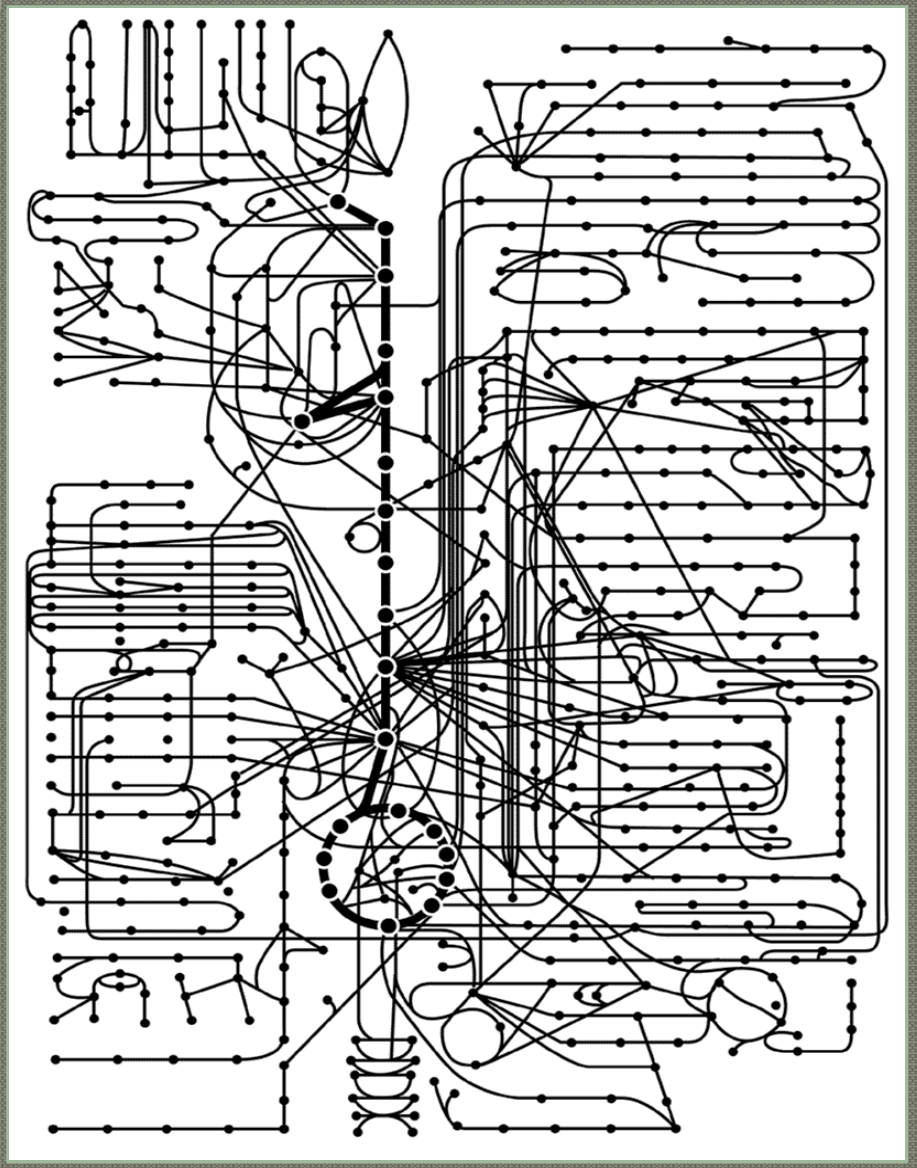
Integration of Metabolism



Integrated CIRCUIT or IC of Metabolism

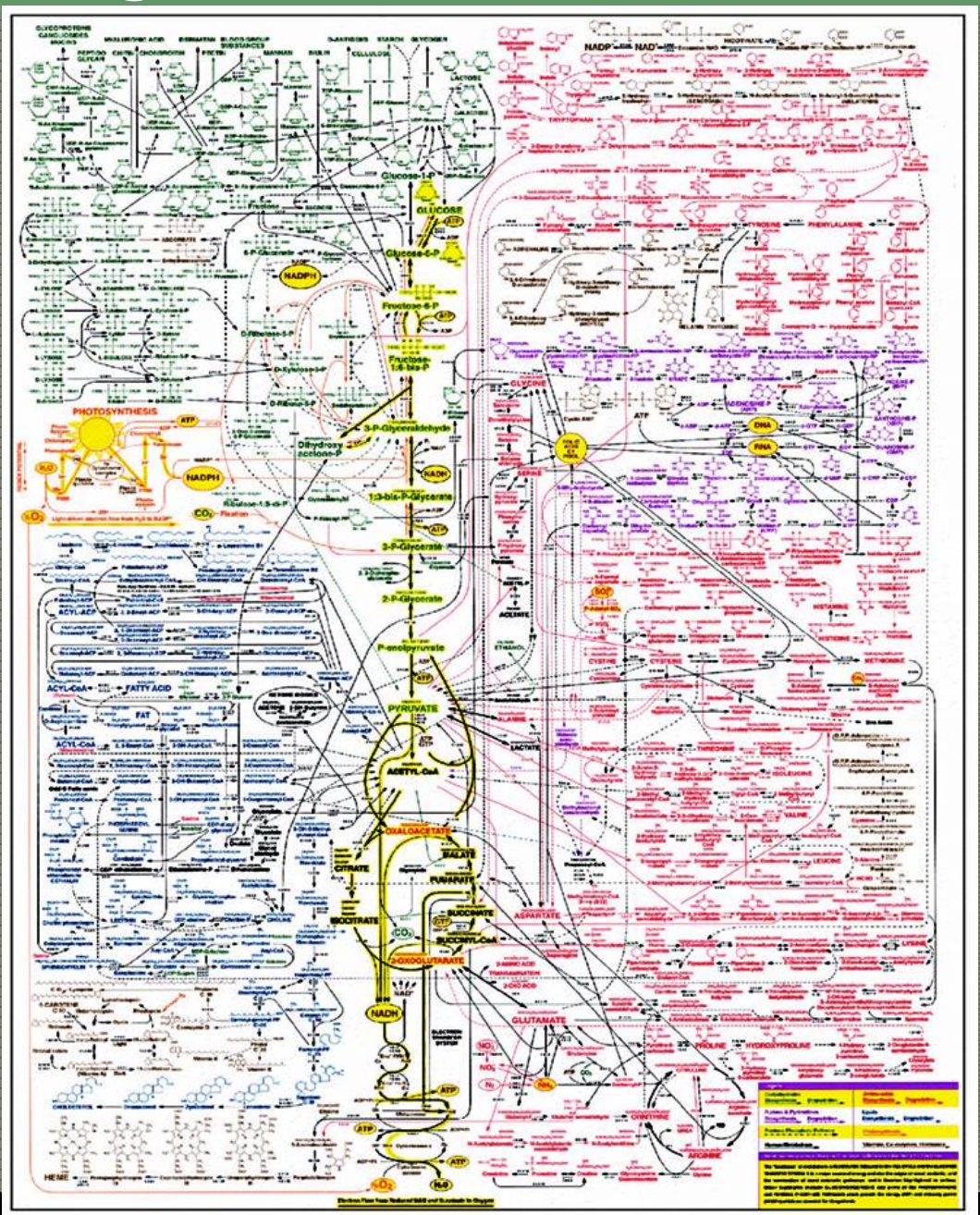
The breakdown and synthesis of **carbohydrates**, **proteins**, and **lipids** connect with the pathways of glucose catabolism. The simple sugars are galactose, fructose, glycogen, and pentose. ... The amino acids from proteins connect with glucose catabolism through **pyruvate, acetyl CoA**, and components of the TCA cycle.

How does sandwich end up as ATP in our body cells? This happens because all of the catabolic pathways for carbohydrates, proteins, and lipids eventually connect into glycolysis and the citric acid cycle pathways (see Figure). Metabolic pathways should be thought of as porous—that is, substances enter from other pathways, and intermediates leave for other pathways. These pathways are not closed systems. Many of the substrates, intermediates, and products in a particular pathway are reactants in other pathways. It's really looks one IC.

Integration of Metabolism

Sugar metabolism

Lipid metabolism



Amino acid metabolism

Nucleotide metabolism

Amino acid metabolism

Interrelationship of Carbohydrate, Lipid, & Protein Metabolism

- Any energy nutrient can fuel the body in the short term
- TCA cycle = amphibolic pathway
- Lipogenesis
  - CHO spares lipolysis - promotes gain
  - Glucose is precursor for glycerol & fatty acids

- Gluconeogenesis
  - Glycerol portion only from fat
  - Fatty acids with odd # of C atoms
  - Glucogenic amino acids
- Conversion among energy nutrients favors lipogenesis

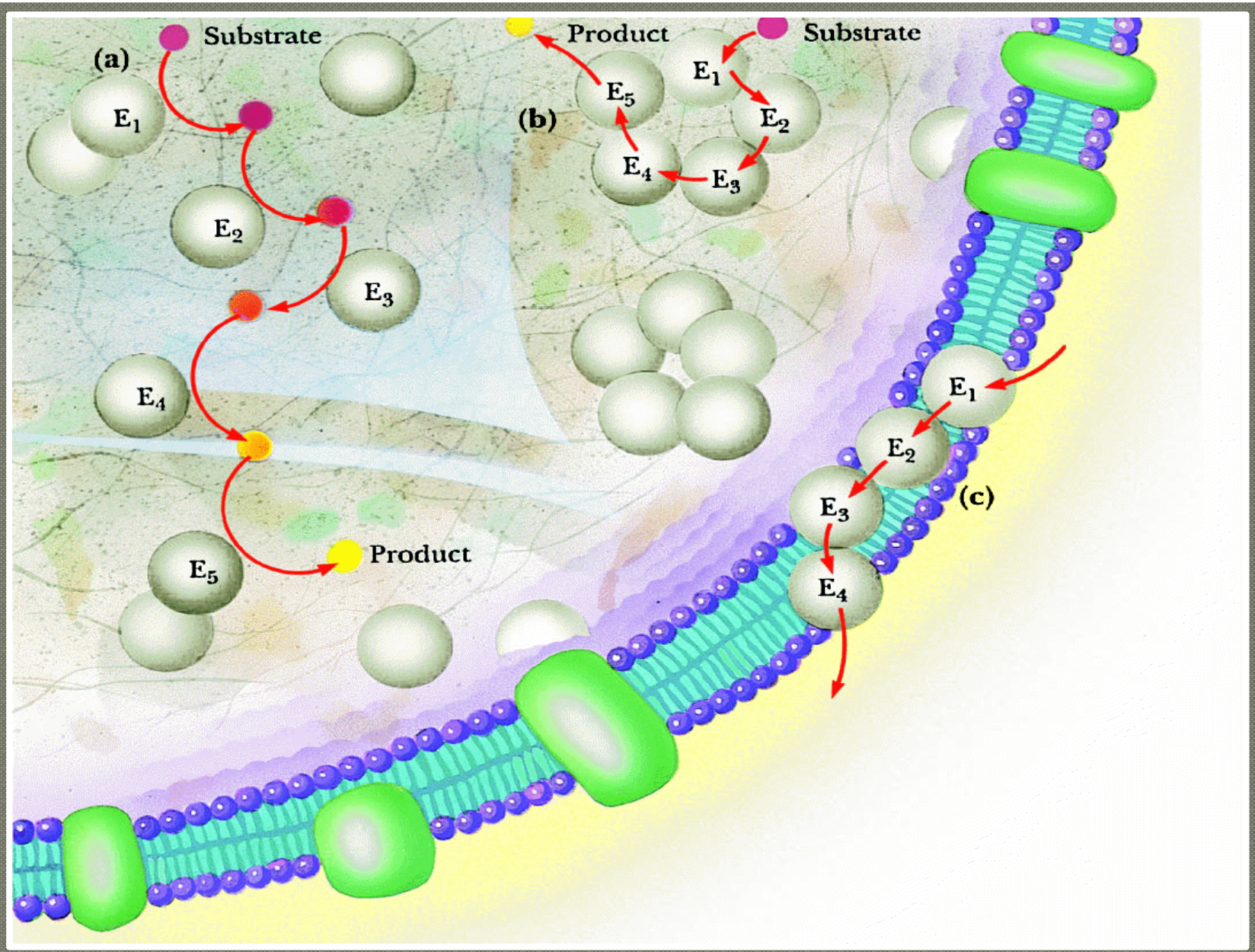
- TCA cycle & electron transport chain - common to all 3
- This catabolic pathway also:
  - Produces CO_2 for carboxylation & C for other needs
  - Provides common intermediates
  - Provides citrate & malate for lipogenesis

Connections of Other Sugars to Glucose Metabolism

Glycogen, a polymer of glucose, is an energy storage molecule in animals. When there is adequate ATP present, excess glucose is shunted into glycogen for storage. Glycogen is made and stored in both liver and muscle. The glycogen will be hydrolyzed into glucose monomers (G-1-P) if blood sugar levels drop. The presence of glycogen as a source of glucose allows ATP to be produced for a longer period of time during exercise. Glycogen is broken down into G-1-P and converted into G-6-P in both muscle and liver cells, and this product enters the glycolytic pathway.

Sucrose is a disaccharide with a molecule of glucose and a molecule of fructose bonded together with a glycosidic linkage. Fructose is one of the three dietary monosaccharides, along with glucose and galactose (which is part of the milk sugar, the disaccharide lactose), which are absorbed directly into the bloodstream during digestion. The catabolism of both fructose and galactose produces the same number of ATP molecules as glucose.

EVERY STEP of REACTIONS in OUR BODY-CELL is DONE by an ENZYME & MOST BIOCHEMICAL ACTIVITIES are CHAIN-REACTIONS



Connections of Proteins to Glucose Metabolism

Proteins are hydrolyzed by a variety of enzymes in cells. Most of the time, the amino acids are recycled into the synthesis of new proteins. If there are excess amino acids, however, or if the body is in a state of starvation, some amino acids will be shunted into the pathways of glucose catabolism (Figure 7.6.17.6.1). Each amino acid must have its amino group removed prior to entry into these pathways. The amino group is converted into ammonia. In mammals, the liver synthesizes urea from two ammonia molecules and a carbon dioxide molecule. Thus, urea is the principal waste product in mammals produced from the nitrogen originating in amino acids, and it leaves the body in urine.

Connecting Proteins to Glucose Metabolism

Excess amino acids are converted into molecules that can enter the pathways of glucose catabolism.

Amino acids must be deaminated before entering any of the pathways of glucose catabolism: the amino group is converted to ammonia, which is used by the liver in the synthesis of urea.

Deaminated amino acids can be converted into pyruvate, acetyl CoA, or some components of the citric acid cycle to enter the pathways of glucose catabolism.

Several amino acids can enter the glucose catabolism pathways at multiple locations.

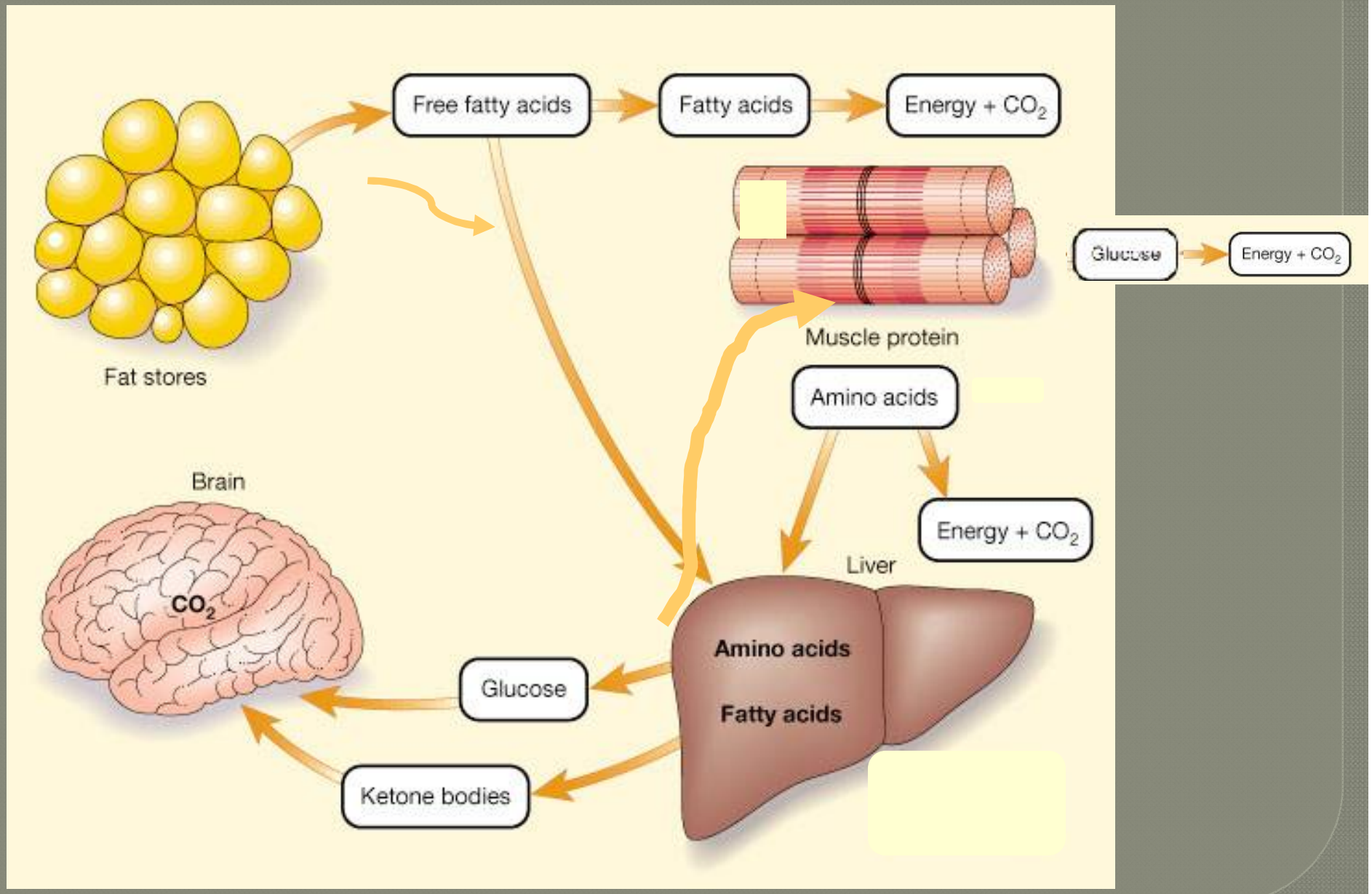
Connection of Amino Acids to Glucose Metabolism Pathways:

The carbon skeletons of certain amino acids (indicated in boxes) are derived from proteins and can feed into pyruvate, acetyl CoA, and the citric acid cycle.

