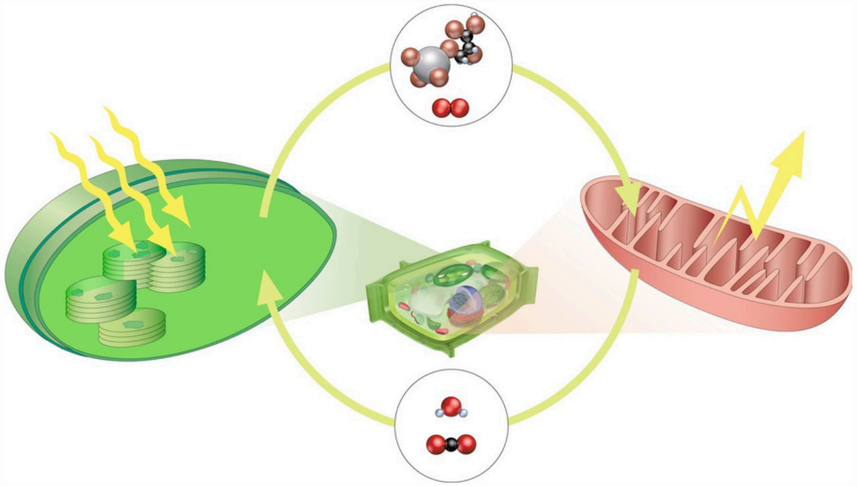
AL-FARABI KAZAKH NATIONAL UNIVERSITY
FACULTY OF BIOLOGY AND BIOTECHNOLOGY
DEPARTMENT OF BIOTECHNOLOGY



Lecture 1

Introduction to Metabolism

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Lecture Plan

01. Definition of metabolism
02. Catabolism and anabolism
03. ATP and biological energy
04. Organisation of metabolic pathways
05. Major metabolic fuels, fed and fasting states
06. Integration of metabolism

CONTENTS

Learning Objectives

By theend of thislecture, students will be able to:

1. Define metabolism and explain its role in cellular homeostasis.
2. Distinguish catabolism from anabolism and give examples of each.
3. Explain how ATP couples nutrient breakdown to cellular work.
4. Identify linear, cyclic and branched metabolic pathways.
5. Compare major fuels and hormonal regulation in fed and fasting states.

Definition of metabolism

Metabolism refers to all the chemical processes going on continuously inside your body that allow life and normal functioning (maintaining normal functioning in the body is called homeostasis). These processes include those that break down nutrients from our food, and those that build and repair our body. It’s the sum of the chemical reactions that take place within each cell of a living organism and that provide energy for vital processes and for synthesizing new organic material

METABOLISM



Chemical Energy

Fats
Carbohydrates
Others

Chemical Waste

CO_2 H_2O

ATP

Metabolism

Main functions of metabolism
Energy Production
Synthesis of biomolecules
Growth and repair
Maintenance of homeostasis
Adaptation to environmental changes

Body’s metabolism never stops — even when resting and sleeping. It constantly sustains basic body functions, like

- Breathing
- Circulating blood
- Digesting food
- Growing and repairing cells.
- Managing hormone levels
- Regulating body temperature

