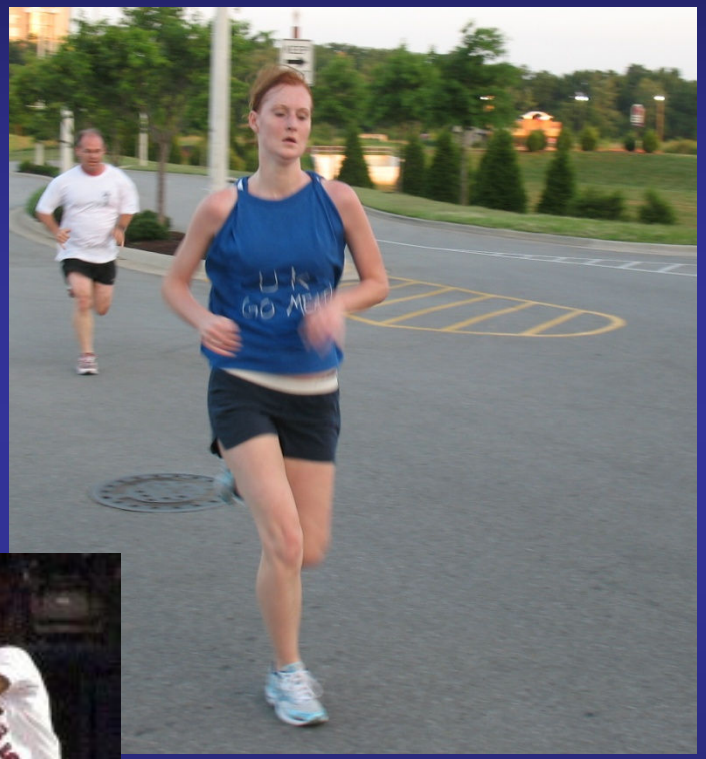
Test next Thursday, the 24th will only cover the lecture material, not lab stuff!

Energy Metabolism

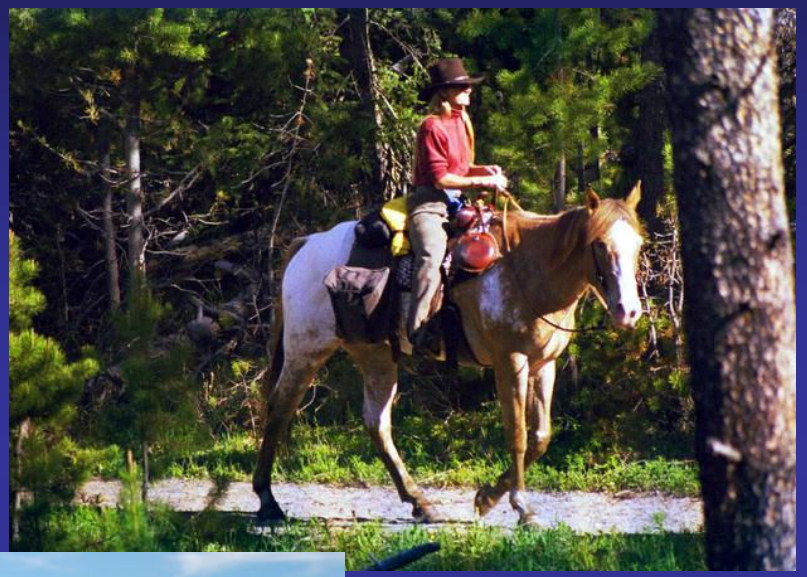
Objectives

- Understand how muscles differ
  - Fiber types
- Understand how we fuel muscle
  - Glycogen
  - Fats
  - How many ATP from each type of metabolism

How do these muscles differ?



Or these muscles?



Muscle Fiber Types

- Type I
- Type IIA
- Type IIX or Type IID
- Type IIB
- Each differ by metabolism (energy they use) and job they perform

Type I

- High Myoglobin content
- Small diameter
- Slow contraction speed
- Very resistant to fatigue
- Very oxidative metabolism
- Very little glycolytic activity and glycogen
- High lipid content
- Long distance runner or endurance athlete

Type IIA

- Moderate myoglobin content
- Small fiber diameter
- Moderate contraction speed
- Moderate fatigue resistant
- Very oxidative metabolism
- Very little glycogen content or glycolytic metabolism
- Moderate lipid content
- Normal everyday muscle contraction or normal everyday horse used for pleasure riding

Type IIX(D)

- Low myoglobin content
- Moderate fiber diameter
- Moderate contraction speed
- Very little fatigue resistance
- Very little oxidative metabolism
- Moderate glycogen content and glycolytic activity
- Low lipid content
- Once thought to be a transitional fiber type, but quickly becoming the 4th fiber type
- Athletes that combine both strength and endurance, like a baseball player or a sprinter, or a race horse