- When blood sugar levels drop, glycogen is broken down into glucose -1-phosphate, which is then converted to glucose-6-phosphate and enters glycolysis for ATP production.
- In the liver, galactose is converted to glucose-6-phosphate in order to enter the glycolytic pathway.
- Fructose is converted into glycogen in the liver and then follows the same pathway as glycogen to enter glycolysis.

Sucrose is broken down into glucose and fructose; glucose enters the pathway directly while fructose is converted to glycogen.

Metabolic Interrelationships



Connecting Lipids to Glucose Metabolism

Lipids can be both made and broken down through parts of the glucose catabolism pathways. Many types of lipids exist, but cholesterol and triglycerides are the lipids that enter the pathways of glucose catabolism. Through the process of phosphorylation, glycerol can be converted to glycerol-3-phosphate during the glycolytic pathway. When fatty acids are broken down into acetyl groups through beta-oxidation, the acetyl groups are used by CoA to form acetyl-CoA, which enters the citric acid cycle to produce ATP. Beta-oxidation produces $FADH_2$ and NADH, which are used by the electron transport chain for ATP production.

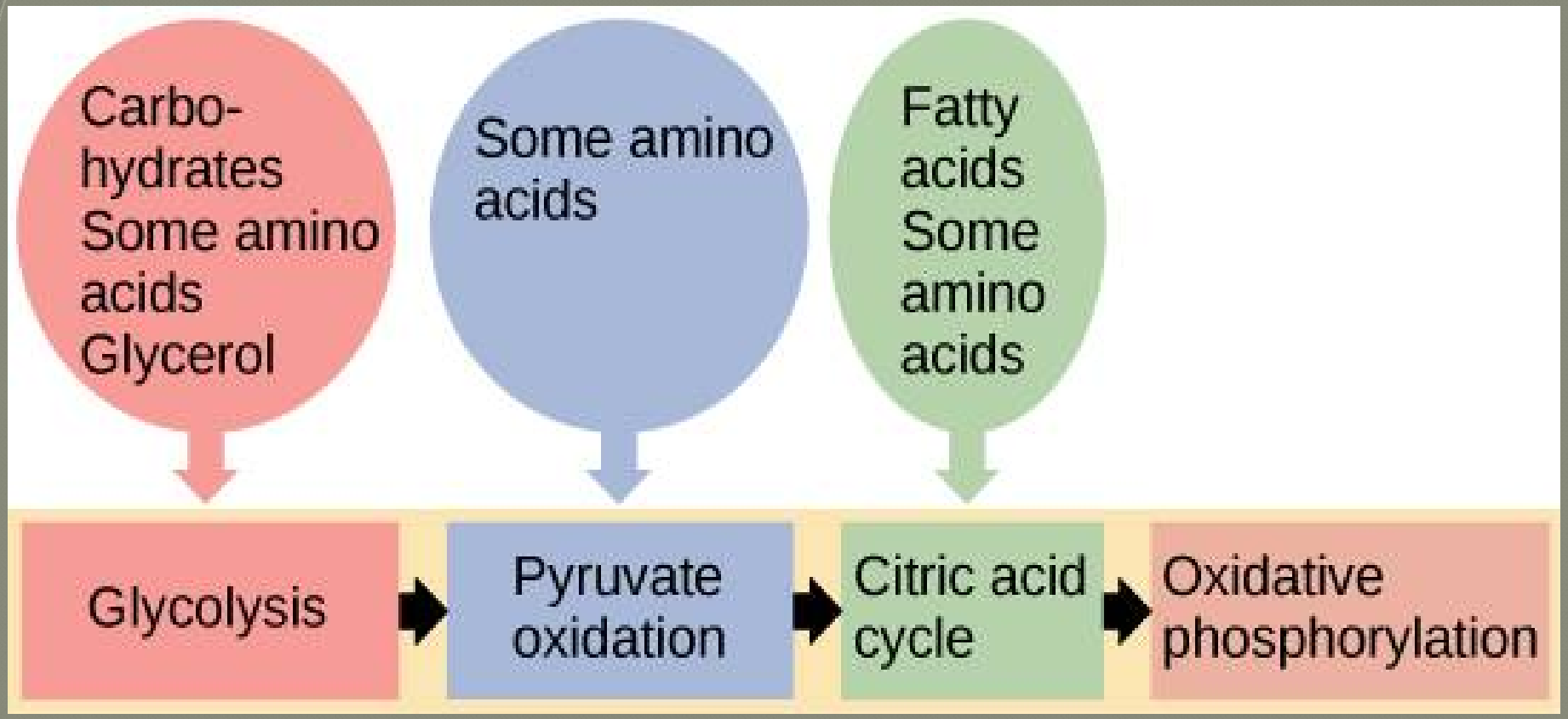
Cholesterol

Cholesterol contributes to cell membrane flexibility and is a precursor to steroid hormones. The synthesis of cholesterol starts with acetyl groups, which are transferred from acetyl CoA, and proceeds in only one direction; the process cannot be reversed. Thus, synthesis of cholesterol requires an intermediate of glucose metabolism.

Triglycerides

Triglycerides, a form of long-term energy storage in animals, are made of glycerol and three fatty acids. Triglycerides can be both made and broken down through parts of the glucose catabolism pathways. Glycerol can be phosphorylated to glycerol-3-phosphate, which continues through glycolysis.

Fatty acids are catabolized in a process called beta-oxidation that takes place in the matrix of the mitochondria and converts their fatty acid chains into two carbon units of acetyl groups, while producing NADH and $FADH_2$. The acetyl groups are picked up by CoA to form acetyl CoA that proceeds into the citric acid cycle as it combines with oxaloacetate. The NADH and $FADH_2$ are then used by the electron transport chain.

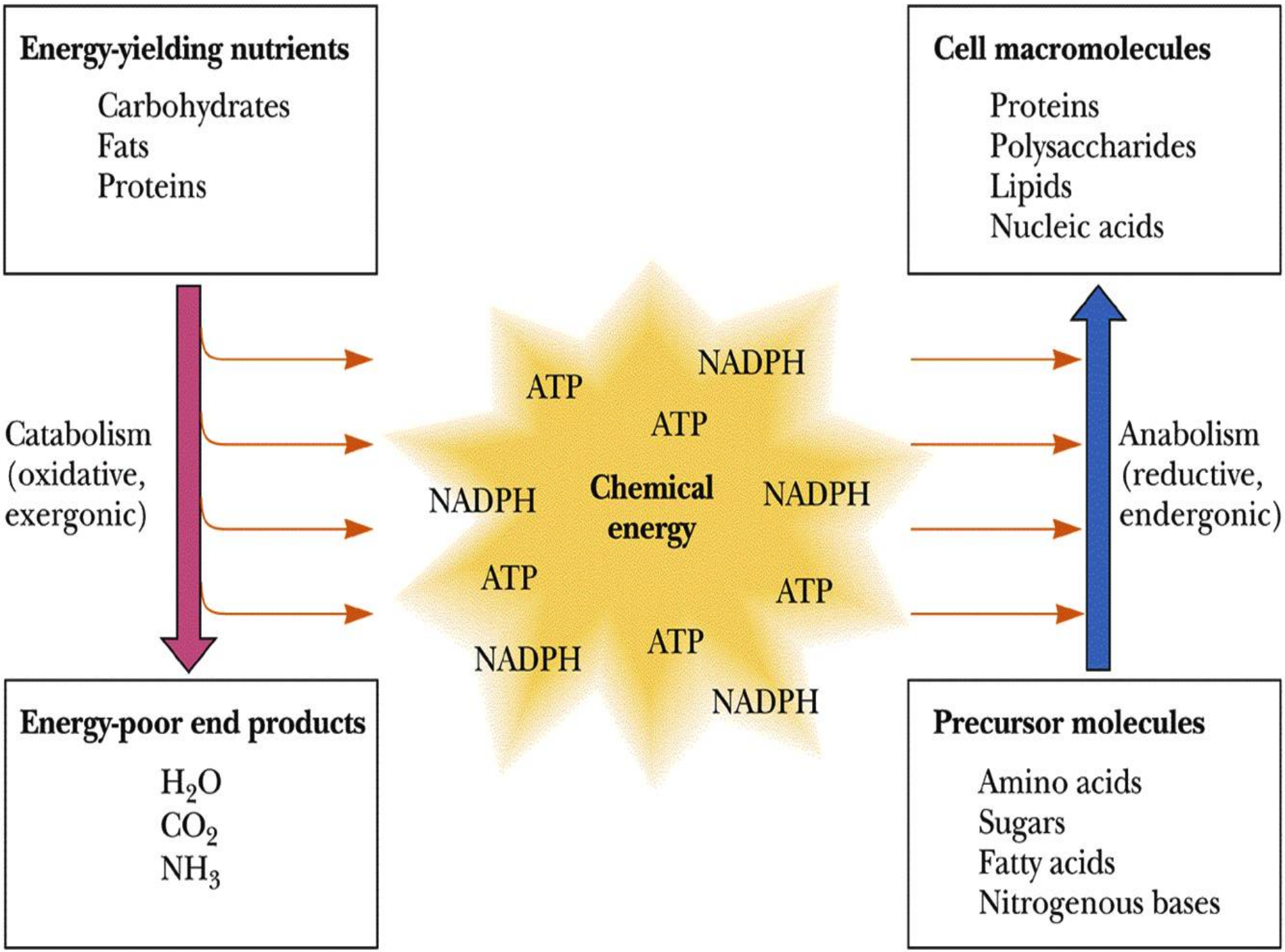


Connections of Carbohydrate, Protein, and Lipid Metabolic Pathways

Connections of Lipid and Glucose Metabolisms

The lipids that are connected to the glucose pathways are cholesterol and triglycerides. Cholesterol is a lipid that contributes to cell membrane flexibility and is a precursor of steroid hormones. The synthesis of cholesterol starts with acetyl groups and proceeds in only one direction. The process cannot be reversed.

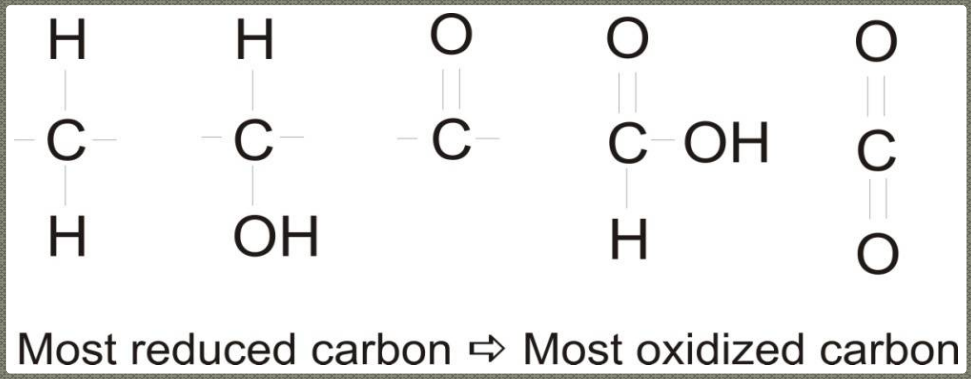
Triglycerides are a form of long-term energy storage in animals. Triglycerides are made of glycerol and three fatty acids. Animals can make most of the fatty acids they need. Triglycerides can be both made and broken down through parts of the glucose catabolism pathways. Glycerol can be phosphorylated to glycerol-3-phosphate, which continues through glycolysis. Fatty acids are catabolized in a process called beta-oxidation that takes place in the matrix of the mitochondria and converts their fatty acid chains into two carbon units of acetyl groups. The acetyl groups are picked up by CoA to form acetyl CoA that proceeds into the citric acid cycle.


Energy-yielding nutrients
Carbohydrates
Fats
Proteins
Cell macromolecules
Proteins
Polysaccharides
Lipids
Nucleic acids
Catabolism (oxidative, exergonic)
ATP
NADPH
ATP
NADPH
Chemical energy
NADPH
ATP
ATP
NADPH
ATP
NADPH
Anabolism (reductive, endergonic)
Energy-poor end products
H_2O
CO_2
NH_3
Precursor molecules
Amino acids
Sugars
Fatty acids
Nitrogenous bases

$O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$

$O_2 + 4H{:}^- \Rightarrow 2H_2O$

Oxygen is the ultimate destination for electrons in respiration
Those electrons are produced by the oxidation of carbon compounds. The electrons are carried by NADH.
NADH provides 1 H+ (hydride ion) during conversion to NAD+



Most reduced carbon ⇨ Most oxidized carbon

The general rule is: Carbons linked to fewer H's or more O's are more oxidized.

In general:

Catabolism is oxidative and requires a compensatory reduction of NAD+ to NADH

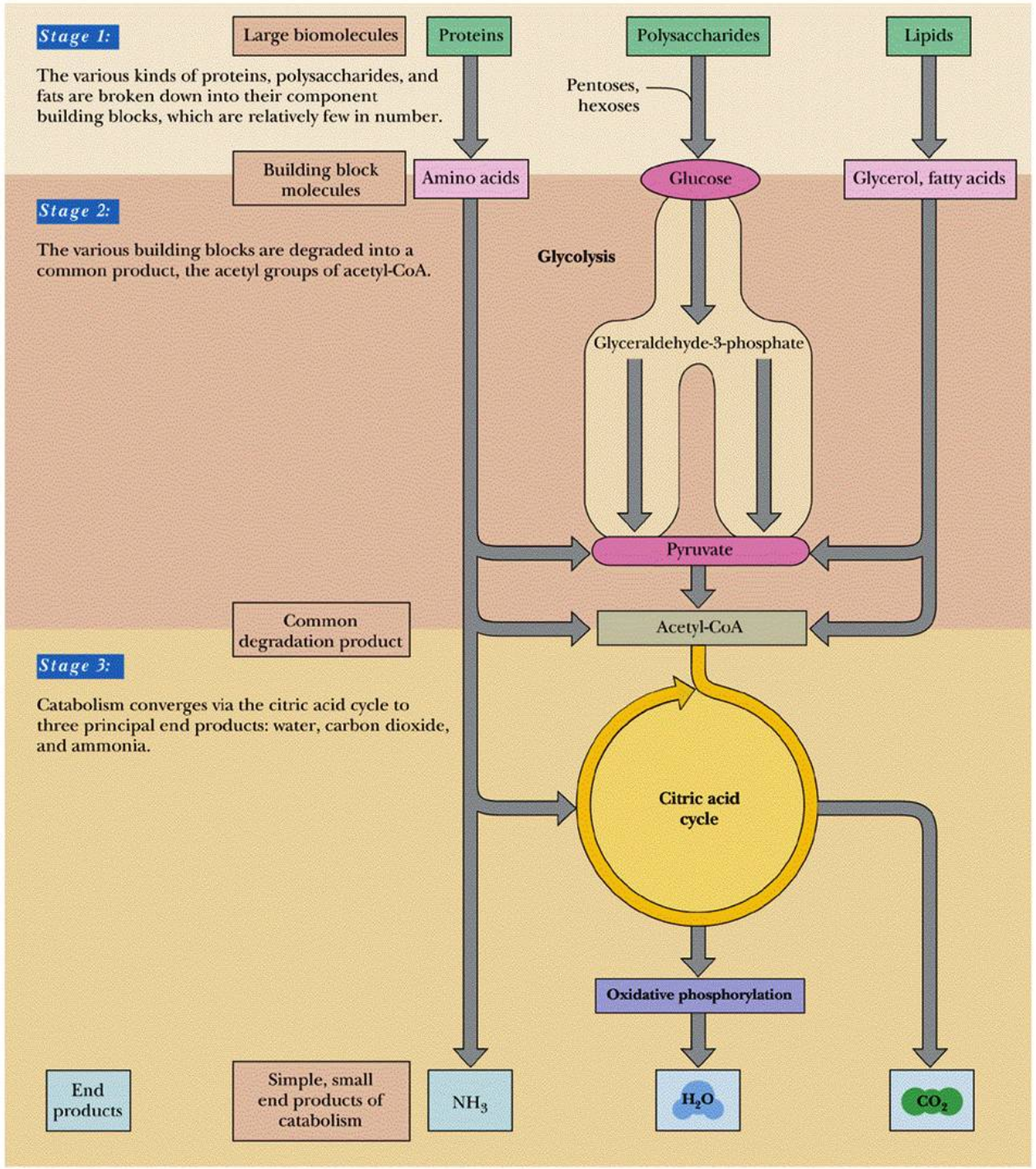
Anabolism is reductive and requires a compensatory oxidation of NADPH to NADP+

3 Stages of Catabolism

1. Polymers are broken down into their building blocks.

2. These building blocks are broken down into the acetyl groups of acetyl-CoA.

3. The end products are CO_2, water, and ammonia.



1.Metabolic pathways are highly conserved.

