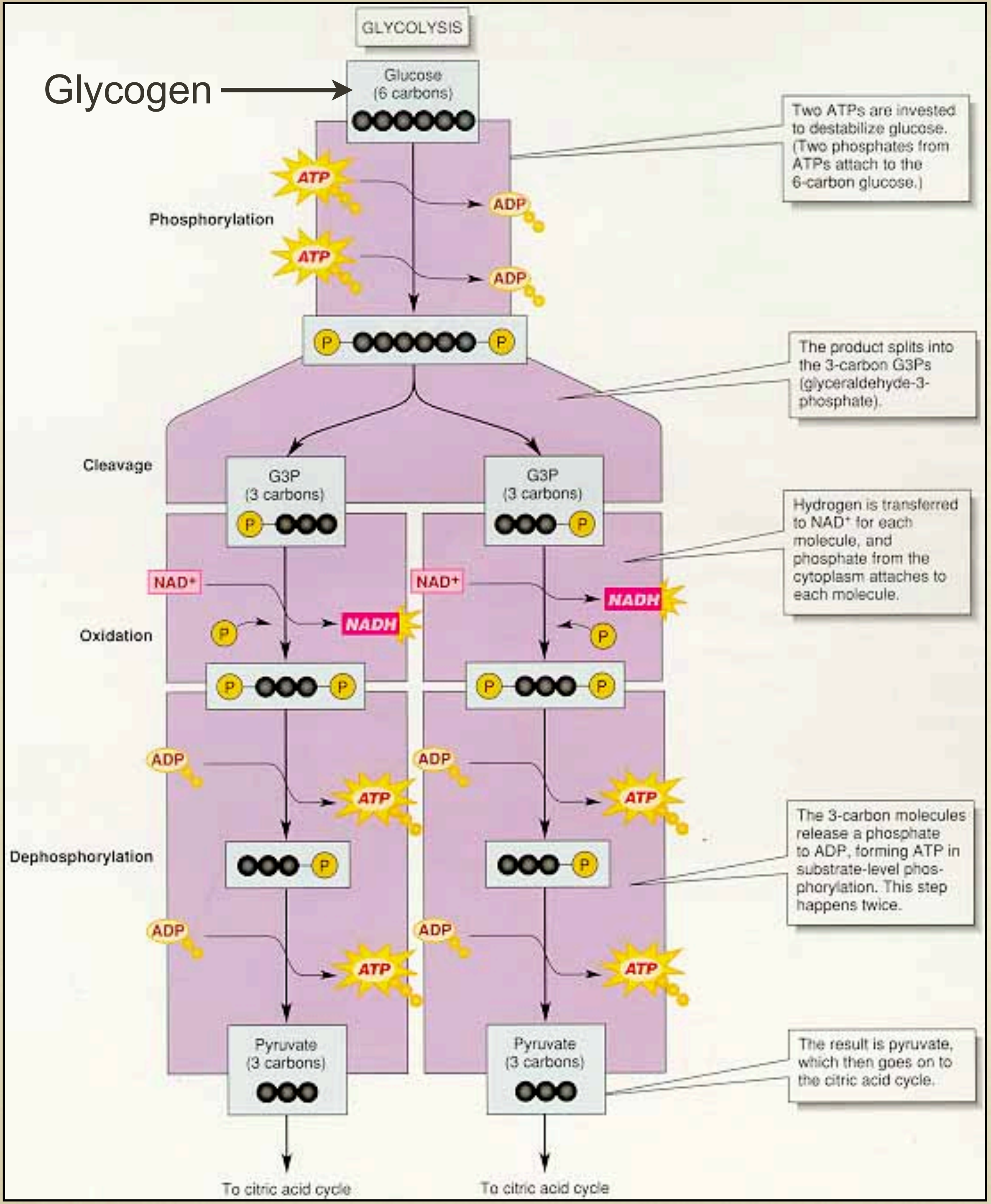
Glycolysis

- Carbohydrates
    - Glucose
    - Glycogen
- Glucose = $C_6 H_{12} O_6$





Glycogen
GLYCOLYSIS
Glucose
(6 carbons)
ATP
ADP
Phosphorylation
P
Cleavage
G3P
(3 carbons)
NAD+
NADH
Oxidation
Dephosphorylation
Pyruvate
(3 carbons)
To citric acid cycle
Two ATPs are invested to destabilize glucose. (Two phosphates from ATPs attach to the 6-carbon glucose.)
The product splits into the 3-carbon G3Ps (glyceraldehyde-3-phosphate).
Hydrogen is transferred to NAD+ for each molecule, and phosphate from the cytoplasm attaches to each molecule.
The 3-carbon molecules release a phosphate to ADP, forming ATP in substrate-level phosphorylation. This step happens twice.
The result is pyruvate, which then goes on to the citric acid cycle.


GLYCOLYSIS
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ATP
ADP
Phosphorylation
ATP
ADP
P
P
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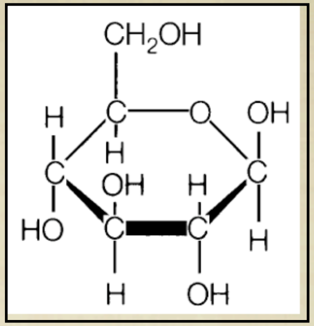
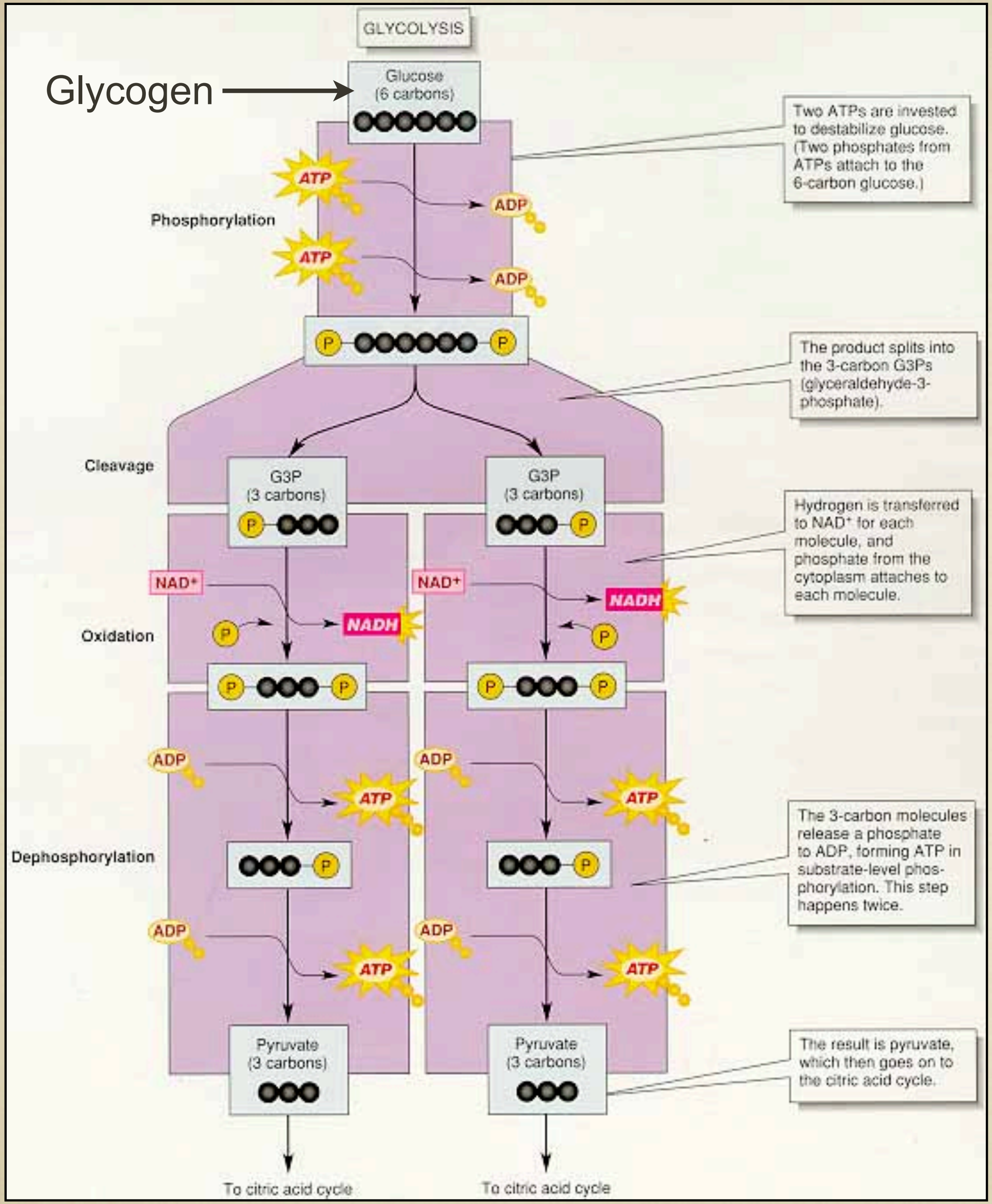
Cleavage
G3P
(3 carbons)
G3P
(3 carbons)
Hydrogen is transferred to NAD+ for each molecule, and phosphate from the cytoplasm attaches to each molecule.
NAD+
NAD+
NADH
NADH
Oxidation
ADP
ATP
ADP
ATP
Dephosphorylation
The 3-carbon molecules release a phosphate to ADP, forming ATP in substrate-level phosphorylation. This step happens twice.
ADP
ATP
ADP
ATP
Pyruvate
(3 carbons)
Pyruvate
(3 carbons)
The result is pyruvate, which then goes on to the citric acid cycle.
To citric acid cycle
To citric acid cycle


CH2OH
H
O
OH
H
C
C
H
OH
H
HO
C
C
H
H
OH


GLYCOLYSIS
Glycogen
Glucose
(6 carbons)
ATP
ADP
ATP
ADP
Phosphorylation
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P
P
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Cleavage
G3P
(3 carbons)
G3P
(3 carbons)
Hydrogen is transferred to NAD+ for each molecule, and phosphate from the cytoplasm attaches to each molecule.
NAD+
NADH
NAD+
NADH
Oxidation
ADP
ATP
ADP
ATP
Dephosphorylation
The 3-carbon molecules release a phosphate to ADP, forming ATP in substrate-level phosphorylation. This step happens twice.
ADP
ATP
ADP
ATP
Pyruvate
(3 carbons)
Pyruvate
(3 carbons)
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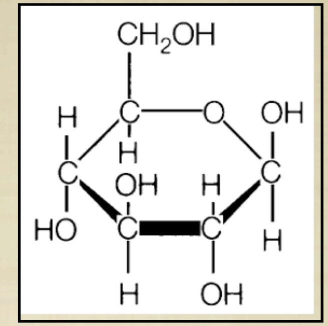
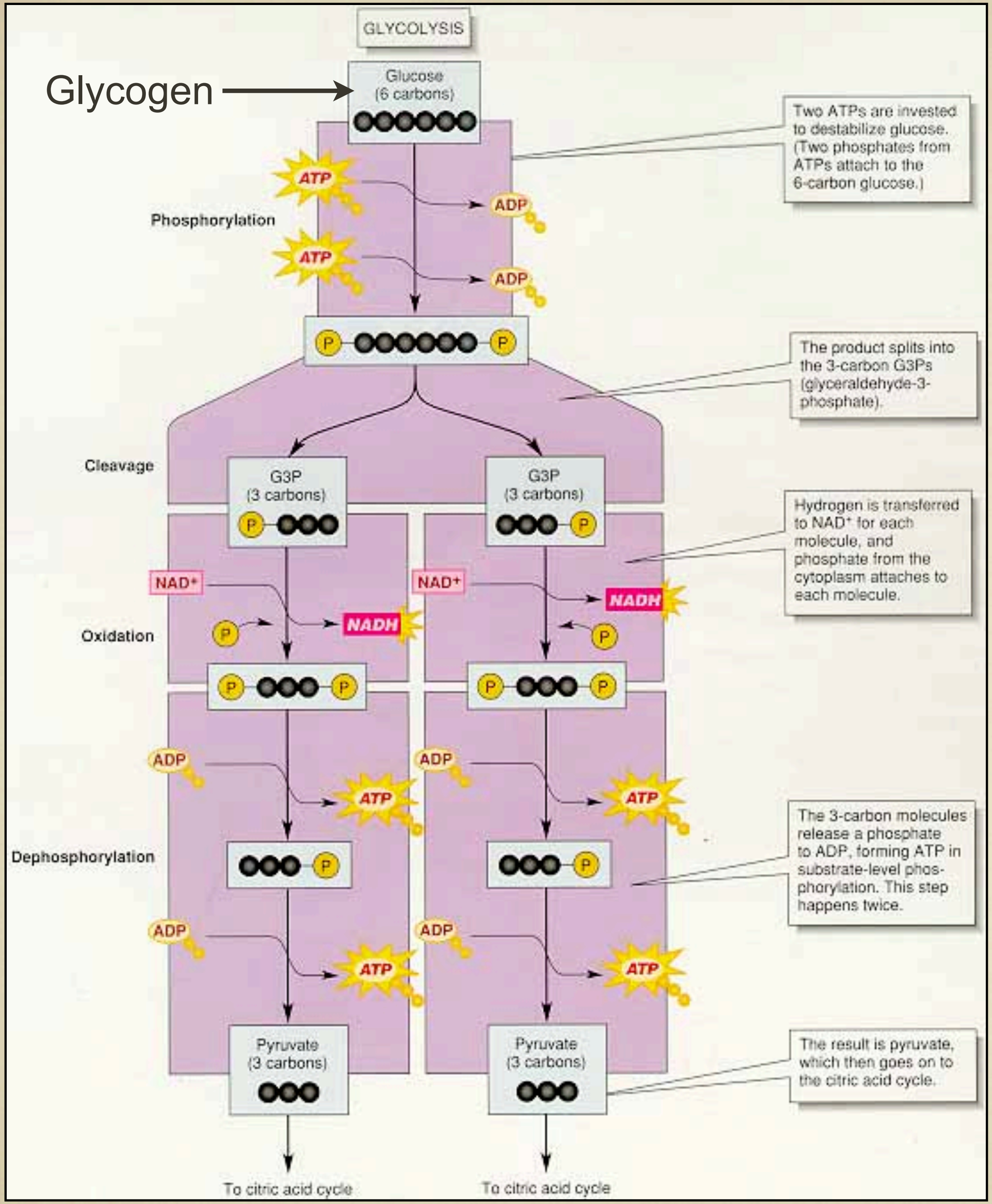
To citric acid cycle
To citric acid cycle


CH2OH
H
C
O
OH
H
C
OH
H
C
HO
C
C
H
H
OH



GLYCOLYSIS
Glycogen
Glucose (6 carbons)
Two ATPs are invested to destabilize glucose. (Two phosphates from ATPs attach to the 6-carbon glucose.)
ATP
ADP
Phosphorylation
ATP
ADP
P
P
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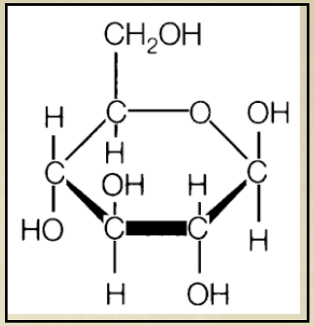
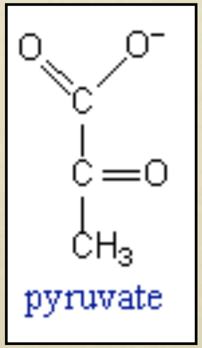
Cleavage
G3P (3 carbons)
G3P (3 carbons)
P
P
Hydrogen is transferred to NAD+ for each molecule, and phosphate from the cytoplasm attaches to each molecule.
NAD+
NAD+
NADH
NADH
Oxidation
P
P
ADP
ATP
ADP
ATP
Dephosphorylation
The 3-carbon molecules release a phosphate to ADP, forming ATP in substrate-level phosphorylation. This step happens twice.
ADP
ATP
ADP
ATP
Pyruvate (3 carbons)
Pyruvate (3 carbons)
The result is pyruvate, which then goes on to the citric acid cycle.
To citric acid cycle
To citric acid cycle