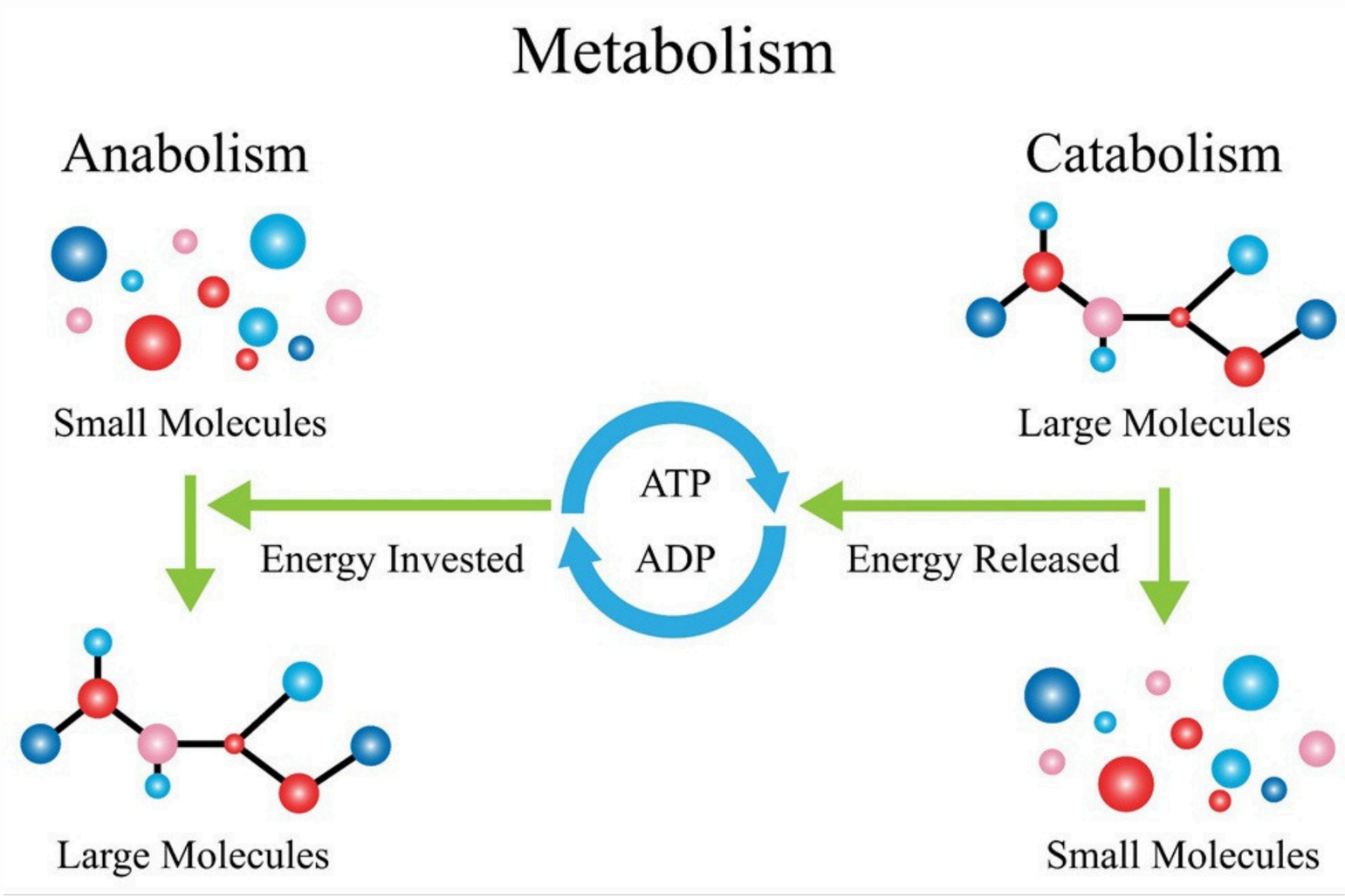
A healthy, life-sustaining metabolism requires cells to function at rest and adapt to a changing environment. This includes adaptation to periods of:

- Eating
- Fasting
- Starvation
- Physical activity
- Illness or injury
- Pregnancy and lactation

Catabolism and Anabolism

Anabolism centers aroundgrowth and building —theorganization of molecules. In this process, small, simple molecules are built up into larger, more complex ones. An example of anabolism is gluconeogenesis. This is when the liver and kidneys produce glucose from noncarbohydrate sources.

Catabolism is what happens when you digest food and the molecules break down in the body for use as energy. Large, complex molecules in the body are broken down into smaller, simple ones. An example of catabolism is glycolysis. This process is almost the reverse of gluconeogenesis.