2.Catabolism typically involves oxidations and is energy-yielding whereas anabolism usually involves reduction and requires energy.

3.Catabolism and anabolism occur simultaneously in the cell in order to serve metabolic needs. The processes are usually highly regulated and may occur in separate compartments.

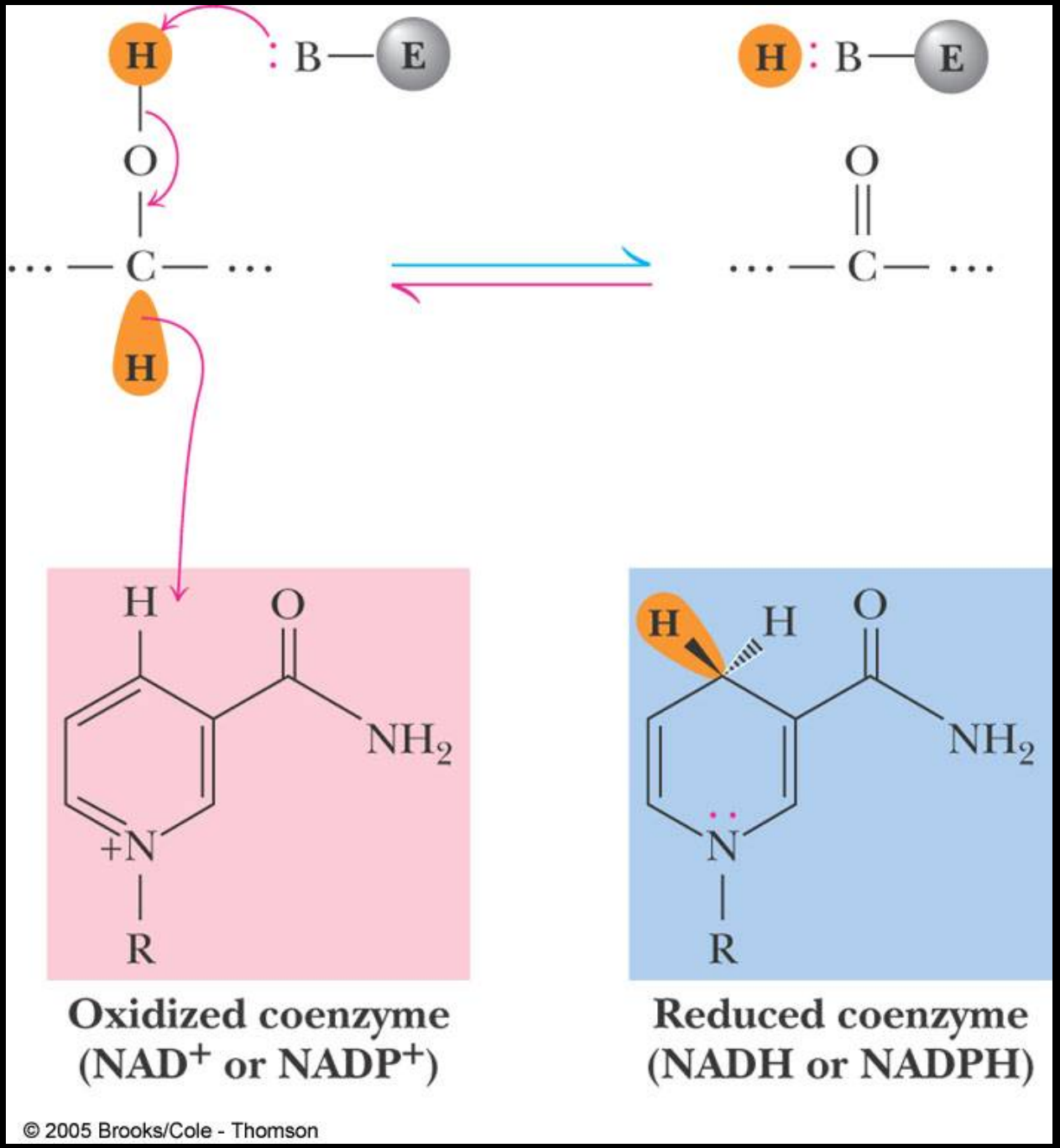
4. Corresponding pathways of catabolism and anabolism must differ in at least one step in order that they can be independently regulated.

5. Many of the oxidative reactions of catabolism involve the release of reducing equivalents, often as hydride ions, which are transferred in dehydrogenase reactions from the substrates to NAD^+.

$$AH_2 + NAD^+ \rightarrow A + NADH + H^+$$

6. During anabolism reducing power is usually provided by NADPH.

NAD^+ and $NADP^+$ participate exclusively in two-electron transfer reactions. For example, alcohols can be oxidized to ketones or aldehydes via hydride transfer to $NAD(P)^+$



Only about 10 catabolic intermediates produced by glycolysis, the citric acid cycle, and the pentose phosphate pathway are the building blocks for almost all of anabolism. These are:

- Sugar phosphates
  - triose-phosphate
  - tetrose phosphate
  - pentose-phosphate
  - hexose-phosphate
- Keto acids
  - pyruvate
  - oxaloacetate
  - a-ketoglutarate
- Coenzyme A derivatives
  - acetyl-CoA
  - succinyl-CoA
- Phosphoenolpyruvate

ATP has Two Metabolic Roles

A fundamental role of ATP is to drive thermodynamically unfavorable reactions.

It also serves as an important allosteric effector in the regulation of metabolic pathways.

ATP and NADPH Couple Anabolism and Catabolism

ATP and NADPH are high energy compounds that are continuously recycled during metabolism. They are used for biosynthesis and are regenerated during catabolism.

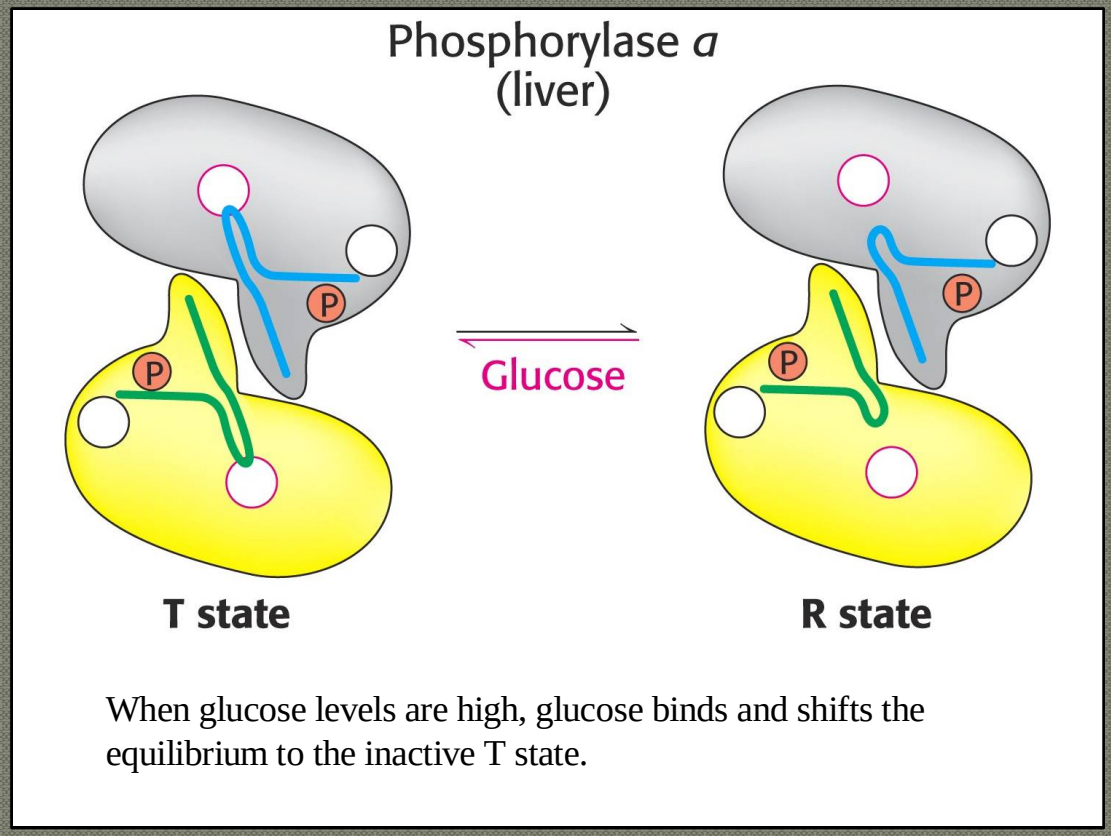
The average sedentary adult makes over a hundred kilograms of ATP/day. (They also break down this much)

Note that NADH and $FADH_2$ are only used in catabolism.

Allosteric Regulation of Enzyme Activity

The first committed step in a biochemical pathway is usually allosterically regulated.

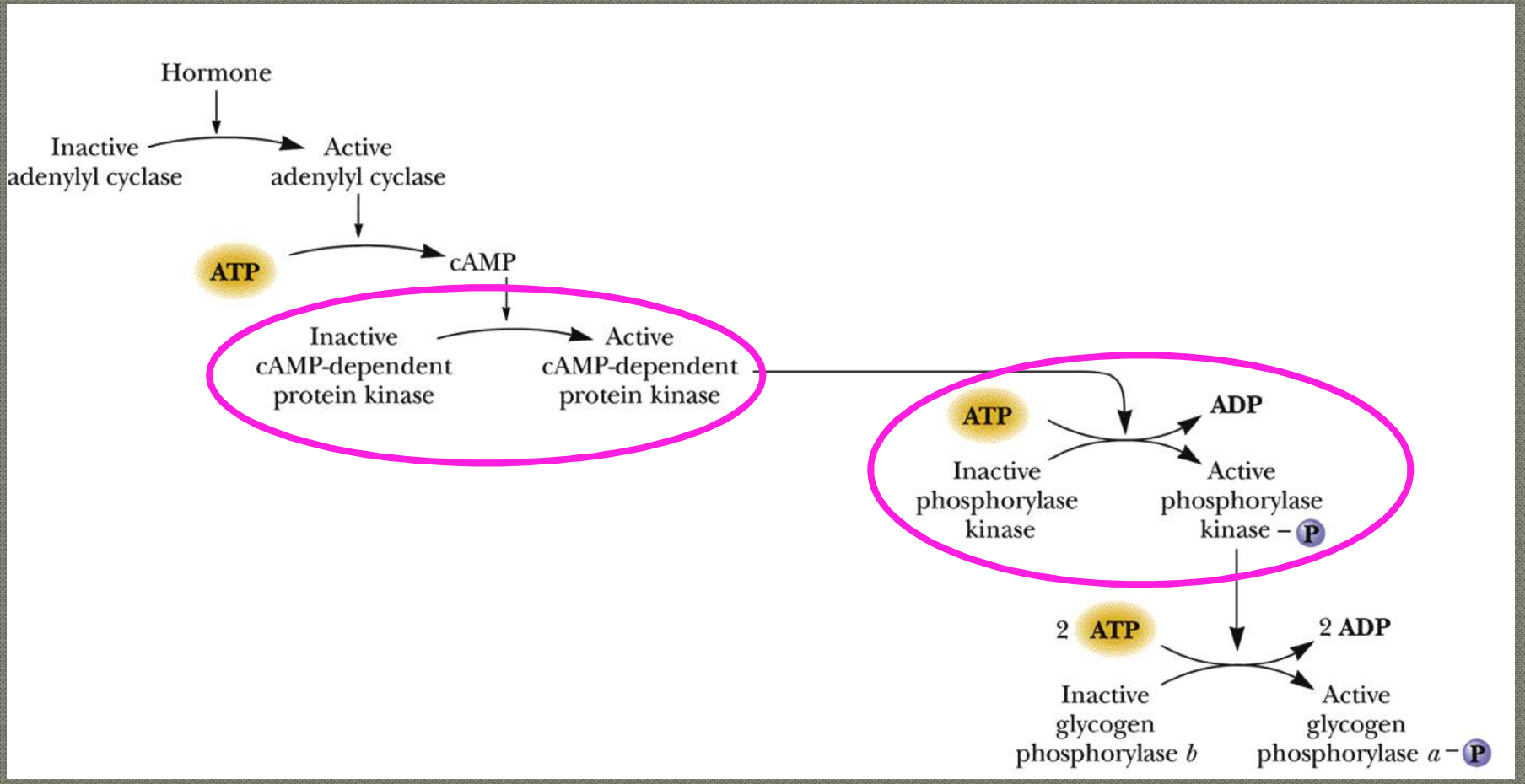
Activators and inhibitors bind at sites distinct from the active site and alter the conformation of the enzyme complex.



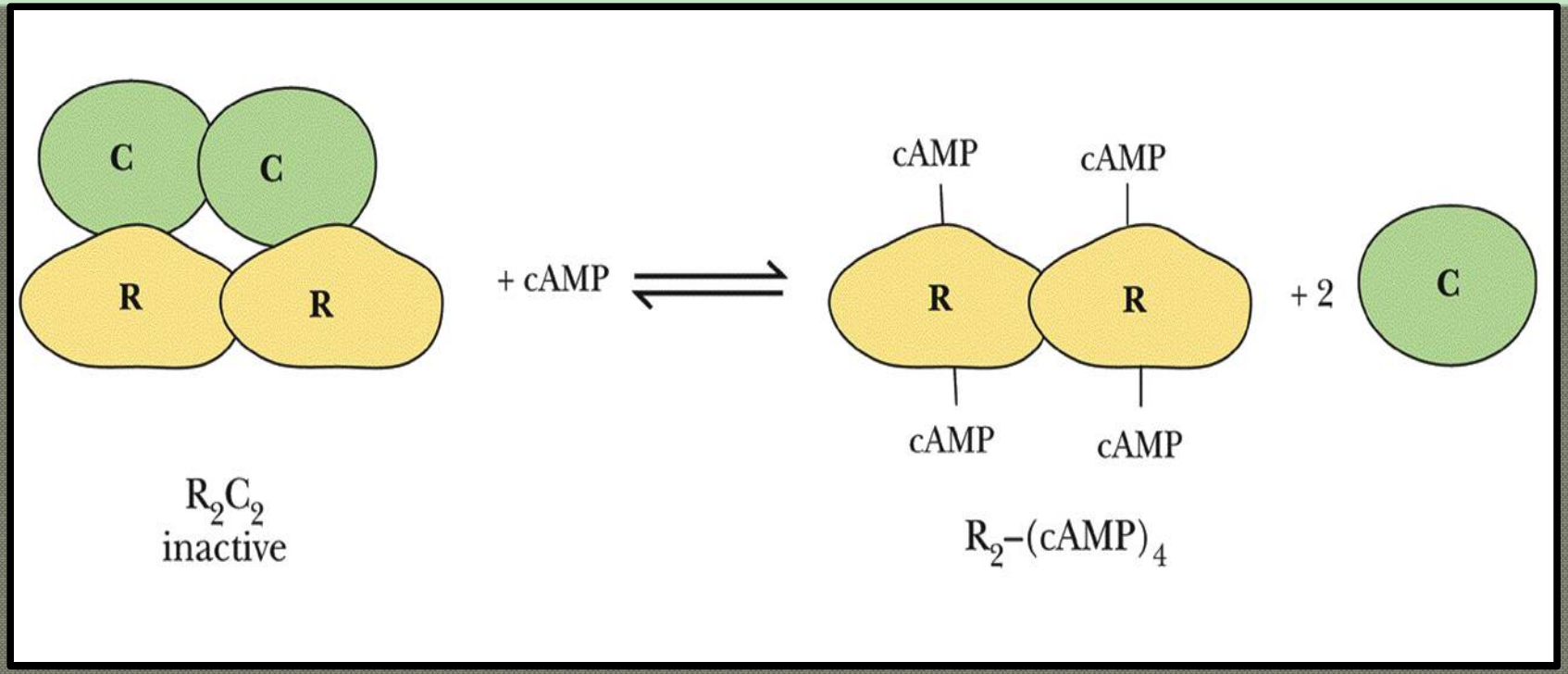
When glucose levels are high, glucose binds and shifts the equilibrium to the inactive T state.

Covalent Regulation of Enzyme Activity

e.g. reversible phosphorylation



Modulator Proteins



Cyclic AMP-dependent protein kinase A (PKA) is activated when the two regulatory subunits bind cAMP and then release the active catalytic subunits.

Another example is phosphoprotein phosphatase inhibitor-1. When it is phosphorylated it binds to phosphoprotein phosphatase and inhibits its activity.