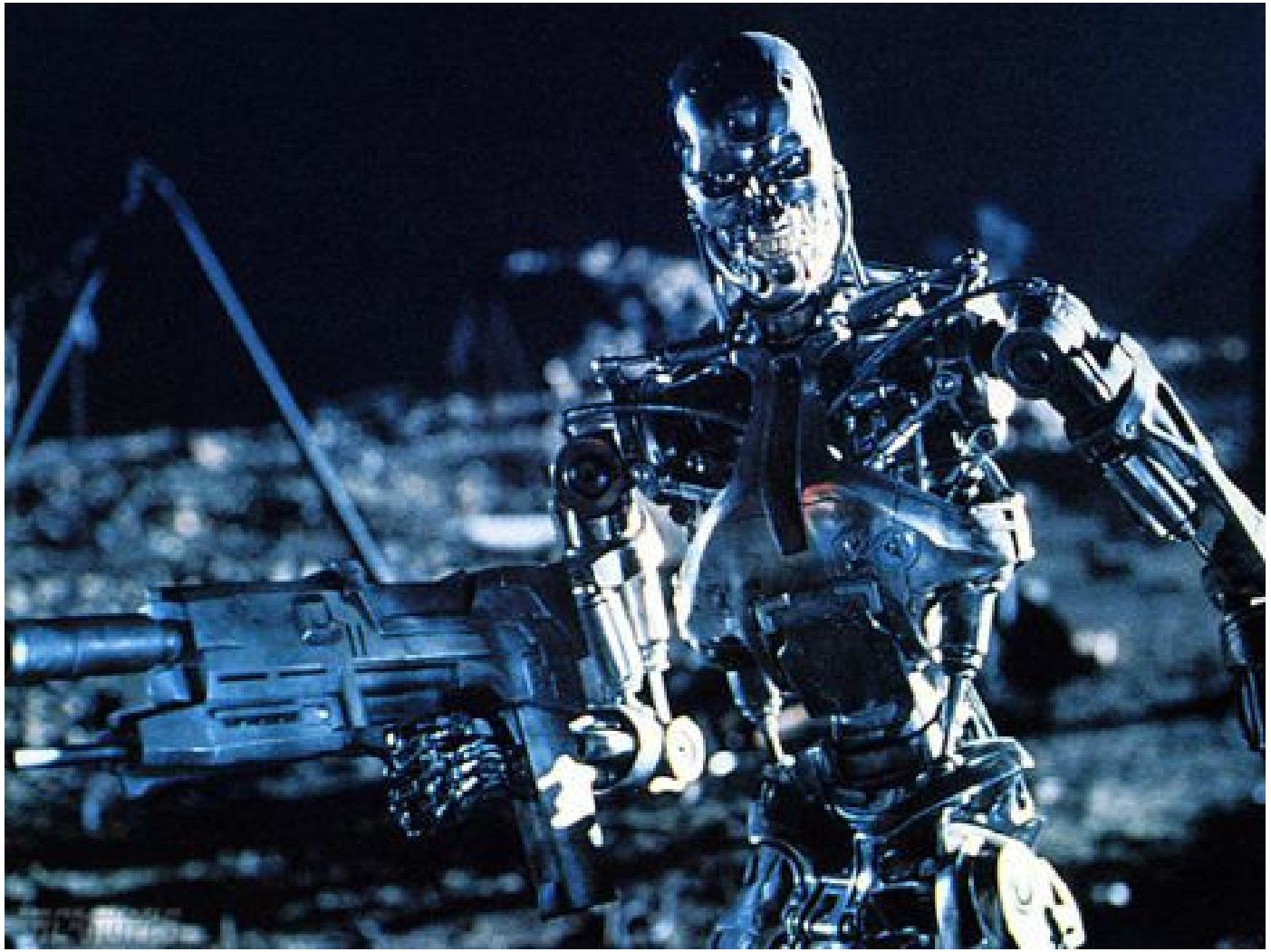
Type IIB

- Low myoglobin content
- Large fiber diameter
- Very little fatigue resistance
- Fast contraction speed
- Very little oxidative metabolism
- High glycogen content and glycolytic metabolism
- Very little lipid content
- Body builders, Powerlifters, Sprinters or Draft horses and Race horses

Muscle Fiber Types

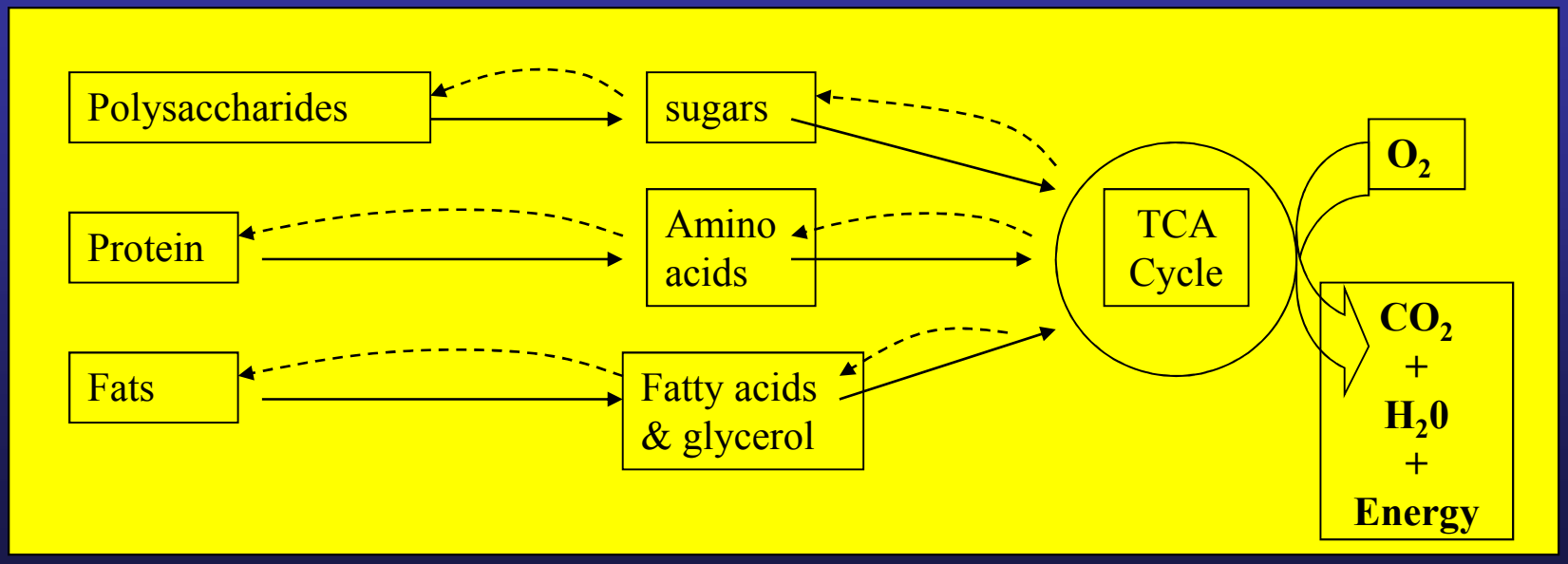
- Most muscles contain all four fiber types
- Some are predominately one specific fiber type
- The most common will dictate the:
  - Type of metabolism
  - Type of work or job that it will perform

Muscle is a machine; how do we fuel this machine?



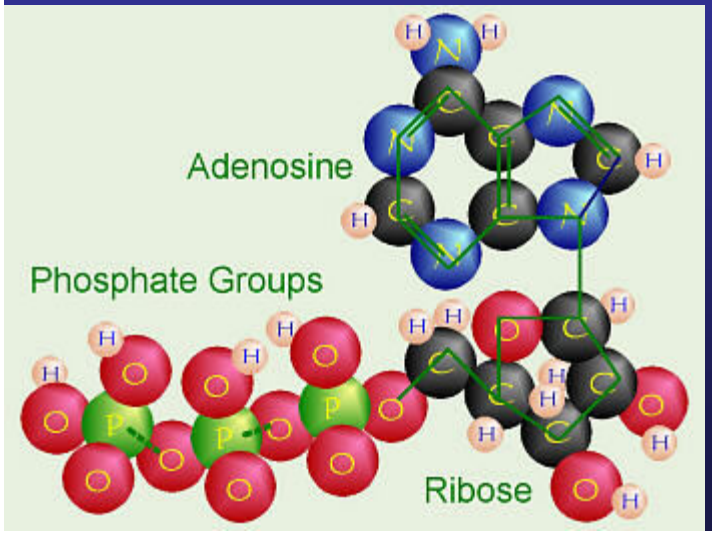
Functions of Metabolism

- Obtain chemical energy from fuel molecules
- Convert exogenous material into building blocks
- Convert building blocks into macromolecules
- Degrade macromolecules as required