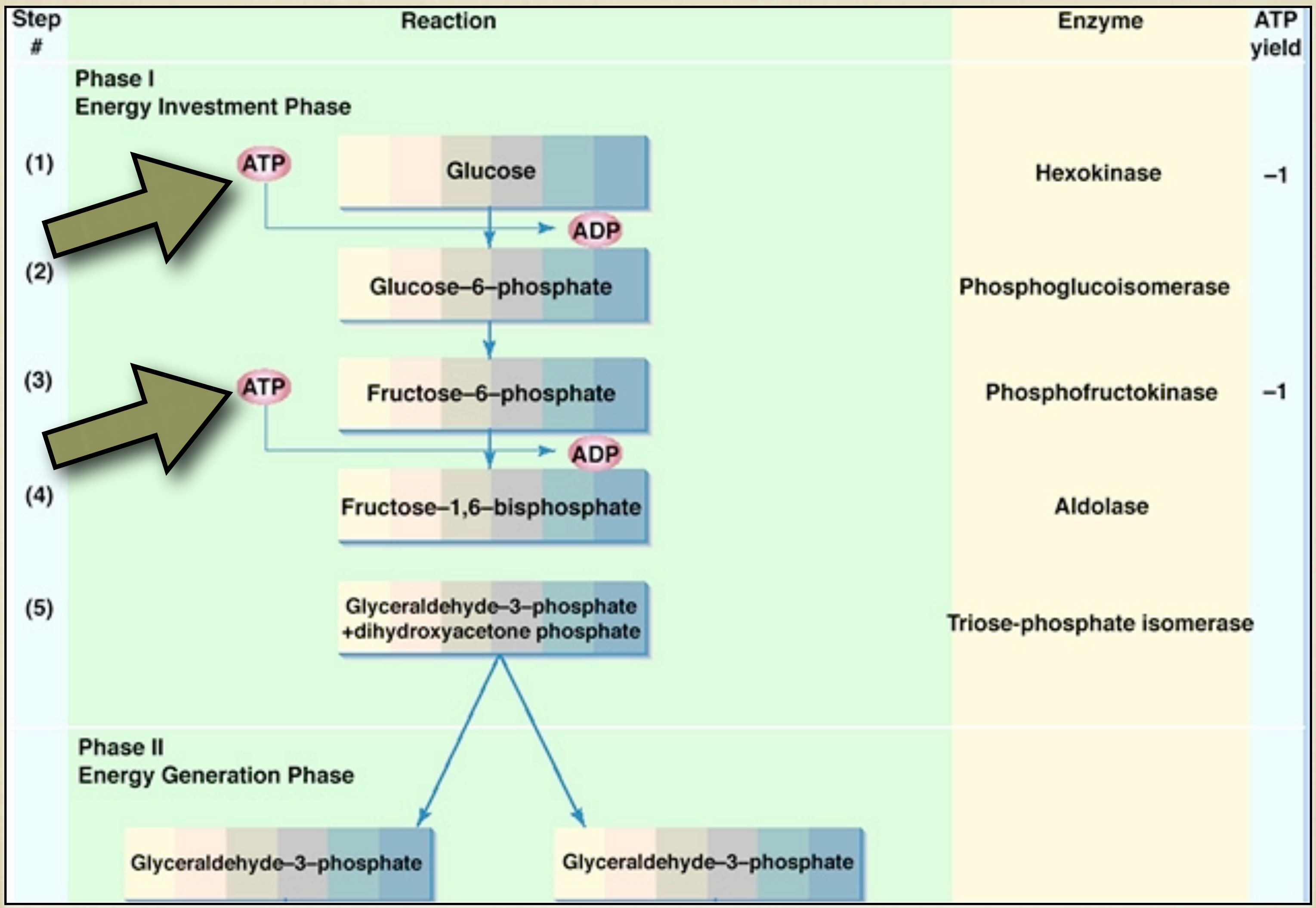




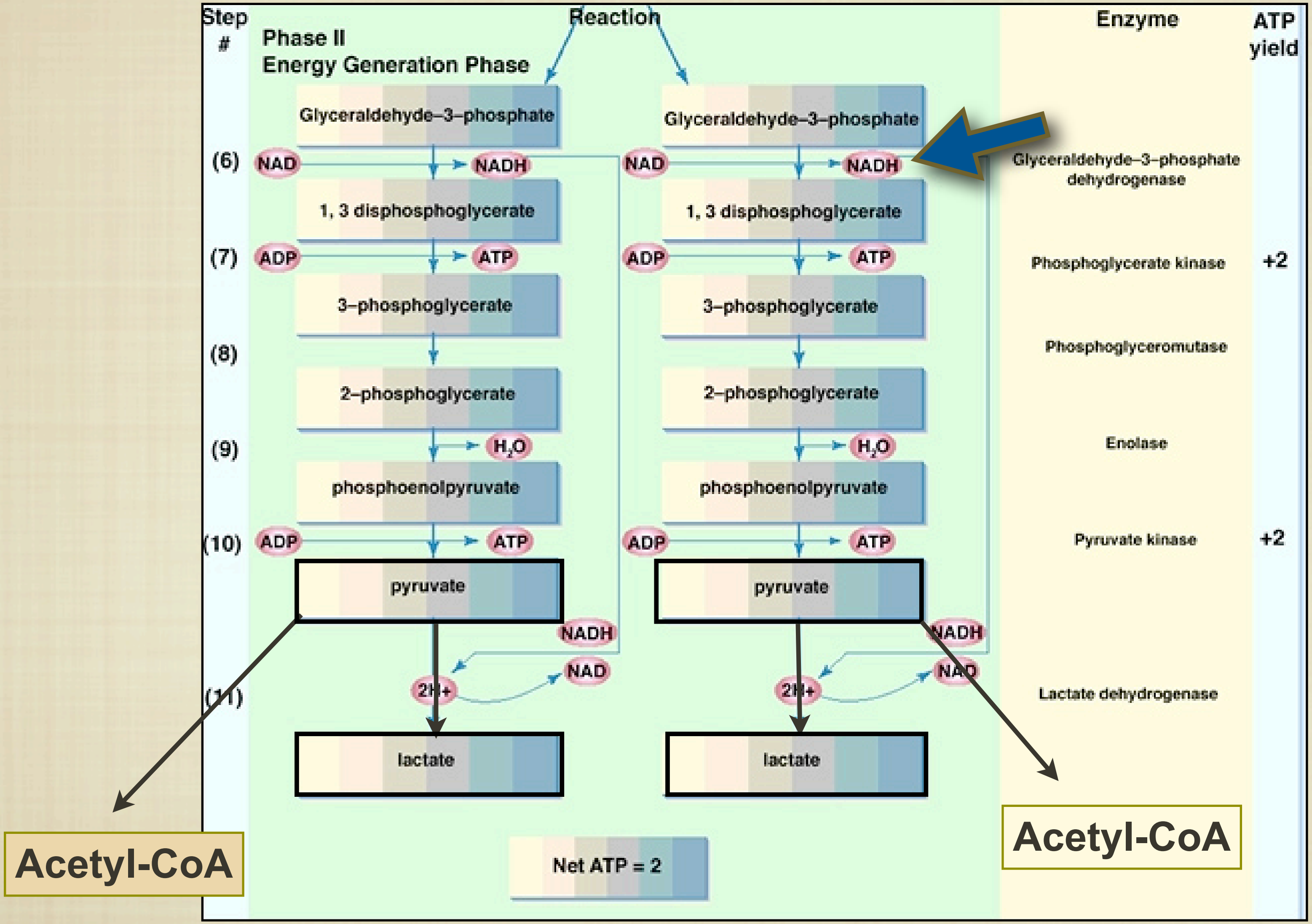
pyruvate

Glycolysis

ATP REQUIRED



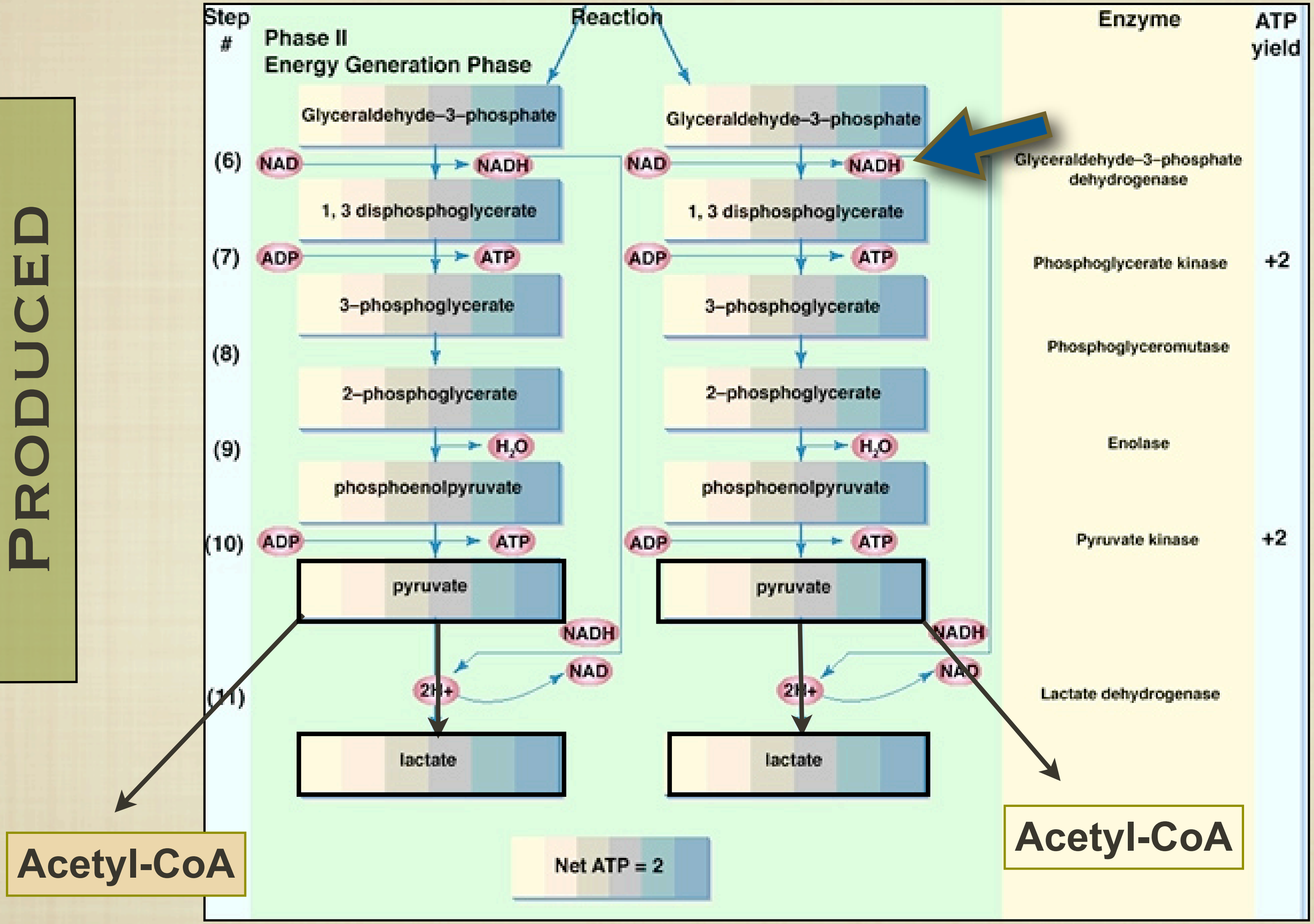
Glycolysis



End product = pyruvate

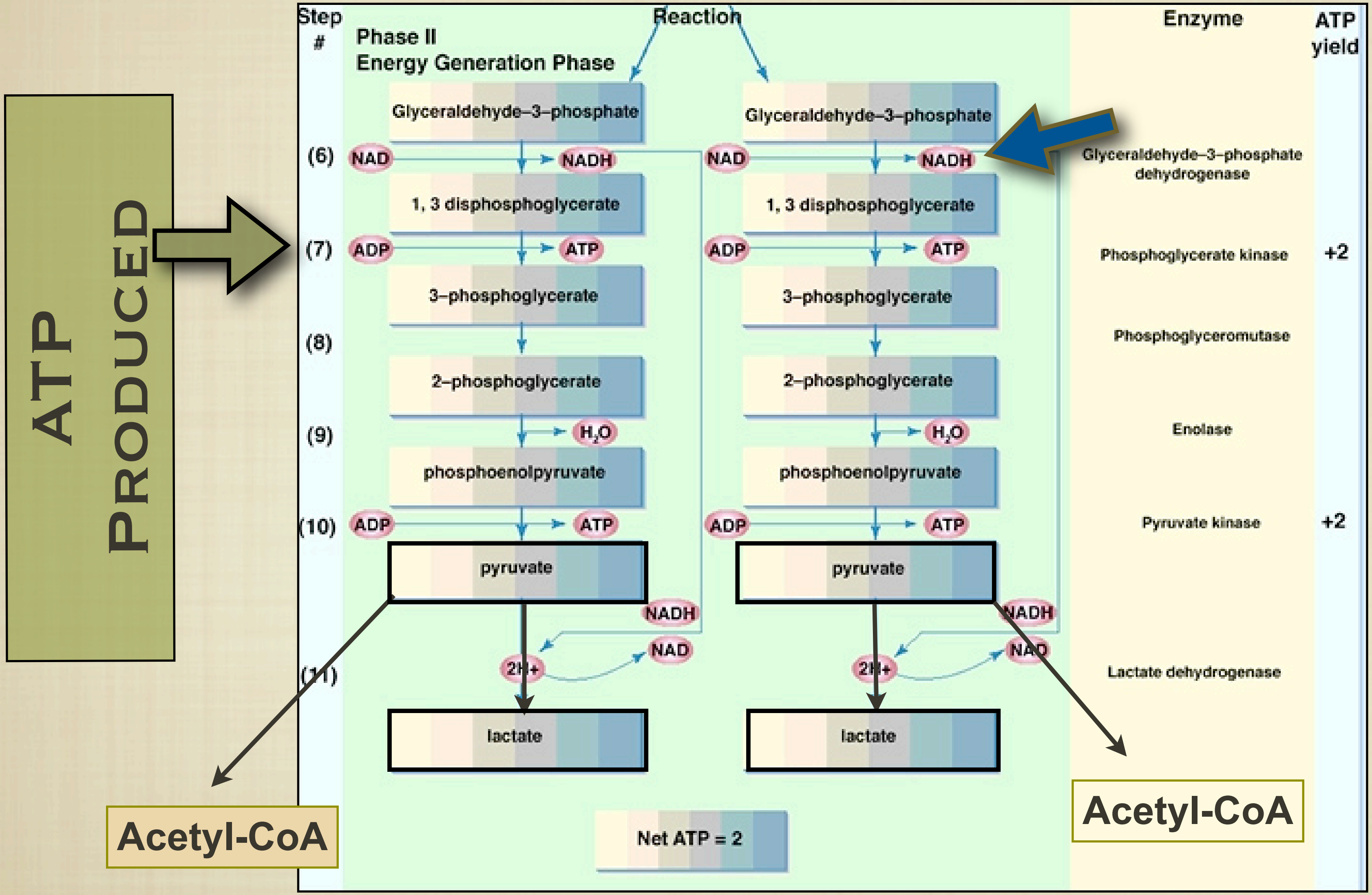
Glycolysis

ATP Produced



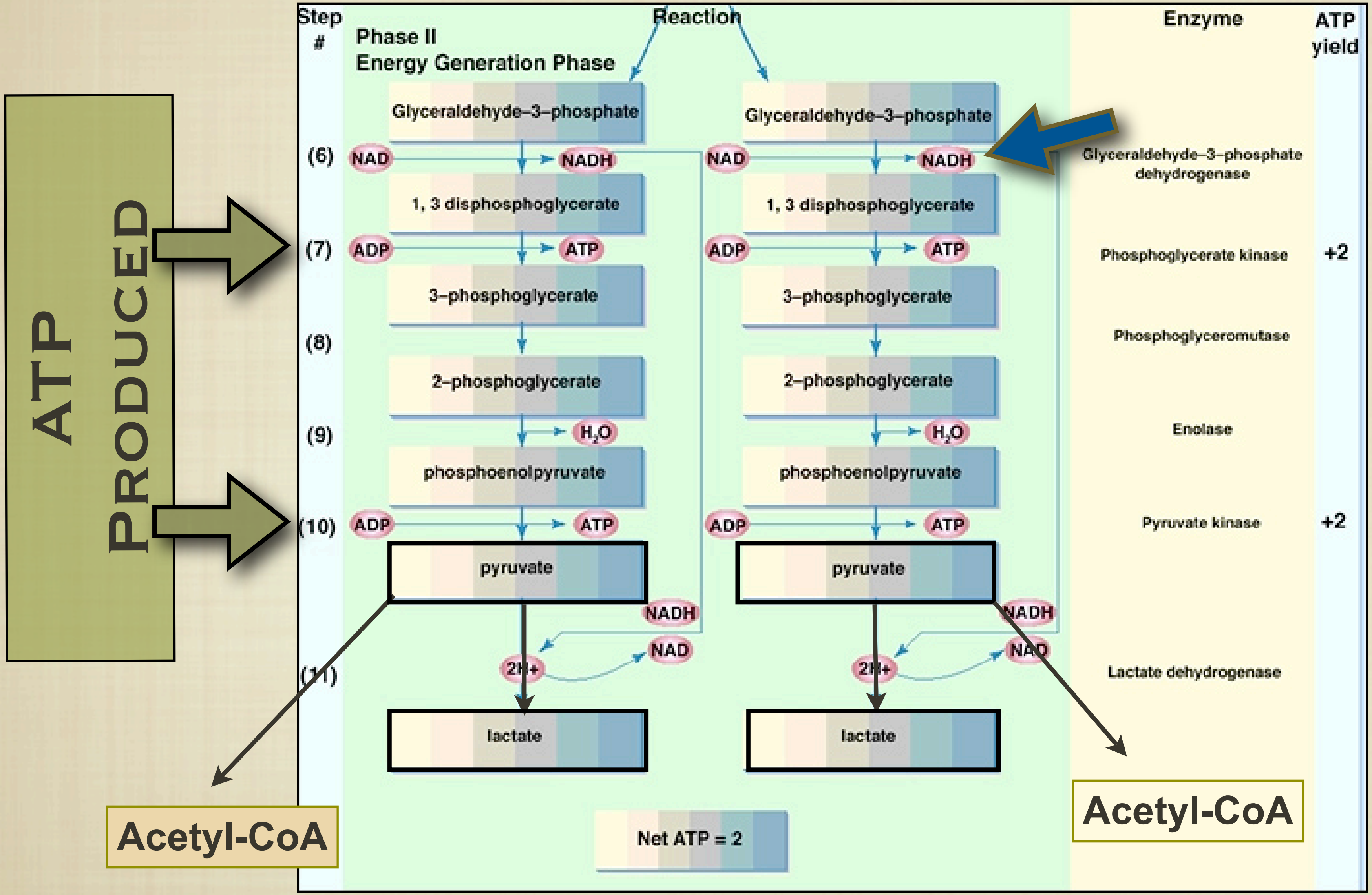
End product = pyruvate

Glycolysis

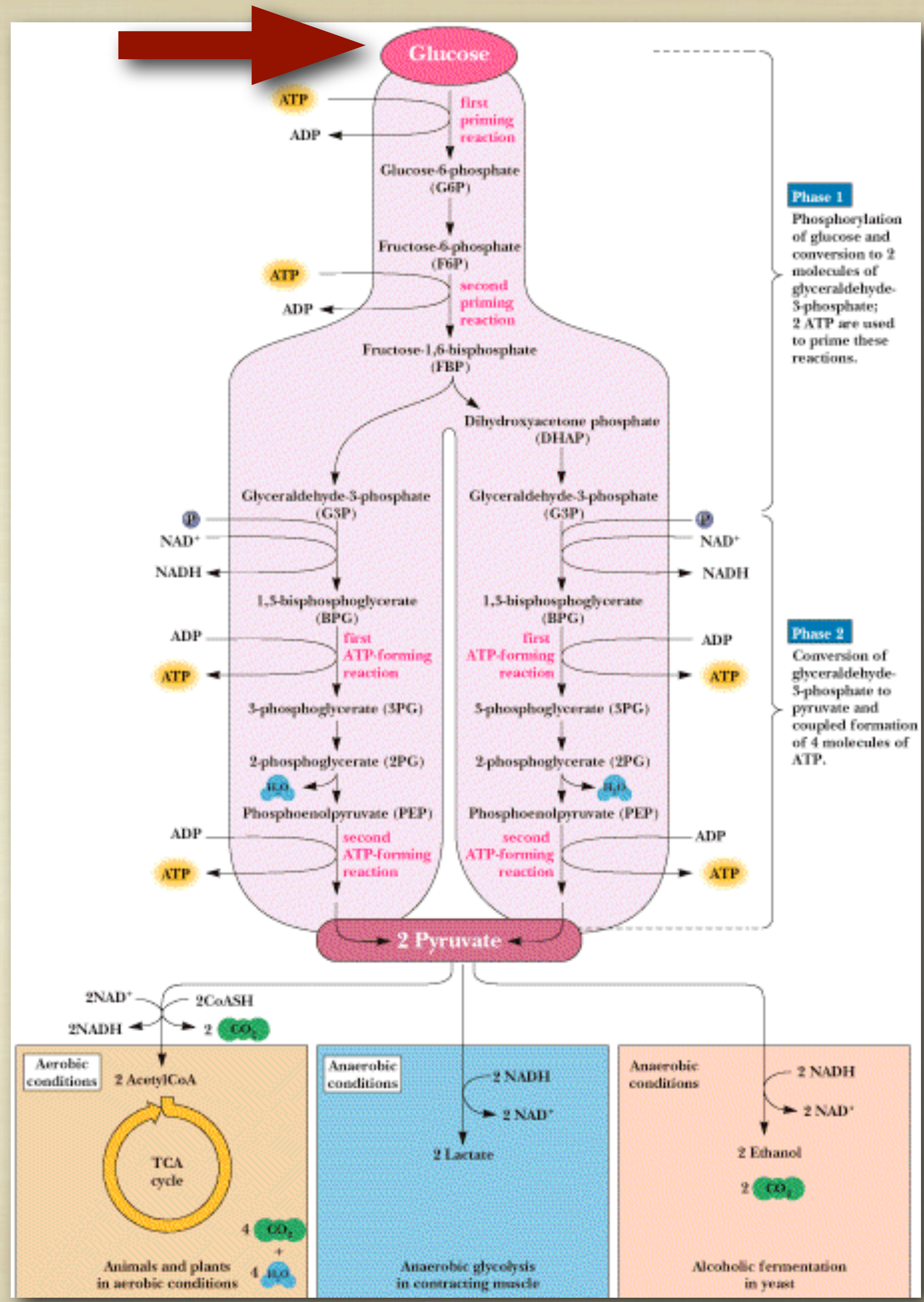


End product = pyruvate

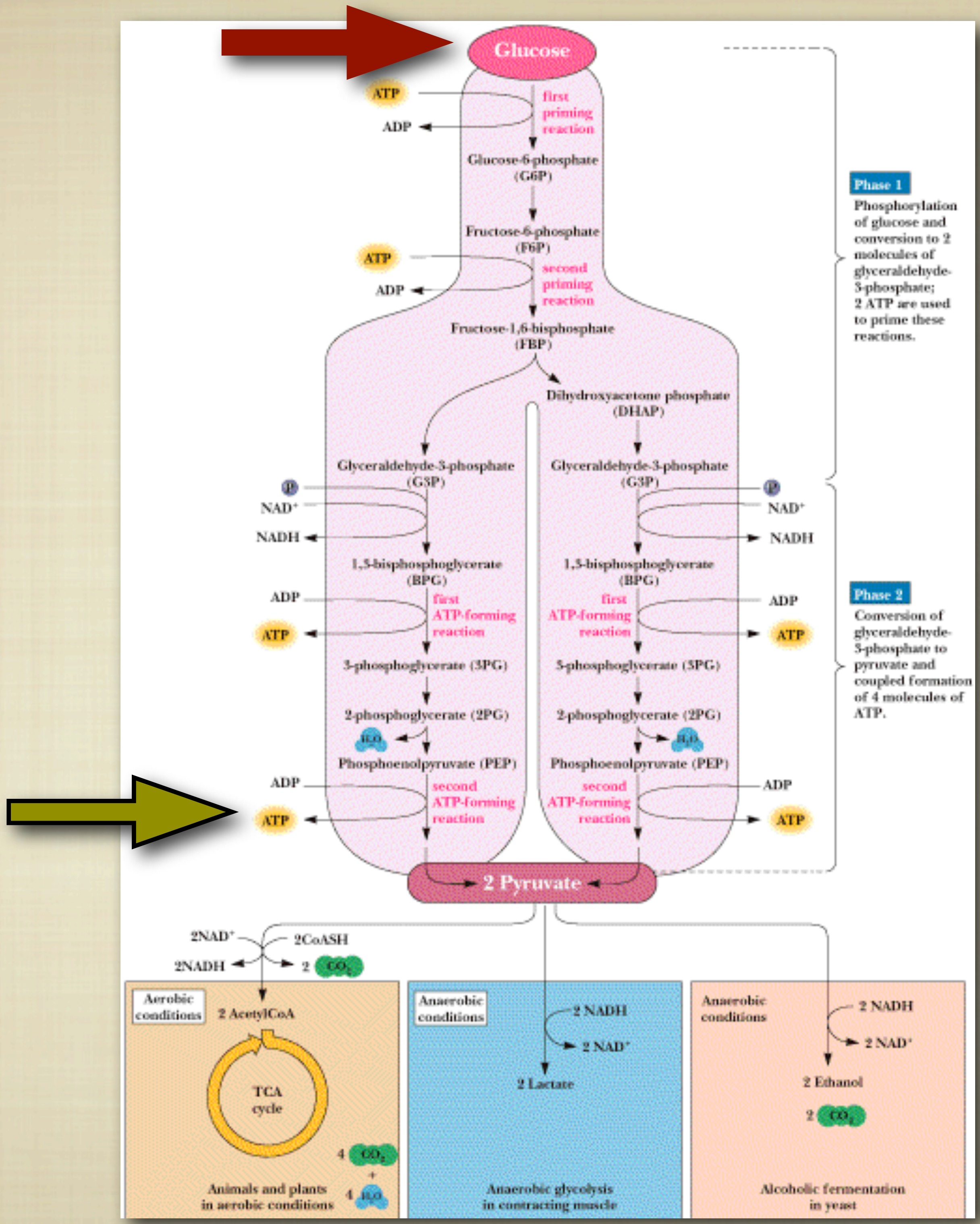
Glycolysis



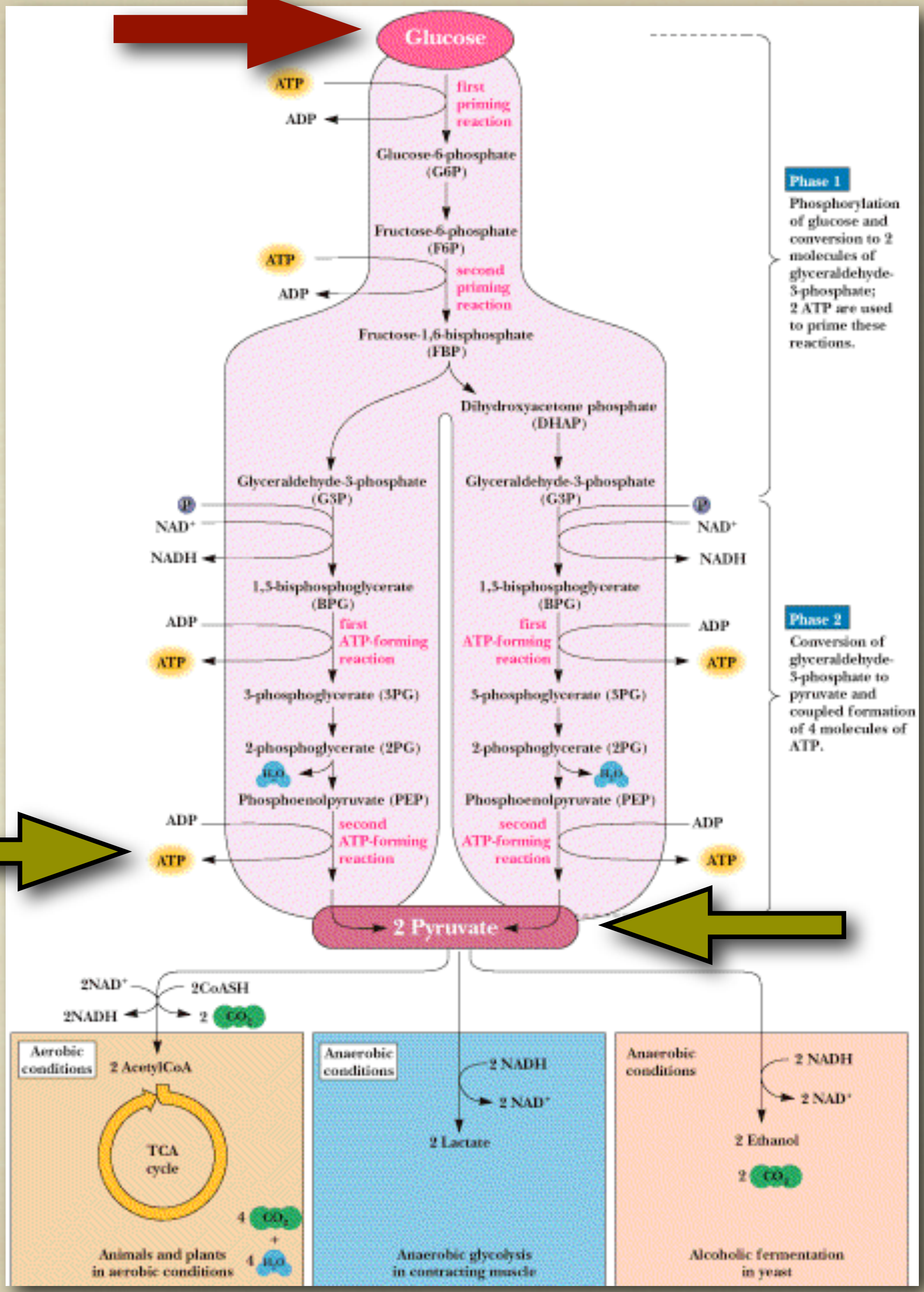
End product = pyruvate



Glucose
ATP
ADP
first priming reaction
Glucose-6-phosphate (G6P)
Fructose-6-phosphate (F6P)
ATP
ADP
second priming reaction
Fructose-1,6-bisphosphate (FBP)
Dihydroxyacetone phosphate (DHAP)
Glyceraldehyde-3-phosphate (G3P)
Glyceraldehyde-3-phosphate (G3P)
NAD+
NADH
1,3-bisphosphoglycerate (BPG)
ADP
first ATP-forming reaction
ATP
3-phosphoglycerate (3PG)
2-phosphoglycerate (2PG)
Phosphoenolpyruvate (PEP)
second ATP-forming reaction
2 Pyruvate
Phase 1
Phosphorylation of glucose and conversion to 2 molecules of glyceraldehyde-3-phosphate; 2 ATP are used to prime these reactions.
Phase 2
Conversion of glyceraldehyde-3-phosphate to pyruvate and coupled formation of 4 molecules of ATP.
2NAD+
2CoASH
2NADH
2 CO2
Aerobic conditions
2 AcetylCoA
TCA cycle
4 CO2
+
4 H2O
Animals and plants in aerobic conditions
Anaerobic conditions
2 NADH
2 NAD+
2 Lactate
Anaerobic glycolysis in contracting muscle
Anaerobic conditions
2 NADH
2 NAD+
2 Ethanol
2 CO2
Alcoholic fermentation in yeast