Control Sites of Major Metabolic Pathways

A. Glycolysis

B. Gluconeogenesis

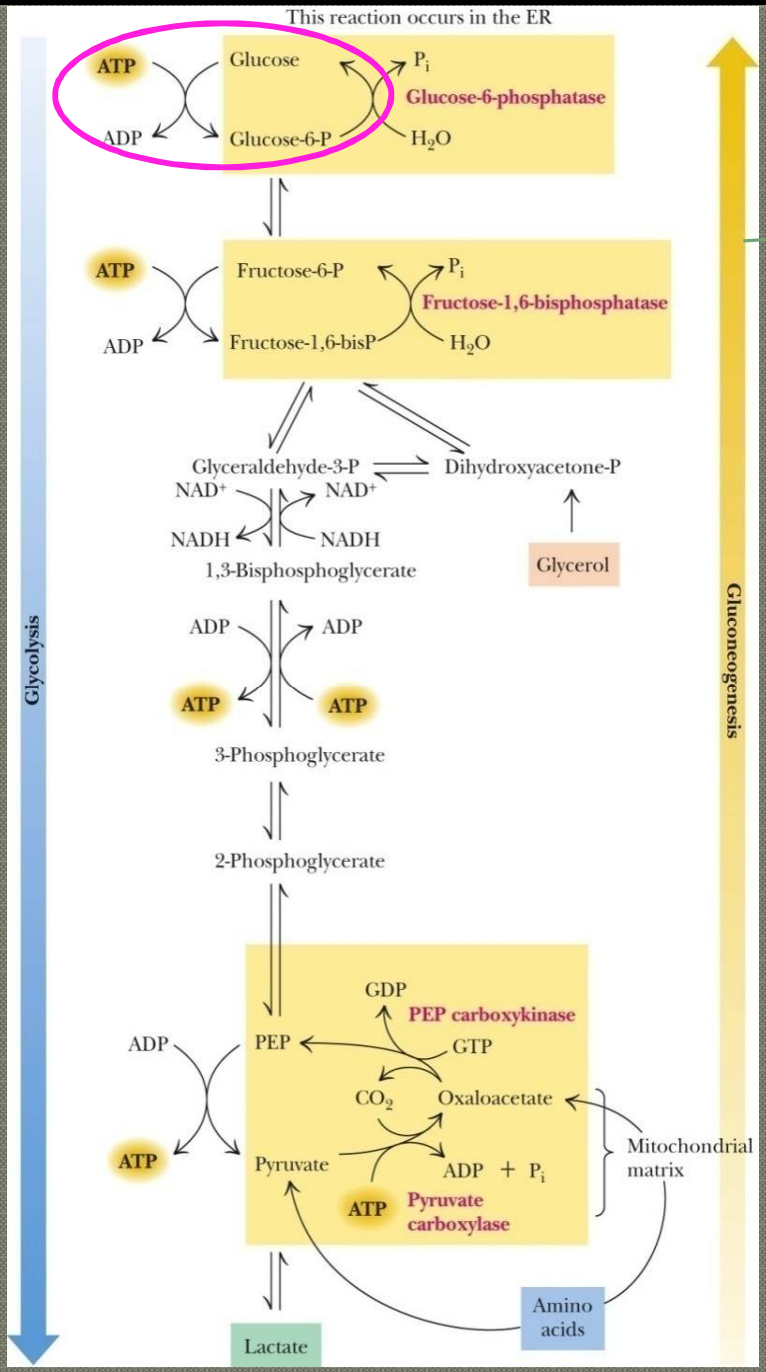
C. Citric Acid Cycle

D. Pentose Phosphate Pathway

E. Glycogen Synthesis and Degradation

F. Fatty Acid Synthesis and Degradation

First committed step in glycolysis

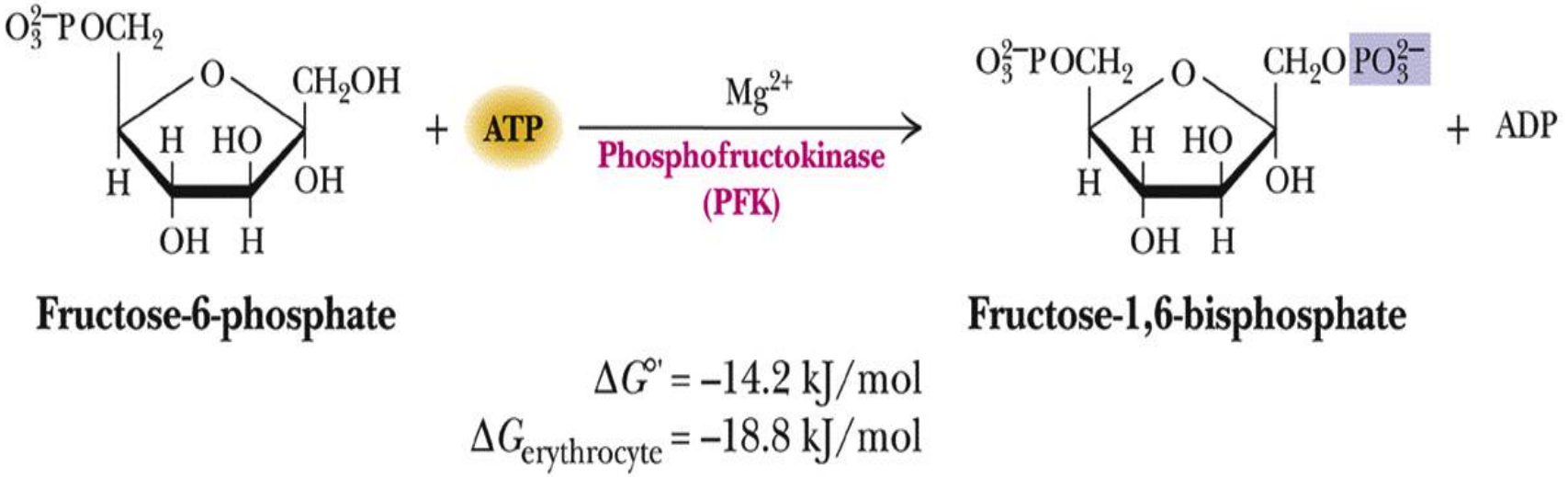


Glycogen synthesis
Pentose Phosphate Pathway

A. Glycolysis

Takes place in the **cytosol**. Degrades glucose for ATP production and carbon skeletons for biosynthesis.

Phosphofructokinase catalyzes 1st committed step. It is the "valve" controlling the rate of glycolysis.



Fructose-6-phosphate + ATP $\xrightarrow{Mg^{2+}}$ (Phosphofructokinase (PFK)) **Fructose-1,6-bisphosphate** + ADP

$\Delta G^{\circ\prime} = -14.2$ kJ/mol

$\Delta G_{\text{erythrocyte}} = -18.8$ kJ/mol

Inhibitors: ATP, citrate

Activators: AMP, F-2,6-BP

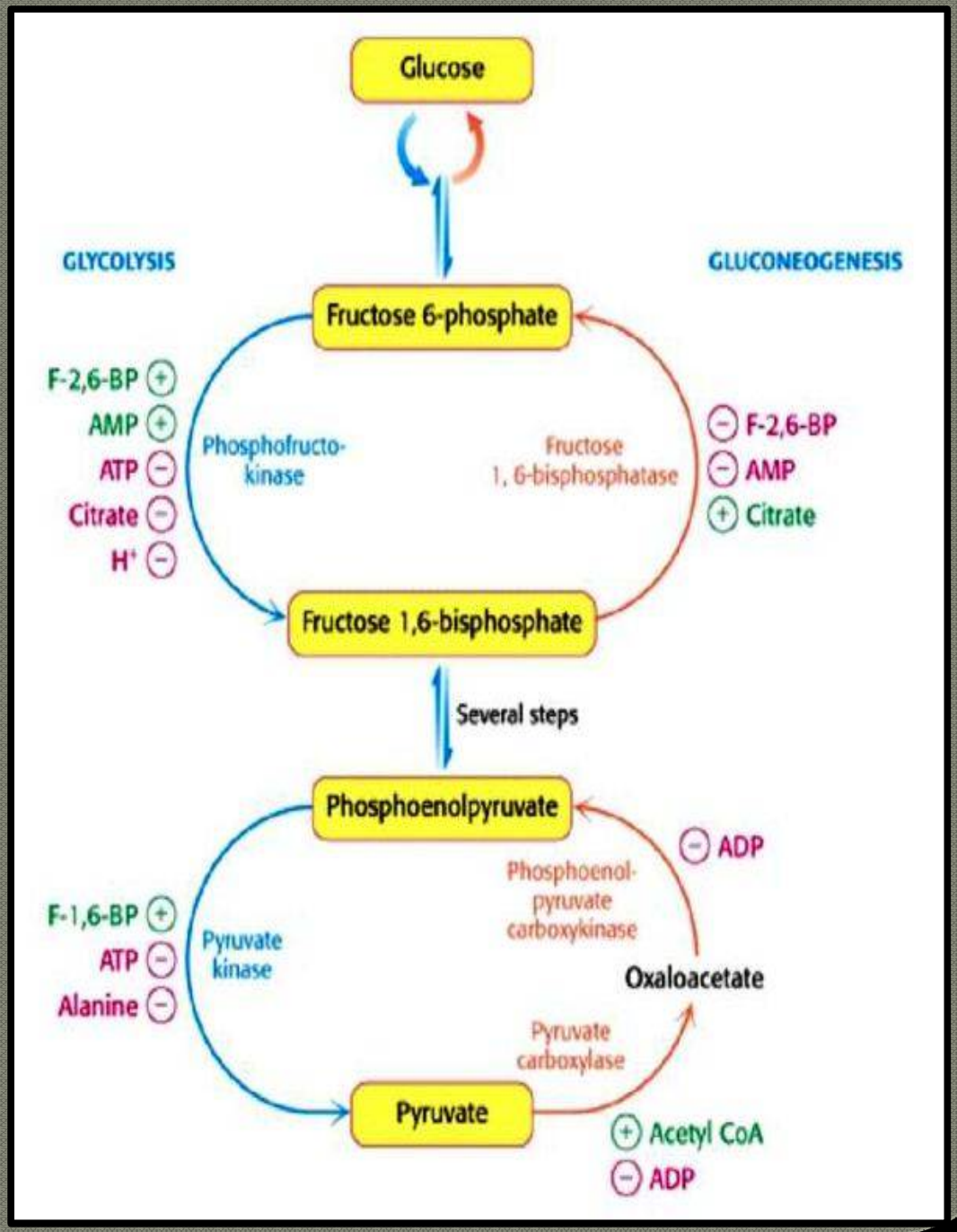
B.Gluconeogenesis

Occurs mainly in the liver and kidneys.

Pruvate is carboxylated in the mitochondria.

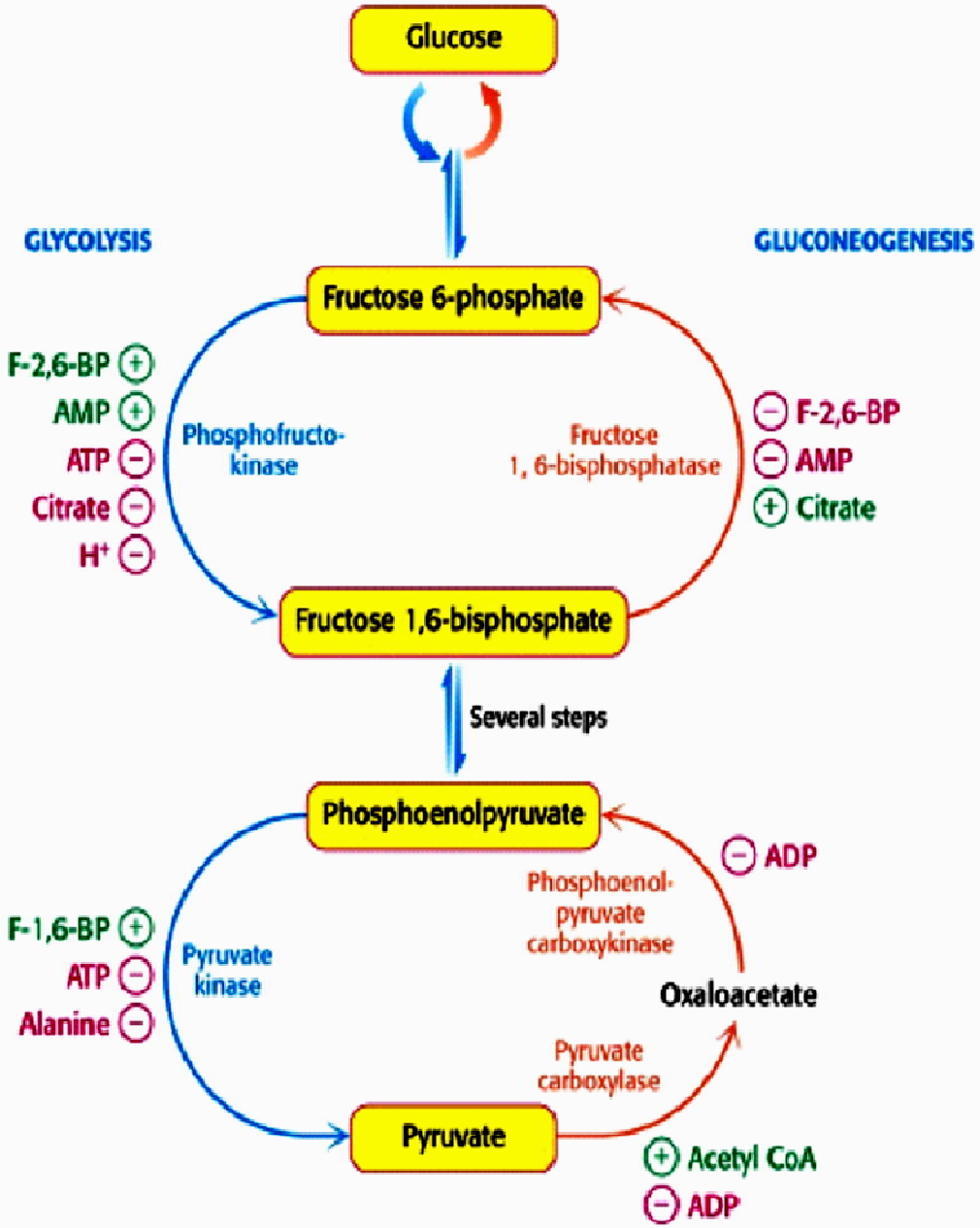
The other reactions occur in the cytosol.

Glycolysis and gluconeogenesis are **reciprocally regulated.**



If ATP is low then AMP will be high and it will activate glycolysis to make more ATP.

If ATP is high don't need to make more ATP so it inhibits glycolysis.



If ATP is low then AMP will be high and it will inhibit gluconeogenesis, which uses ATP.

C. Citric Acid Cycle

Occurs in the mitochondria.

1 acetyl unit → 1 GTP, 3NADH, 1 $FADH_2$ → 9 ATP

Respiratory Control: NADH and $FADH_2$ are oxidized and recycled back to the citric acid cycle only if ADP is simultaneously phosphorylated back to ATP.

High ATP inhibits citrate synthase and isocitrate dehydrogenase.

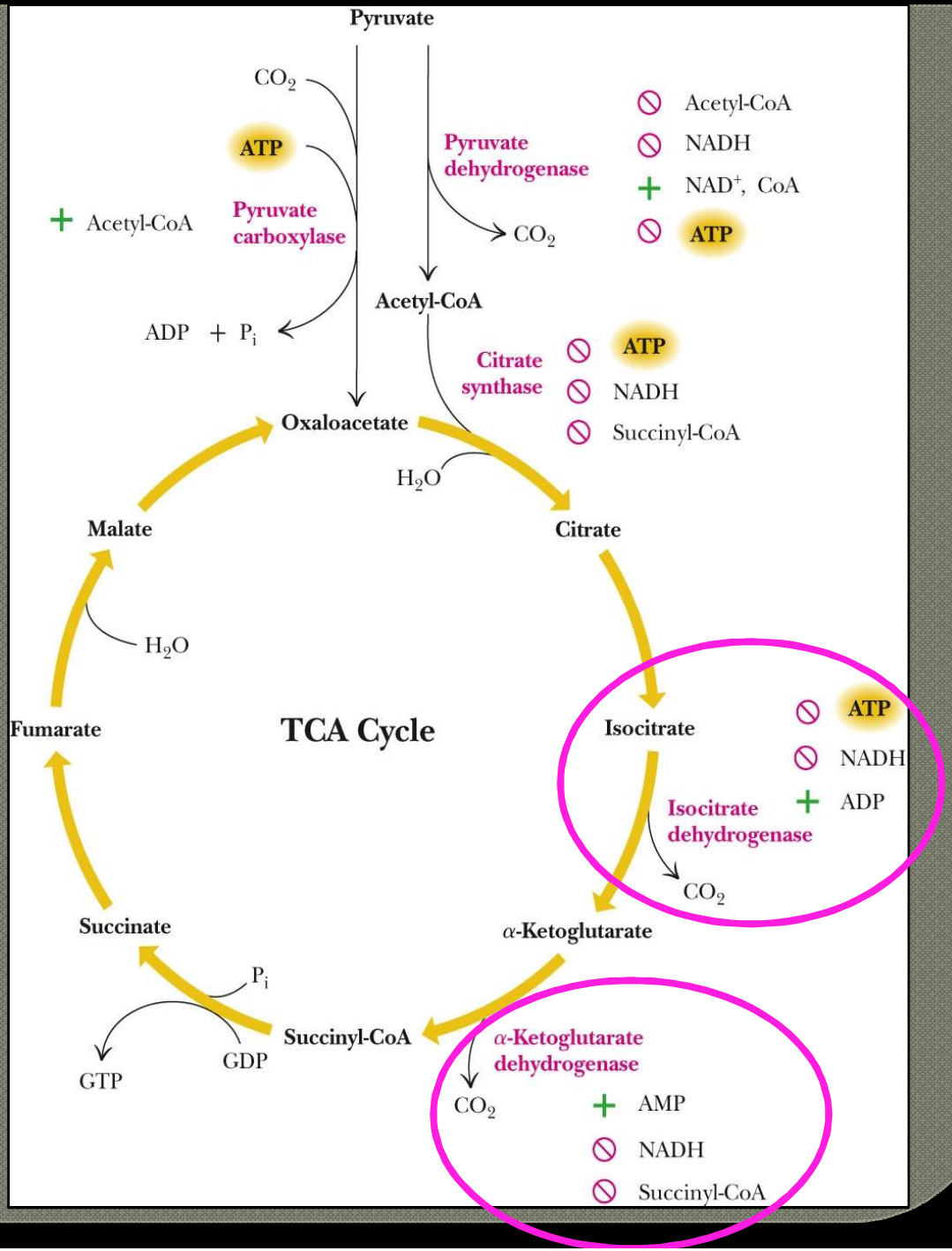
High NADH inhibits citrate synthase, isocitrate dehydrogenase, and α-ketoglutarate dehydrogenase.