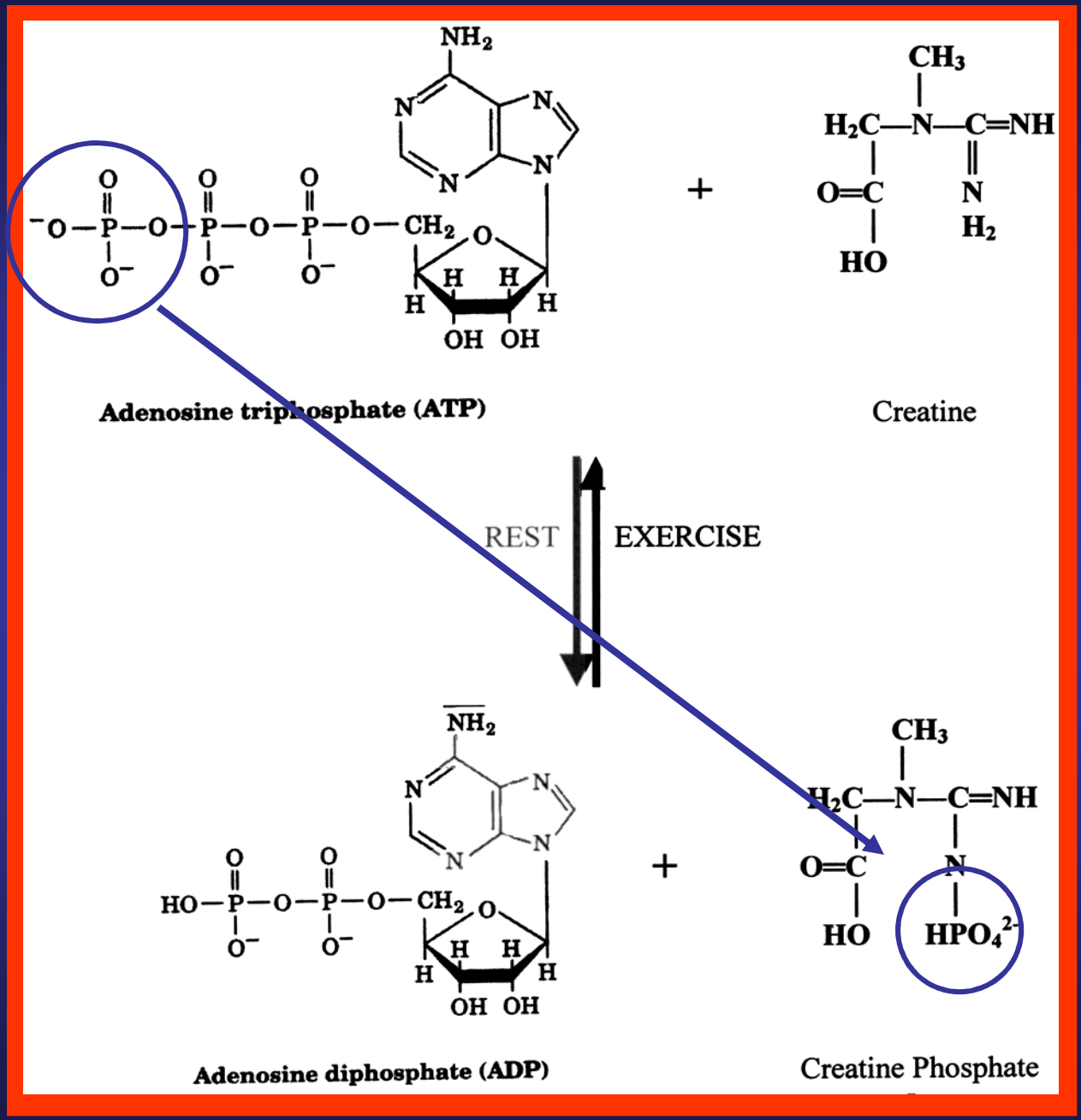
What form of energy is need for contraction?

- Immediate sources of energy
  - Adenosine Triphosphate (ATP)
  - Phosphocreatine (creatine phosphate)



Immediate Energy

- ATP
  - Main energy currency
  - 3-5mM resting concentration
  - ~10 twitches
- Phosphocreatine
  - Rapid rephosphorylation of ADP
  - Extra P*i* for another 80-100 twitches


Adenosine triphosphate (ATP)
Creatine
REST
EXERCISE
Adenosine diphosphate (ADP)
Creatine Phosphate

Carbohydrates

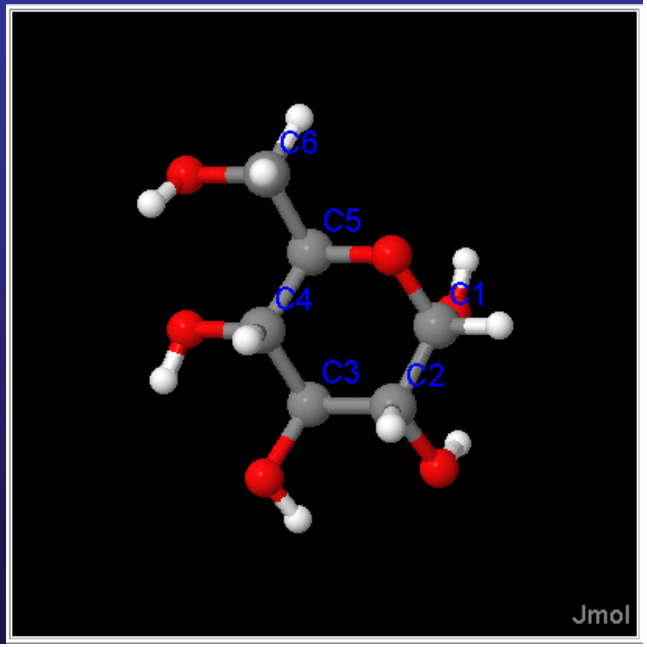
- Fed State (after eating)
  - Intake complex carbohydrates
    - Starches
    - Polysaccharides
  - Eventually converted to glucose
    - Often referred to as “blood glucose” or “blood sugar”

Carbohydrates

- Insulin
  - Increase in blood glucose triggers insulin release
  - Escorts glucose into the muscle cell, cardiac, or fat
  - Muscle – GLUT 4 glucose transproters
  - High insulin levels will trigger the release of glucagon, insulin's arch nemesis

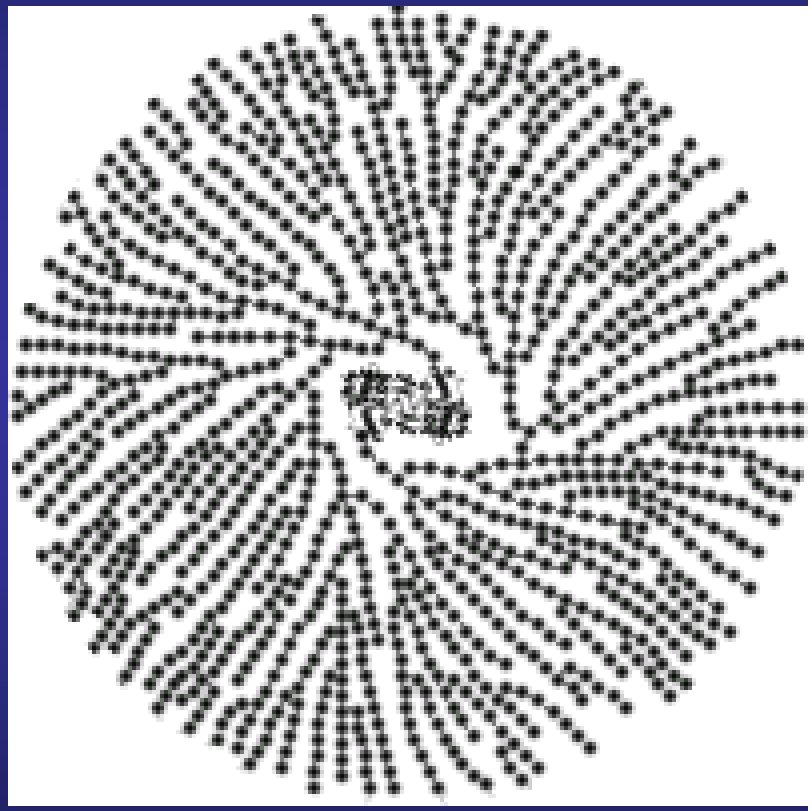
Glucose ⟶ Glycogen

- Glucose is stored as glycogen
- Glycogen
- Highly branched molecule
  - Glycogenin – protein core (self-glycosylating protein)
  - Tyr 194 residue
  - α – 1,4 linkages
  - β – 1,6 branches



Types of Glycogen

- **Proglycogen**
  - Smaller (~400 kDa)
  - Acid inslouble
  - 2500 glucose residues
- **Macroglycogen**
  - Larger (~10^7 kDa)
  - 60,000 glucose residues
  - aka Depot Glycogen