Anabolism uses that energy to build small molecules into large ones for growth and repair.

Catabolism breaks down large molecules into small ones and releases energy.

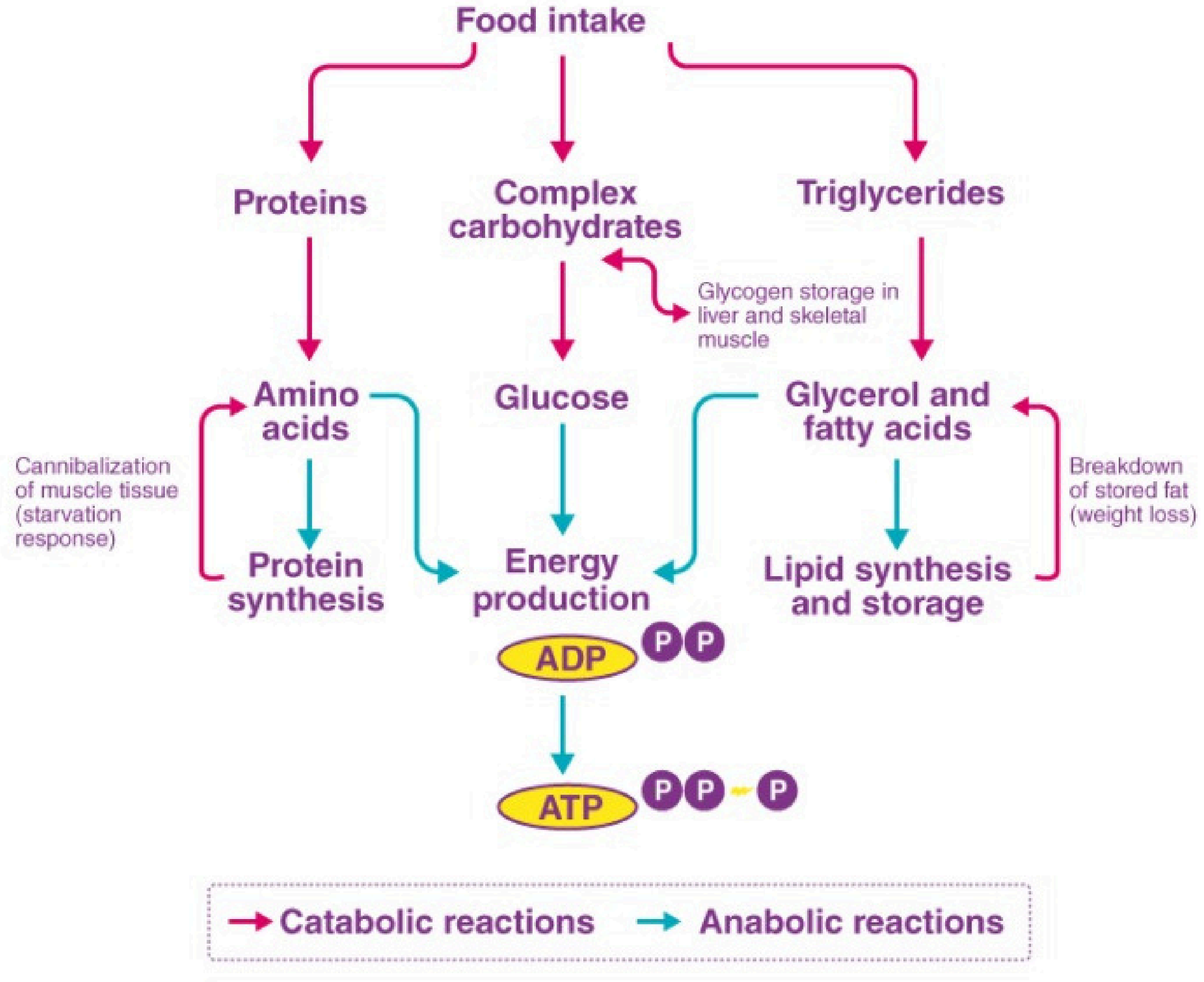
Hormones play an important role in these processes. Different hormones in the body are associated with either anabolism and catabolism.