- ensures that the rate of the citric acid cycle matches the need for ATP.

Regulation of the TCA cycle.

The citric acid cycle is regulated primarily by the concentration of ATP and NADH. The key **control** points are the enzymes:
i) isocitrate dehydrogenase and
ii) α-ketoglutarate dehydrogenase.

Isocitrate dehydrogenase is allosterically stimulated by ADP, which enhances the enzyme's affinity for substrates.

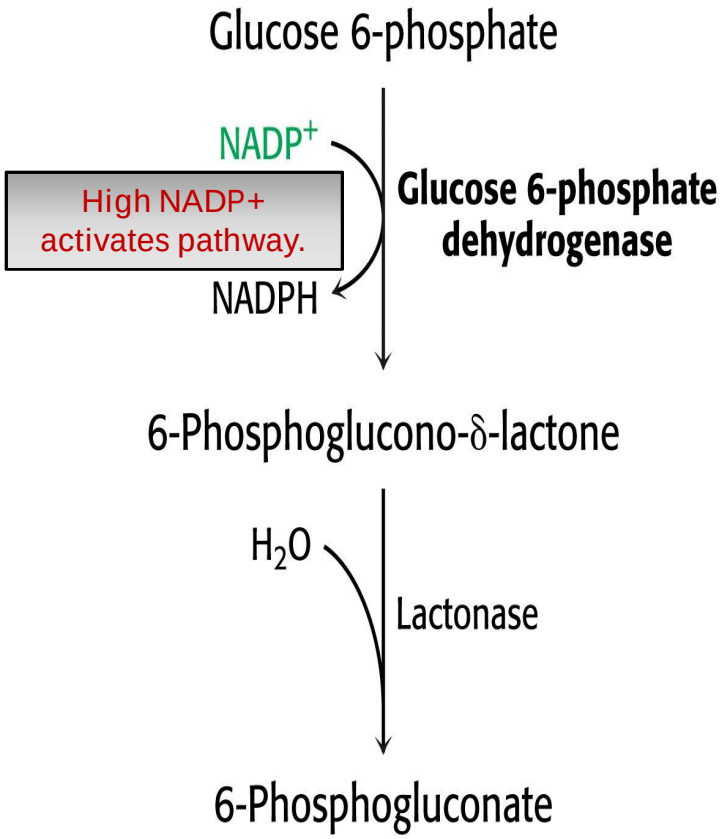


D. Pentose Phosphate Pathway

Takes place in the **cytosol**.

First committed step is catalyzed by **glucose-6-phosphate dehydrogenase**.

The pentose phosphate shunt is a semi-independent alternative pathway that parallels glycolysis . It generates the reducing agent reduced nicotinamide adenine dinucleotide phosphate (NADPH), which is independent of the NADH of oxidative phosphorylation, and pentoses. There are two distinct phases in the pentose phosphate shunt. The first is the **oxidative phase**, in which NADPH is generated, and the second is the **synthesis of 5-carbon sugars**.



E. Glycogen Synthesis and Degradation

Glycogen metabolism is regulated by controlling the activities of two critical enzymes, **glycogen phosphorylase** and **glycogen synthase.**

1. Hormonal regulation through **reversible phosphorylation.**
   a) Activates phosphorylase.
   b) Phosphorylation inactivates glycogen synthase.

2. Allosteric regulation

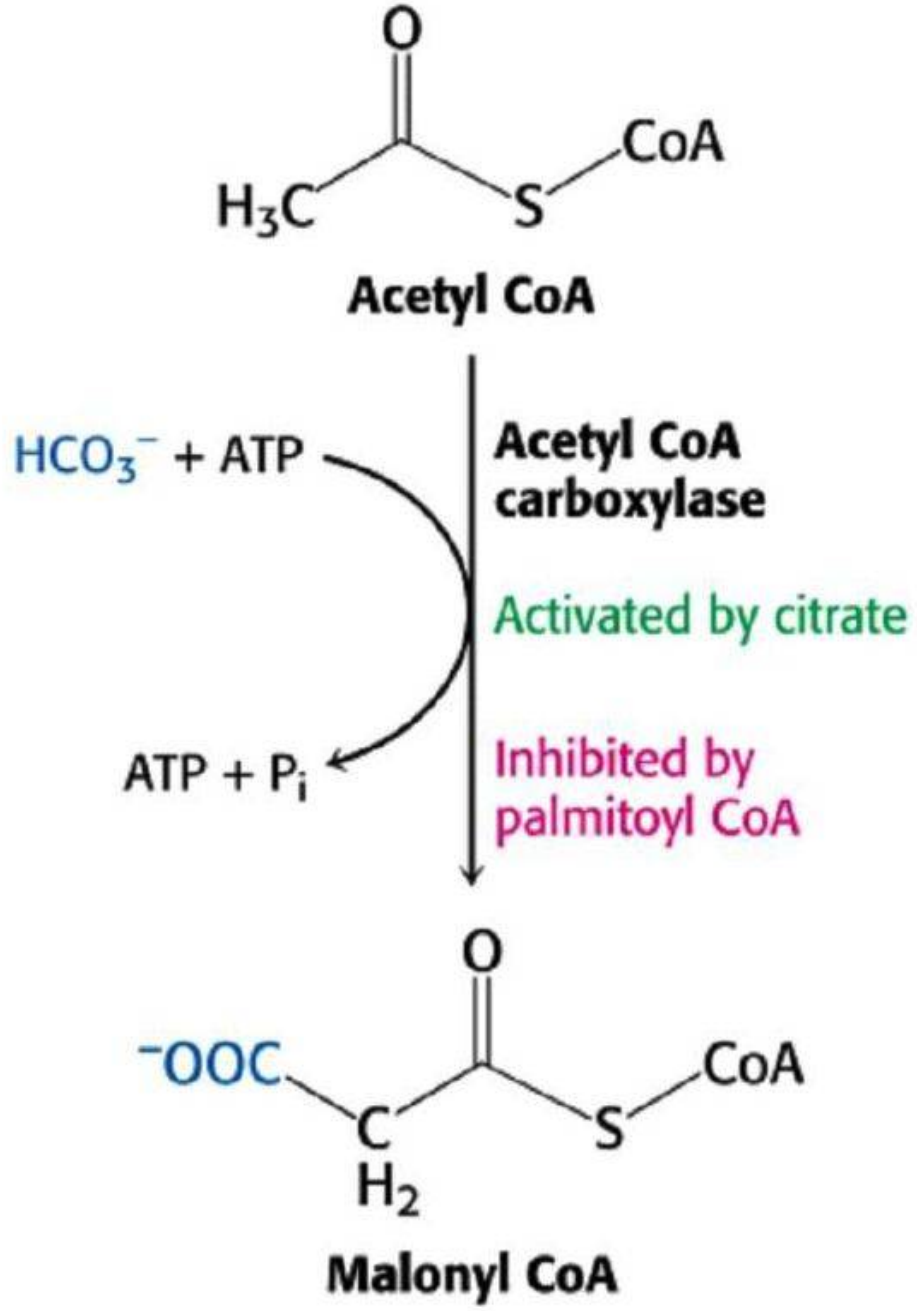
e.g. AMP activates muscle (but not liver) phosphorylase.
High glucose inactivates liver phosphorylase.

F. Fatty acid Synthesis

Occurs in cytosol.

Acetyl CoA carboxylase catalyzes the 1st committed step.

This step is stimulated by citrate which increases when ATP and acetyl CoA are abundant.

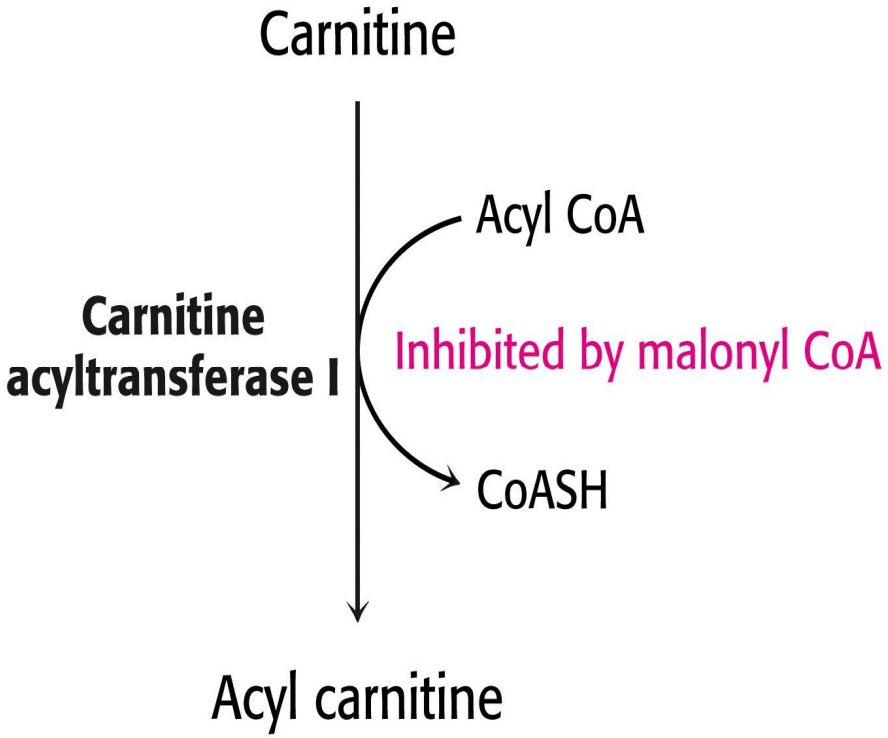


G. Fatty acid Degradation

Occurs in the mitochondria where fatty acids are degraded to acetyl CoA which then enter the citric acid cycle if the supply of oxaloacetate is adequate. Ketone bodies form if oxaloacetate levels are low.

Carnitine transports the fatty acids into the mitochondria.

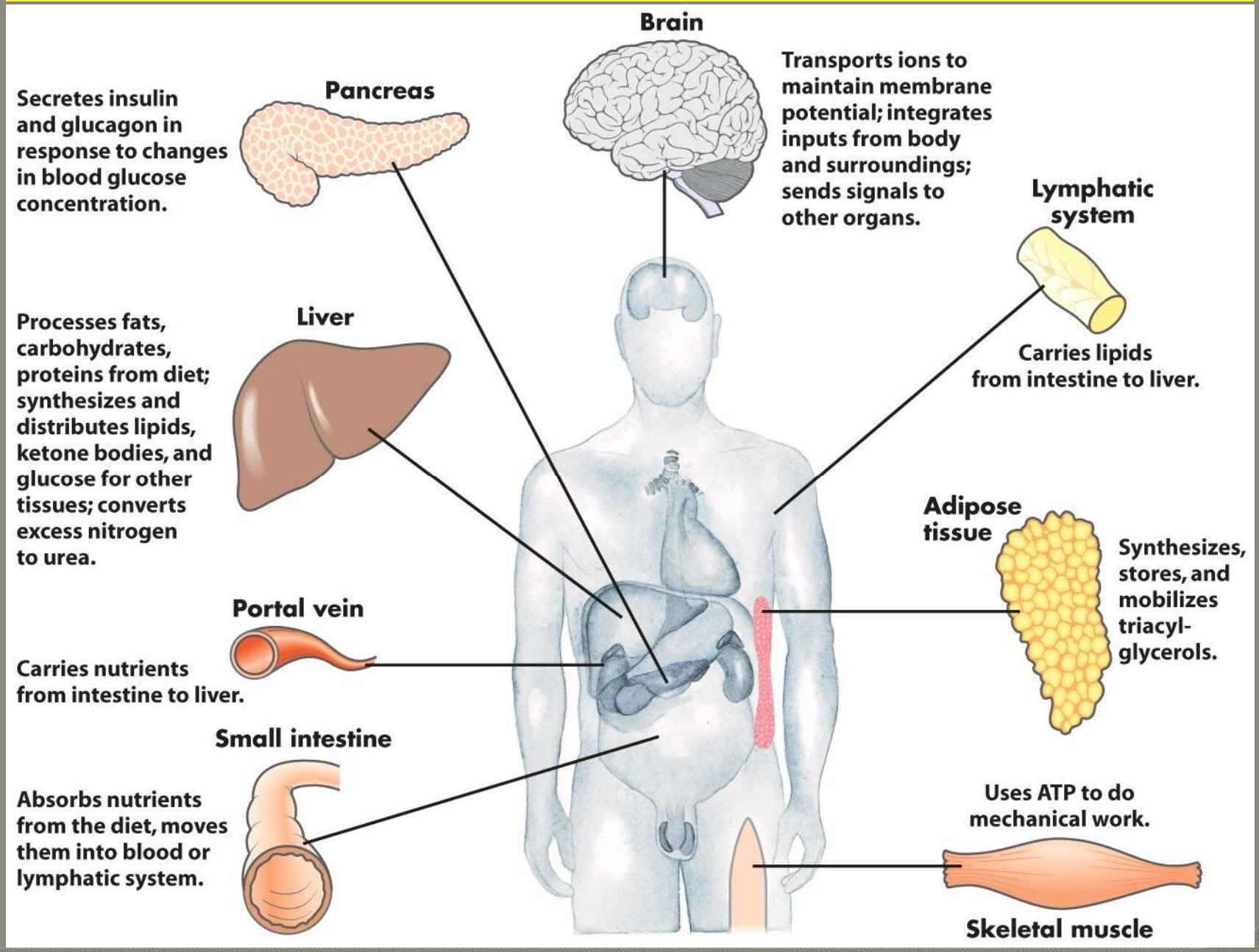
Like the citric acid cycle, β-oxidation can continue only if NAD^+ and FAD are regenerated. So, the rate of fatty acid degradation is also coupled to the need for ATP.

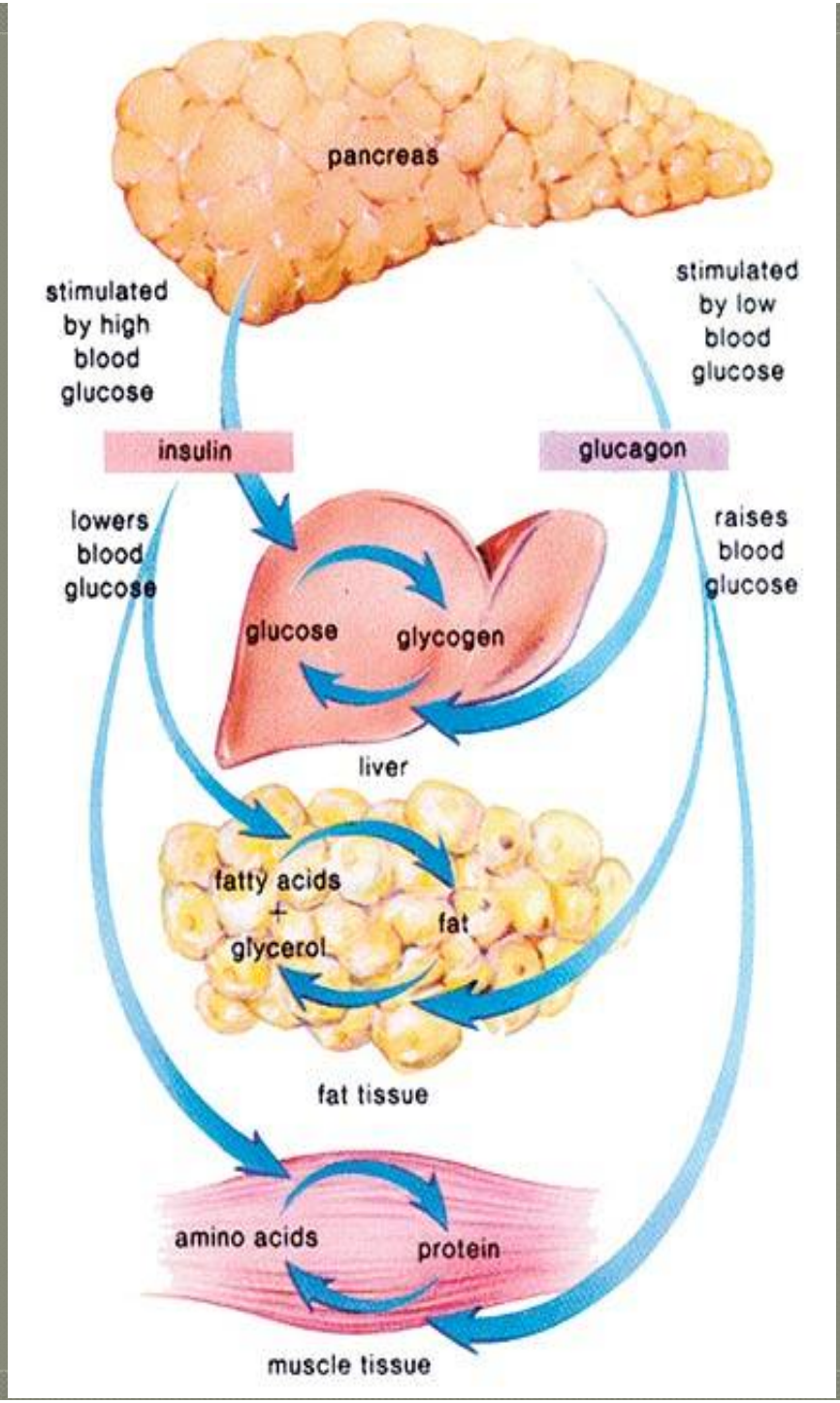


4 gal fat

26 gal H_2O

Tissues & organs are specialized.