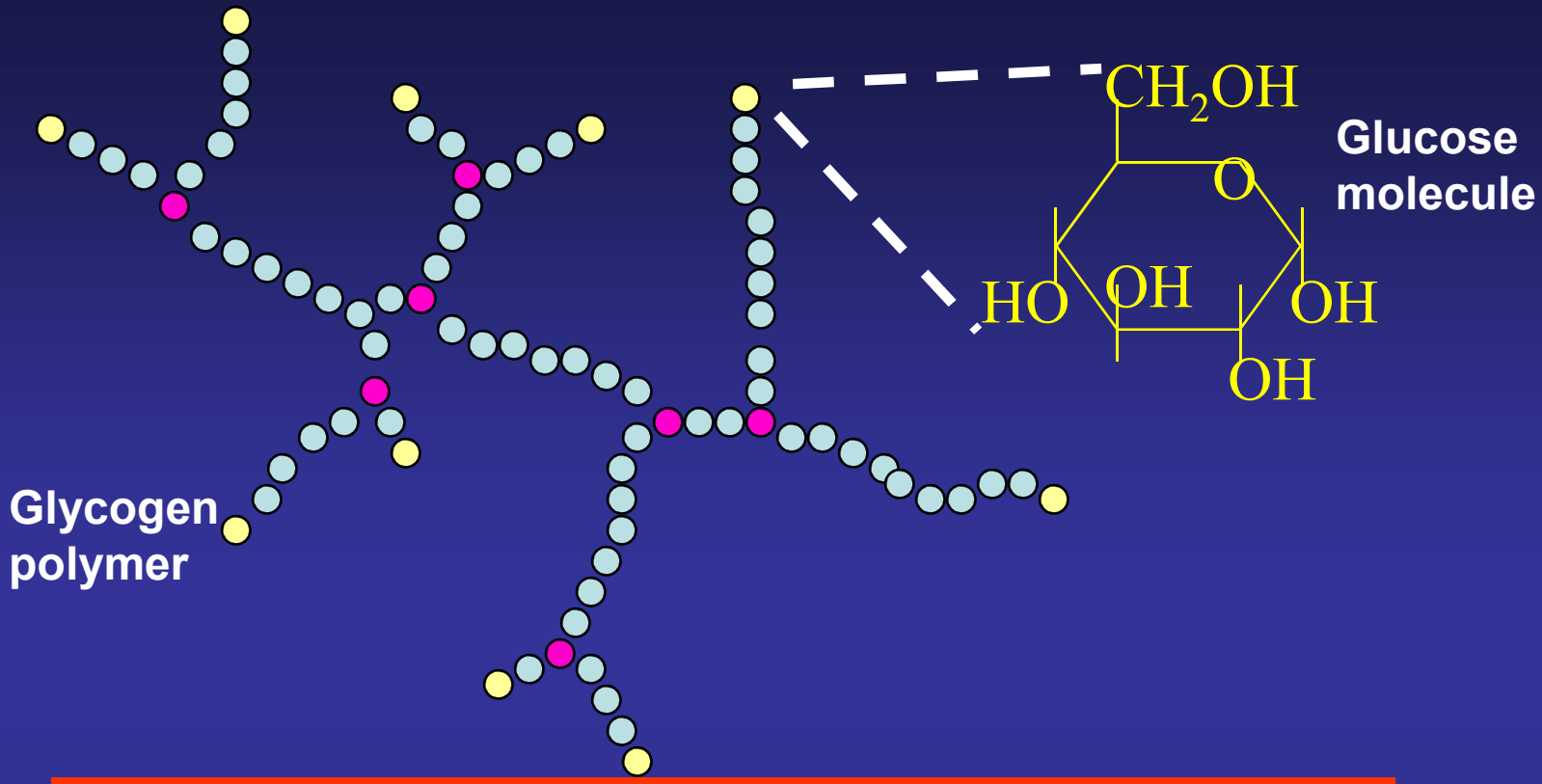
How it forms?

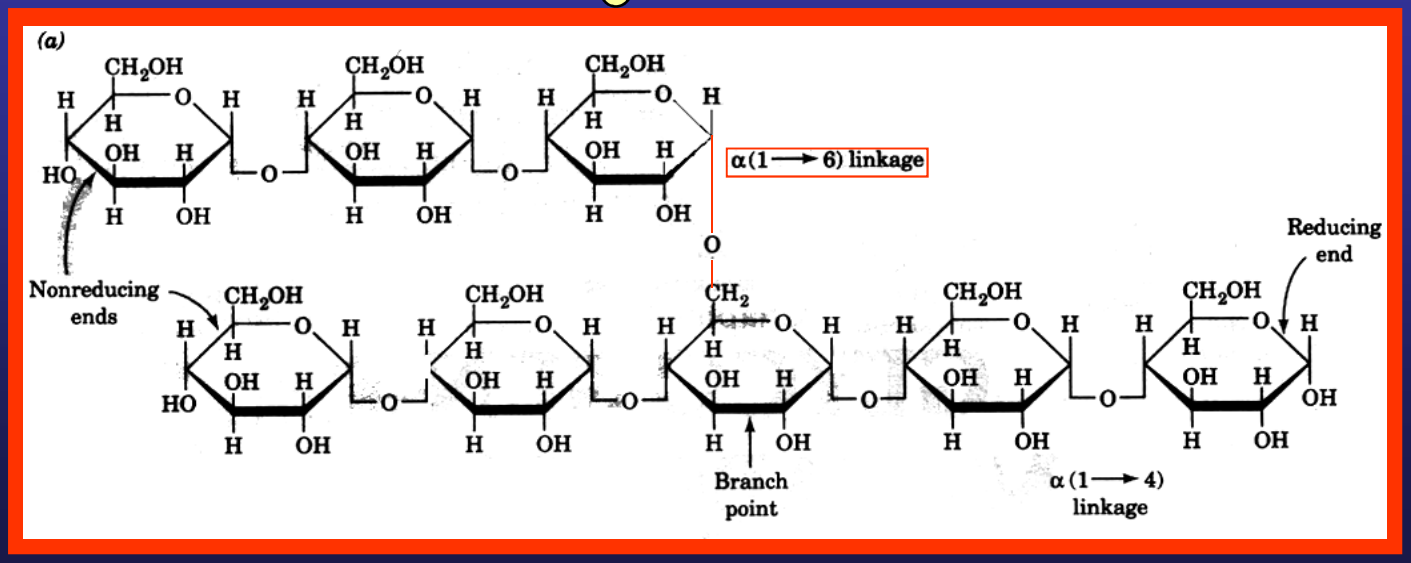
- Two schools of thought
- G → PG → MG
  - Just a continuance of size

- Glycogen synthase – formation of glycogen
  - Proglycogen synthase
  - Glycogen synthase = Macroglycogen