Anabolism involves the hormones:

- estrogen
- insulin
- growth hormone
- testosterone

Catabolism involves the hormones:

- adrenaline
- cortisol
- cytokines
- glucagon

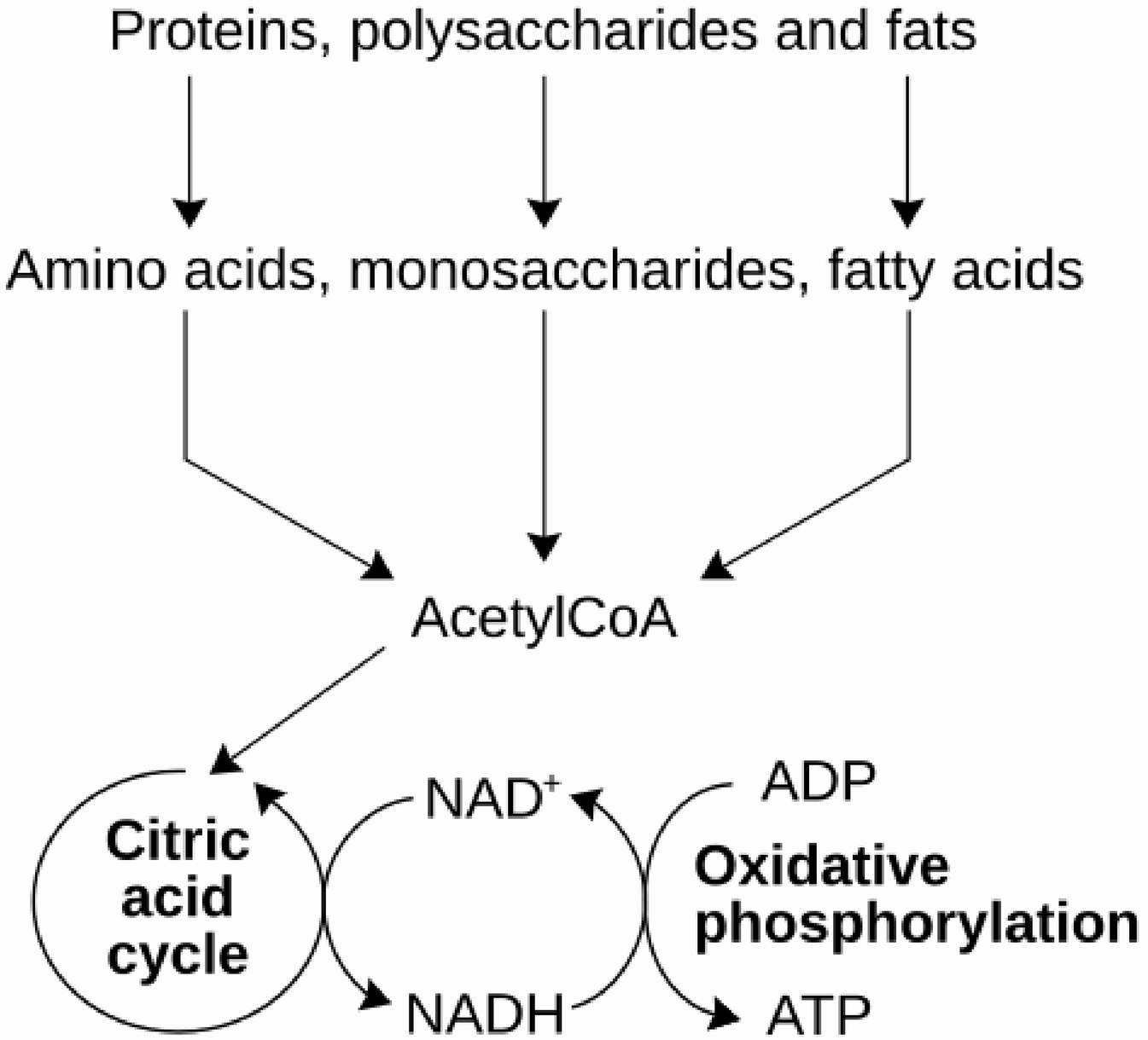

Food intake
Proteins
Complex carbohydrates
Triglycerides
Glycogen storage in liver and skeletal muscle
Amino acids
Glucose
Glycerol and fatty acids
Cannibalization of muscle tissue (starvation response)
Breakdown of stored fat (weight loss)
Protein synthesis
Energy production
Lipid synthesis and storage
ADP
P P
ATP
P P P
Catabolic reactions
Anabolic reactions

Catabolism

Catabolism is the metabolic pathway that breaks down complex molecules into simpler ones, releasing energy in the process. This energy is often stored in the form of adenosine triphosphate (ATP), which cells use to perform various functions. Catabolic reactions are typically exergonic, meaning they release energy.

Catabolism is the process which provides the energy required for cellular activities. These include muscle contraction, nerve impulse propagation, and biosynthesis of essential molecules. For example, during periods of fasting or intense exercise, catabolic processes break down stored glycogen, fats, and proteins to meet the body’s energy demands.

Catabolic processes include glycolysis in which glucose is broken down to pyruvate, producing ATP and NADH. The Citric Acid Cycle (Krebs Cycle) is also a catabolic process in which the oxidation of acetyl-CoA to carbon dioxide and water, generates ATP, NADH, and FADH2.