Glucose
ATP
ADP
first priming reaction
Glucose-6-phosphate (G6P)
Fructose-6-phosphate (F6P)
second priming reaction
Fructose-1,6-bisphosphate (FBP)
Dihydroxyacetone phosphate (DHAP)
Glyceraldehyde-3-phosphate (G3P)
NAD+
NADH
1,3-bisphosphoglycerate (BPG)
first ATP-forming reaction
3-phosphoglycerate (3PG)
2-phosphoglycerate (2PG)
Phosphoenolpyruvate (PEP)
second ATP-forming reaction
2 Pyruvate
Phase 1
Phosphorylation of glucose and conversion to 2 molecules of glyceraldehyde-3-phosphate; 2 ATP are used to prime these reactions.
Phase 2
Conversion of glyceraldehyde-3-phosphate to pyruvate and coupled formation of 4 molecules of ATP.
2NAD+
2NADH
2CoASH
2 CO2
Aerobic conditions
2 AcetylCoA
TCA cycle
4 CO2
4 H2O
Animals and plants in aerobic conditions
Anaerobic conditions
2 NADH
2 NAD+
2 Lactate
Anaerobic glycolysis in contracting muscle
2 Ethanol
2 CO2
Alcoholic fermentation in yeast


Glucose
ATP
ADP
first priming reaction
Glucose-6-phosphate (G6P)
Fructose-6-phosphate (F6P)
ATP
ADP
second priming reaction
Fructose-1,6-bisphosphate (FBP)
Dihydroxyacetone phosphate (DHAP)
Glyceraldehyde-3-phosphate (G3P)
Glyceraldehyde-3-phosphate (G3P)
P
NAD+
NADH
1,3-bisphosphoglycerate (BPG)
ADP
ATP
first ATP-forming reaction
3-phosphoglycerate (3PG)
2-phosphoglycerate (2PG)
H_2O
Phosphoenolpyruvate (PEP)
ADP
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second ATP-forming reaction
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+
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Animals and plants in aerobic conditions
Anaerobic conditions
2 NADH
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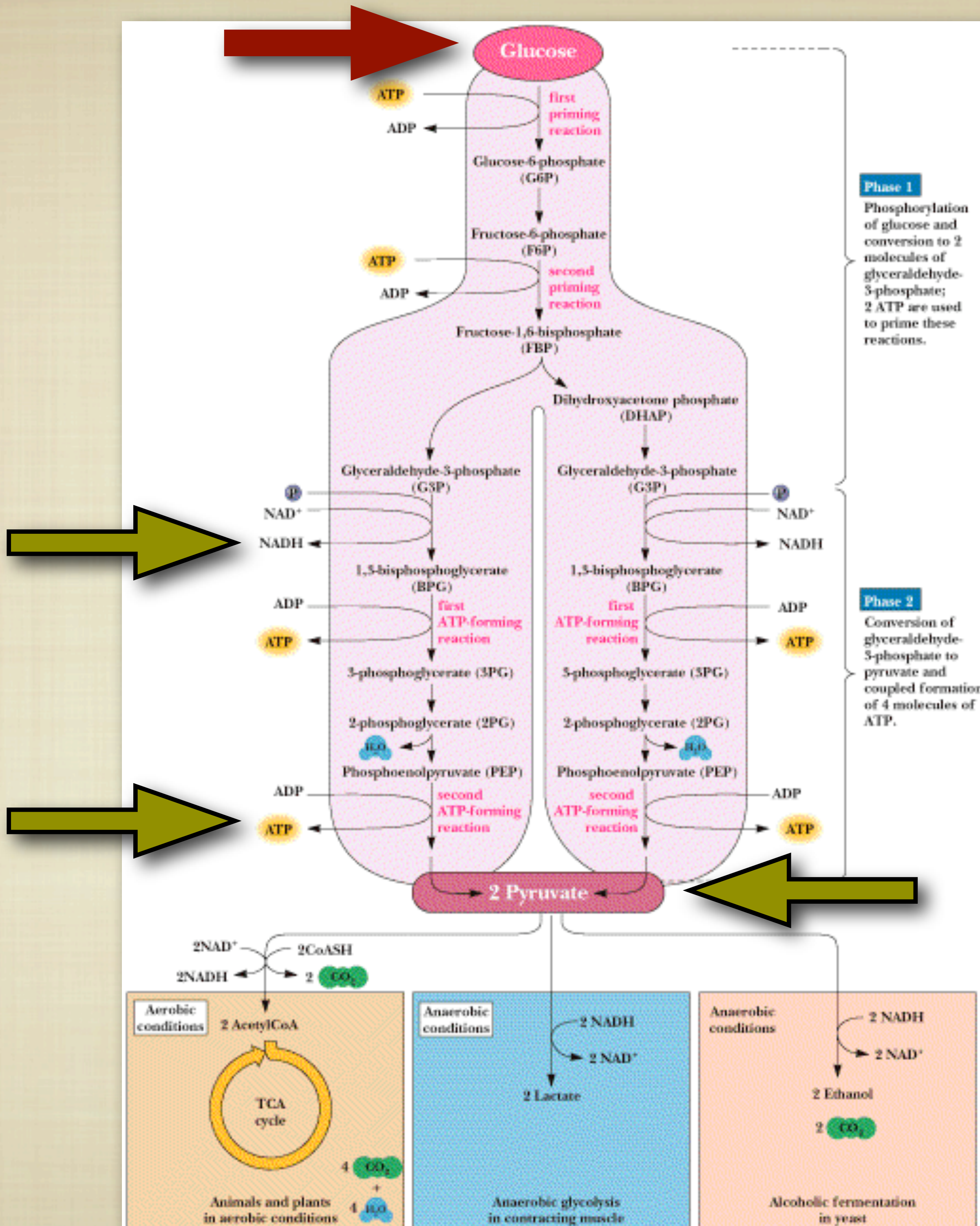
Anaerobic glycolysis in contracting muscle
Anaerobic conditions
2 NADH
2 NAD+
2 Ethanol
2 CO_2
Alcoholic fermentation in yeast


Glucose
ATP
ADP
first priming reaction
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Anaerobic conditions
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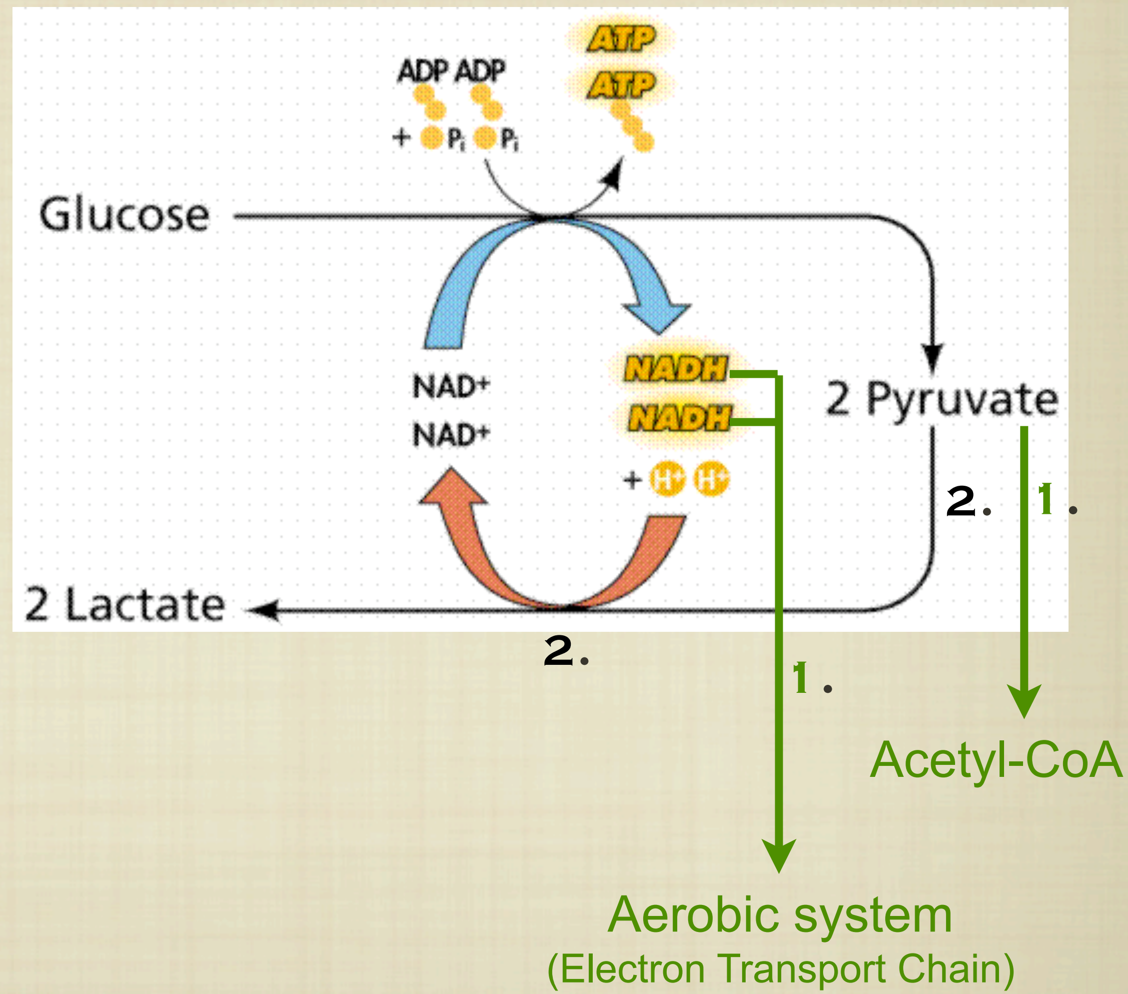
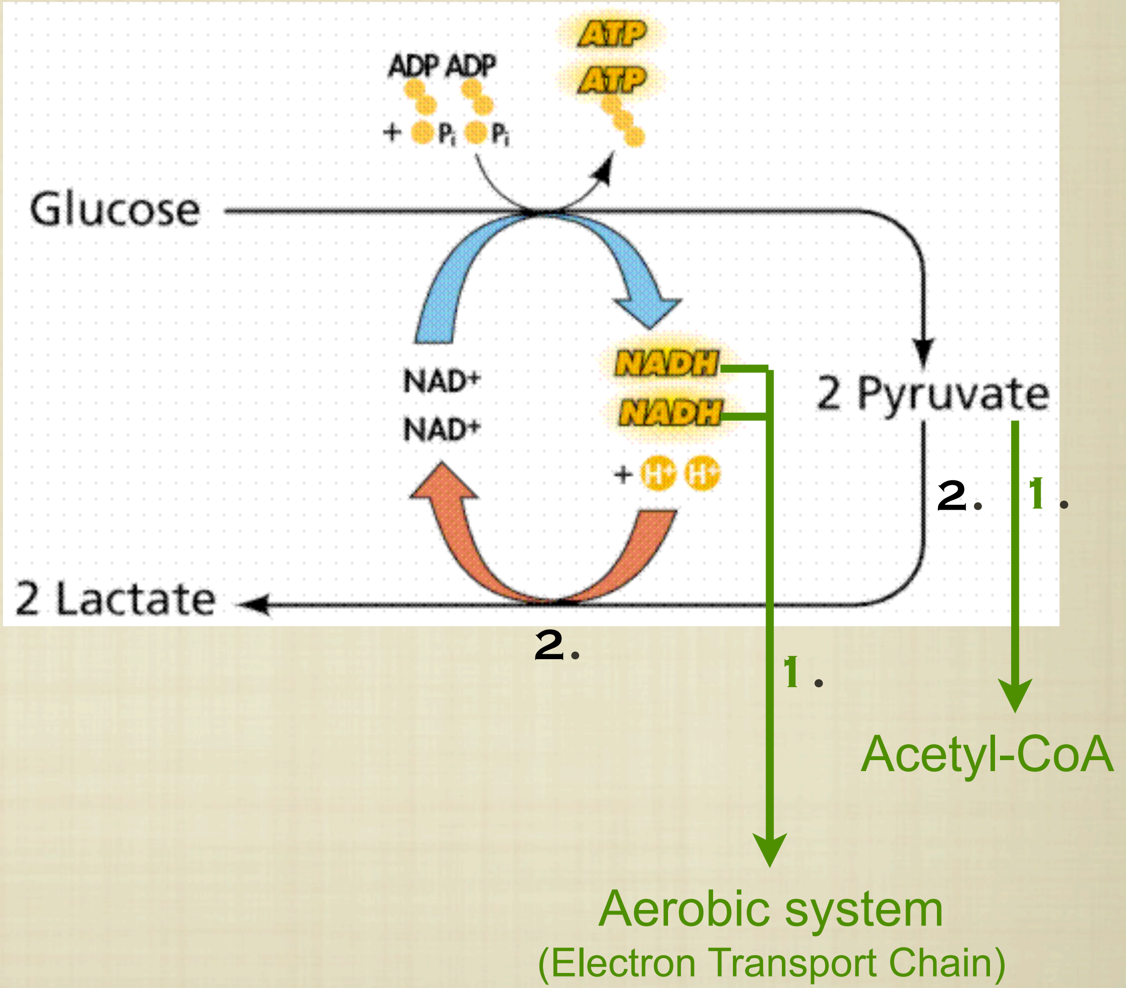
2 Lactate
Anaerobic glycolysis in contracting muscle
Anaerobic conditions
2 Ethanol
2 CO2
Alcoholic fermentation in yeast

Glycolysis


ATP
ATP
ADP ADP
+ Pi Pi
Glucose
NADH
NADH
NAD+
NAD+
+ H+ H+
2 Pyruvate
2.
1.
2 Lactate
2.
1.
Acetyl-CoA
Aerobic system
(Electron Transport Chain)

Glycolysis

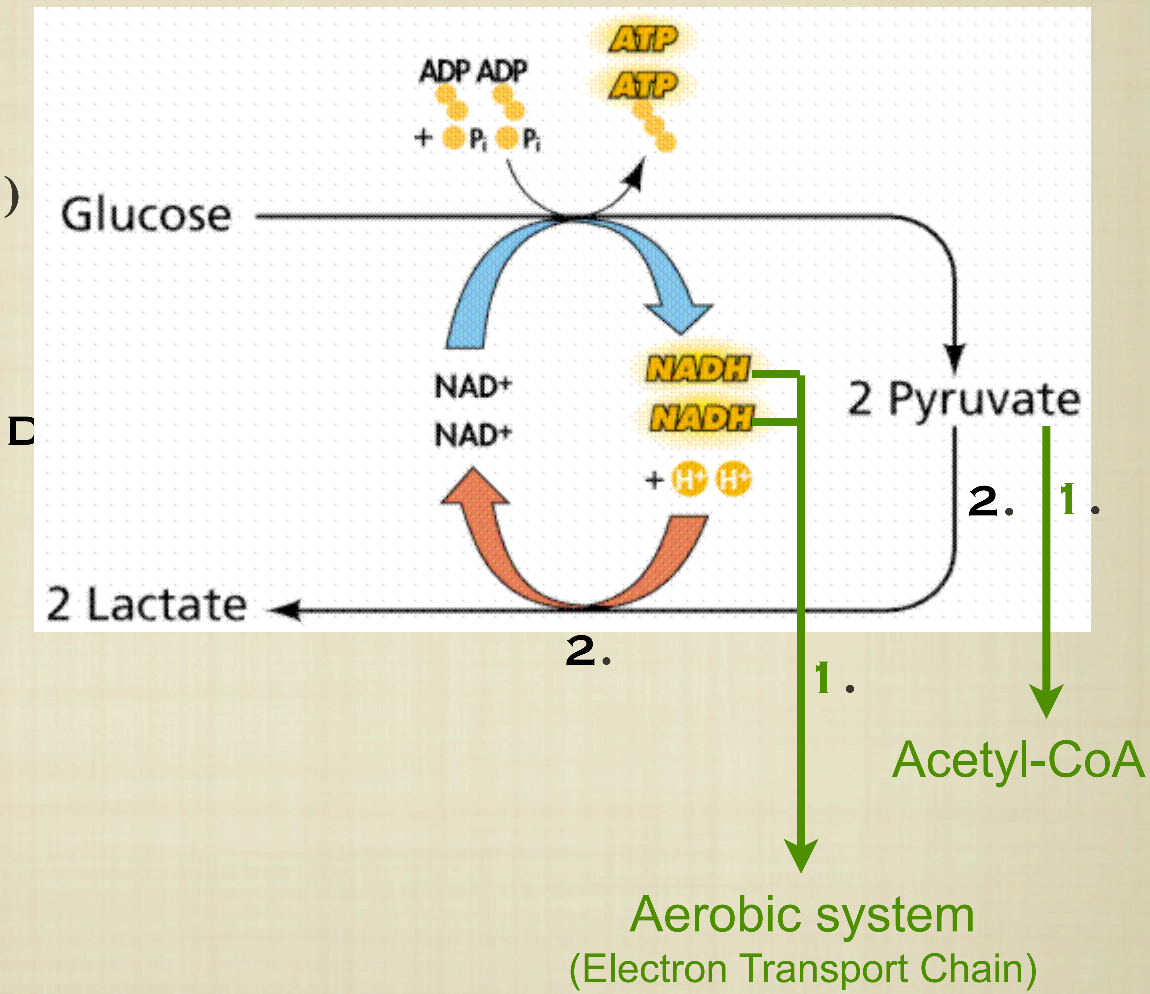
- ATP



Glycolysis

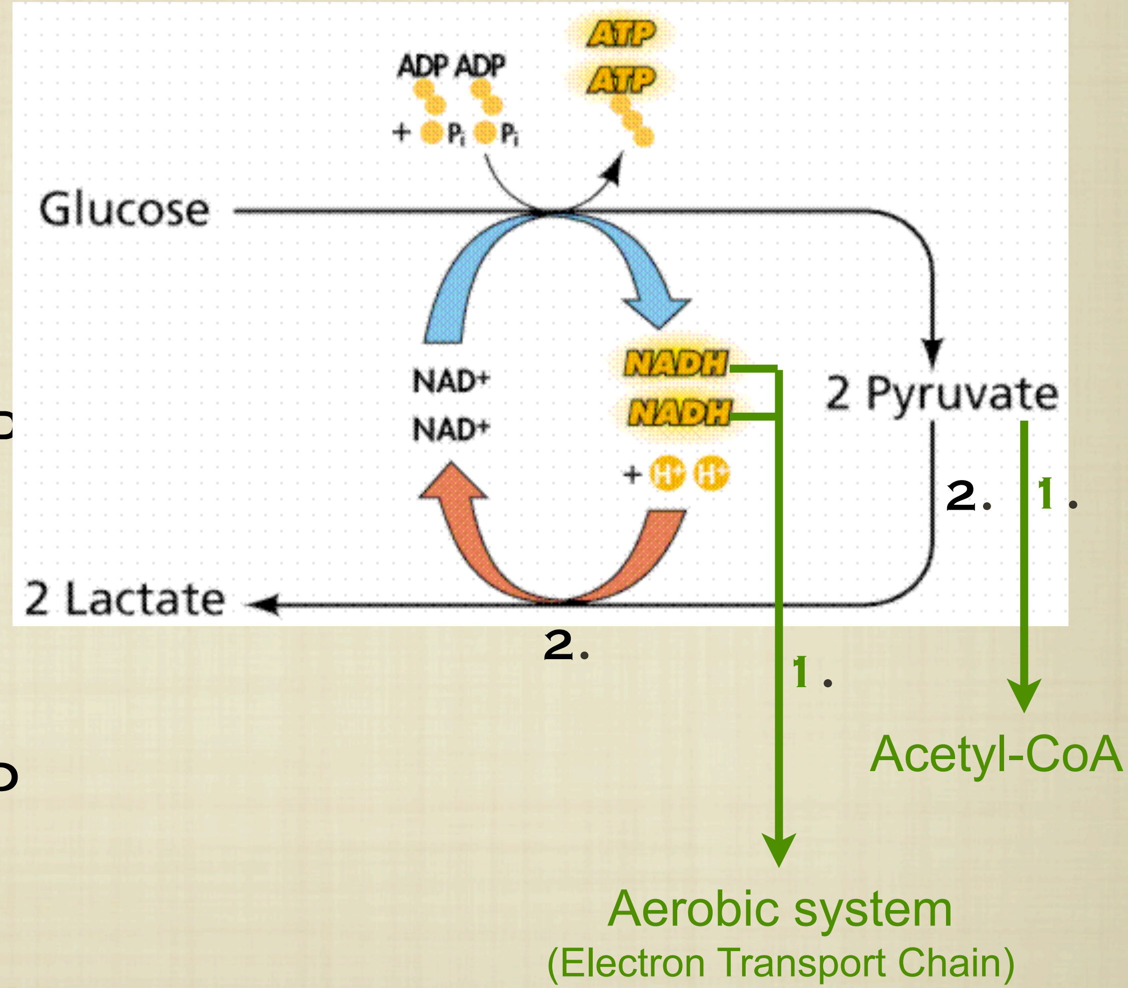
- ATP
- Pyruvate (pyruvic acid)

1. Actyl-CoA
2. Lactate (lacatic acid



Glycolysis

- ATP
- Pyruvate (pyruvic acid)
  1. Actyl-CoA
  2. Lactate (lacatic acid
- H (NADH)
  1. Aerobic system
  2. Convert pyruvate to lactate



Glycolysis

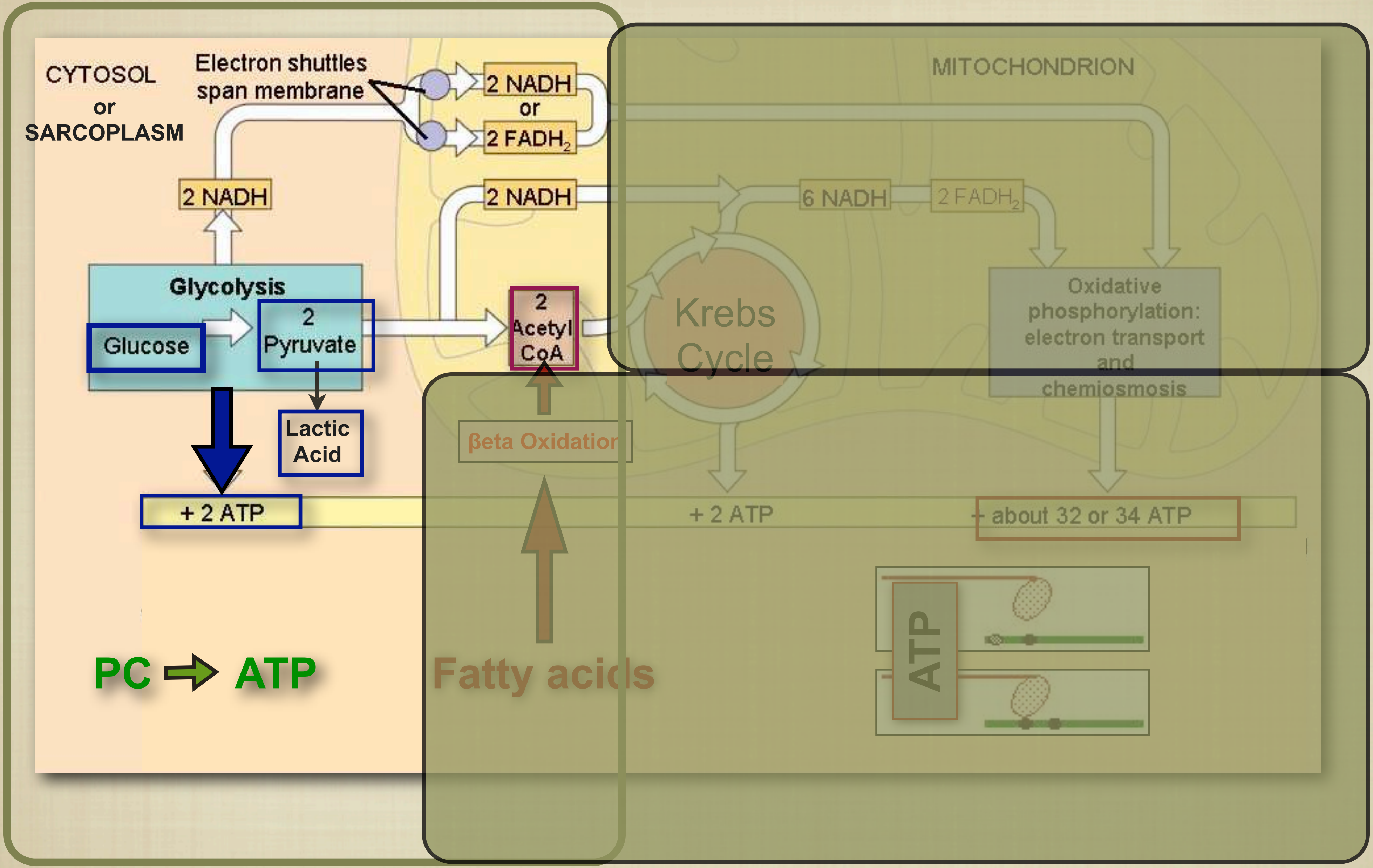
Glycolysis

- Advantages?