Metabolism

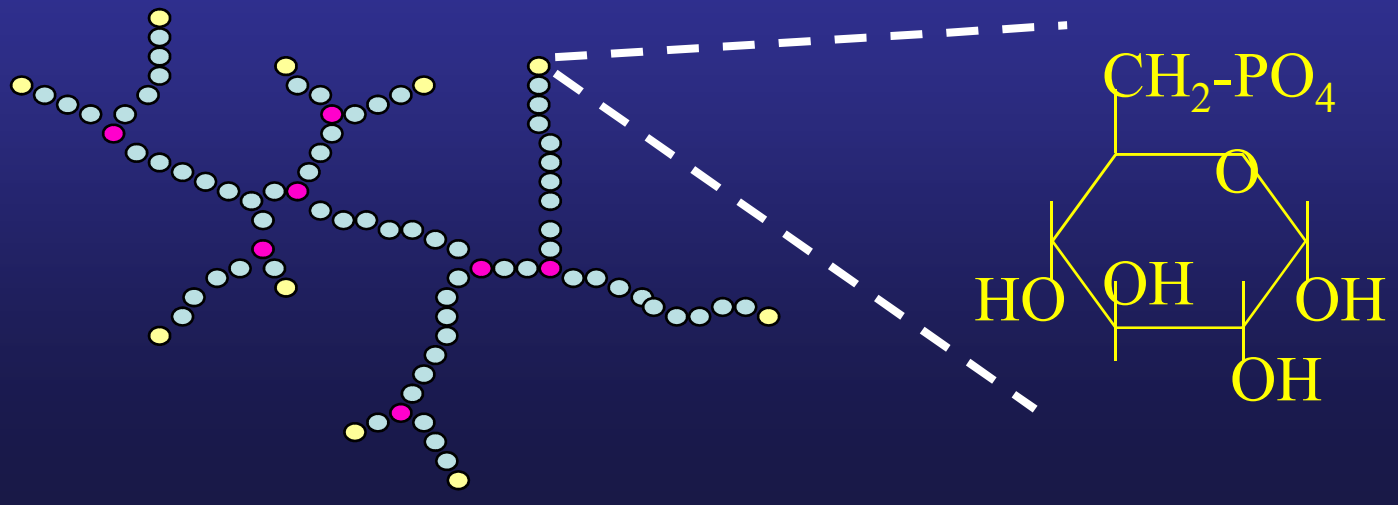
- Low to medium intensity = PG
- High intensity = MG
- PG re-synthesized before MG
- Cardiac = 4:1 PG:MG
- Liver = 3% PG
- Pork Ultimate pH
  - Higher ultimate pH = more MG metabolized
  - Lower ultimate pH = more PG metabolized