- Interactions between tissues and organs are mediated by *hormone* signals carried via bloodstream.

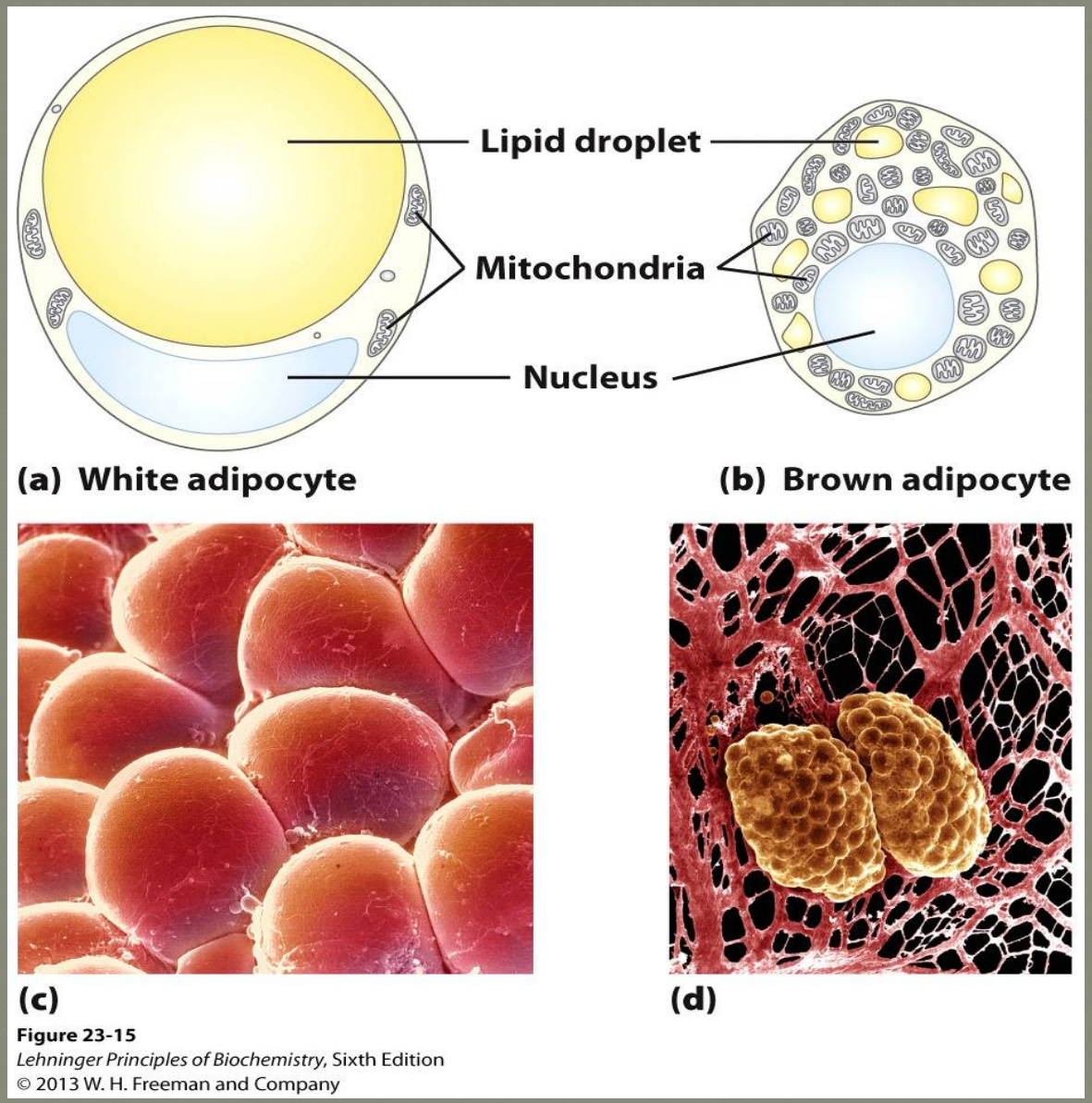
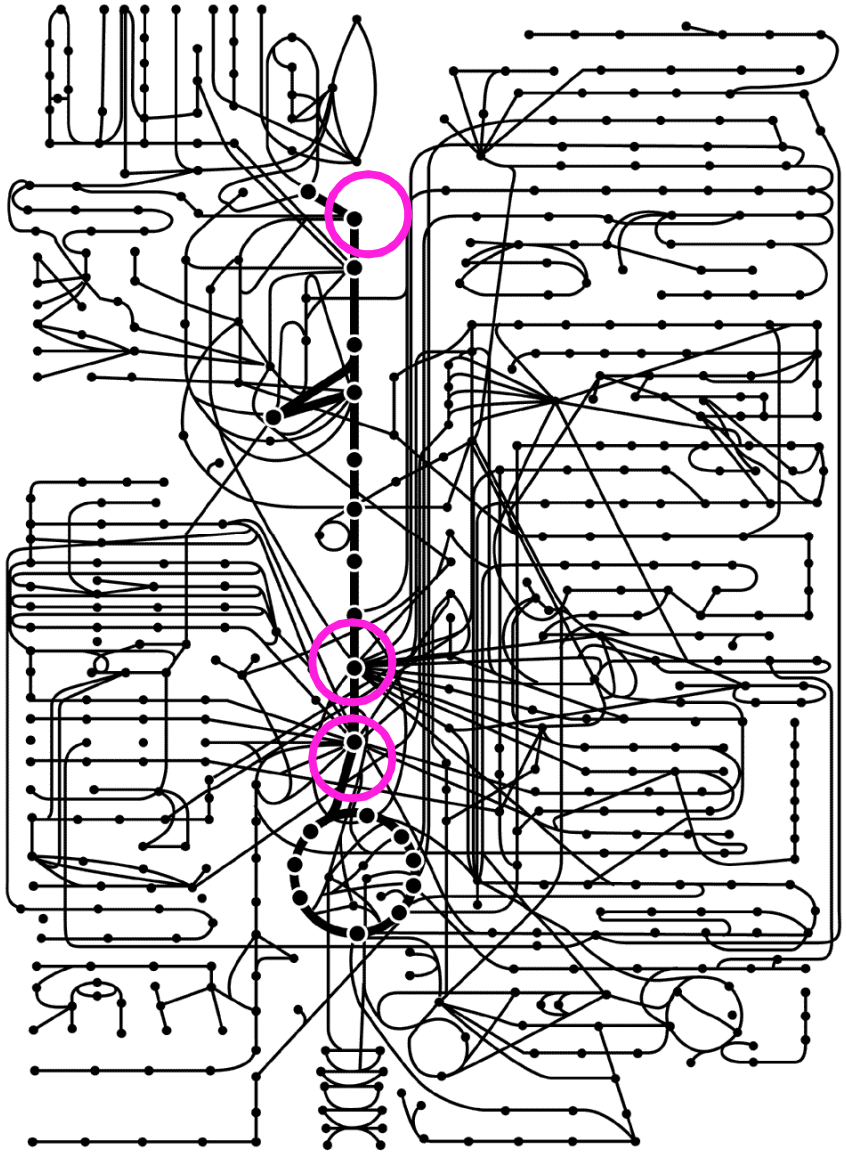


Figure 23-15
Lehninger Principles of Biochemistry, Sixth Edition

- Two distinct types: white adipose tissue and brown adipose tissue.
- Brown fat has high levels of thermogenin, which are metabolically activated by cold exposure.

Garrett/Grisham, Biochemistry with a Human Focus
Figure 14.1

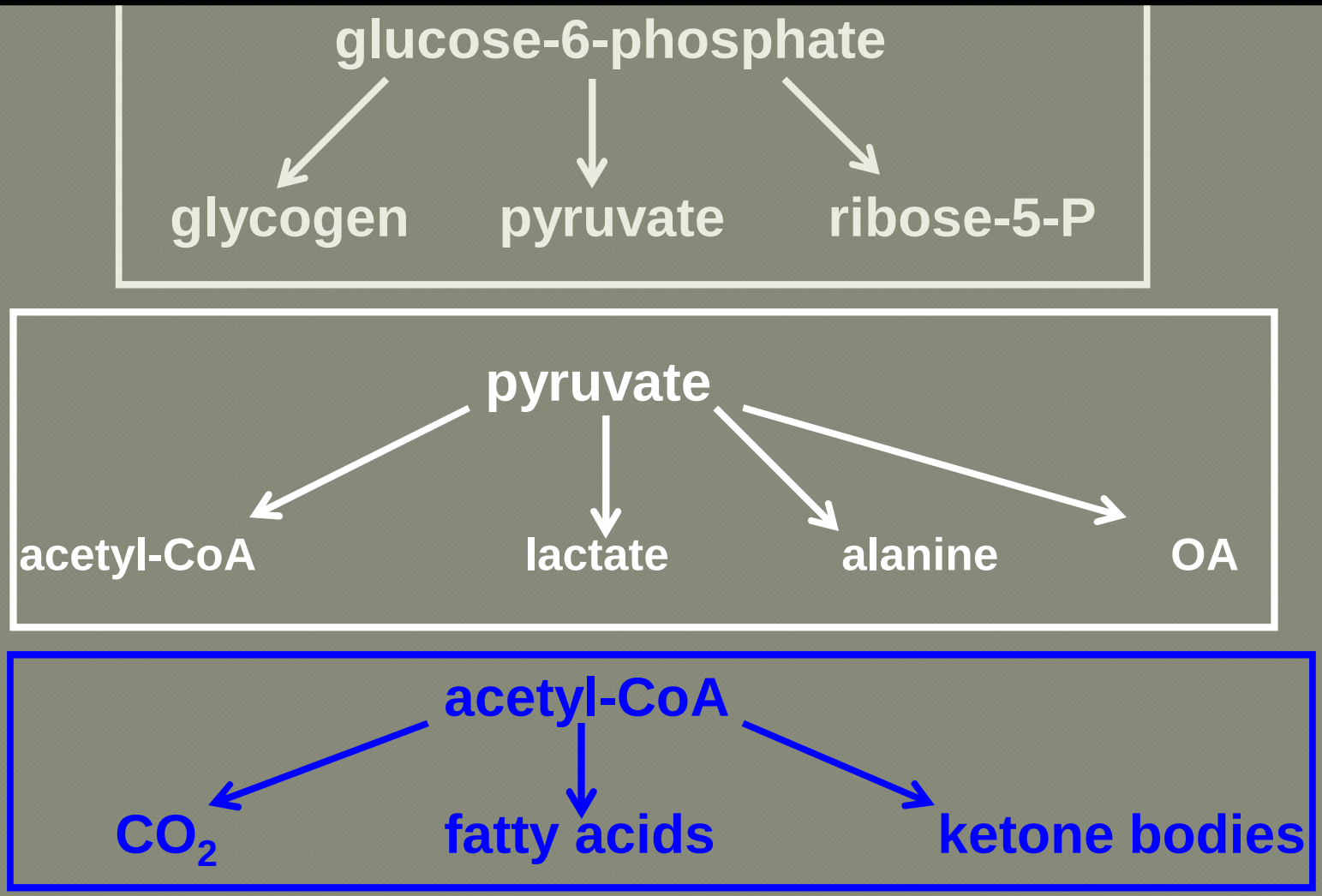


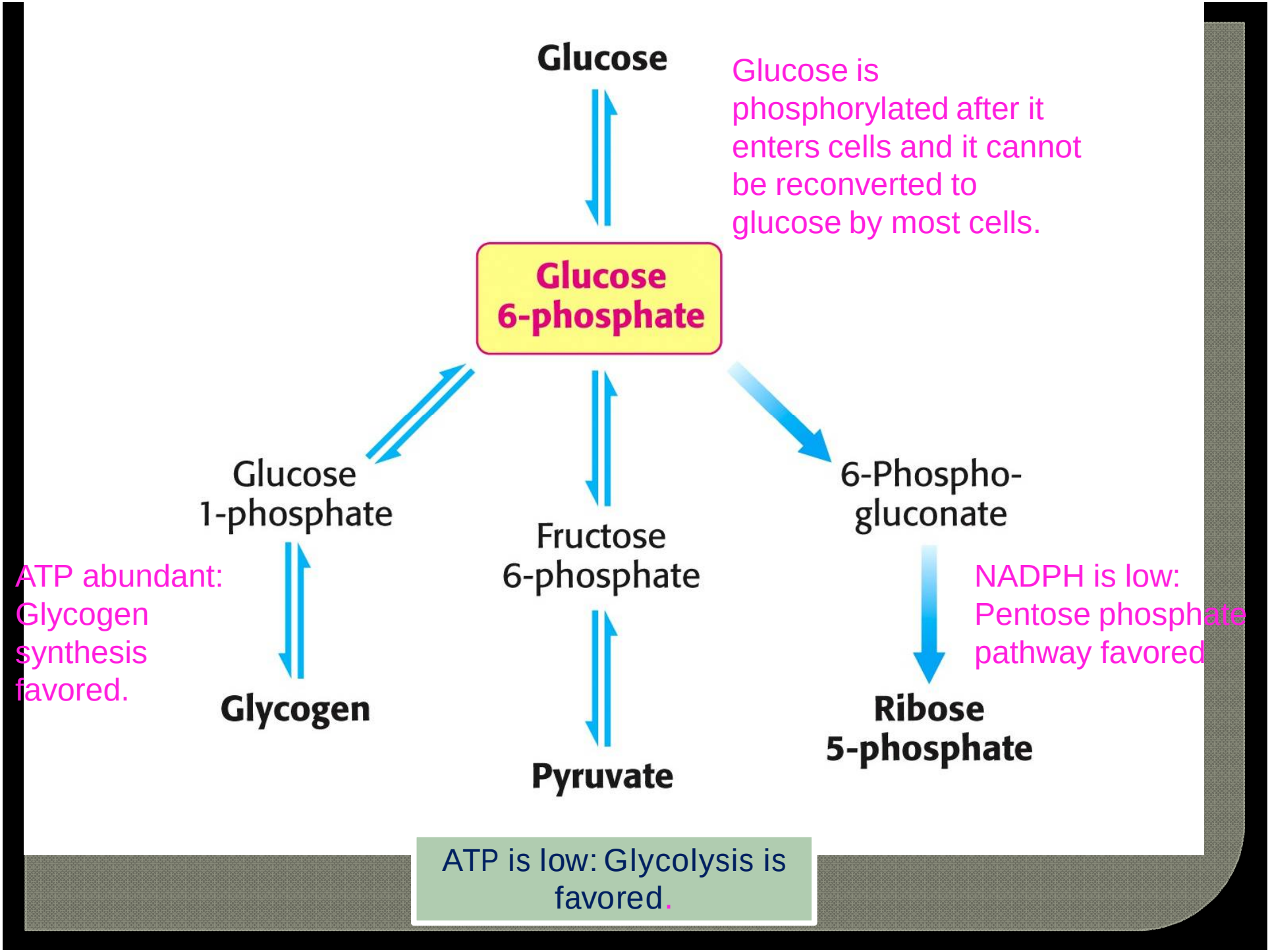
Key Junctions

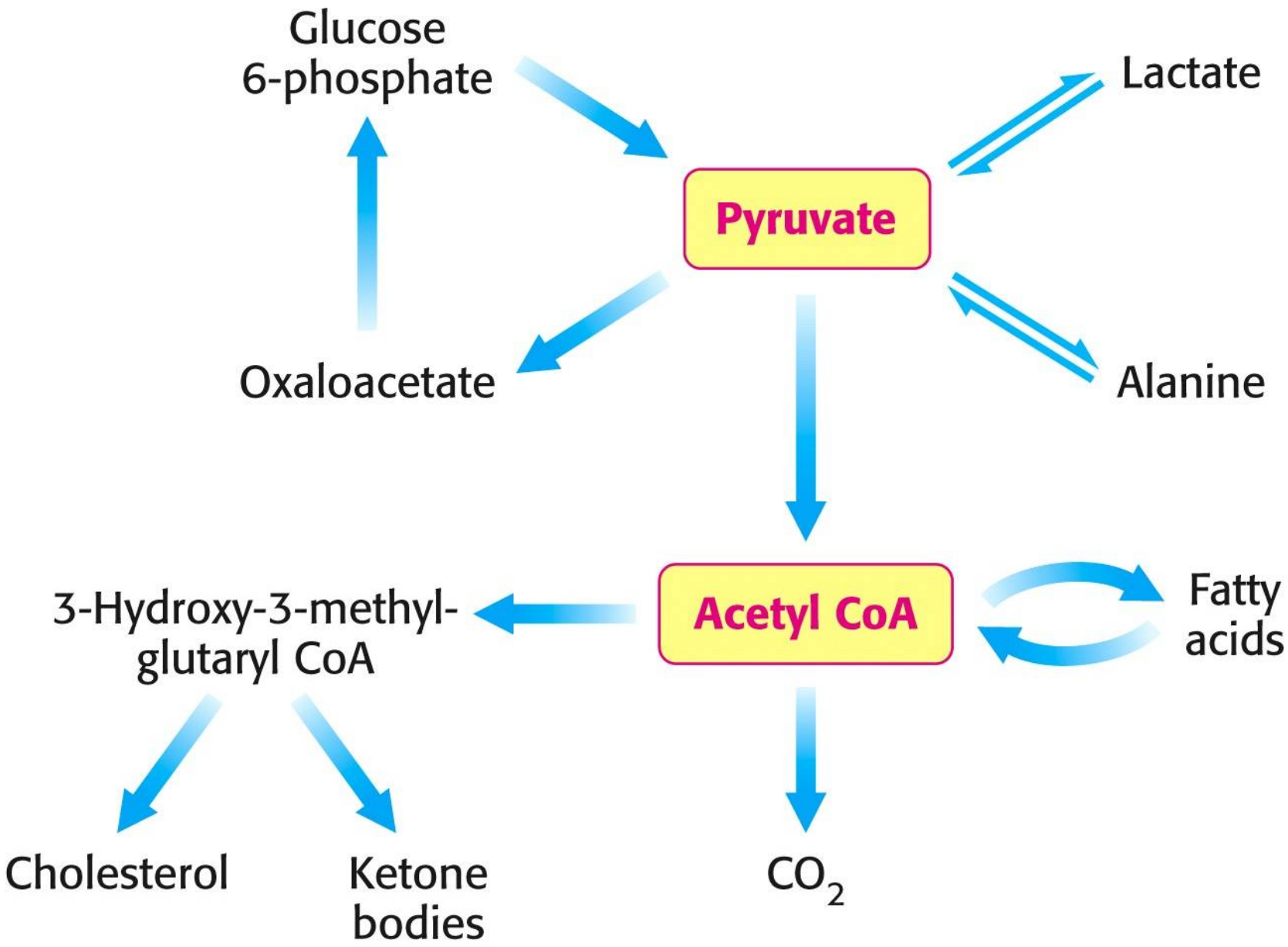
Glucose
-6-phosphate

Pyruvate
Acetyl CoA

Several molecules act as metabolic junction points




Glucose
Glucose is phosphorylated after it enters cells and it cannot be reconverted to glucose by most cells.
Glucose 6-phosphate
Glucose 1-phosphate
Fructose 6-phosphate
6-Phospho-gluconate
ATP abundant: Glycogen synthesis favored.
NADPH is low: Pentose phosphate pathway favored
Glycogen
Pyruvate
Ribose 5-phosphate
ATP is low: Glycolysis is favored.