Glycolysis

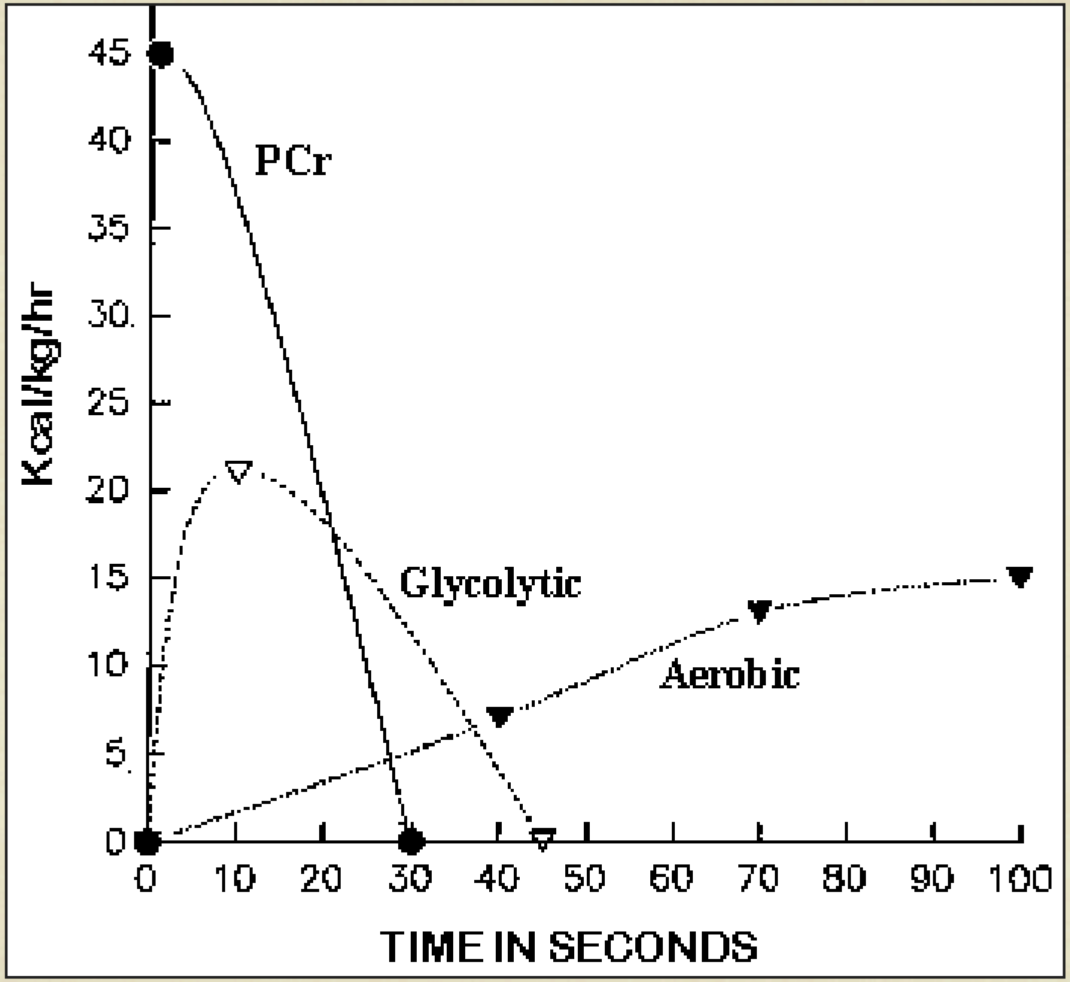
- Advantages?
- Disadvantages?

Anaerobic Aerobic



Anaerobic Systems

Intensity



Note the over lapping of the systems

Aerobic Metabolism

Aerobic Metabolism
or Oxidative Phosphorylation

Aerobic Metabolism
or Oxidative Phosphorylation

- Where? Mitochondria

Aerobic Metabolism
or Oxidative Phosphorylation

- Where? Mitochondria
- Three pathways

Aerobic Metabolism
or Oxidative Phosphorylation

- Where? Mitochondria
- Three pathways
  - Krebs cycle

Aerobic Metabolism
or Oxidative Phosphorylation

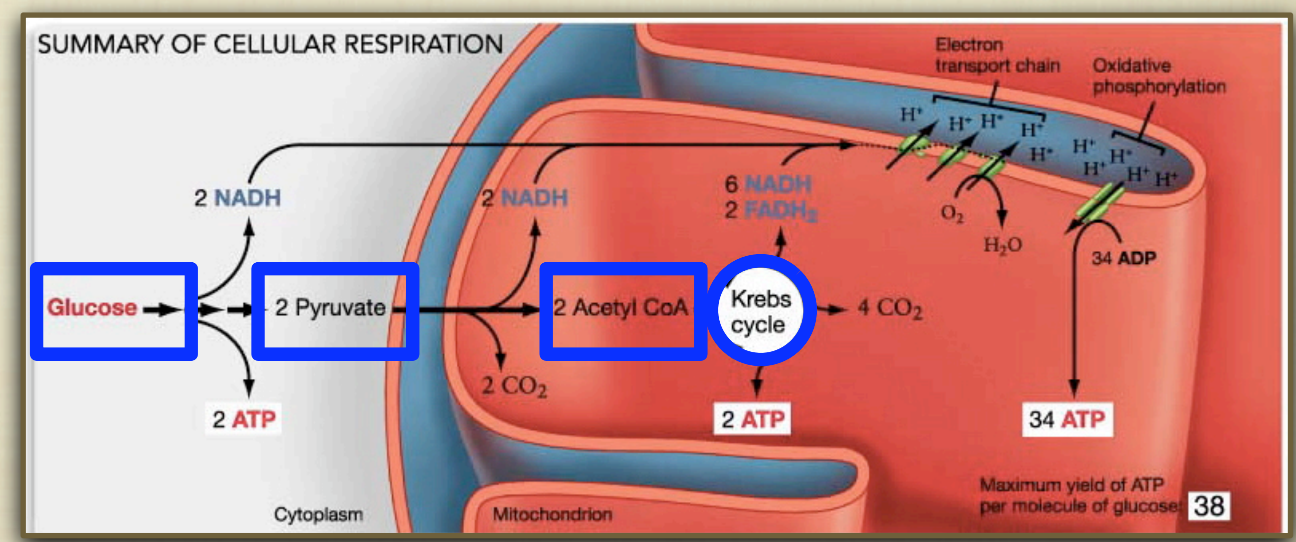
- Where? Mitochondria
- Three pathways
  - Krebs cycle
  - Beta oxidation (fats only)

Aerobic Metabolism
or Oxidative Phosphorylation

- Where? Mitochondria
- Three pathways
    - Krebs cycle
    - Beta oxidation (fats only)
    - Electron transport chain