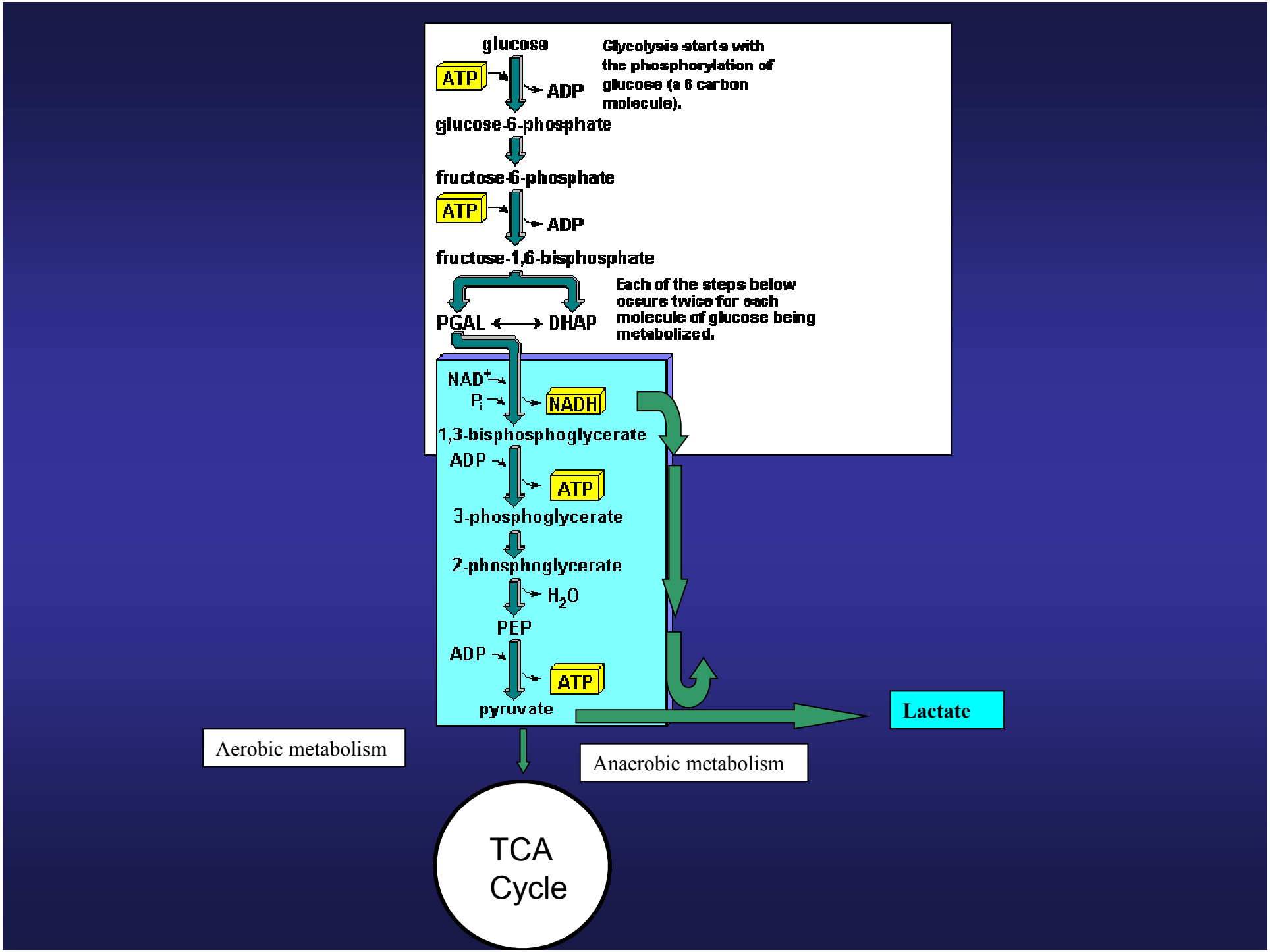

Glycogen polymer
Glucose molecule
CH2OH
O
HO
OH
OH
OH

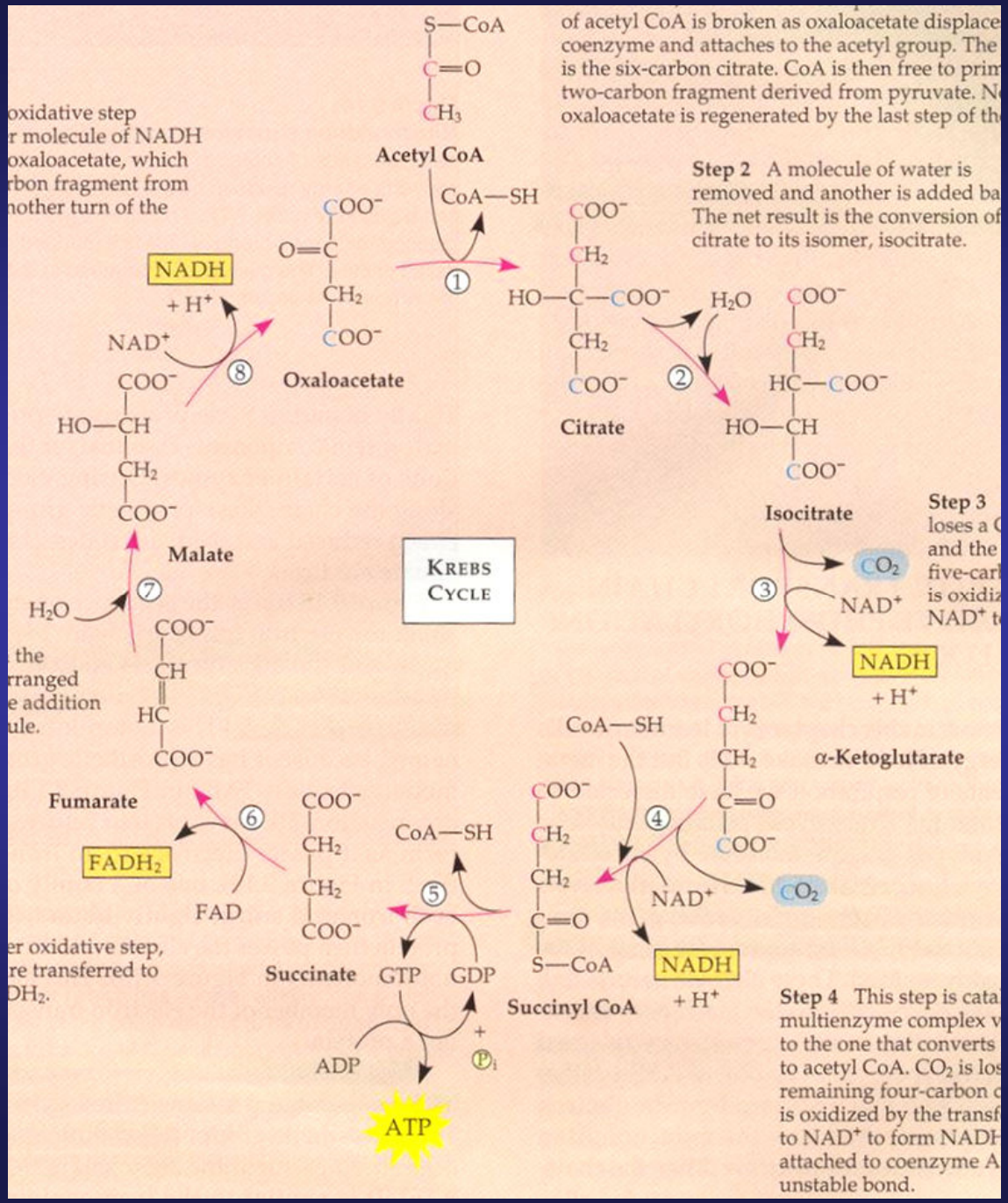

(a)
α(1 → 6) linkage
Nonreducing ends
Reducing end
Branch point
α (1 → 4) linkage

Glycogen

- **In muscle:**
  - **Low ATP levels will triggers the release of glucose from glycogen**
  - **Glycolysis**
  - **Glucose 6-Phosphate**




glucose
ATP
ADP
Glycolysis starts with the phosphorylation of glucose (a 6 carbon molecule).
glucose-6-phosphate
fructose-6-phosphate
ATP
ADP
fructose-1,6-bisphosphate
PGAL
DHAP
Each of the steps below occure twice for each molecule of glucose being metabolized.
NAD+
Pi
NADH
1,3-bisphosphoglycerate
ADP
ATP
3-phosphoglycerate
2-phosphoglycerate
H2O
PEP
ADP
ATP
pyruvate
Lactate
Aerobic metabolism
Anaerobic metabolism
TCA Cycle



oxidative step
r molecule of NADH
oxaloacetate, which
rbon fragment from
nother turn of the

of acetyl CoA is broken as oxaloacetate displace
coenzyme and attaches to the acetyl group. The
is the six-carbon citrate. CoA is then free to prim
two-carbon fragment derived from pyruvate. N
oxaloacetate is regenerated by the last step of th

Step 2 A molecule of water is removed and another is added ba
The net result is the conversion of
citrate to its isomer, isocitrate.

Step 3
loses a
and the
five-car
is oxidiz
NAD+ t

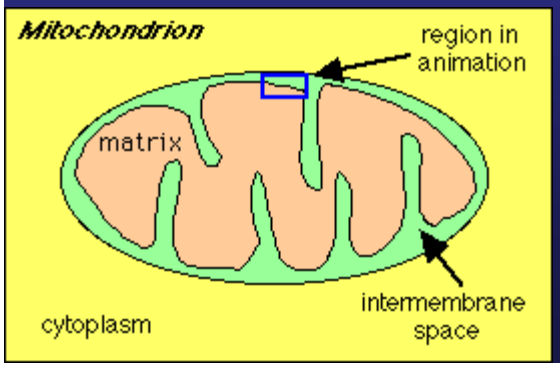
the
rranged
e addition
ule.

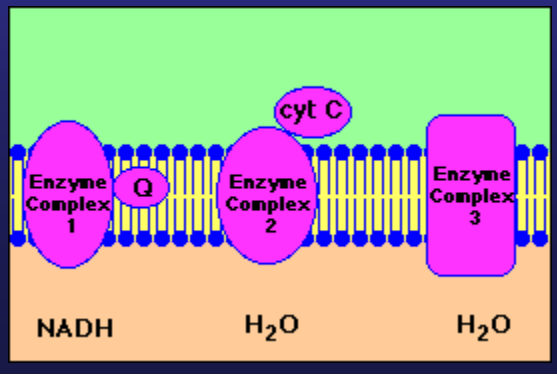
er oxidative step,
re transferred to
$FADH_2$.

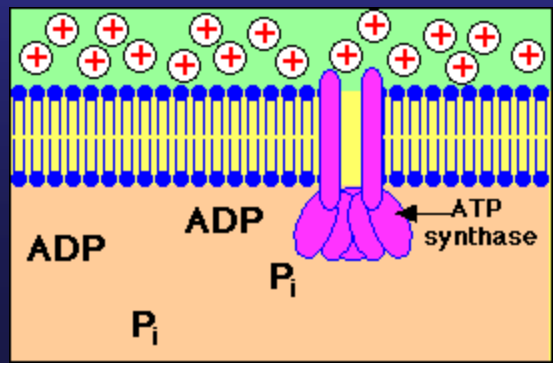
Step 4 This step is cata
multienzyme complex v
to the one that converts
to acetyl CoA. CO_2 is los
remaining four-carbon
is oxidized by the transf
to NAD^+ to form NADH
attached to coenzyme A
unstable bond.