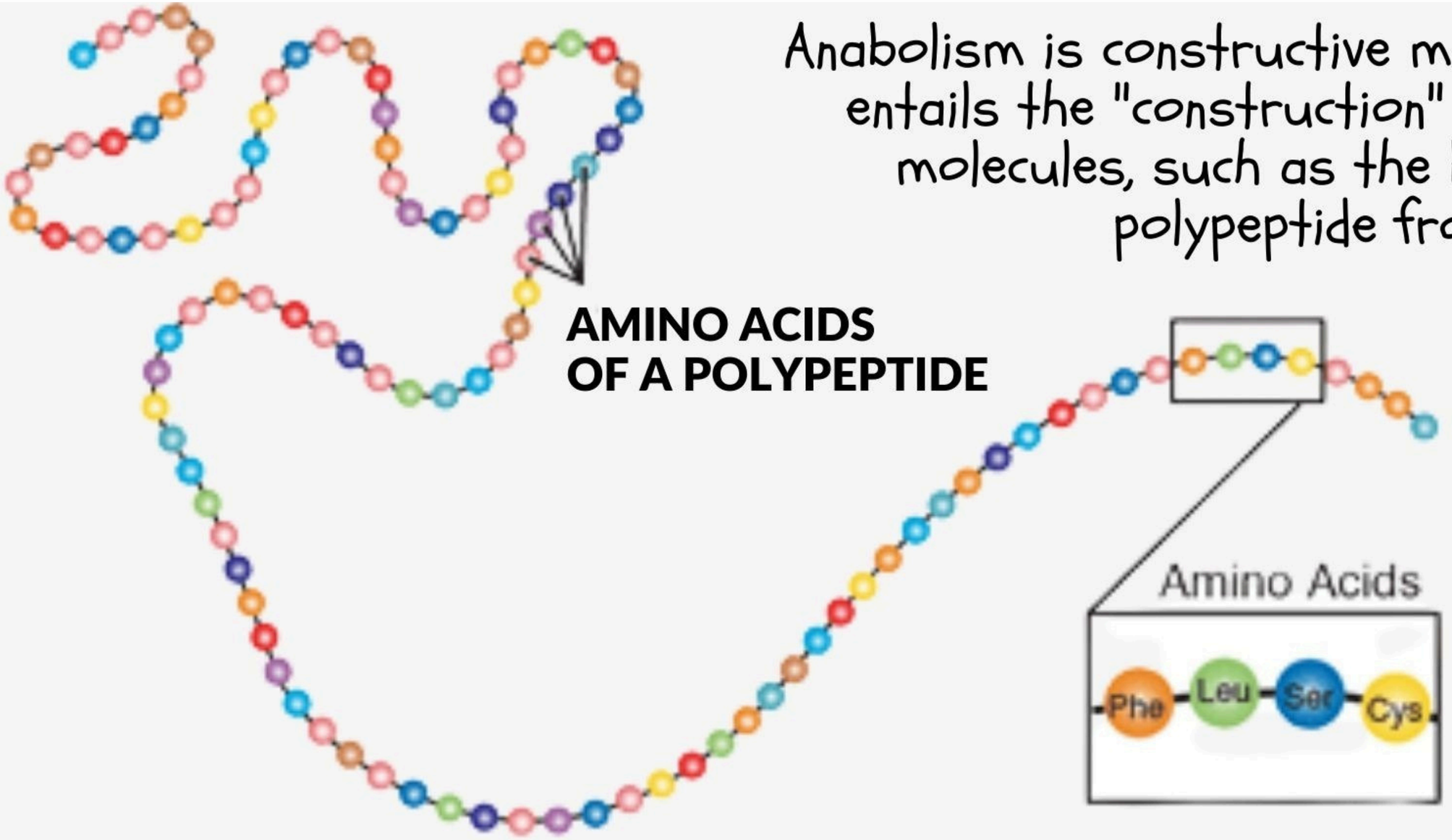


Anabolism

Anabolism is the metabolicpathway that constructs complex molecules from simpler ones, consuming energy in the process. Thus anabolic drugs, such as anabolic steroids, promote the formation of mass, notable muscle mass. Anabolic reactions are typically endergonic, meaning they require an input of energy, usually in the form of ATP.

Examples of anabolic processes include protein synthesis, DNA replication, glycogenesis - the formation of