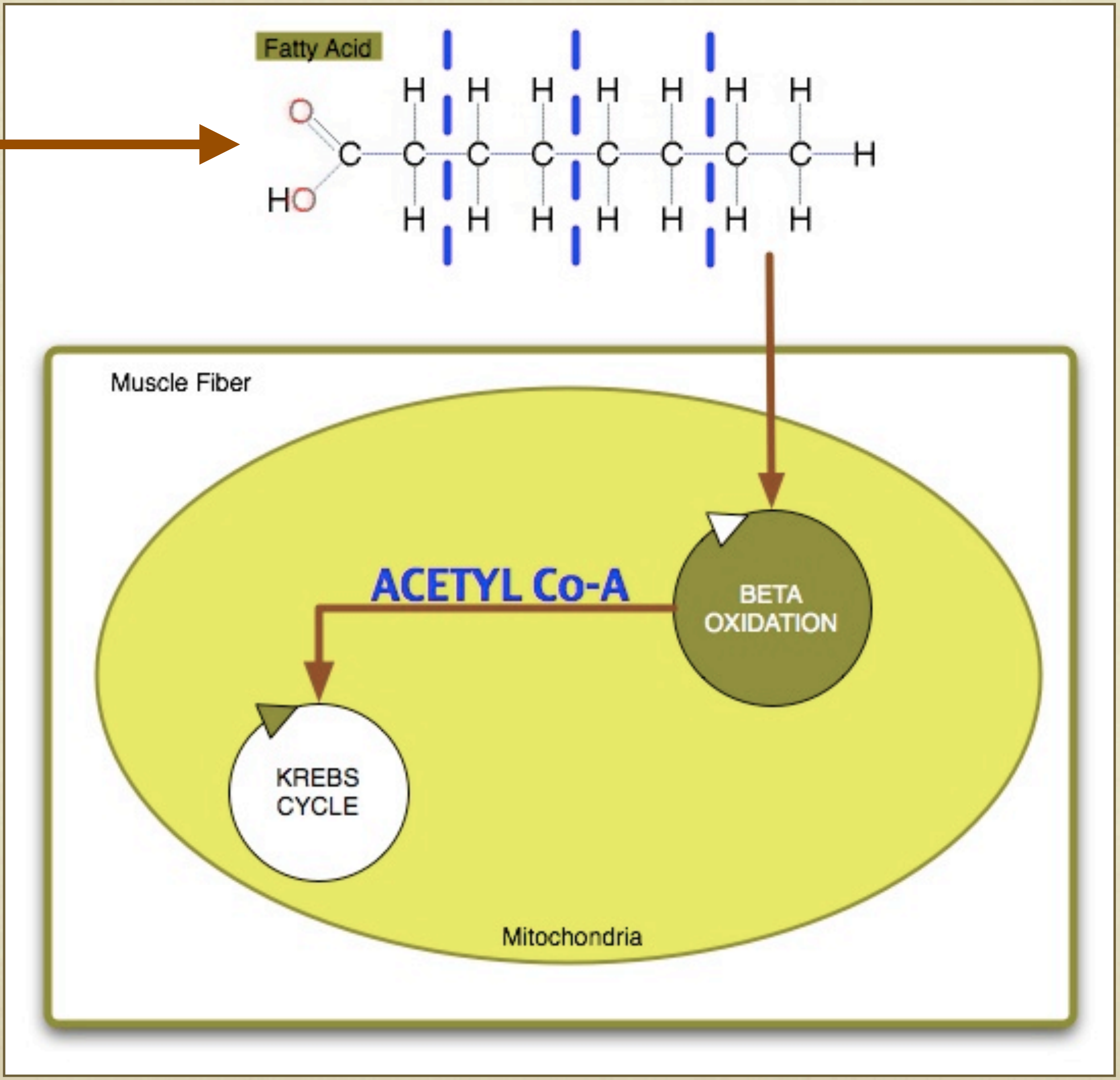
Acetyl-CoA

- Glucose, Fat and Protein
- Krebs cycle



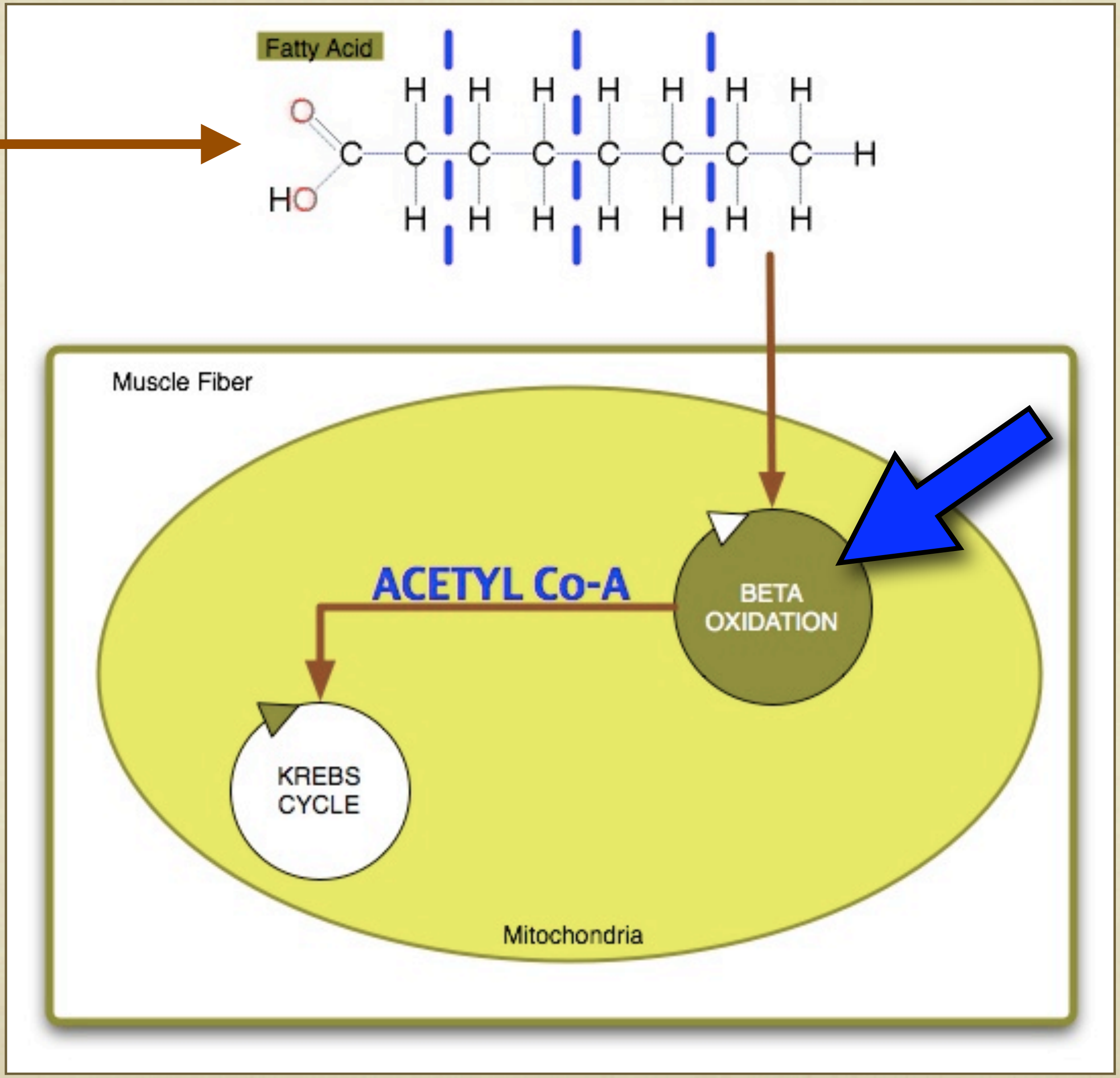
Beta Oxidation

Fat



Beta Oxidation

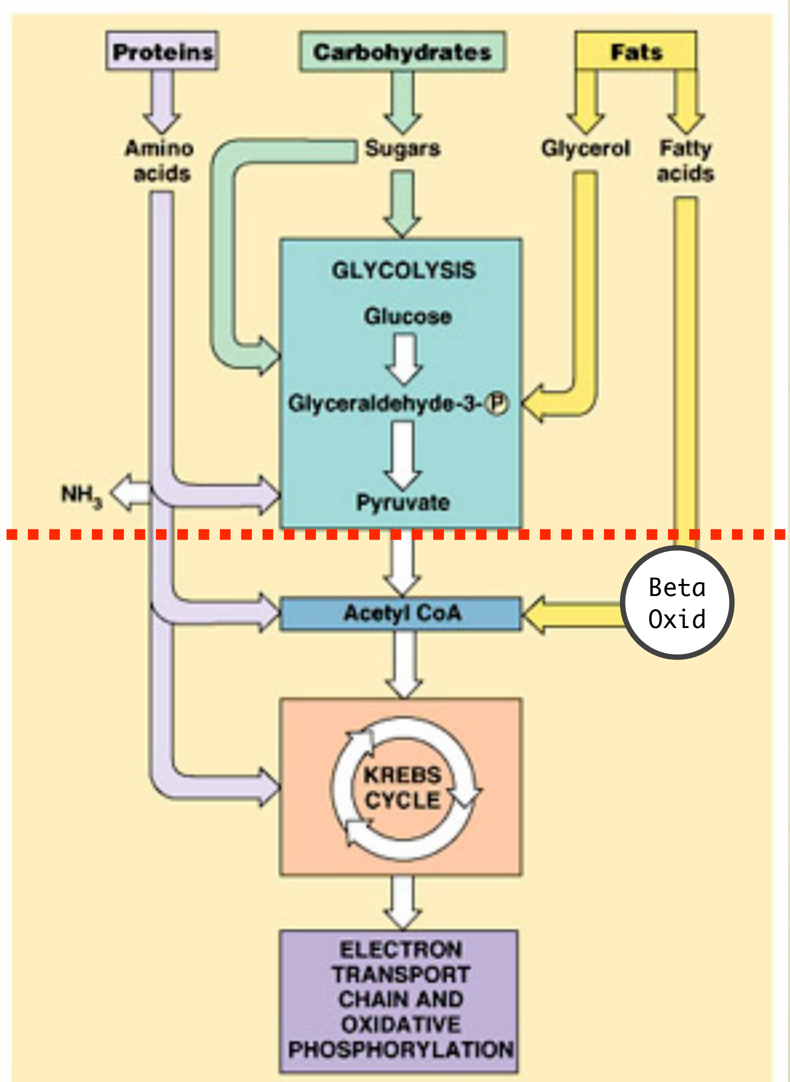
Fat



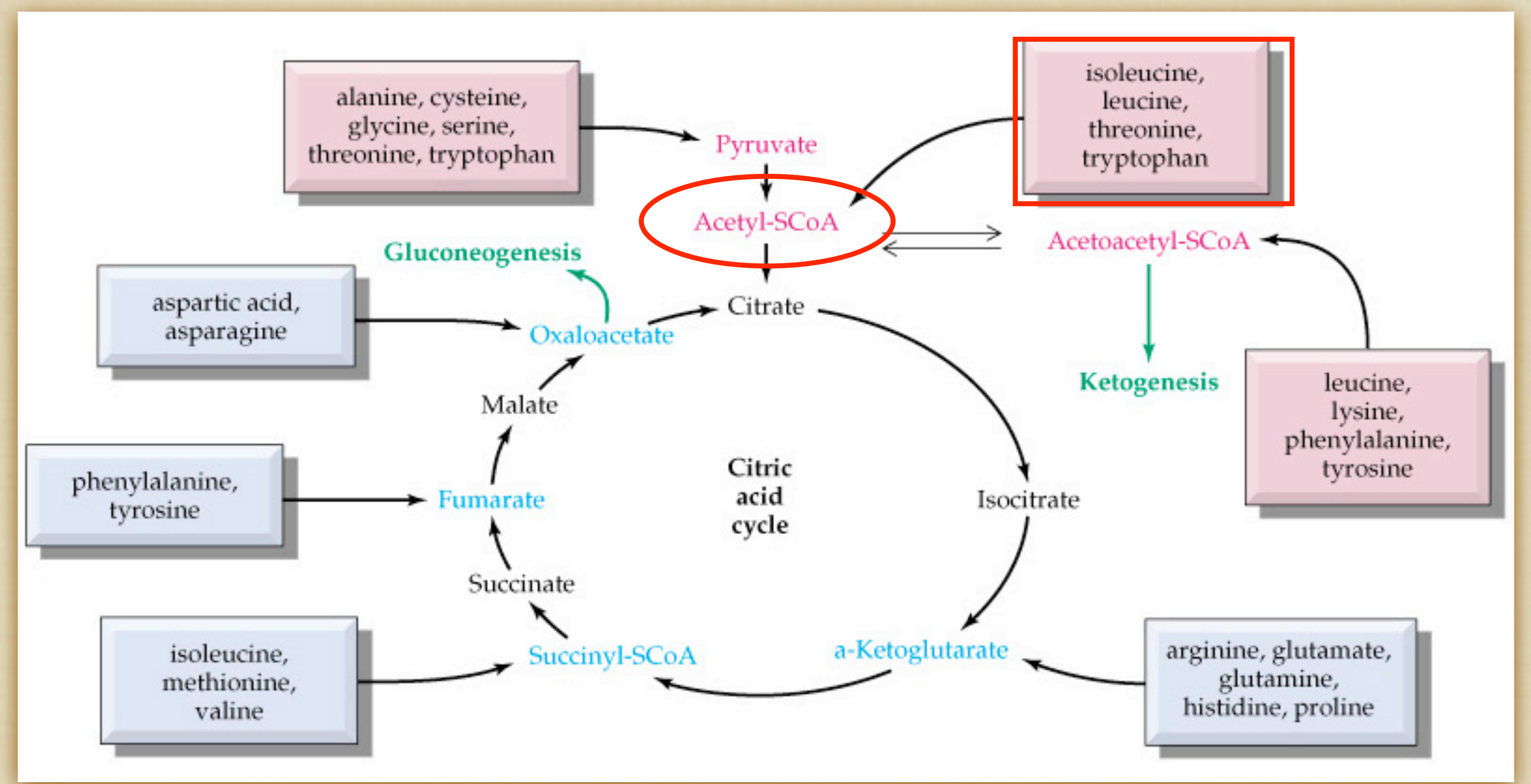
Acetyl-CoA

Sarcoplasm

Mitochondria

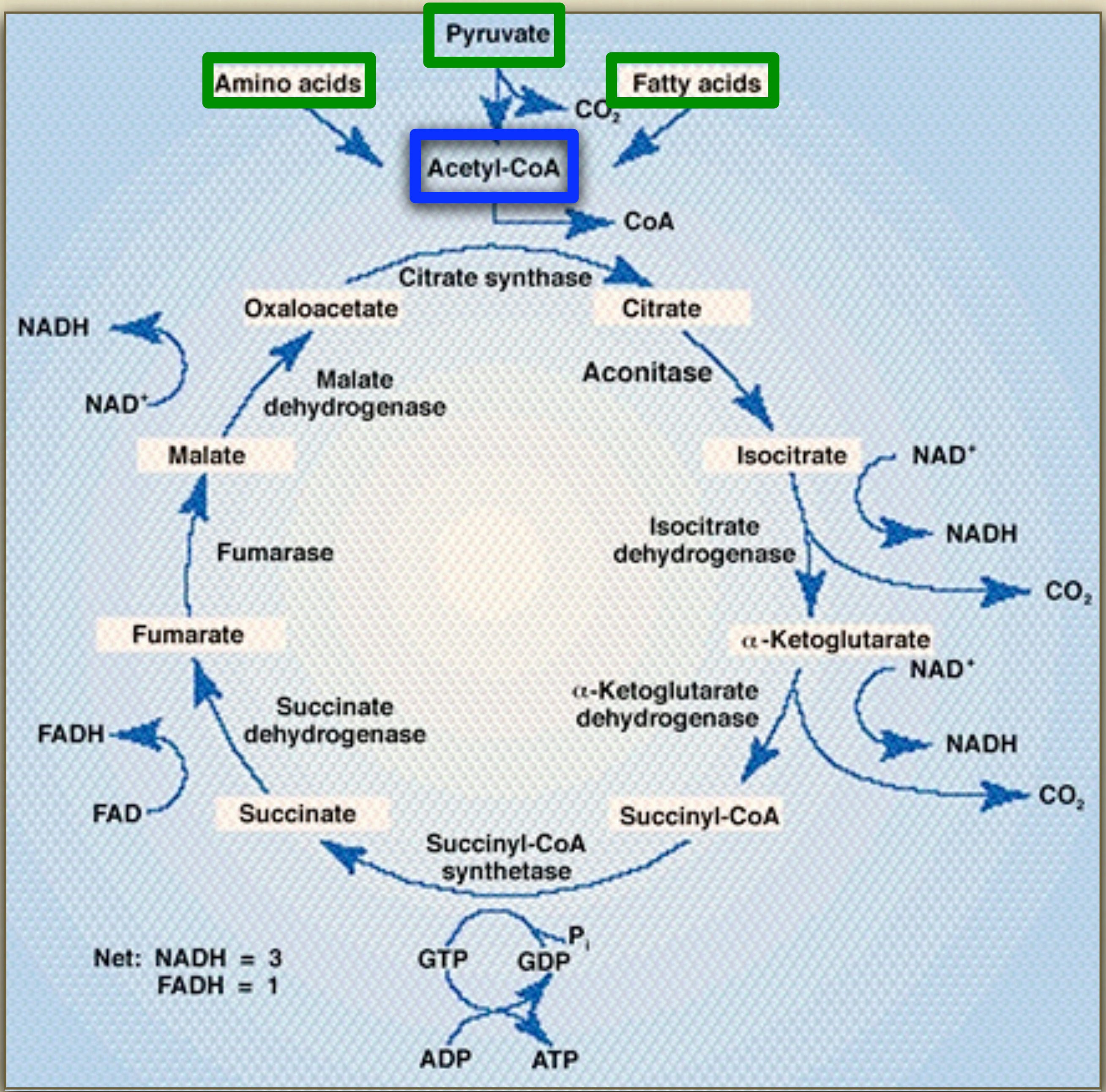


Acetyl-CoA



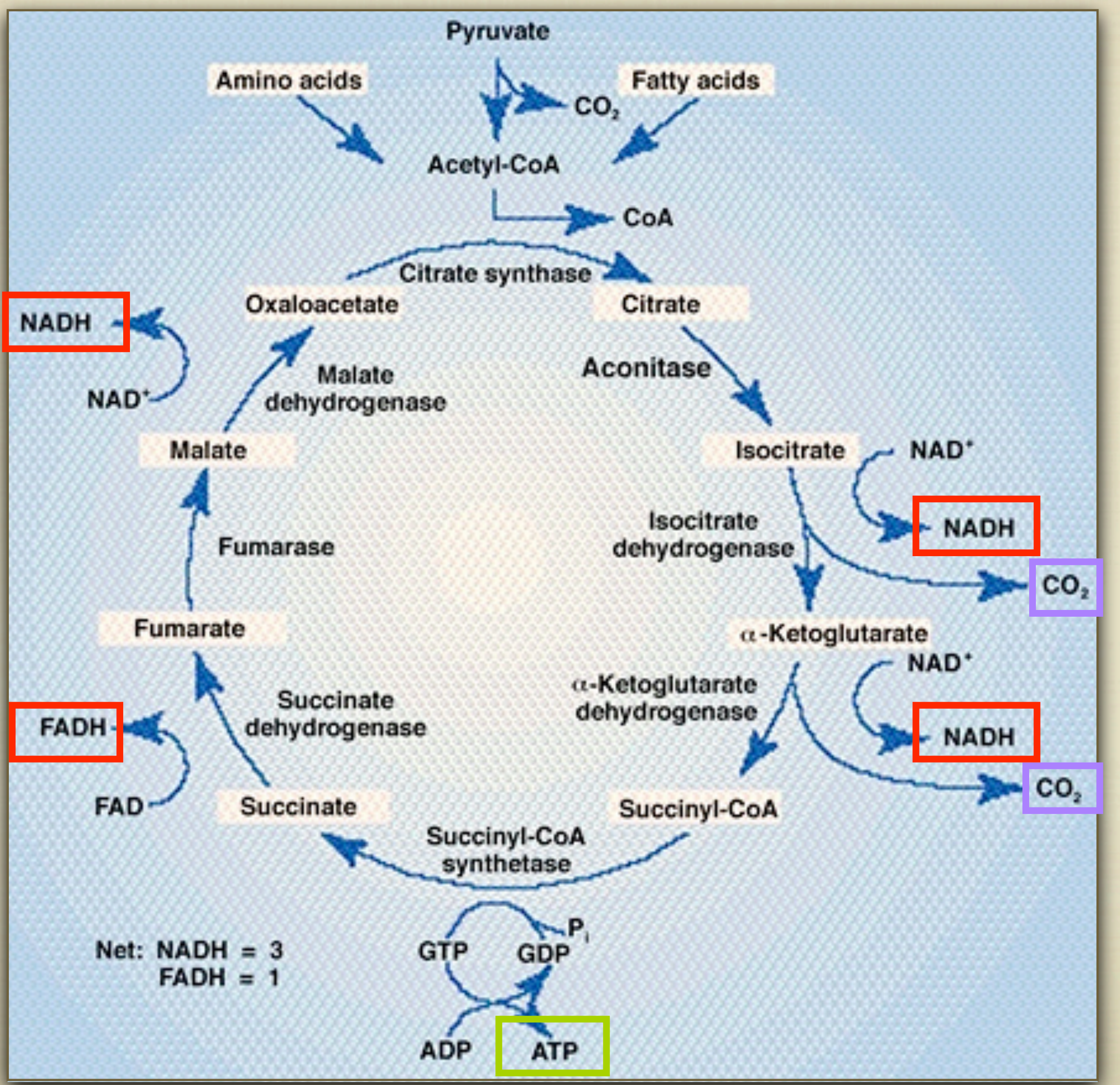
Amino acids from **protein** converted into Acetyl Co-A

Krebs Cycle



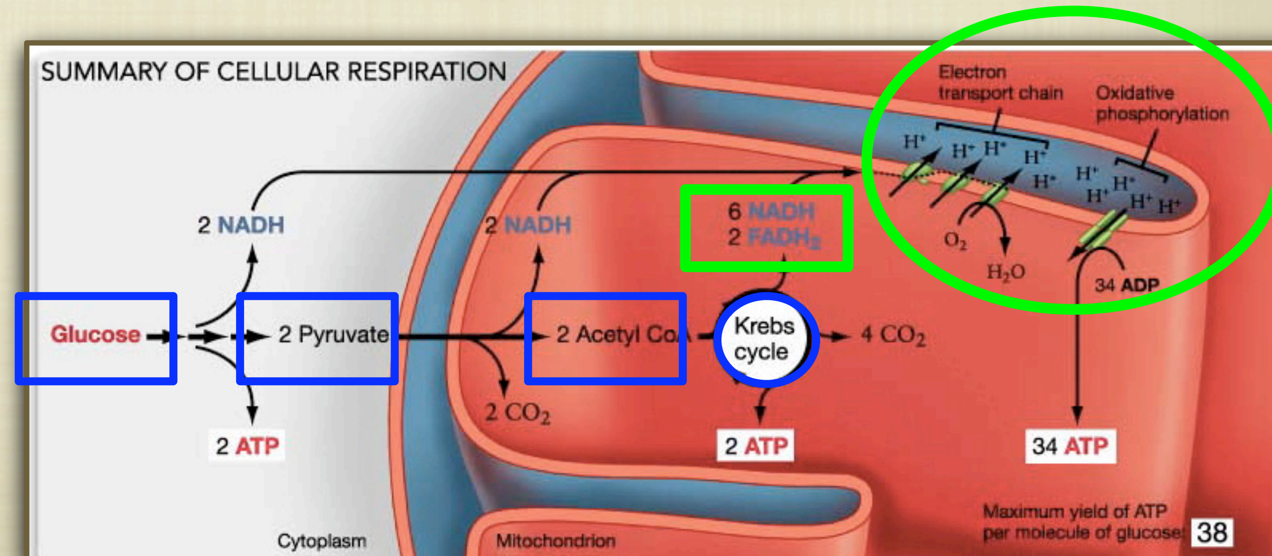
Pyruvate
Amino acids
Fatty acids
CO_2
Acetyl-CoA
CoA
Citrate synthase
Oxaloacetate
Citrate
NADH
NAD^+
Malate dehydrogenase
Aconitase
Malate
Isocitrate
NAD^+
NADH
Isocitrate dehydrogenase
Fumarase
CO_2
Fumarate
α-Ketoglutarate
NAD^+
α-Ketoglutarate dehydrogenase
Succinate dehydrogenase
NADH
FADH
FAD
Succinate
Succinyl-CoA
CO_2
Succinyl-CoA synthetase
P_i
Net: NADH = 3
FADH = 1
GTP
GDP
ADP
ATP

Krebs Cycle



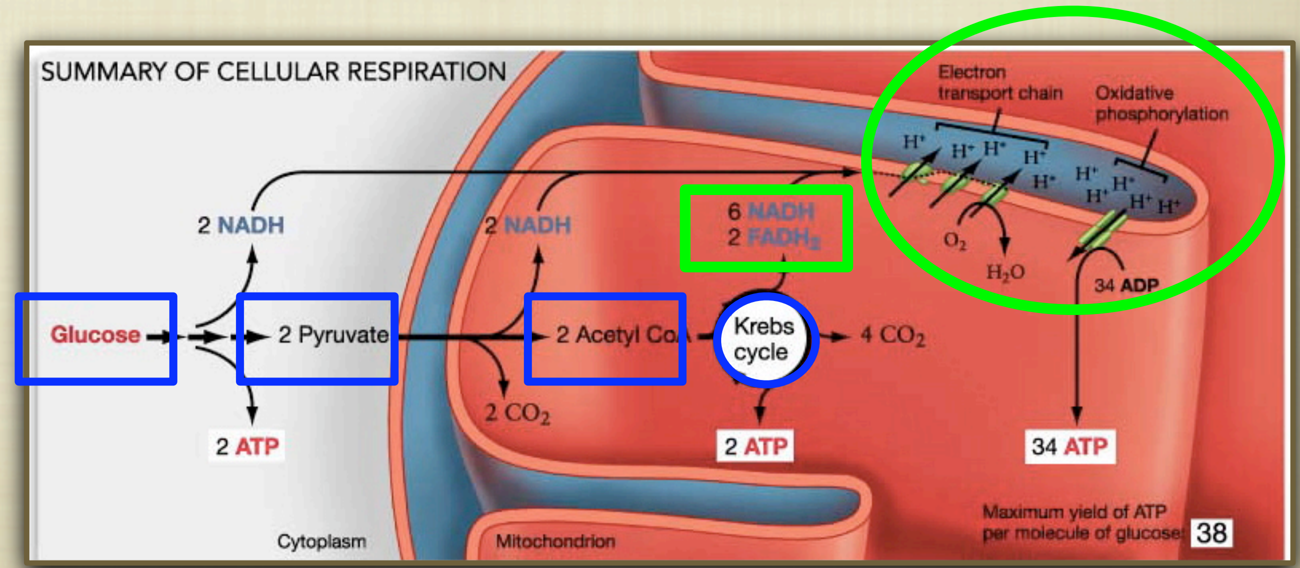
Pyruvate
Amino acids
Fatty acids
CO_2
Acetyl-CoA
CoA
Citrate synthase
Oxaloacetate
Citrate
Aconitase
NADH
NAD^+
Malate dehydrogenase
Malate
Isocitrate
NAD^+
NADH
Isocitrate dehydrogenase
Fumarase
CO_2
Fumarate
α-Ketoglutarate
NAD^+
α-Ketoglutarate dehydrogenase
Succinate dehydrogenase
NADH
FADH
CO_2
FAD
Succinate
Succinyl-CoA
Succinyl-CoA synthetase
P_i
GTP
GDP
Net: NADH = 3
FADH = 1
ADP
ATP

Electron Transport Chain



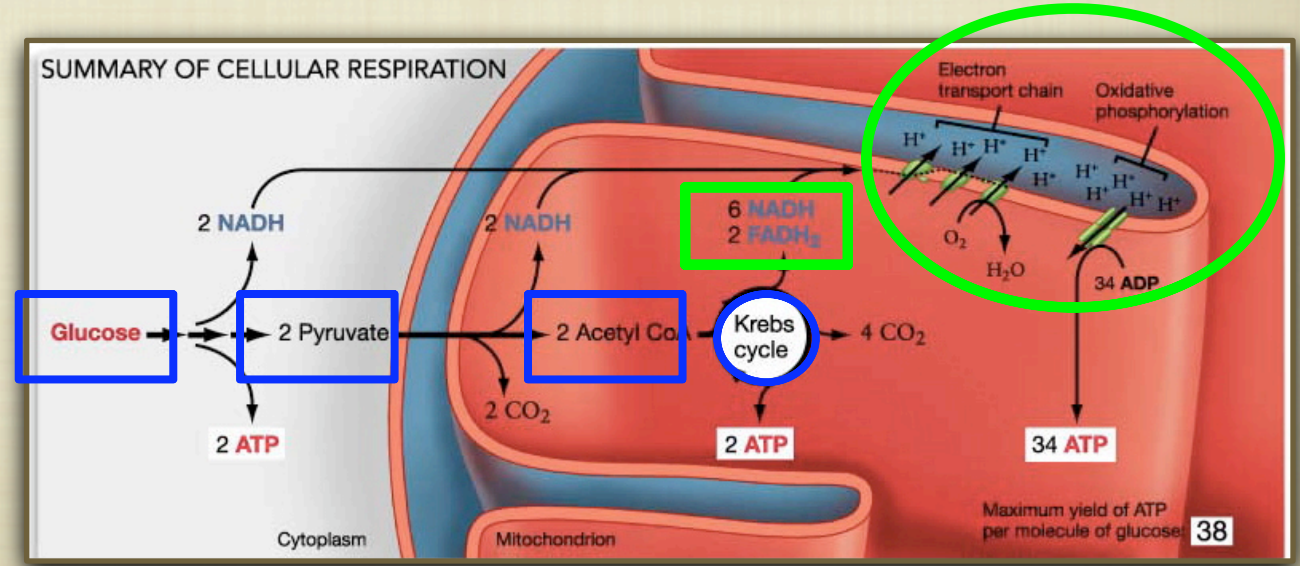
Electron Transport Chain

- Where? Mitochondria



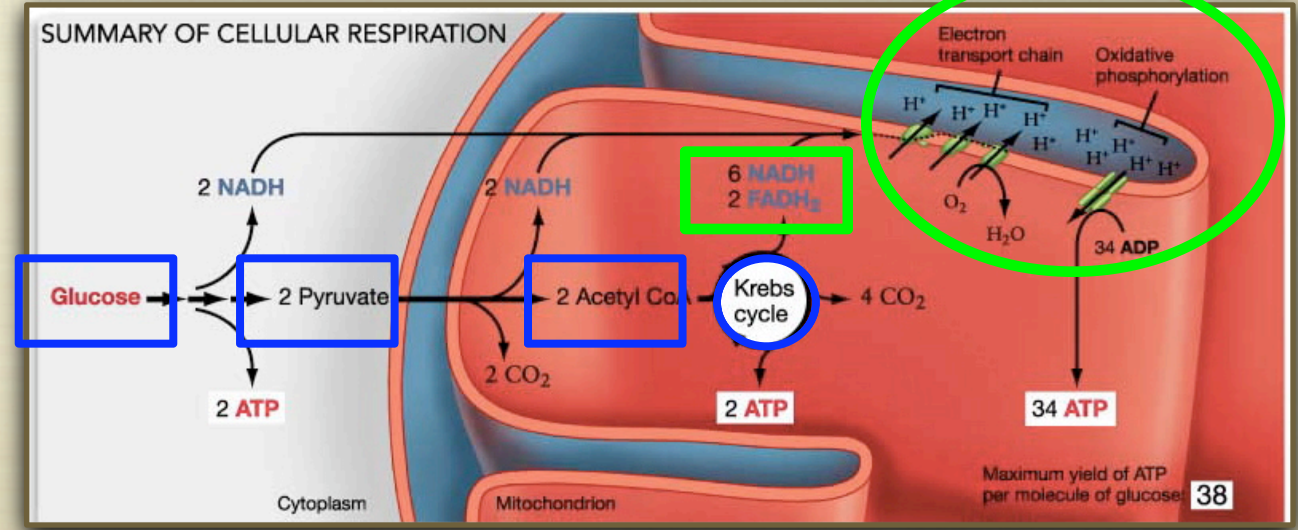
Electron Transport Chain

- Where? Mitochondria
- What is produced?



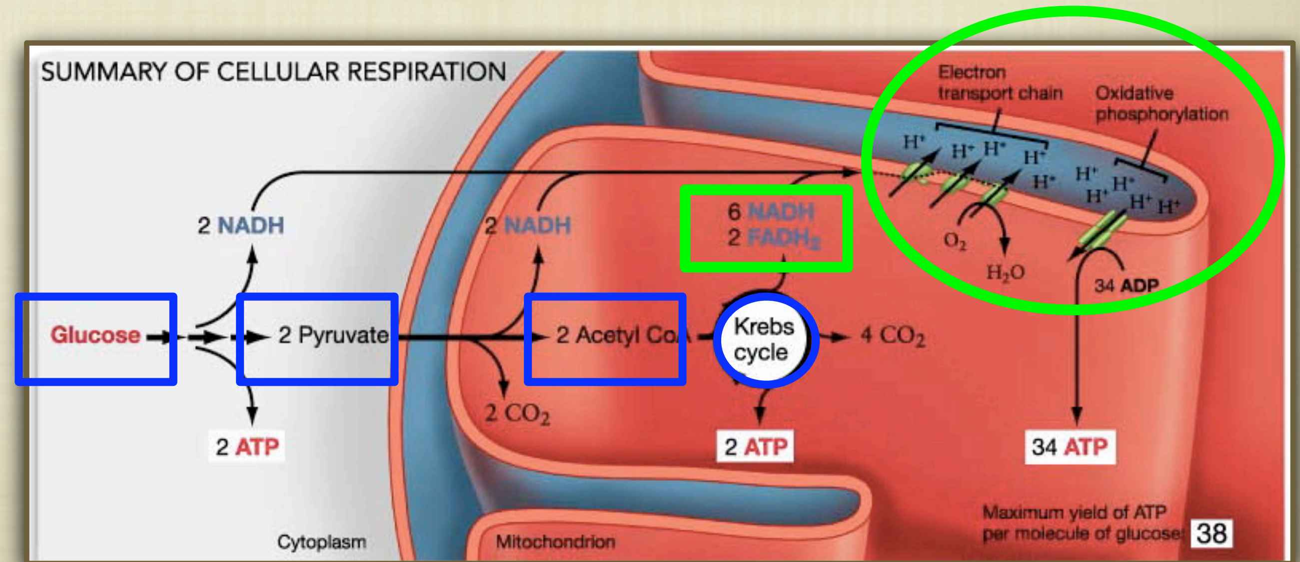
Electron Transport Chain

- Where? Mitochondria
- What is produced?
    - ATP



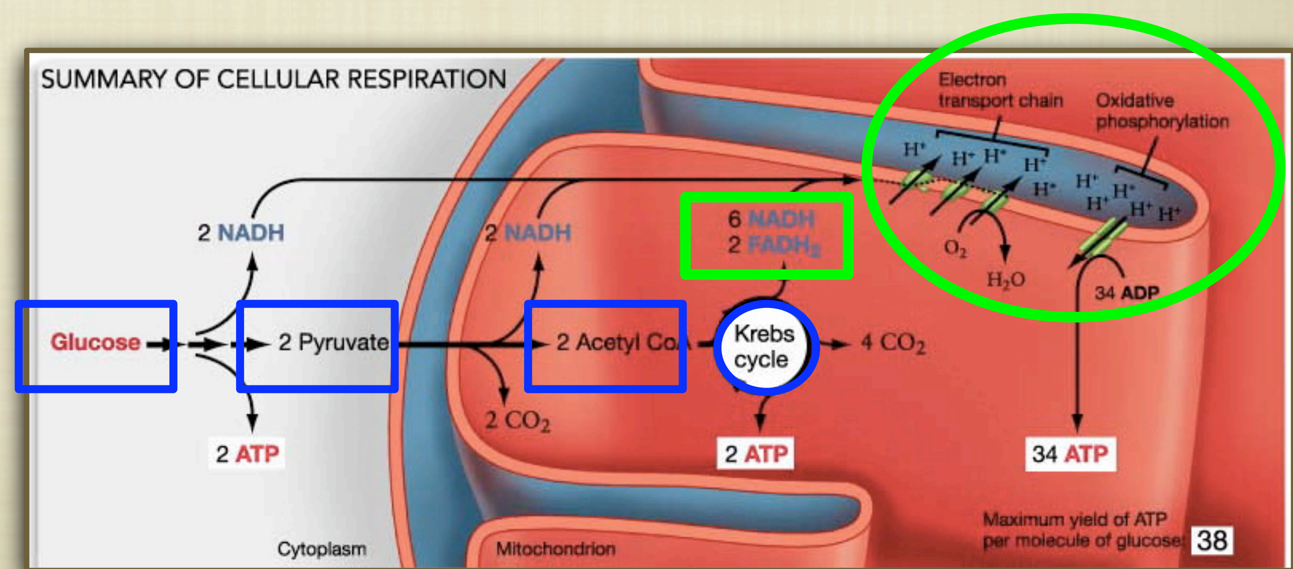
Electron Transport Chain

- Where? Mitochondria
- What is produced?
  - ATP
  - H2O



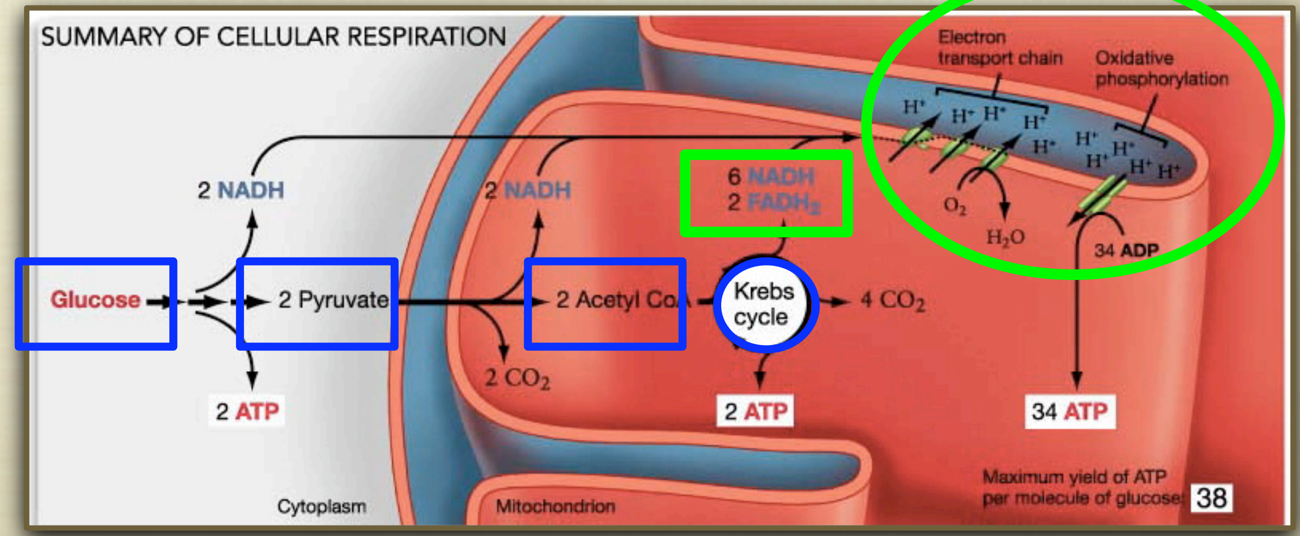
Electron Transport Chain

- Where? Mitochondria
- What is produced?
  - ATP
  - H2O
- How?