Glucose
6-phosphate
Lactate
Pyruvate
Oxaloacetate
Alanine
Acetyl CoA
3-Hydroxy-3-methyl-
glutaryl CoA
Fatty
acids
Cholesterol
Ketone
bodies
CO_2

Fuel Storage

The major fuel depots in animals are:

- fat stored in adipose tissue
- glycogen in liver and muscle
- protein mainly in skeletal muscle

In general, the order of preference for use of the different fuels is:

glycogen > fat > protein

Fuel Use During Exercise

- running speed depends upon rate of ATP production

- a **100 m sprint** (~10 sec) is powered by stored ATP, creatine phosphate, and anaerobic glycolysis.

- but in a **1000 m run** (~132 sec) creatine phosphate would be depleted and anaerobic glycolysis cannot last this long because NAD^+ supplies would also be depleted and too much lactic acid will be produced.

- Some of the required ATP will come from oxidative phosphorylation. – **but much slower**!

running a **marathon** (~2 hrs) would completely deplete body glycogen supplies so ATP is also made by **fatty acid oxidation**. But this is slow!

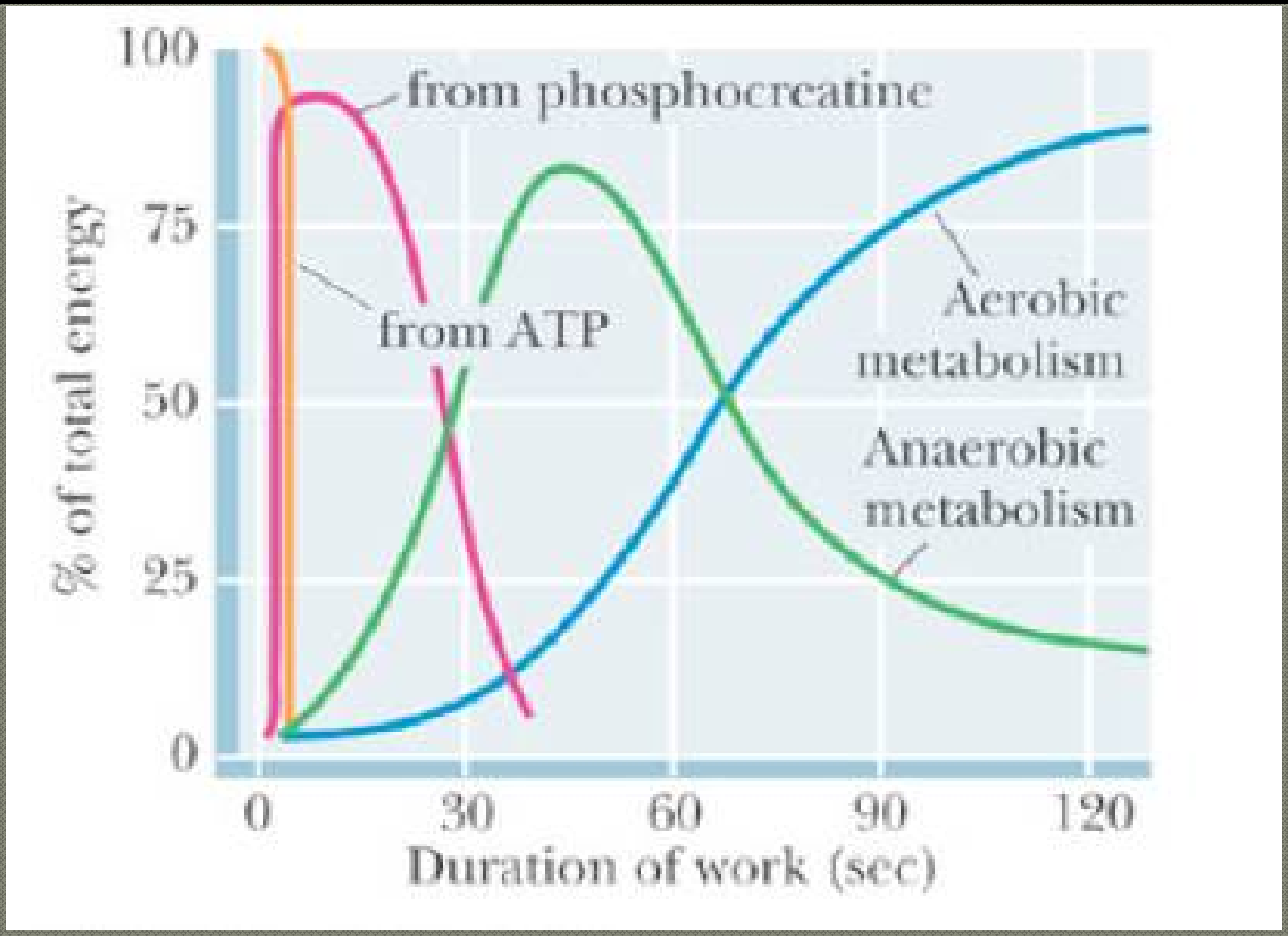
The best marathon runners **consume** about equal amounts of **fatty acids** and **glycogen** during a race.

Low blood glucose results in an increase in glucagon levels.

High glucagon causes fatty acid breakdown to acetyl-CoA.

High acetyl-CoA inhibits pyruvate dehydrogenase so pyruvate → glucose.

glucose → glycogen



Contribution of various energy sources during mild exercise.

Brain

- in resting adults, the brain uses 20% of the oxygen consumed, although it is only ~2% of body mass.

- it has no fuel reserves.

- the brain uses the glucose to make ATP which it needs to power the Na^+,K^+-ATPase to maintain the membrane potential necessary for transmission of nerve impulses.

- glucose is the normal fuel but ketone bodies (e.g. β-hydroxybutyrate) can partially substitute for glucose during starvation. The β-hydroxybutyrate is converted to acetyl-CoA for energy production via the citric acid cycle.

Muscle

- in resting adults, skeletal muscle uses 30% of the oxygen consumed, although during intense exercise it may use 90%.

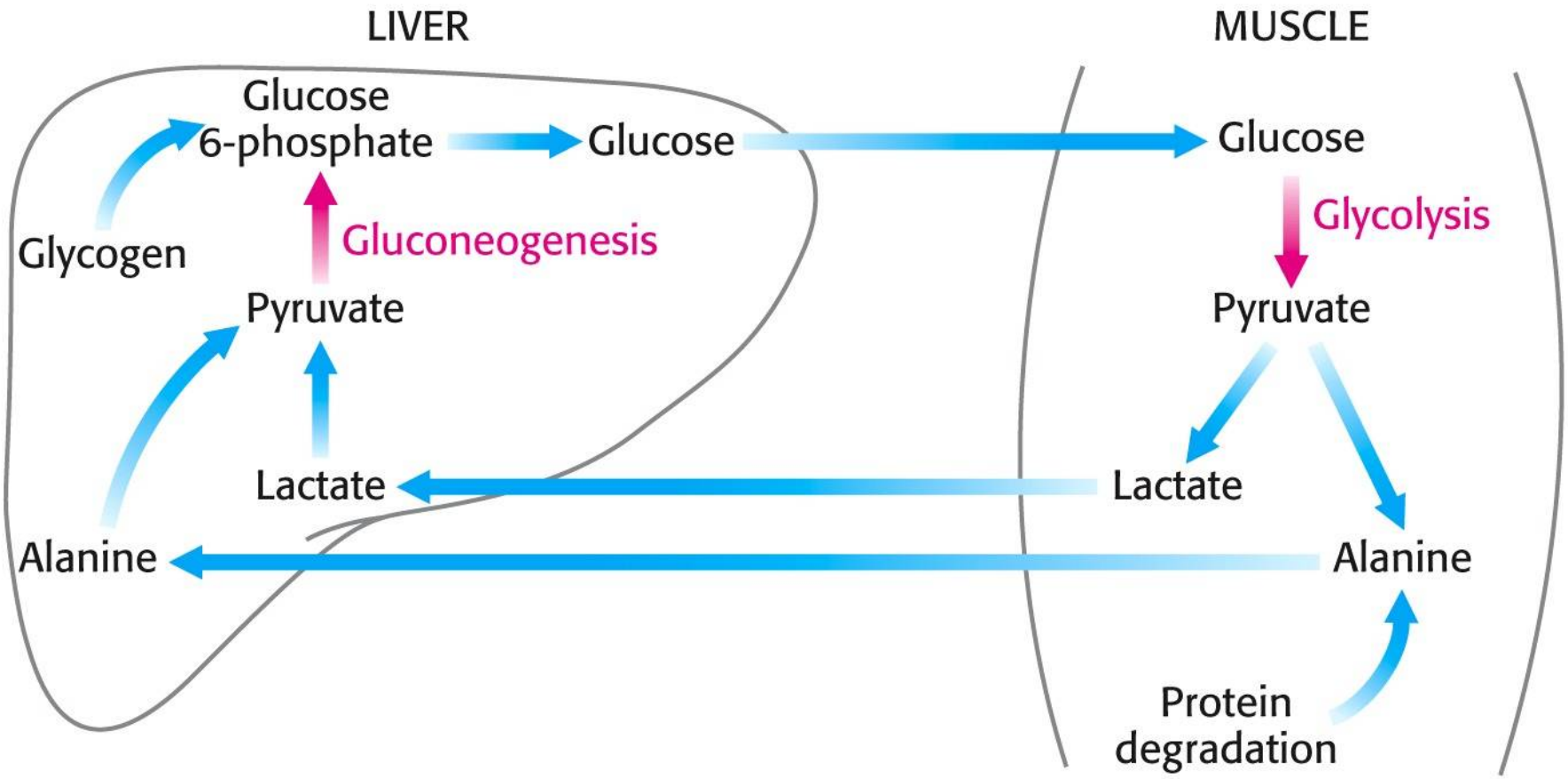
- ATP is needed for muscle contraction and relaxation.

- Resting muscle uses **fatty acids**, glucose, and ketone bodies for fuel and makes ATP via oxidative phosphorylation.

- Muscle fatigue (inability to maintain power output) begins about 20 seconds after maximum exertion and is caused by a decrease in intramuscular pH as protons are generated during glycolysis.

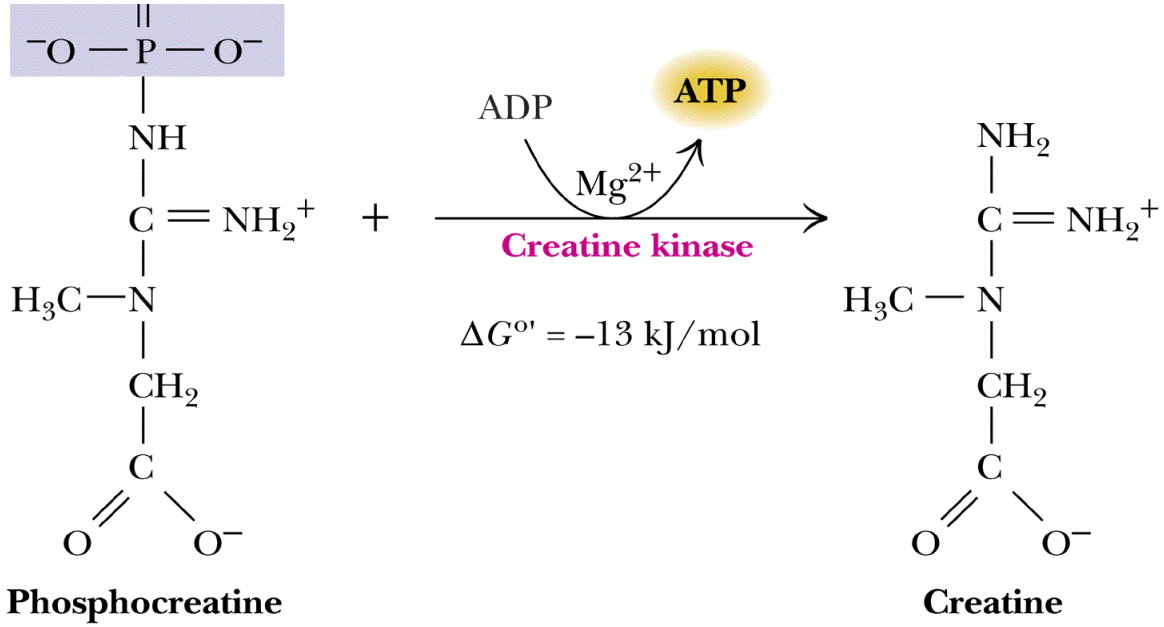
- Resting muscle contains about 2% glycogen and an amount of phosphocreatine capable of providing enough ATP to power about 4 seconds of exertion.

ORGANS for GLYCOLYSIS & GLUCONEOGENESIS



Phosphocreatine serves as a reservoir of ATP-synthesizing potential.

- during intense muscular activity existing ATP supplies are exhausted in about 2 seconds. Phosphocreatine regenerates ATP levels for a few extra seconds.



Heart

- functions as a completely aerobic organ.

- the normal fuel is fatty acids which are converted to acetyl-CoA and oxidized in the citric acid cycle and ATP is produced by oxidative phosphorylation.

- about half the volume of the cytoplasm of heart muscle cells made up of mitochondria.

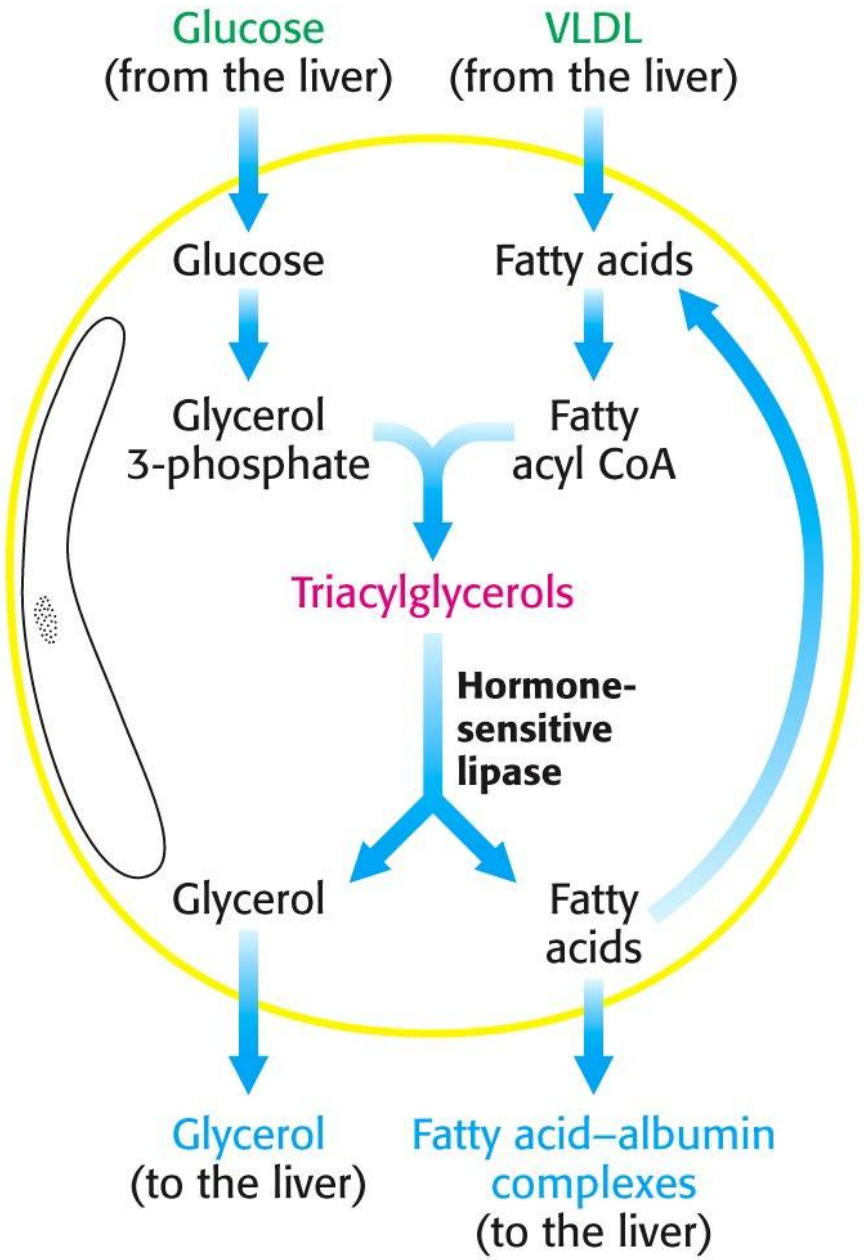
- the heart has low levels of glycogen and little phosphocreatine so it must always have adequate oxygen

- in addition to fatty acids the heart also utilizes glucose and ketone bodies as fuel.