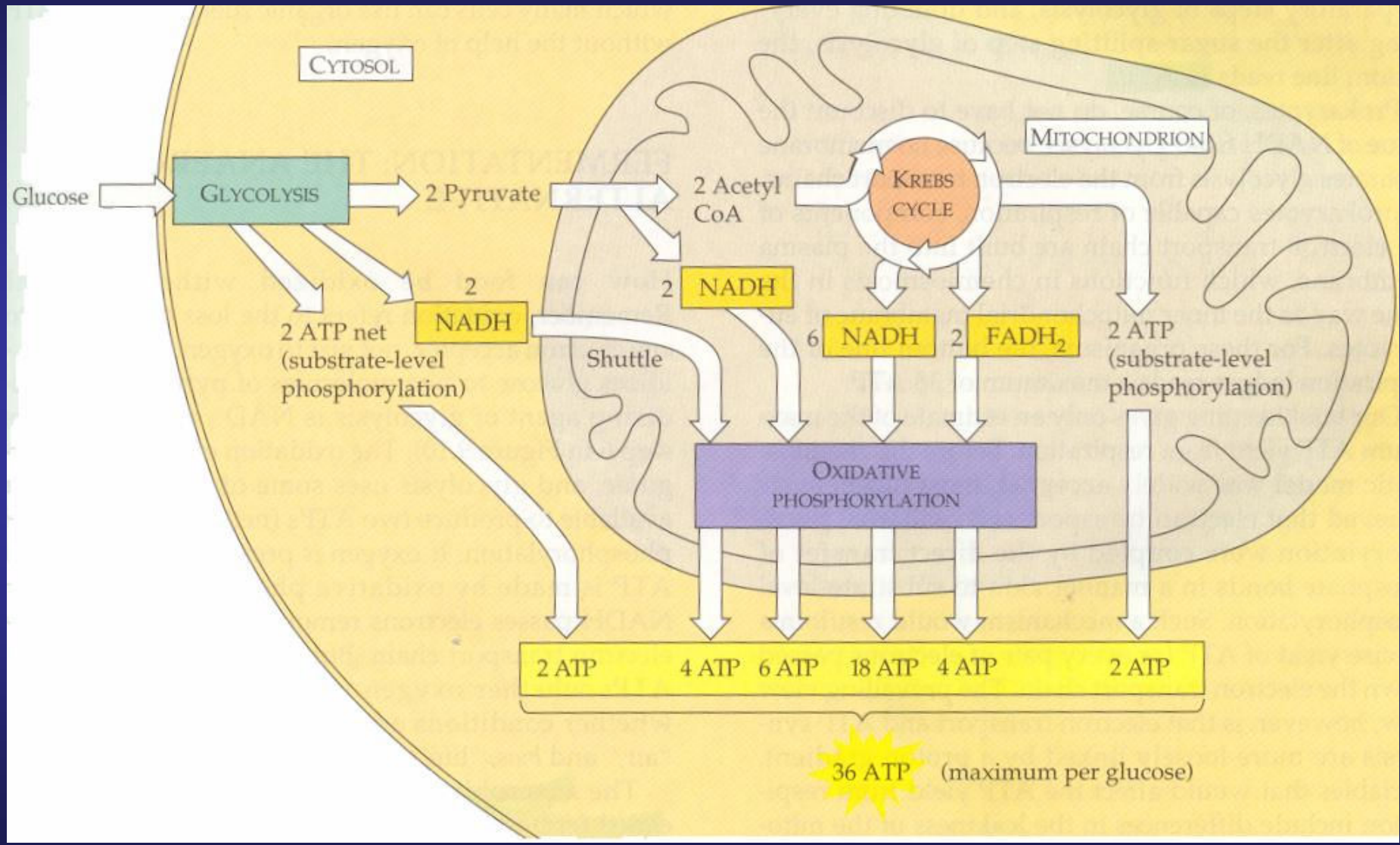
The Electron Transport Chain

- Mitochondria
- Complex series of reactions
- NADH = 3 ATP
- $FADH_2$ = 2 ATP



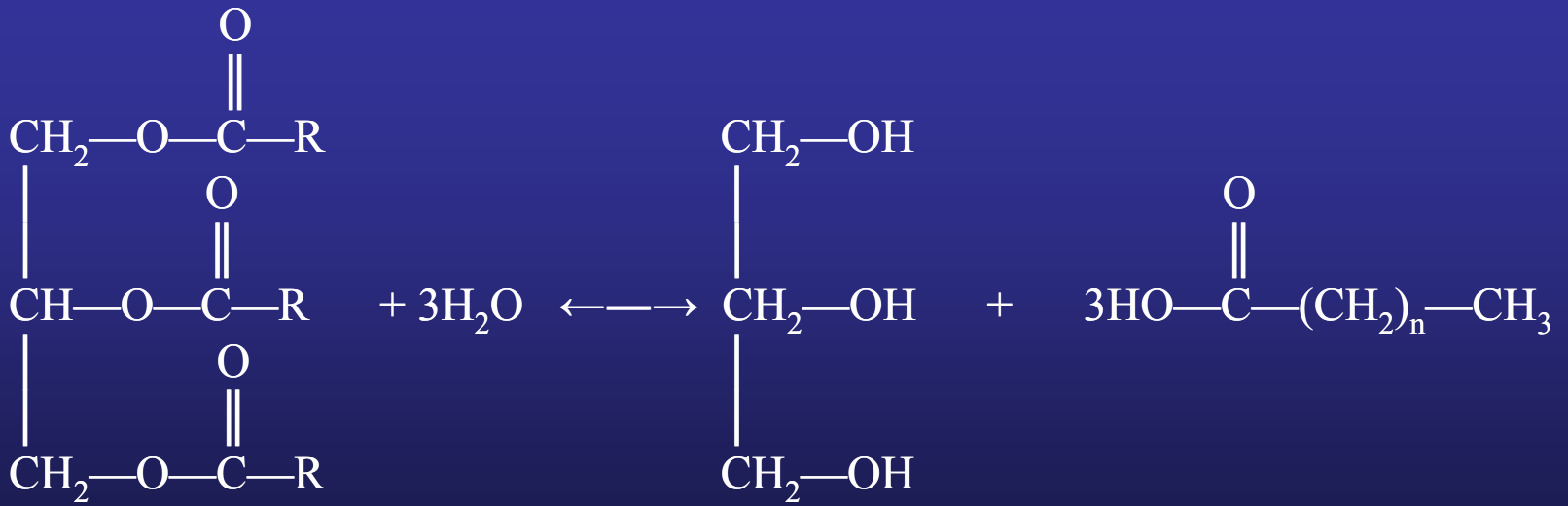





CYTOSOL
MITOCHONDRION
Glucose
GLYCOLYSIS
2 Pyruvate
2 Acetyl CoA
KREBS CYCLE
2 NADH
2 NADH
2 ATP net (substrate-level phosphorylation)
Shuttle
6 NADH
2 FADH2
2 ATP (substrate-level phosphorylation)
OXIDATIVE PHOSPHORYLATION
2 ATP
4 ATP
6 ATP
18 ATP
4 ATP
2 ATP
36 ATP
(maximum per glucose)