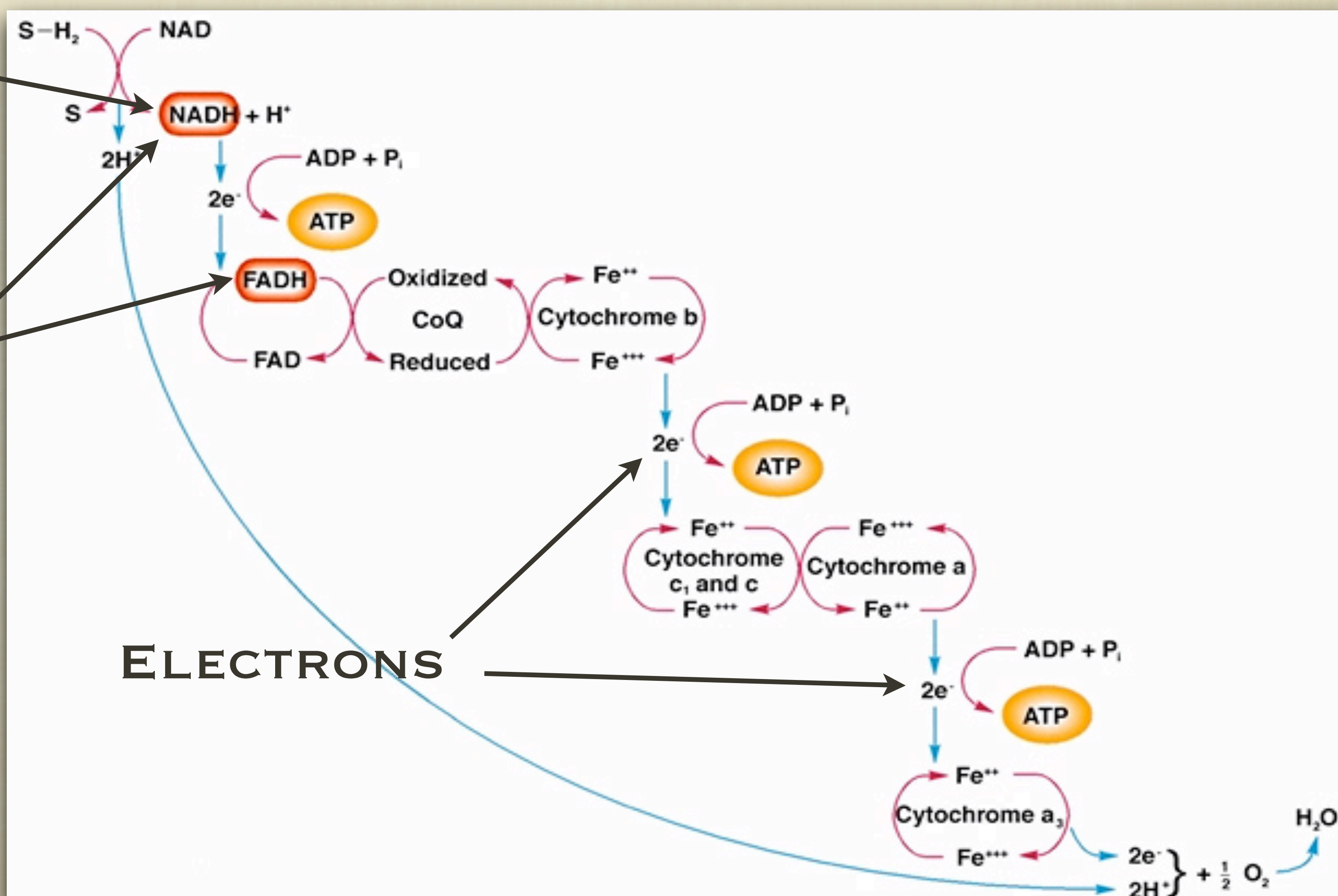
Electron Transport Chain

- Where? Mitochondria
- What is produced?
  - ATP
  - H2O
- How?
  - Electrons from Hydrogens



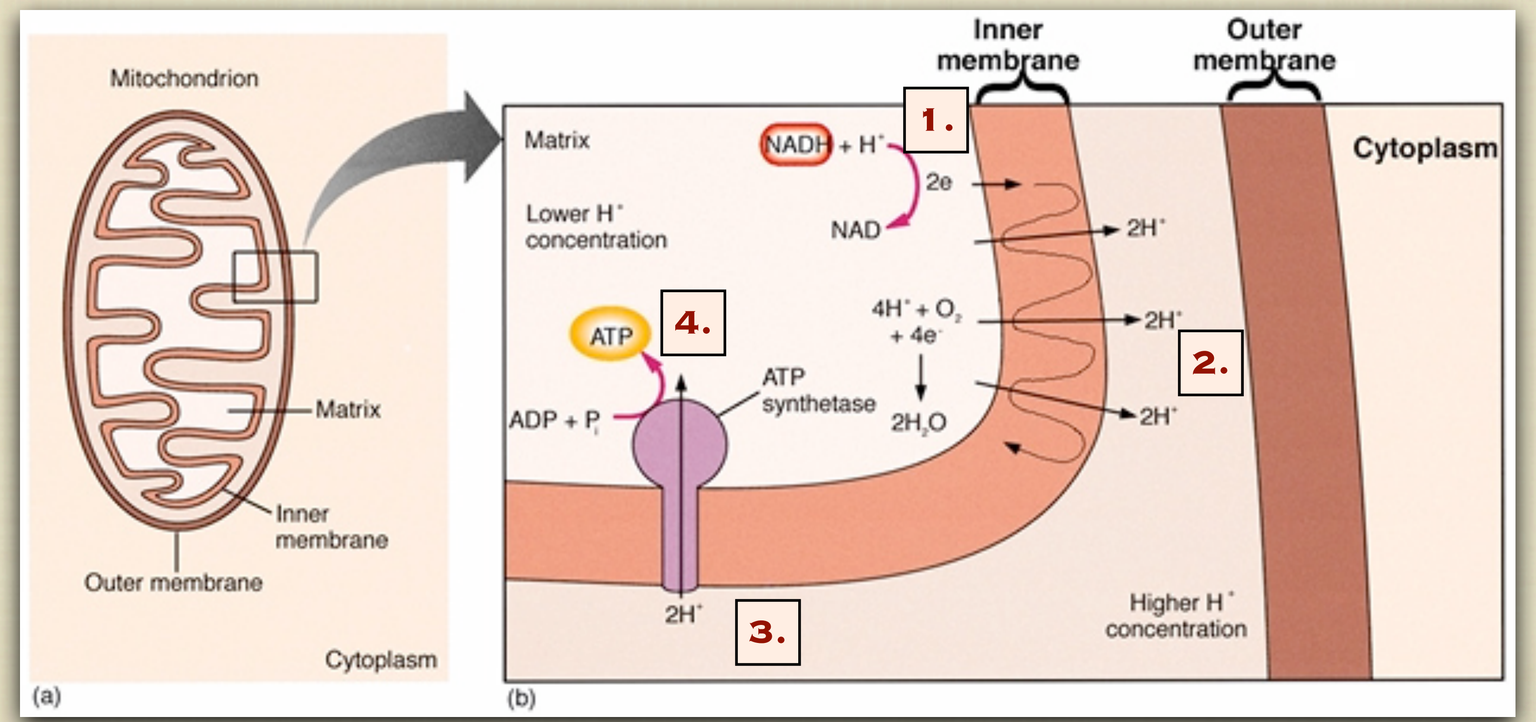
Electron Transport Chain

From Glycolysis or from the Krebs Cycle

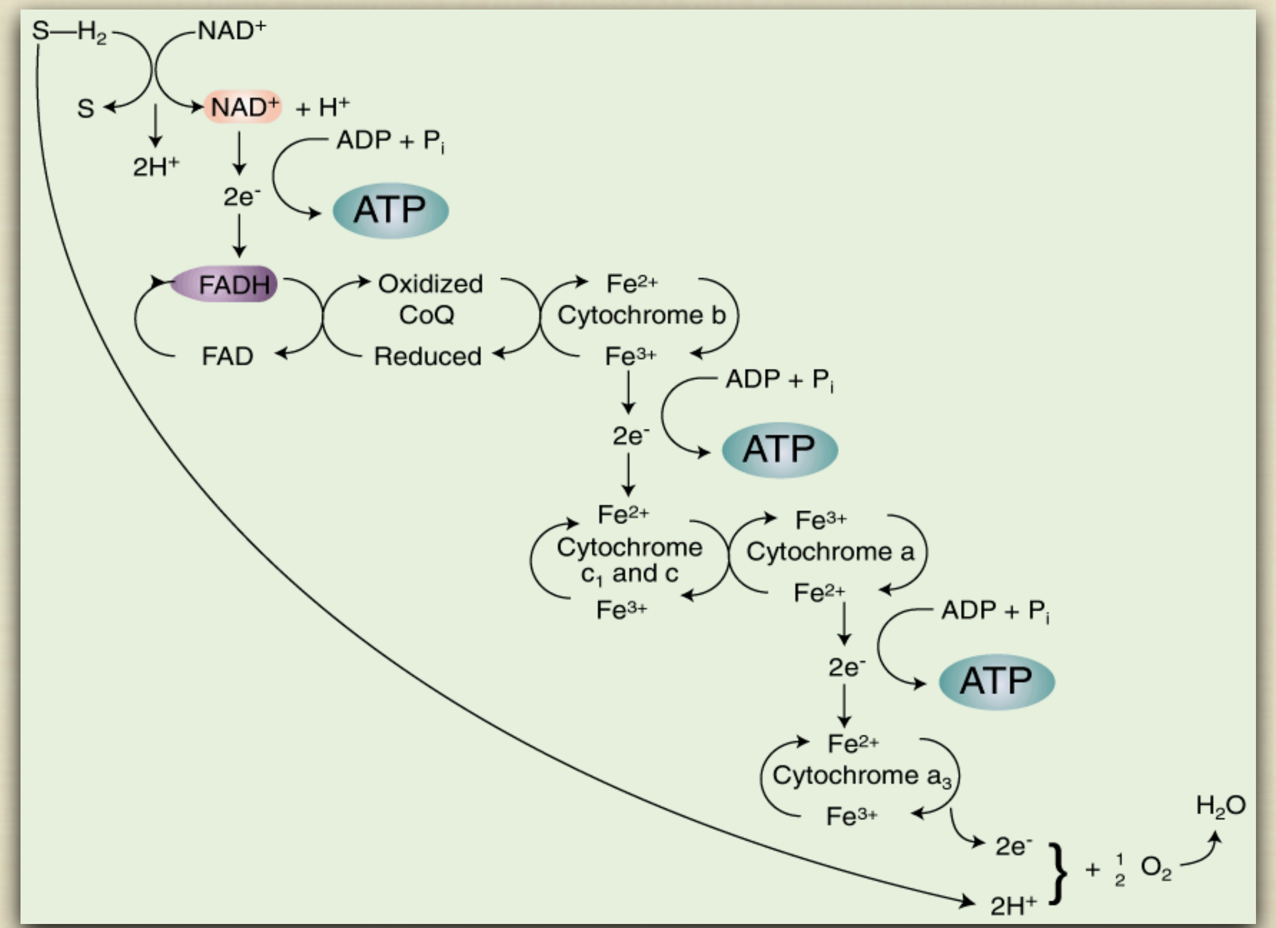


Electrons

Electron Transport Chain

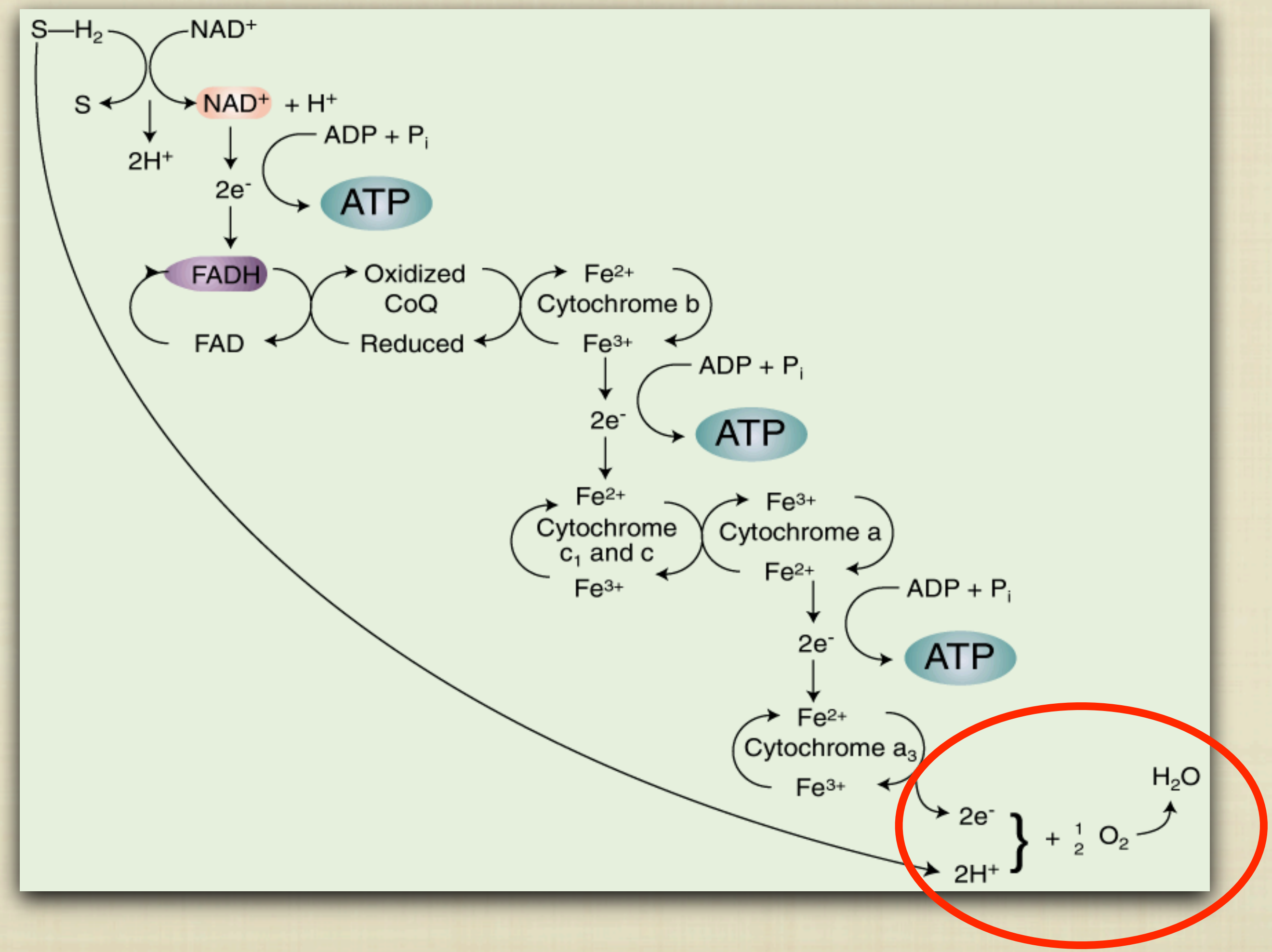


Electron Transport Chain



What roles does oxygen play?

Electron Transport Chain



What roles does oxygen play?

Electron Transport Chain

Electron Transport Chain

- What happens when not enough oxygen is supplied to the muscles?

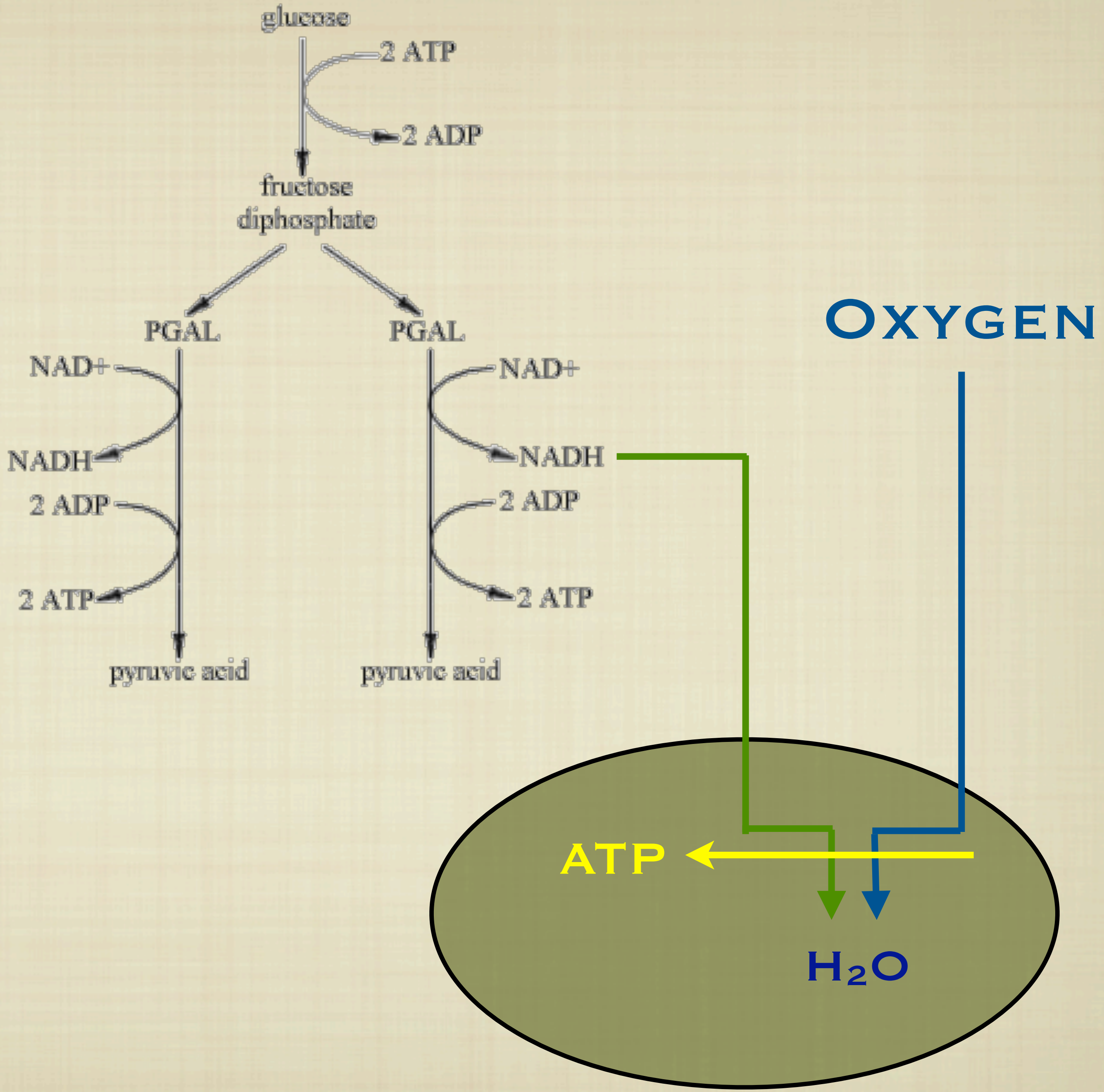
Electron Transport Chain

- What happens when not enough oxygen is supplied to the muscles?
- Hydrogens from glycolysis?

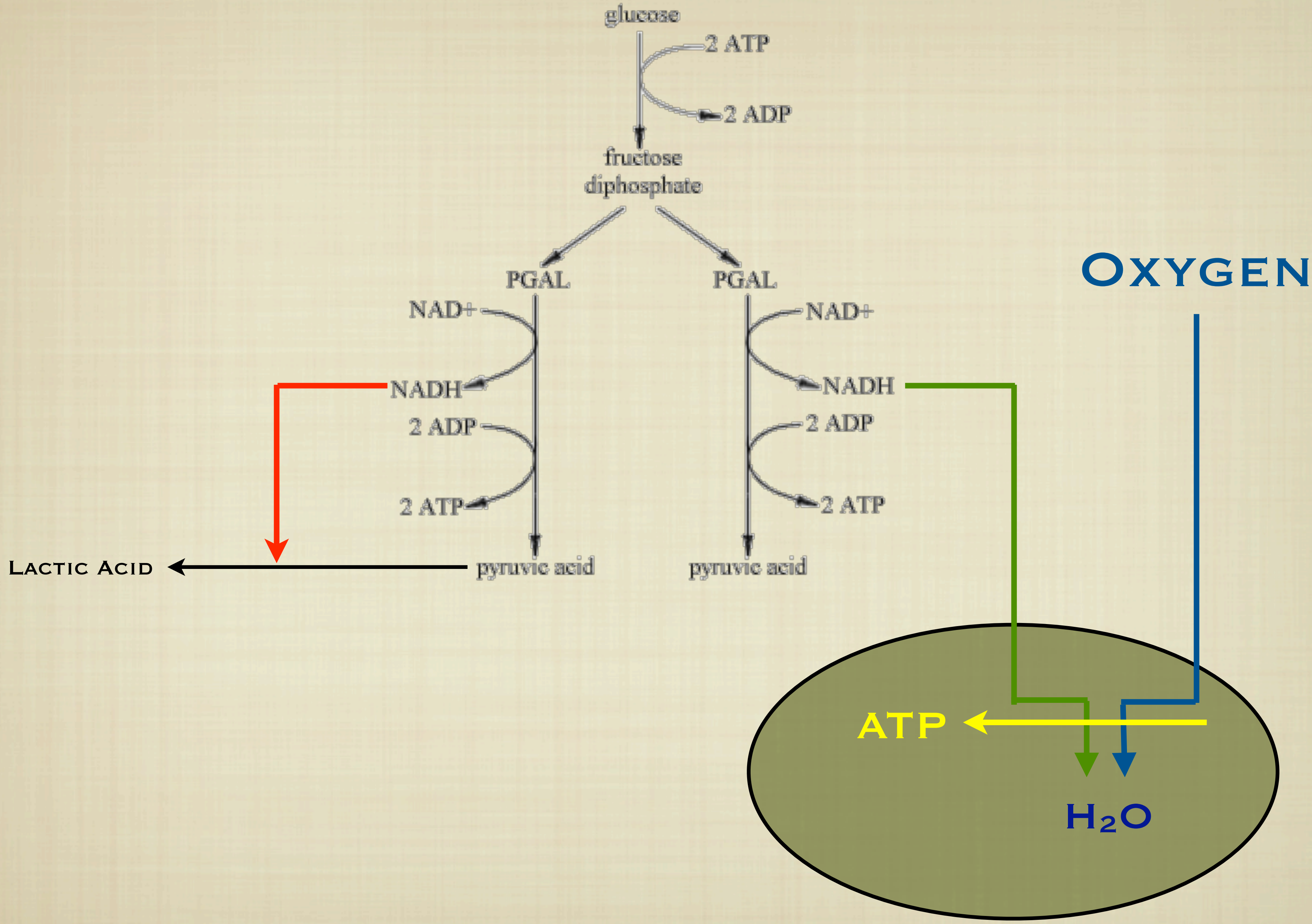
Electron Transport Chain

- What happens when not enough oxygen is supplied to the muscles?
- Hydrogens from glycolysis?
- Pyruvate to Lactate