Adipose Tissue

- consists mainly of cells called **adipocytes** that do not replicate.
- people usually store enough fat to sustain energy production for ~3 months.
-Adipocytes have a high rate of metabolic activity - triacylglycerol molecules turn over every few days.
- normally, free fatty acids are obtained from the liver for fat synthesis.
- because adipocytes lack glycerol kinase they cannot recycle the glycerol from fat breakdown but must obtain glycerol-3-phosphate by reducing the DHAP produced by glycolysis.
- adipocytes also need glucose to feed the pentose phosphate pathway for NADPH production.
-Insulin is required for glucose uptake.

Simple interelation between Glucose & Lipid In LIVER



Kidneys

Major function is to produce urine in order to excrete waste products and maintain osmolarity.

Blood plasma is filtered about 60 times a day.

Most of the material filtered out of the blood is reabsorbed. This reabsorption requires a lot of energy.

Kidneys are only 0.5% of body mass but consume 10% of the oxygen.

During starvation the kidneys become an important site of gluconeogenesis and may contribute as much as half of the blood sugar.

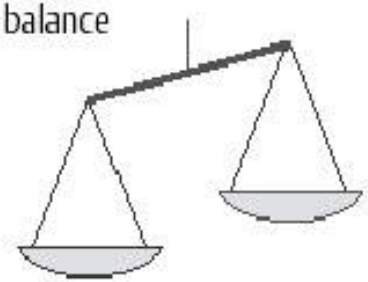
Functions of the kidneys

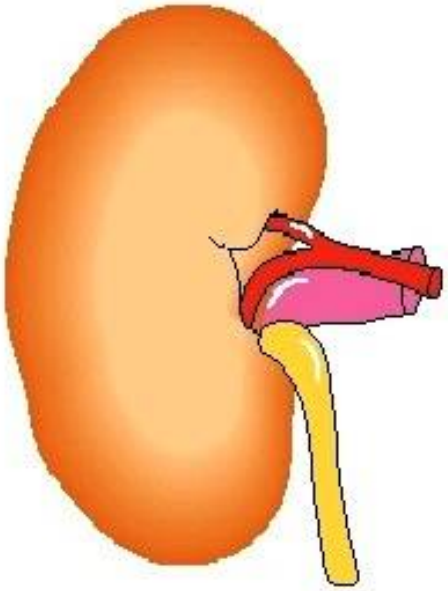
1. Excretion

Water
Salts
Metabolic wastes
Foreign substances

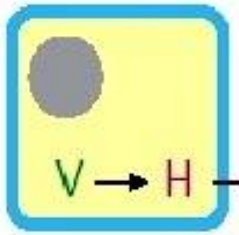
2. Homeostasis

Acid-base balance
Electrolyte balance





3. Hormone synthesis



→ Erythropoietin
Calcitriol

4. Metabolism

Glucose → Blood

Amino acids → Gluconeo-genesis → Glucose

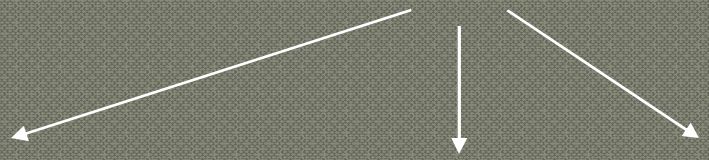
Amino acids → NH_3 → Urine

Liver

The liver is the **metabolic hub** of the body. It makes the fuel that supplies the brain, muscles, and other organs.

The liver plays a central role in the regulation of **carbohydrate, lipid, and amino acid** metabolism.

The liver removes about two-thirds of the **glucose** absorbed by the intestine and converts it to **glucose-6-phosphate**.



The liver also makes glucose by gluconeogenesis and glycogen breakdown and releases it into the blood.

The liver also plays a central role in **lipid metabolism**.

In the **well fed state** dietary fatty acids are converted to **triacylglycerols** (fat) and secreted into the blood as **VLDL**.

In the **fasted state** the liver converts fatty acids into ketone bodies.

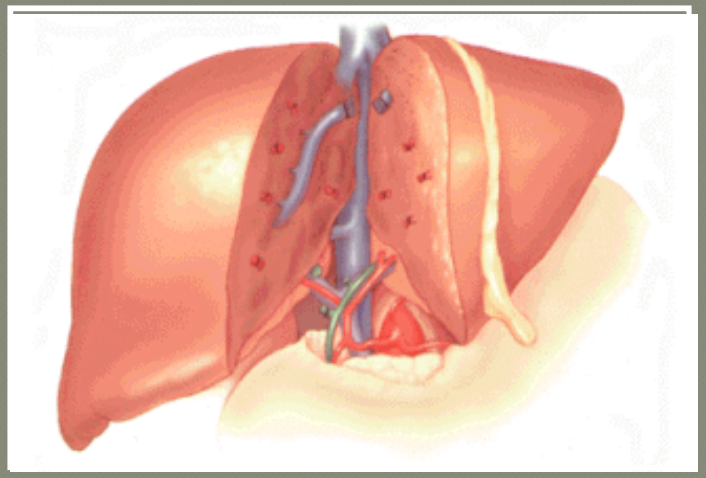
Regulation:

- long chain fatty acids must be **esterified** to **carnitine** in order to be transported across inner mitochondrial membrane.

- ***carnitine acyltransferase I*** is inhibited by malonyl CoA, the committed intermediate in fatty acid synthesis.

- when malonyl CoA is abundant long chain fatty acids cannot enter the mitochondrial matrix to be broken down and are exported to adipose tissue to be stored as fat. But when malonyl CoA is low (fasting state) the fatty acids are broken down into ketone bodies.

Liver- #1 metabolic player



- Primarily depends on

β-oxidation of fatty acids for its own energy needs.

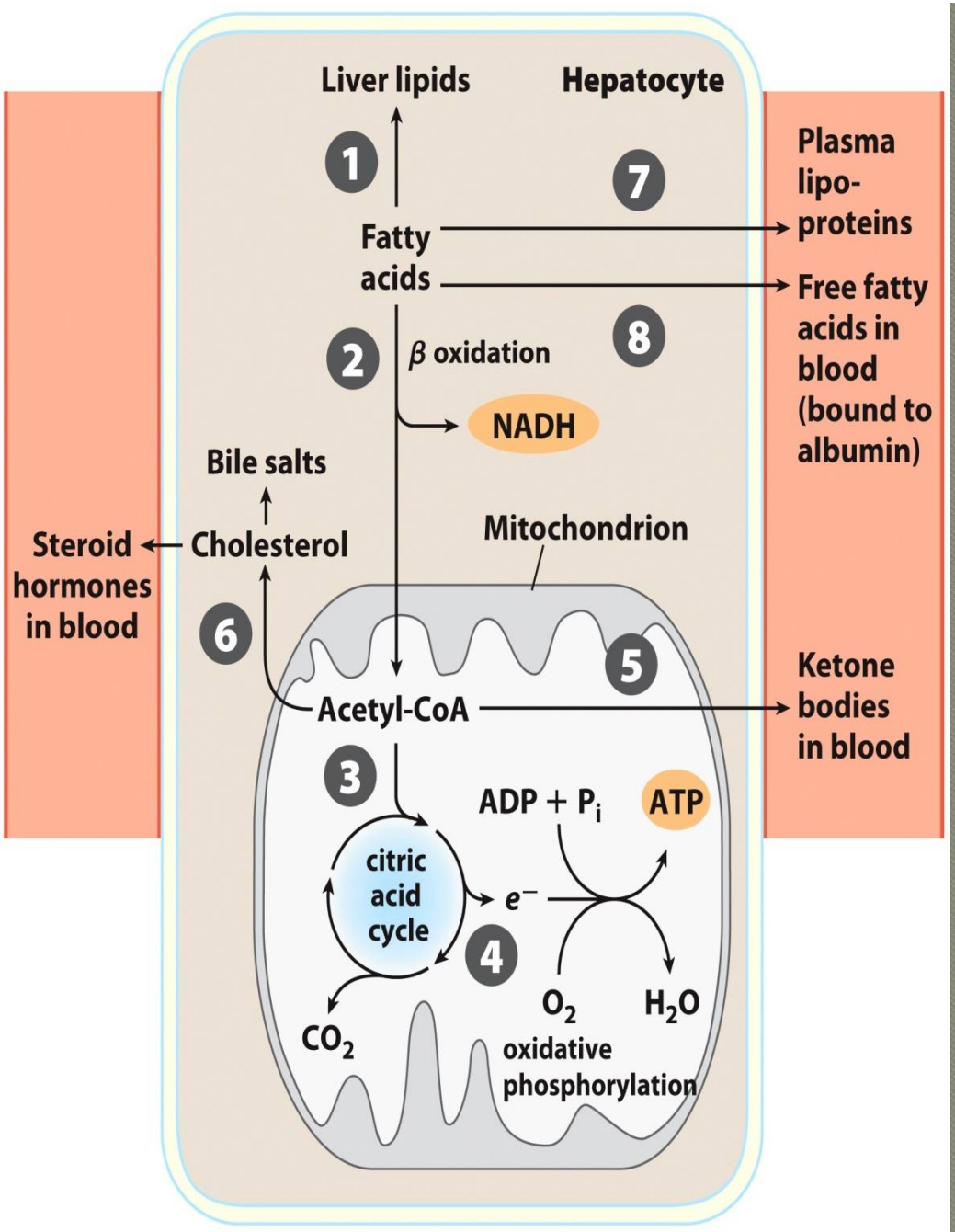


Figure 23-14
Lehninger Principles of Biochemistry, Sixth Edition

The liver also plays a central role in **amino acid metabolism.**

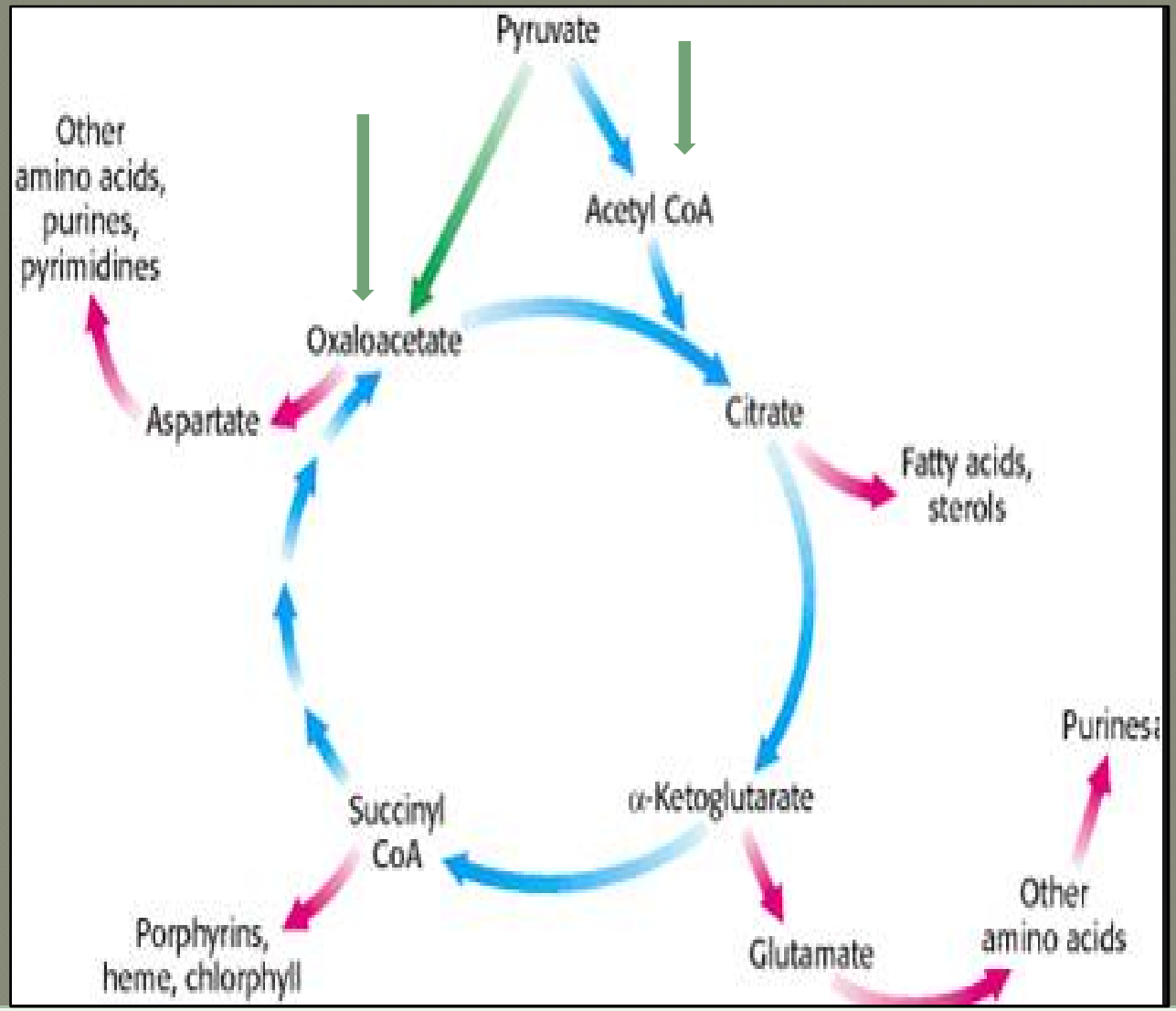
The liver removes most of the **amino acids** absorbed by the intestine. The priority use is protein synthesis.

Excess amino acids are **deaminated** and converted into common metabolic intermediates.

- the liver secretes about 30 g of urea/day.
- the **α-ketoacids** are used as fuels or for gluconeogenesis.
- α-ketoacids are the major fuel for the liver itself.

Carbs, Amino Acids

Fats, Amino Acids



TCA Cycle is an excellent example of an amphibolic pathway

EVOLUTION CONNECTION: PATHWAYS OF PHOTOSYNTHESIS AND CELLULAR METABOLISM

The processes of photosynthesis and cellular metabolism consist of several very complex pathways. It is generally thought that the first cells arose in an aqueous environment—a "soup" of nutrients—probably on the surface of some porous clays. If these cells reproduced successfully and their numbers climbed steadily, it follows that the cells would begin to deplete the nutrients from the medium in which they lived as they shifted the nutrients into the components of their own bodies. This hypothetical situation would have resulted in natural selection favoring those organisms that could exist by using the nutrients that remained in their environment and by manipulating these nutrients into materials upon which they could survive. Selection would favor those organisms that could extract maximal value from the nutrients to which they had access.

An early form of photosynthesis developed that harnessed the sun's energy using water as a source of hydrogen atoms, but this pathway did not produce free oxygen (**anoxygenic photosynthesis**). (NOTE: *Early photosynthesis did not produce free oxygen because it did not use water as the source of hydrogen ions; instead, it used materials like hydrogen sulfide and consequently produced sulfur*). It is thought that **glycolysis** developed at this time and could take advantage of the simple sugars being produced, but these reactions were unable to fully extract the energy stored in the carbohydrates. The development of glycolysis probably predated the evolution of photosynthesis, as it was well suited to extract energy from materials spontaneously accumulating in the **"primeval soup."** A later form of photosynthesis used water as a source of electrons and hydrogen, and generated free oxygen. Over time, the atmosphere became oxygenated, but not before the oxygen released oxidized metals in the ocean and created a **"rust" laye**r in the sediment, permitting the dating of the rise of the first oxygenic photosynthesizers. Living things adapted to exploit this new atmosphere that allowed aerobic respiration as we know it to evolve. When the full process of oxygenic photosynthesis developed and the atmosphere became oxygenated, cells were finally able to use the oxygen expelled by photosynthesis to extract considerably more energy from the sugar molecules using the **citric acid cycle** and **oxidative phosphorylation**.

Summary

The breakdown and synthesis of carbohydrates, proteins, and lipids connect with the pathways of glucose catabolism. The simple sugars are galactose, fructose, glycogen, and pentose. These are catabolized during glycolysis. The amino acids from proteins connect with glucose catabolism through pyruvate, acetyl CoA, and components of the citric acid cycle. Cholesterol synthesis starts with acetyl groups, and the components of triglycerides come from glycerol-3-phosphate from glycolysis and acetyl groups produced in the mitochondria from pyruvate.

THANKS

16/04/2019