glycogen from glucose, which is then stored in the liver and muscles for future energy needs. Anabolic processes are vital for growth, repair, and maintenance of tissues. They enable organisms to build and maintain their cellular structures, store energy for future use, and reproduce.

Anabolism is constructive metabolism as it entails the "construction" or "building" of molecules, such as the building up of a polypeptide from amino acids.

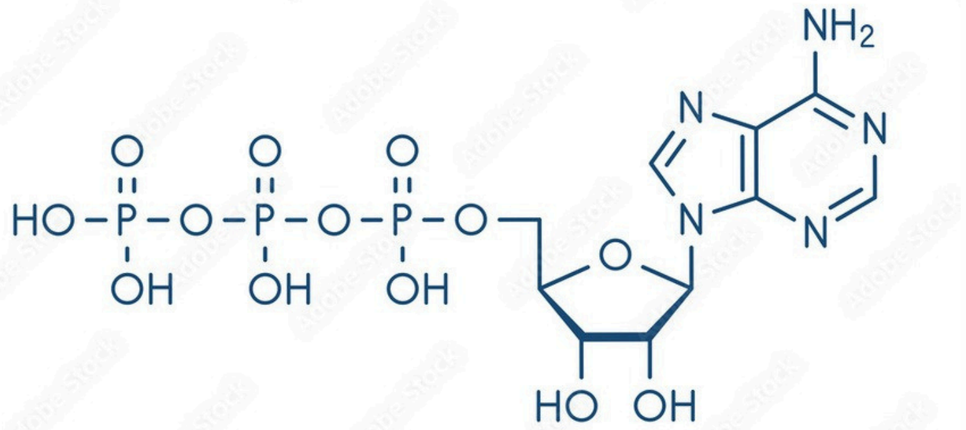


What is ATP?