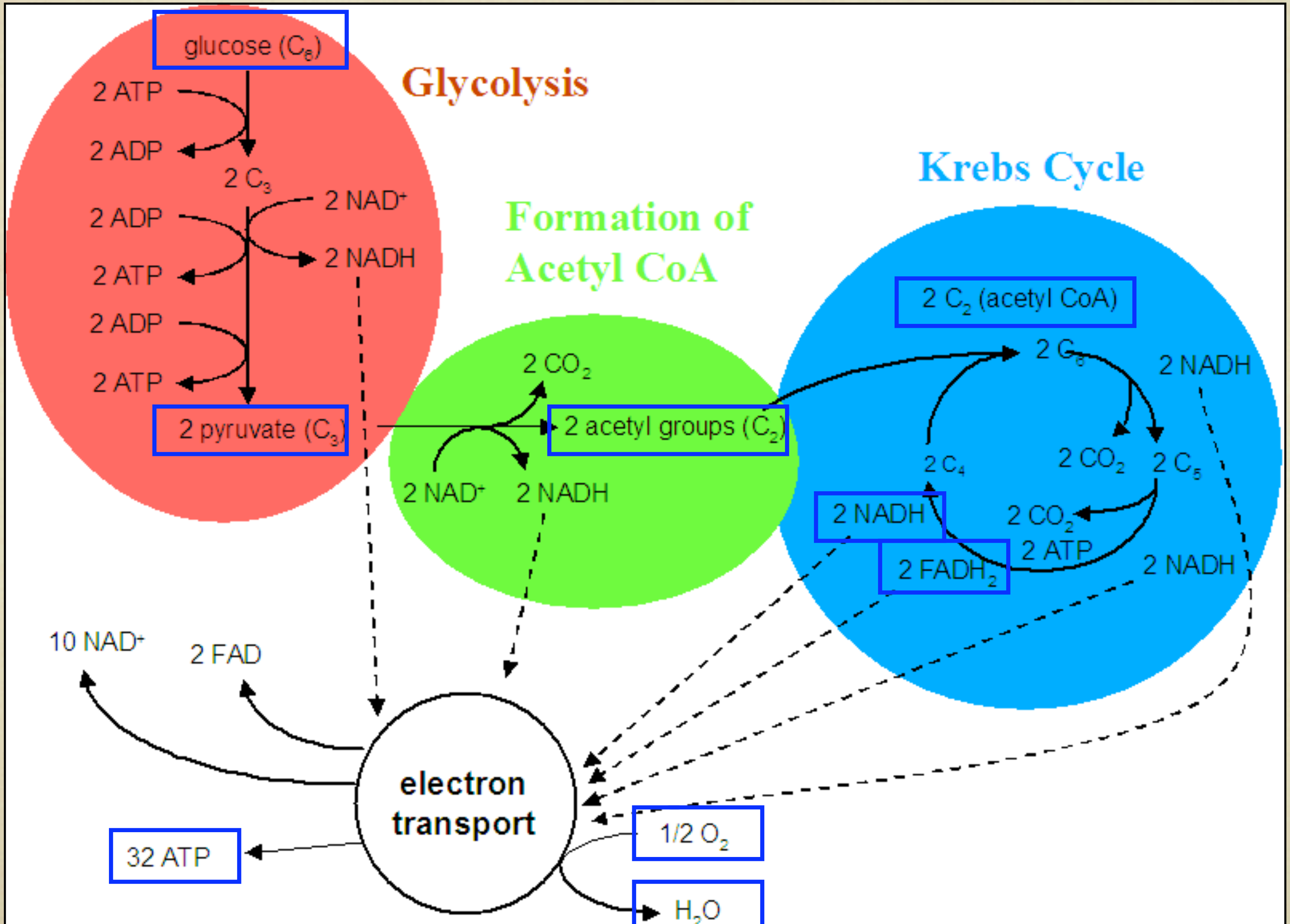
Glycolysis


glucose
2 ATP
2 ADP
fructose
diphosphate
PGAL
PGAL
NAD+
NADH
2 ADP
2 ATP
NAD+
NADH
2 ADP
2 ATP
pyruvic acid
pyruvic acid
Oxygen
ATP
H_2O

Glycolysis

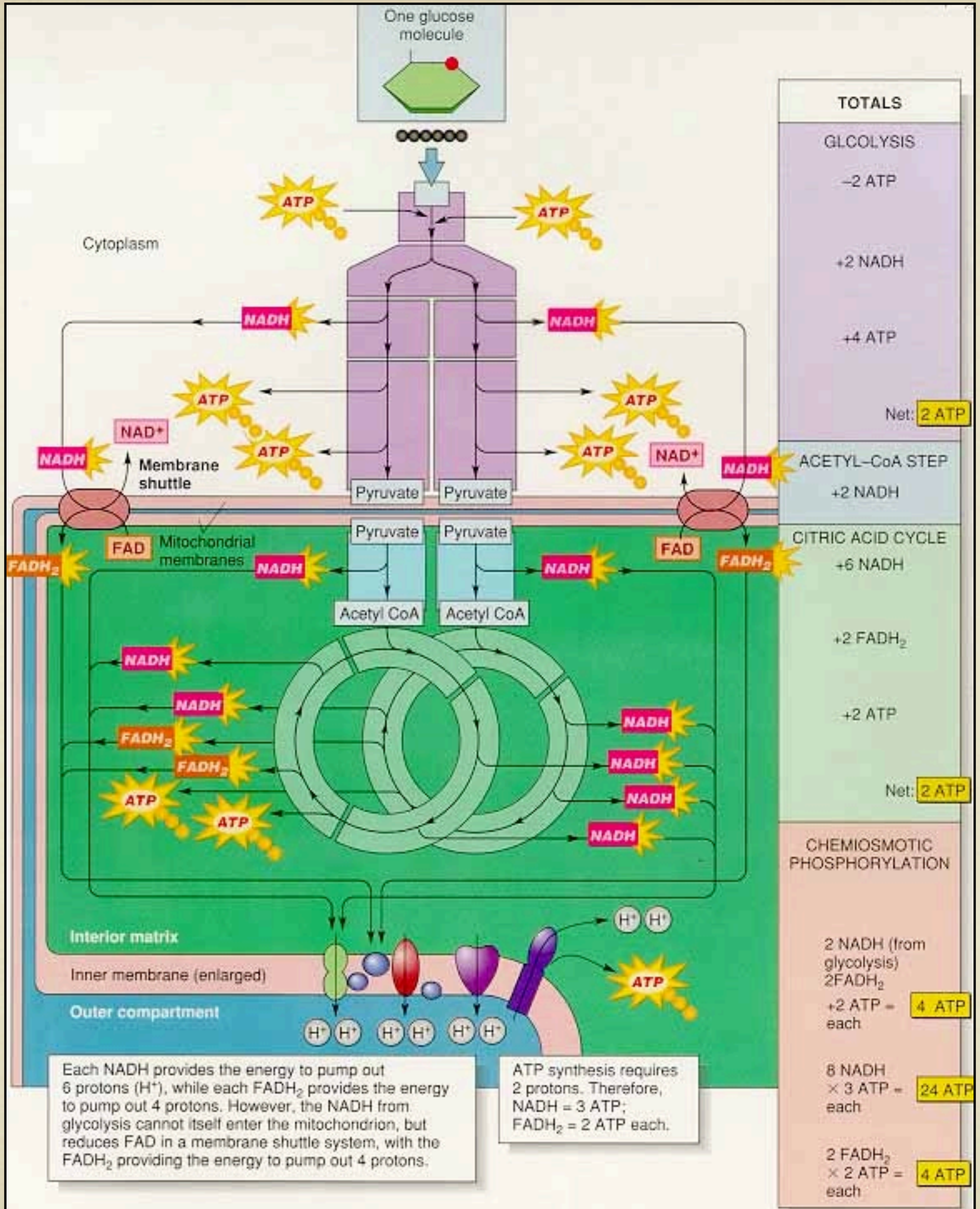

glucose
2 ATP
2 ADP
fructose diphosphate
PGAL
PGAL
NAD+
NADH
2 ADP
2 ATP
NAD+
NADH
2 ADP
2 ATP
pyruvic acid
pyruvic acid
Lactic Acid
Oxygen
ATP
H_2O

Summary



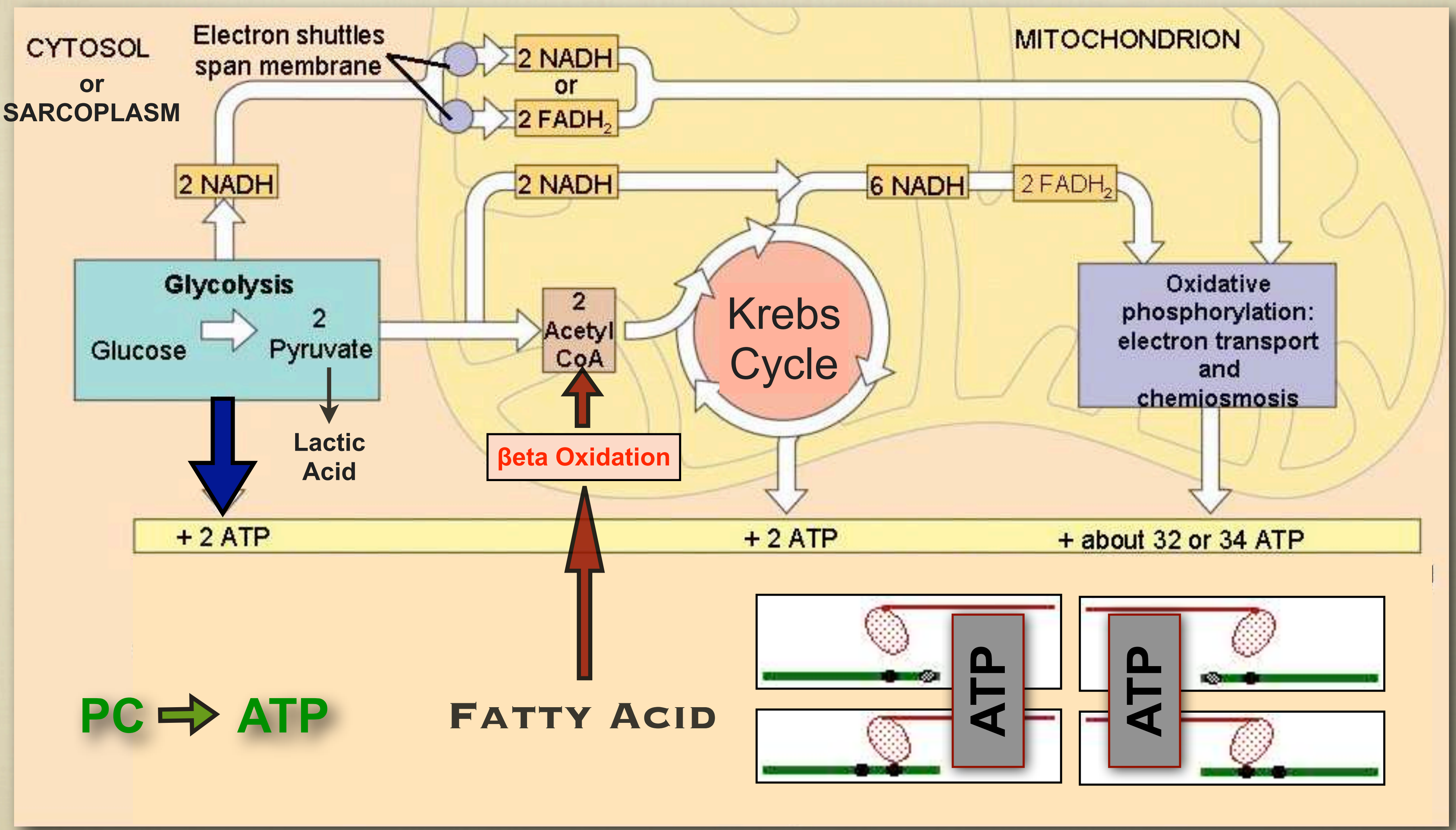
glucose (C_6)
Glycolysis
2 ATP
2 ADP
2 C_3
2 ADP
2 NAD^+
2 NADH
2 ATP
2 ADP
2 ATP
2 pyruvate (C_3)
Formation of Acetyl CoA
2 CO_2
2 acetyl groups (C_2)
2 NAD^+
2 NADH
Krebs Cycle
2 C_2 (acetyl CoA)
2 C_6
2 NADH
2 CO_2
2 C_5
2 C_4
2 NADH
2 CO_2
2 ATP
2 $FADH_2$
2 NADH
10 NAD^+
2 FAD
electron transport
32 ATP
1/2 O_2
H_2O

SUMMARY



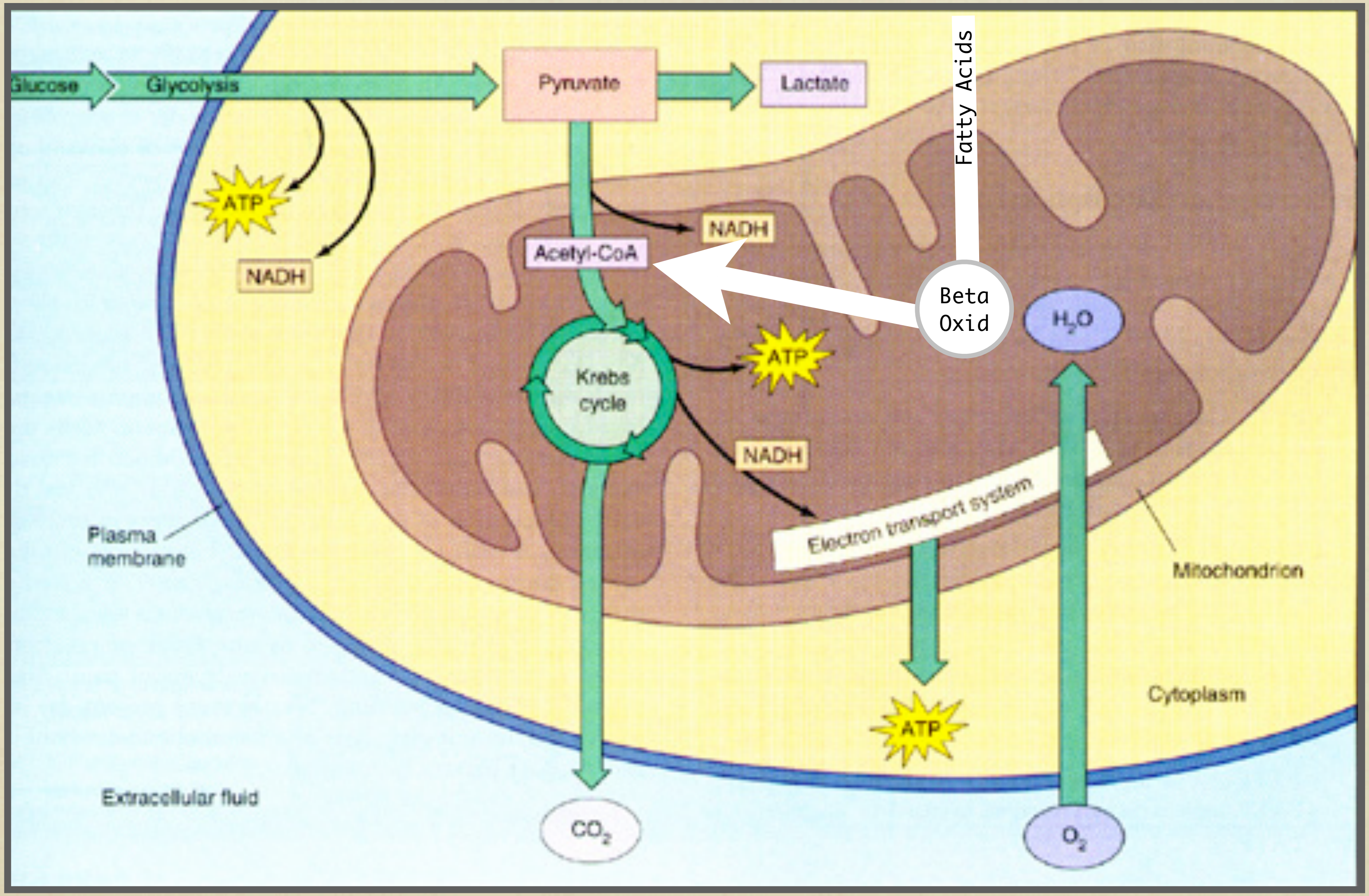
One glucose molecule
Cytoplasm
ATP
NADH
NAD+
Membrane shuttle
FAD
FADH2
Mitochondrial membranes
Pyruvate
Acetyl CoA
Interior matrix
Inner membrane (enlarged)
Outer compartment
H+
TOTALS
GLCOLYSIS
–2 ATP
+2 NADH
+4 ATP
Net: 2 ATP
ACETYL–CoA STEP
+2 NADH
CITRIC ACID CYCLE
+6 NADH
+2 FADH2
+2 ATP
Net: 2 ATP
CHEMIOSMOTIC PHOSPHORYLATION
2 NADH (from glycolysis) 2FADH2 +2 ATP = each
4 ATP
8 NADH × 3 ATP = each
24 ATP
2 FADH2 × 2 ATP = each
4 ATP
Each NADH provides the energy to pump out 6 protons (H+), while each FADH2 provides the energy to pump out 4 protons. However, the NADH from glycolysis cannot itself enter the mitochondrion, but reduces FAD in a membrane shuttle system, with the FADH2 providing the energy to pump out 4 protons.
ATP synthesis requires 2 protons. Therefore, NADH = 3 ATP; FADH2 = 2 ATP each.

SUMMARY



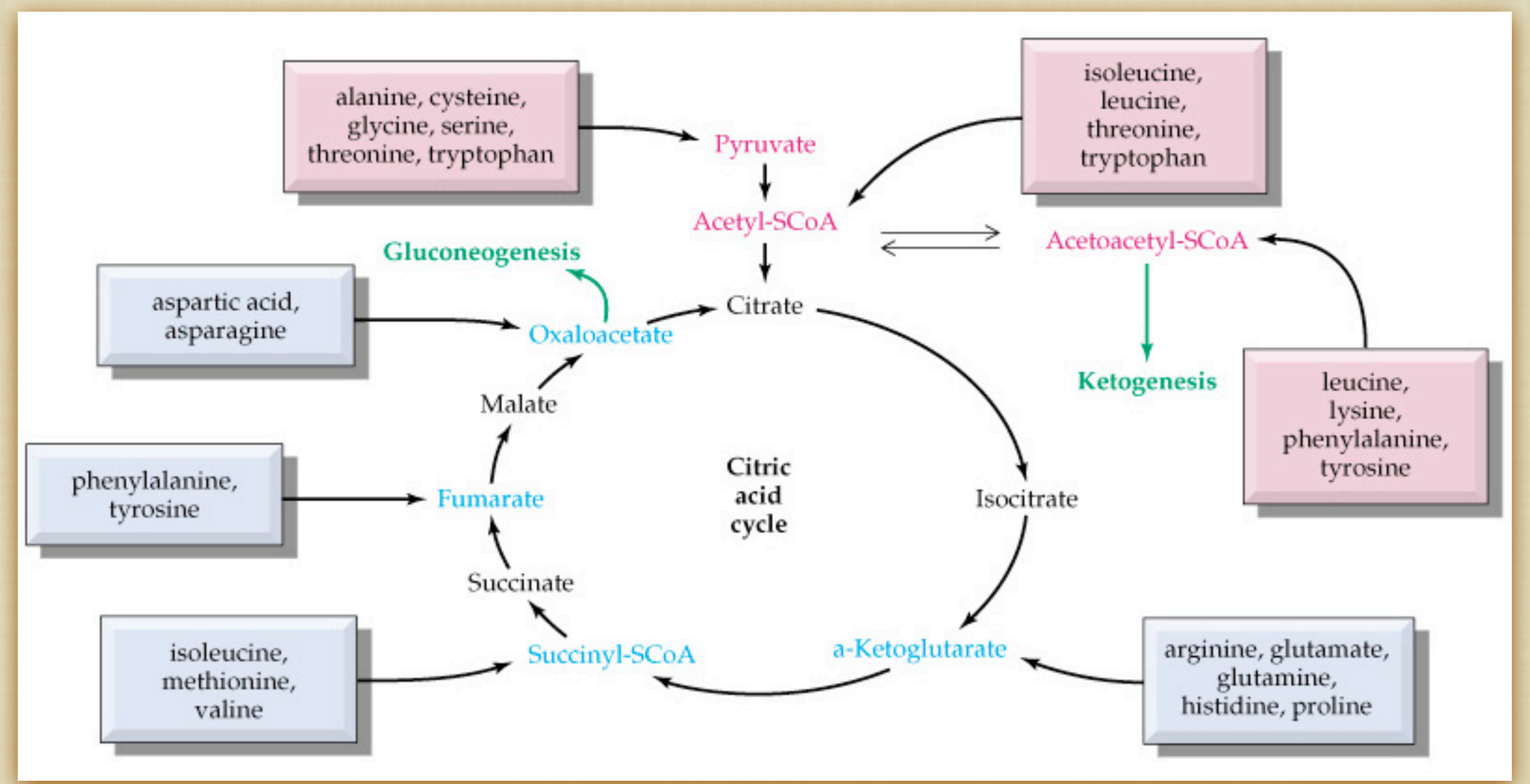
CYTOSOL
or
SARCOPLASM
Electron shuttles
span membrane
MITOCHONDRION
2 NADH
or
2 FADH2
2 NADH
2 NADH
6 NADH
2 FADH2
Glycolysis
Glucose
2
Pyruvate
Lactic
Acid
2
Acetyl
CoA
Krebs
Cycle
Oxidative
phosphorylation:
electron transport
and
chemiosmosis
βeta Oxidation
+ 2 ATP
+ 2 ATP
+ about 32 or 34 ATP
PC
ATP
FATTY ACID
ATP
ATP

Summary



Glucose
Glycolysis
Pyruvate
Lactate
Fatty Acids
ATP
NADH
NADH
Acetyl-CoA
Beta Oxid
H_2O
ATP
Krebs cycle
NADH
Electron transport system
Plasma membrane
Mitochondrion
Cytoplasm
ATP
Extracellular fluid
CO_2
O_2

Proteins



- Only 5-10% of energy during exercise

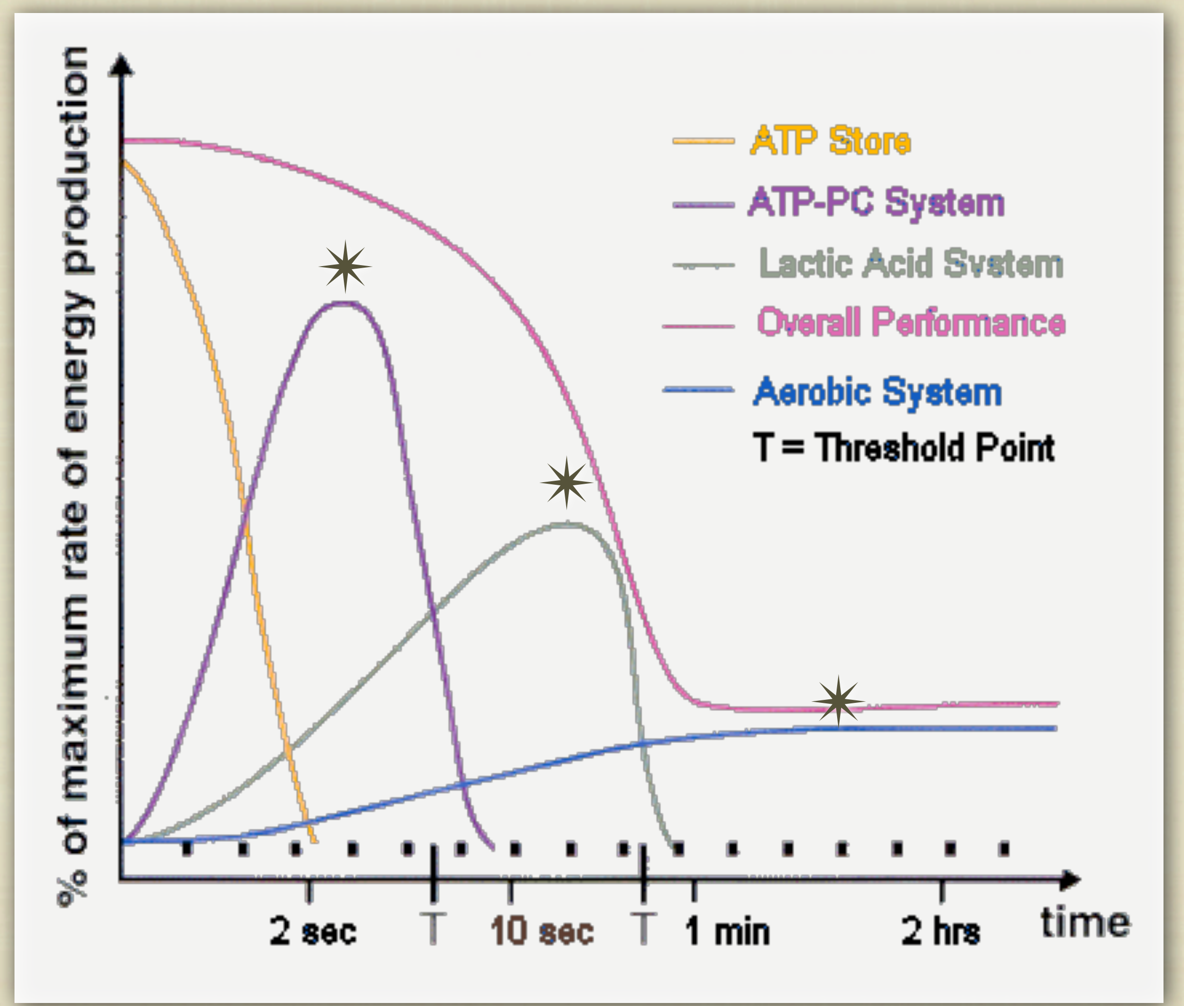
ATP Tally

- Phophocreatine: 1 ATP
- Carbohydrates/Glucose ($C_6 H_{12} O_6$)
  - Glycolysis: 2 ATP
  - Aerobic: 34 ATP
- Fatty Acid ($C_{16} H_{32} O_2$) - 129 ATP

Efficiency

- What percentage of the energy from ATP goes into doing "work"?
- Where does the rest of the energy go?