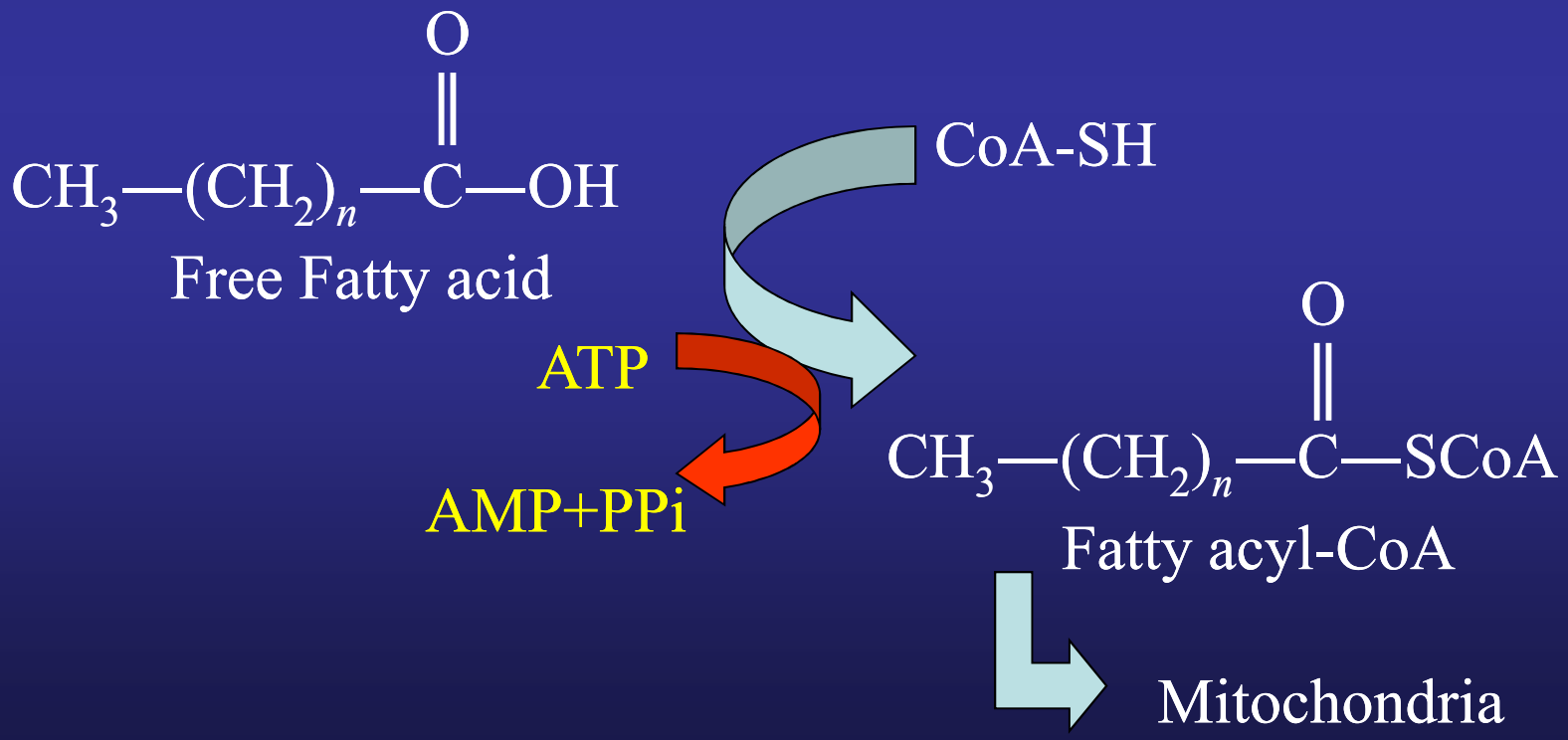
Fat

- Fat is the major storage form of energy
- Fatty acid oxidation
- Fatty acids make up fat
- Attached to a triglyceride backbone



Fatty Acid Oxidation

- **Individual fatty acids are removed**
- **Acetyl-CoA binds to the FA**

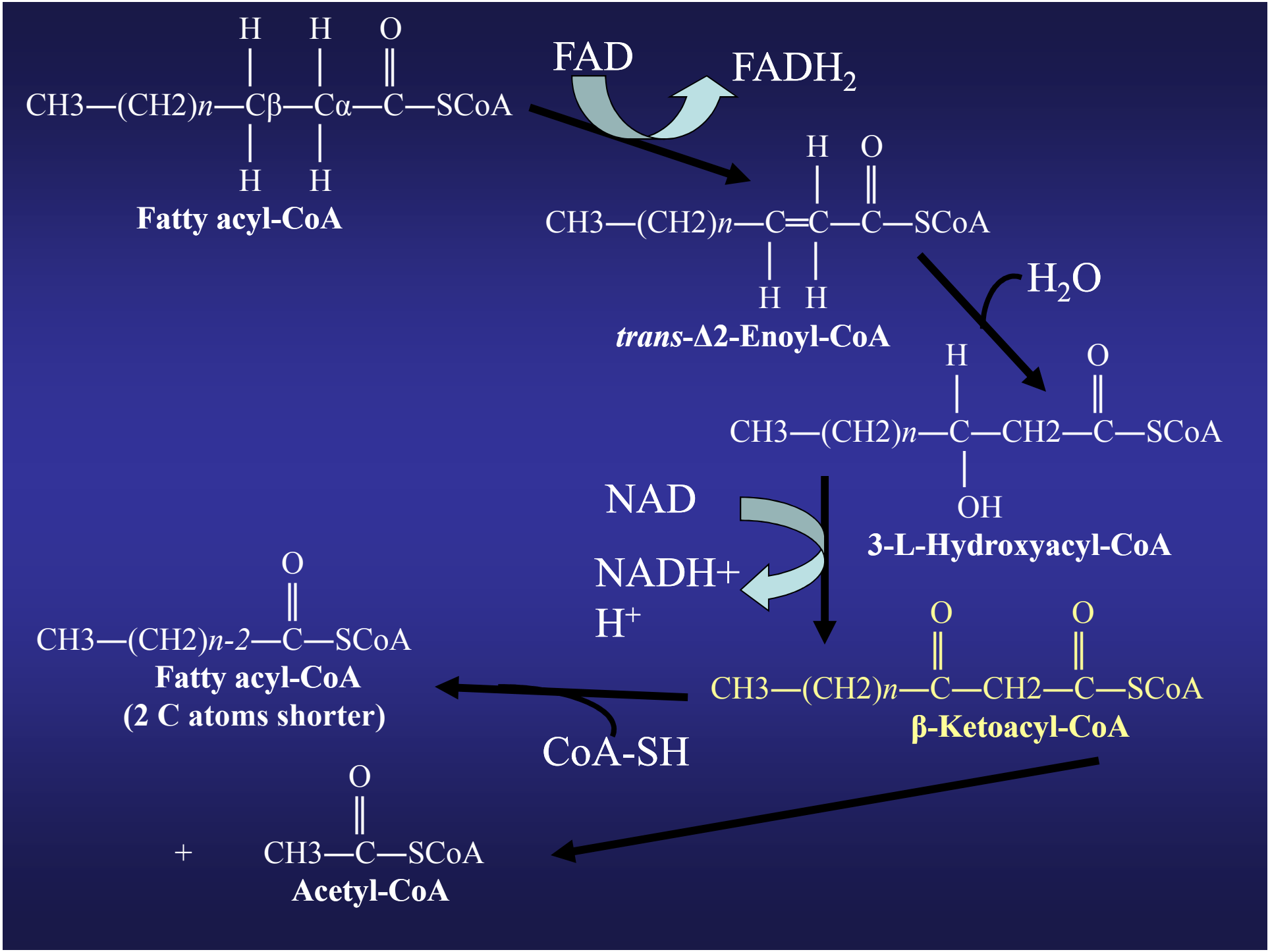


Lets go here to understand this further!!

- http://www.brookscole.com/chemistry_d/templates/student_resources/shared_resources/animations/carnitine/carnitine1.html

Fatty Acid Oxidation

- β – Oxidation (three stages)
- 1st A series of enzymatic reactions will create a shorter chained fatty acid by removing two carbon units
  - Forms Acetyl-CoA
- 2nd Enter the TCA Cycle to produce ATP & CO2
- 3rd NADH & FADH2 enter electron transport chain
- Palmiate (16 carbon chain) = 8 acetyl-CoA
- Depending on length of chain FA Oxidation = 130+ ATP


CH3—(CH2)n—Cβ—Cα—C—SCoA
Fatty acyl-CoA
FAD
FADH2
CH3—(CH2)n—C=C—C—SCoA
trans-Δ2-Enoyl-CoA
H2O
CH3—(CH2)n—C—CH2—C—SCoA
OH
3-L-Hydroxyacyl-CoA
NAD
NADH+
H+
CH3—(CH2)n—C—CH2—C—SCoA
β-Ketoacyl-CoA
CoA-SH
CH3—(CH2)n-2—C—SCoA
Fatty acyl-CoA
(2 C atoms shorter)
+
CH3—C—SCoA
Acetyl-CoA

Proteins

- Proteins can be used for energy
- Extreme circumstances
- Costly energy

Let's put this together

- Aerobic Glycolysis = 36 ATP
- Anaerobic Glycolysis = 2 to 3 ATP
- Fatty Acid Oxidation = 130+ ATP
- How does Muscle Fiber Type fit into the picture?
- Type I
- Type IIB