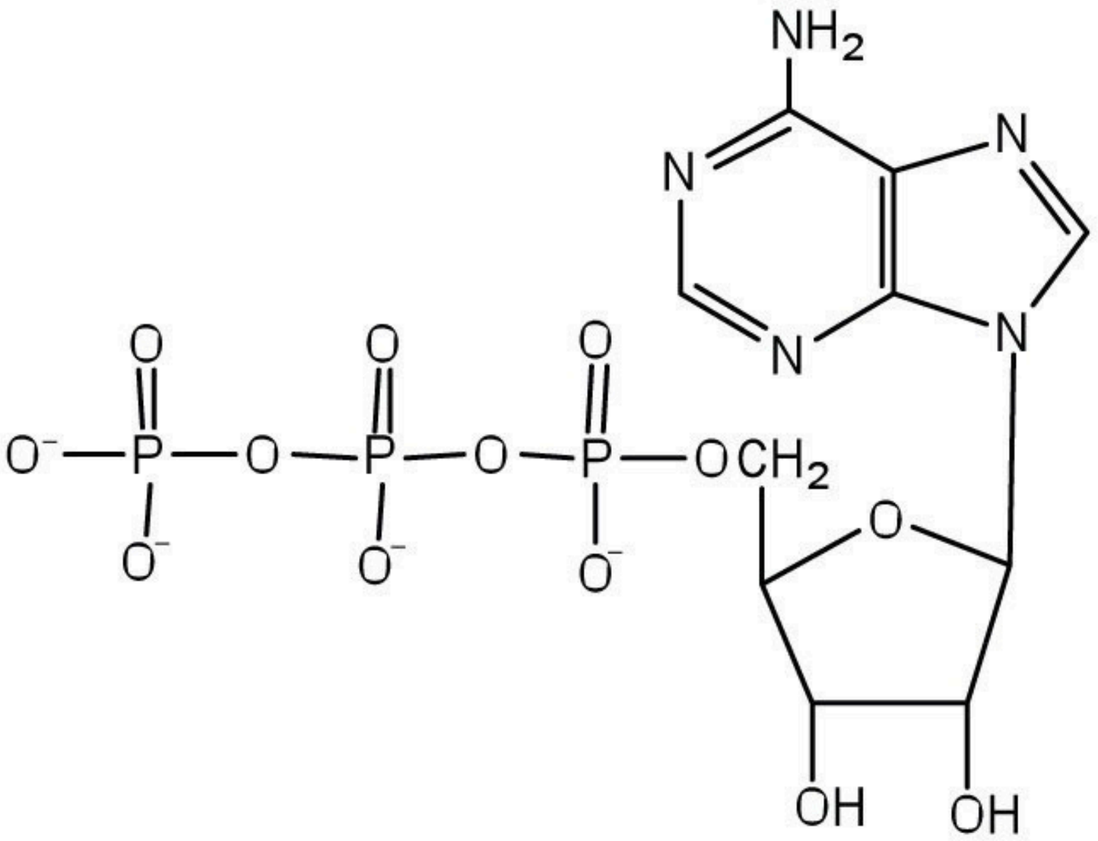
ATP (adenosine triphosphate) is a nucleotide composed of:

- adenine,
- ribose,
- three phosphate groups.

The bonds between phosphate groups store a large amount of chemical energy.