Aerobic/Anaerobic Interaction



The energy systems: time at maximal capacity

Aerobic/Anaerobic Interaction

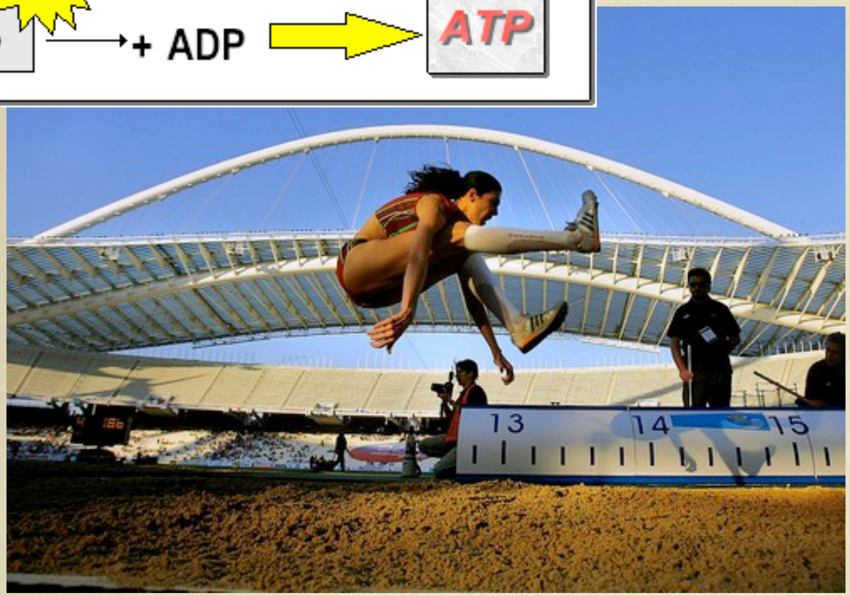
	Seconds				Minutes				
	10	30	60	2	4	10	30	60	120
Aerobic	10	20	30	40	65	85	95	98	99
Anaero bic	90	80	70	60	35	15	5	2	1

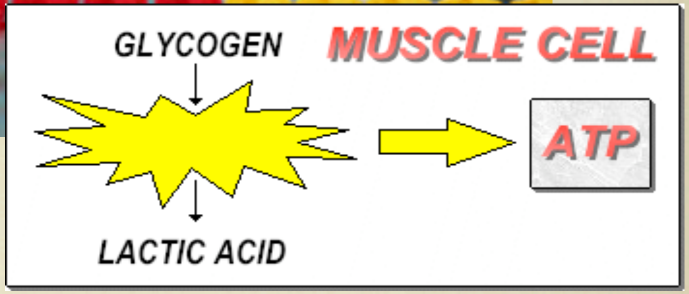
Summary

Summary

Summary

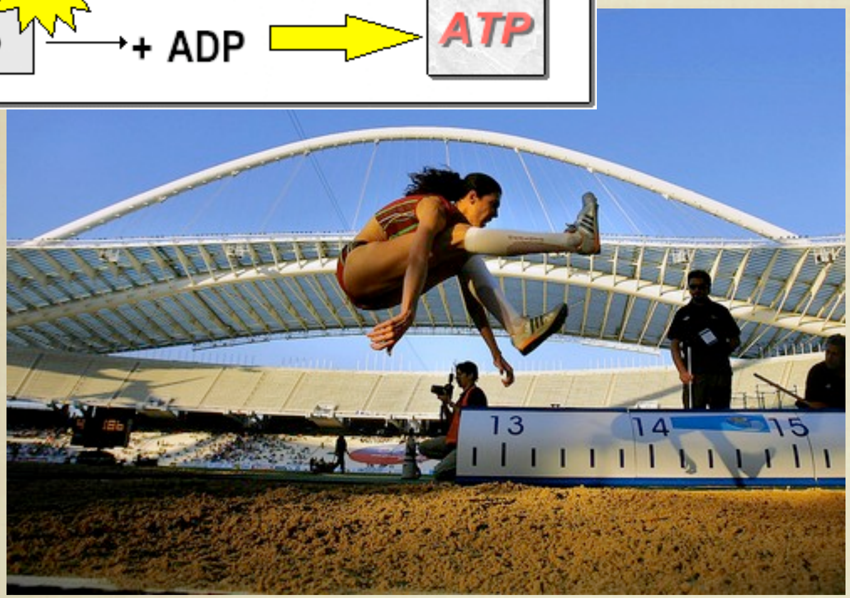

MUSCLE CELL
CREATINE
P
+ ADP
ATP

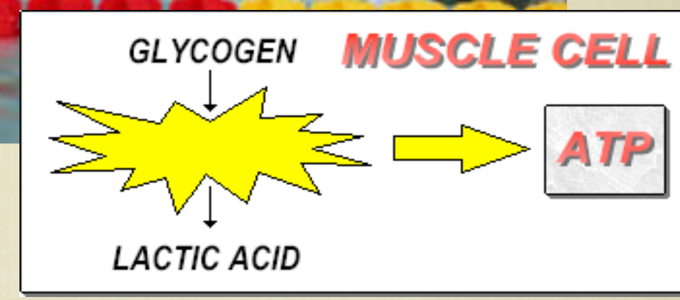


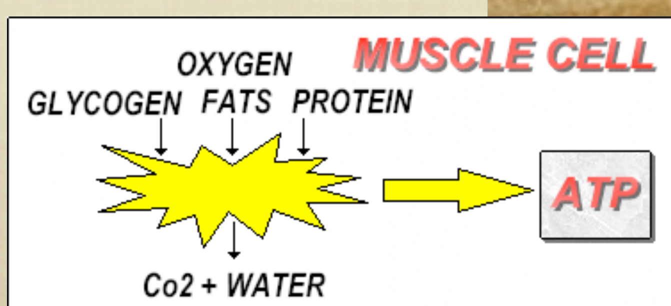

GLYCOGEN
MUSCLE CELL
ATP
LACTIC ACID

Summary

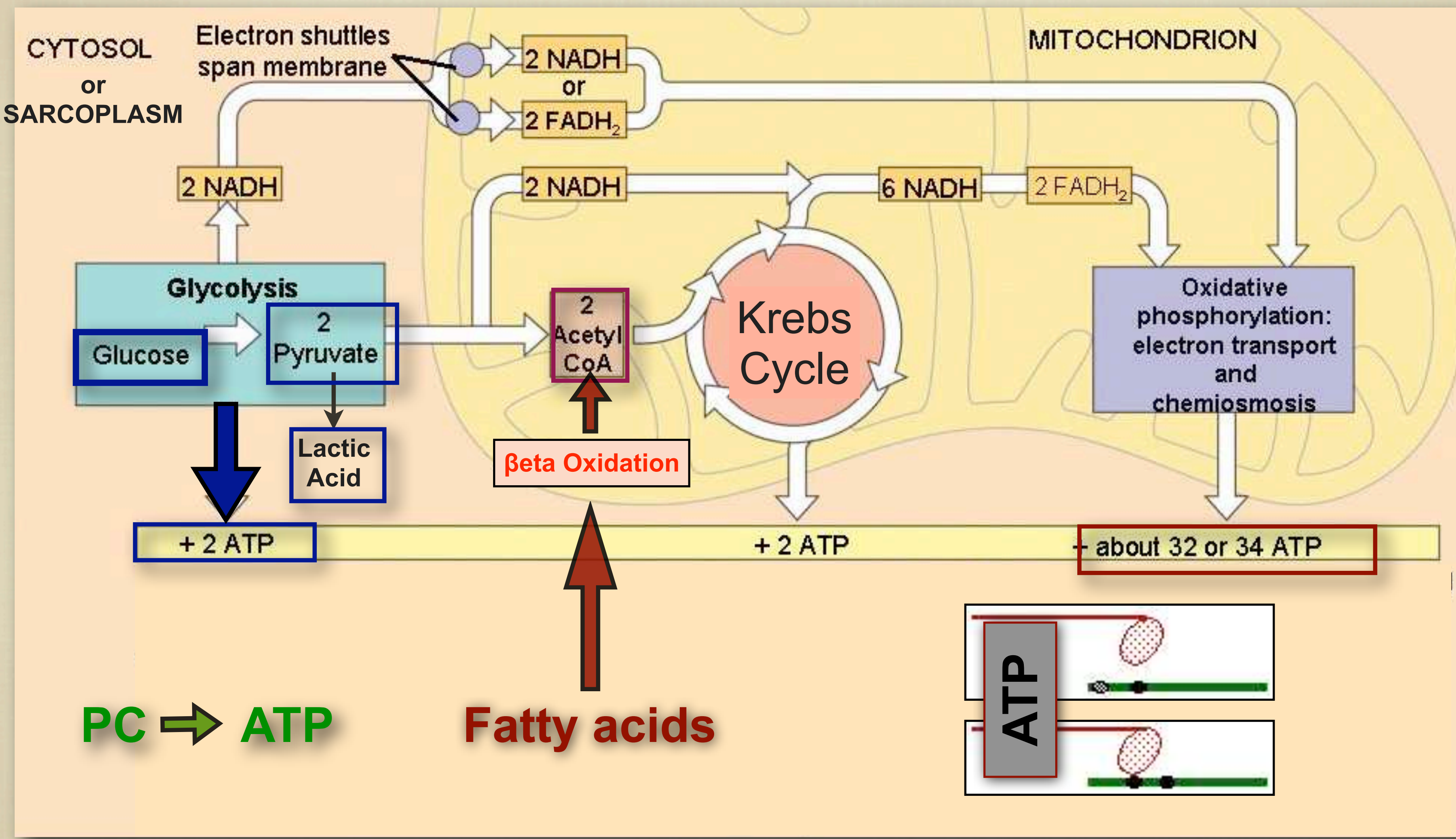

MUSCLE CELL
CREATINE
P
+ ADP
ATP




GLYCOGEN
MUSCLE CELL
ATP
LACTIC ACID


OXYGEN
MUSCLE CELL
GLYCOGEN
FATS
PROTEIN
ATP
Co2 + WATER

Summary



CYTOSOL
or
SARCOPLASM
Electron shuttles
span membrane
MITOCHONDRION
2 NADH
or
2 FADH2
2 NADH
2 NADH
6 NADH
2 FADH2
Glycolysis
Glucose
2
Pyruvate
Lactic
Acid
2
Acetyl
CoA
βeta Oxidation
Krebs
Cycle
Oxidative
phosphorylation:
electron transport
and
chemiosmosis
+ 2 ATP
+ 2 ATP
+ about 32 or 34 ATP
ATP
PC → ATP
Fatty acids

Summary of Energy Systems

Summary of Energy Systems

System
ATP-PC
Glycolysis
Aerobic

Summary of Energy Systems

System	Fuel
ATP-PC	PC
Glycolysis	Carbohydrate (glycogen & glucose)
Aerobic	Carbohydrate (glycogen & glucose)
	Fat
	Protein

Summary of Energy Systems

system	Fuel	Waste Product
ATP-PC	PC	P and Cr
Glycolysis	Carbohydrate (glycogen & glucose)	Lactic Acid
Aerobic	Carbohydrate (glycogen & glucose)	CO_2 and H_2O
	Fat	
	Protein	

Summary of Energy Systems

System	Fuel	Waste Product	ATP
ATP-PC	PC	P and Cr	1
Glycolysis	Carbohydrate (glycogen & glucose)	Lactic Acid	2
Aerobic	Carbohydrate (glycogen & glucose)	CO_2 and H_2O	34
	Fat		129+
	Protein		?

Summary of Energy Systems

System	Fuel	Waste Product	ATP	Speed
ATP-PC	PC	P and Cr	1	Fastest
Glycolysis	Carbohydrate (glycogen & glucose)	Lactic Acid	2	Fast
Aerobic	Carbohydrate (glycogen & glucose)	CO2 and H20	34	Slow
	Fat		129+	Slower
	Protein		?	?

Summary of Energy Systems

System	Fuel	Waste Product	ATP	Speed	Endurance
ATP-PC	PC	P and Cr	1	Fastest	Second
Glycolysis	Carbohydrate (glycogen & glucose)	Lactic Acid	2	Fast	Minutes
Aerobic	Carbohydrate (glycogen & glucose)	CO_2 and H_2O	34	Slow	Hours
	Fat		129+	Slower	Unlimited
	Protein		?	?	?

Summary of Energy Systems

SYSTEM	Fuel	Waste Product	ATP	Speed	Endurance	
ATP-PC	PC	P and Cr	1	Fastest	Second	Power/ Strength
Glycolysis	Carbohydrate (glycogen & glucose)	Lactic Acid	2	Fast	Minutes	Speed
Aerobic	Carbohydrate (glycogen & glucose)	CO2 and H20	34	Slow	Hours	Endurance
	Fat		129+	Slower	Unlimited	
	Protein		?	?	?	

Summary of Fuels

Fuels provide the energy for the systems to make ATP

Summary of Fuels

FUEL
STORED
ENERGY SYSTEM

Fuels provide the energy for the systems to make ATP

Summary of Fuels

FUEL	Phospho-creatine
STORED	Phospho-creatine
ENERGY SYSTEM	ATP-PC

Fuels provide the energy for the systems to make ATP

Summary of Fuels

Fuel	Phospho-creatine	Carbo-hydrates
Stored	Phospho-creatine	Glycogen
		Glucose
Energy System	ATP-PC	Glycolysis
		Aerobic

Fuels provide the energy for the systems to make ATP

Summary of Fuels

FUEL	Phospho-creatine	Carbo-hydrates	Fats
STORED	Phospho-creatine	Glycogen	Fatty acids
		Glucose	
ENERGY SYSTEM	ATP-PC	Glycolysis	
		Aerobic	Aerobic

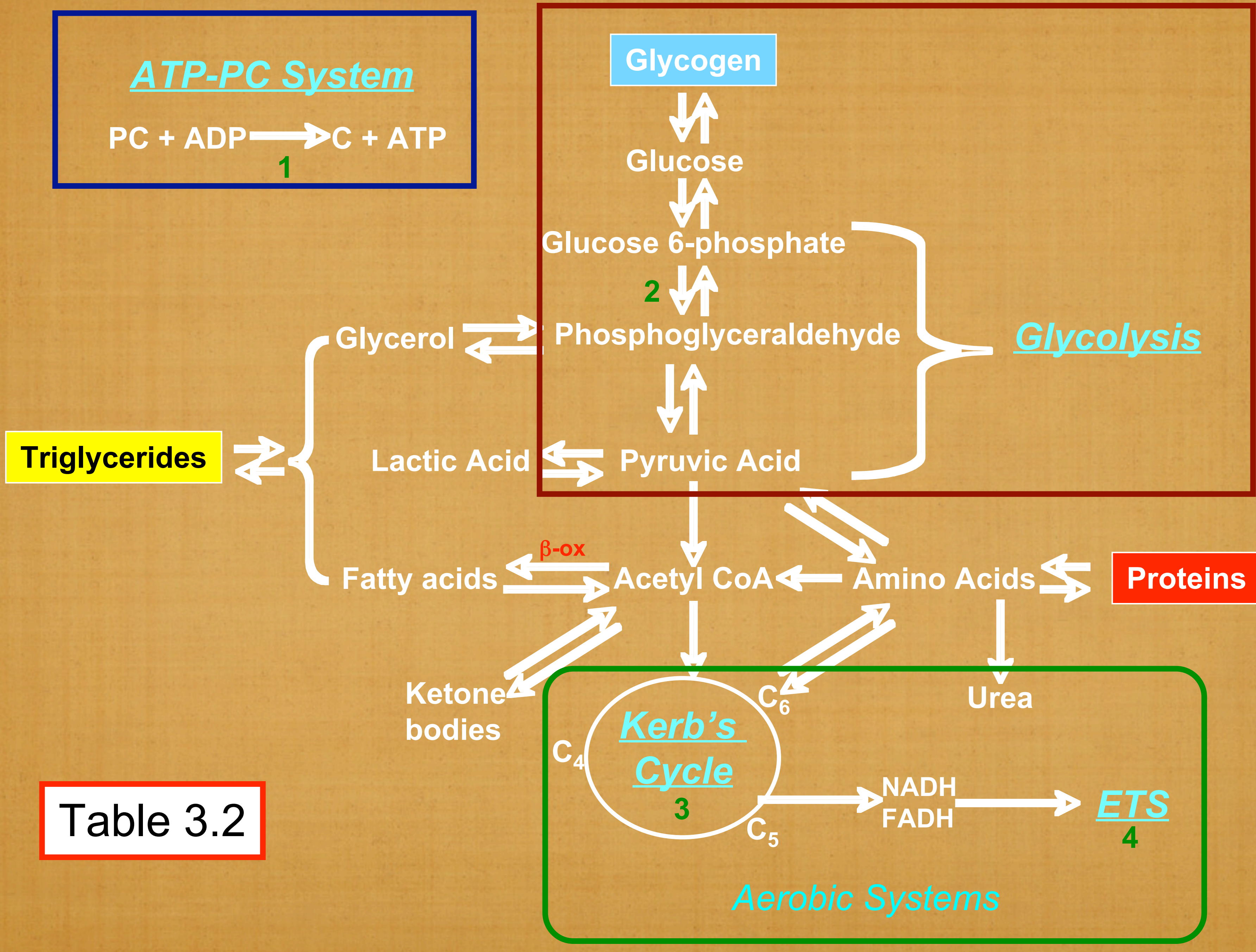
Fuels provide the energy for the systems to make ATP

Summary of Fuels

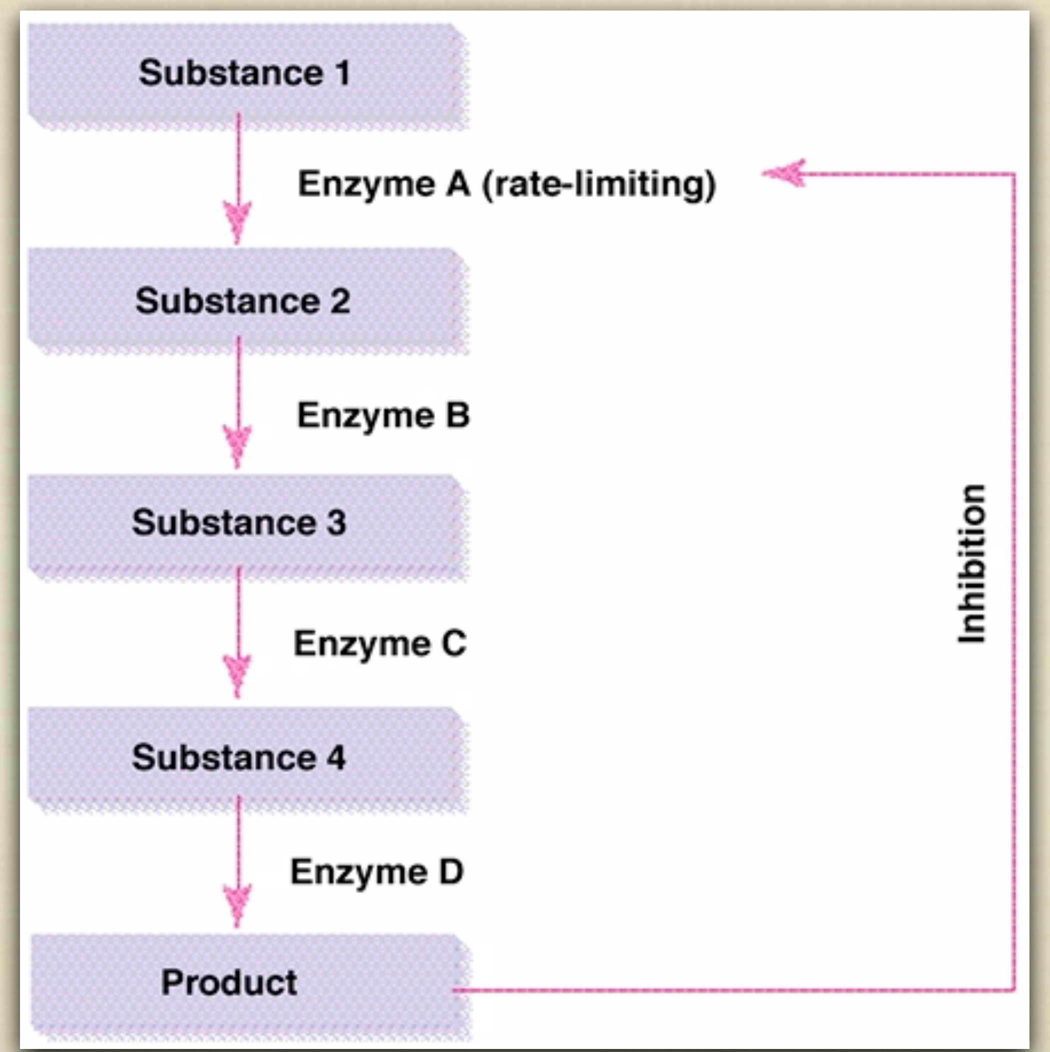
Fuel	Phospho-creatine	Carbo-hydrates	Fats	Protein
Stored	Phospho-creatine	Glycogen	Fatty acids	
		Glucose		Amino acids
Energy system	ATP-PC	Glycolysis		
		Aerobic	Aerobic	Aerobic

Fuels provide the energy for the systems to make ATP

Summary: Fuels and Energy



Control of Bioenergetics



What is a rate limiting enzyme?

Control of Bioenergetics

Pathway	Rate-limiting Enzyme	Stimulators	Inhibitors
ATP-PC	Creatine kinase	ADP	ATP
Glycolysis	Phosphofructo-kinase	ADP, ↑pH	ATP, ↓pH
Krebs	Isocitrate Dehydrogenasese	ADP, Ca, NAD	ATP, NADH
E.T.C.	Cytochrome oxidase	ADP, P	ATP