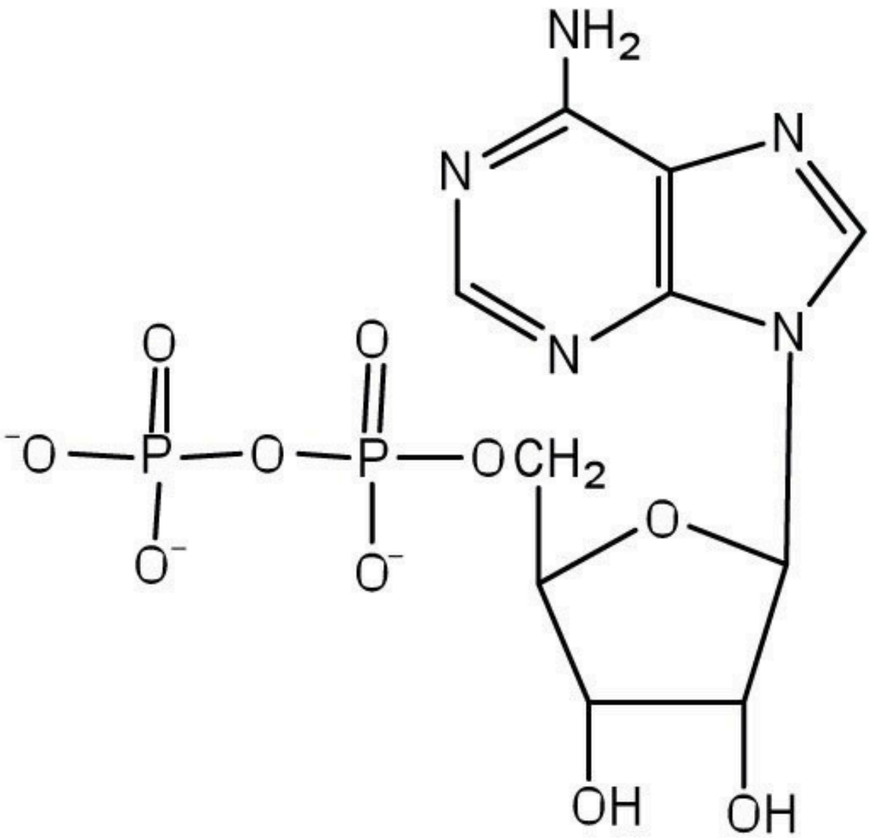
ATP



Adenosine triphosphate (ATP)

H_2O

Energy
+
Phosphate ion



Adenosine diphosphate (ADP)

$$ATP + H_2O \rightarrow ADP + Pi + Energy$$

Hydrolysis of ATP releases energy that can be used by the cell.

Main sources of ATP production

- Carbohydrates → glycolysis → cellular respiration.
- Fatty acids → β-oxidation → cellular respiration.
- Amino acids → oxidation in metabolic pathways.

Main site of ATP synthesis

- Mitochondria during oxidative phosphorylation.

A smaller amount of ATP is produced in the cytoplasm during glycolysis.

Role of ATP in metabolism

ATP transfers energy from catabolic reactions to anabolic reactions and other cellular processes.

ATP is required for

- biosynthesis of proteins, lipids, and nucleic acids,
- active transport across membranes,
- muscle contraction,
- nerve impulse transmission,
- cell signaling,
- maintenance of ion gradients.

ATP acts as an energy intermediate that links nutrient breakdown with cellular work.

Biological Energy

Livingorganismsrequirea constantsupply ofenergy to maintain life.

The primaryenergysource isthechemical energy contained in nutrients:

- glucose,
- fatty acids,
- amino acids.

During catabolism, these molecules are oxidized and energy is released.

Energy transformation

Nutrients → Catabolism → ATP → Cellular work

The energy released from nutrients is captured in ATP and then used for:

- biosynthesis,
- transport,
- movement,
- growth,
- maintenance of homeostasis.

Metabolic pathways

Ametabolic pathway is a sequence of enzyme-catalyzed reactions in which the product of one reaction becomes the substrate for the next reaction.
Substrate → Intermediate 1 → Intermediate 2 → Product
Each step is catalyzed by a specific enzyme.

Metabolic pathways allow cells to:

- obtain energy from nutrients,
- synthesize essential biomolecules,
- degrade damaged or unnecessary molecules,
- store energy for future use,
- maintain cellular homeostasis.

Pathways make metabolism efficient and highly organized.

Types of Metabolic pathways

Cyclic pathways

The initial molecule is regenerated.

Example: citric acid cycle; Krebs cycle.

Branched pathways

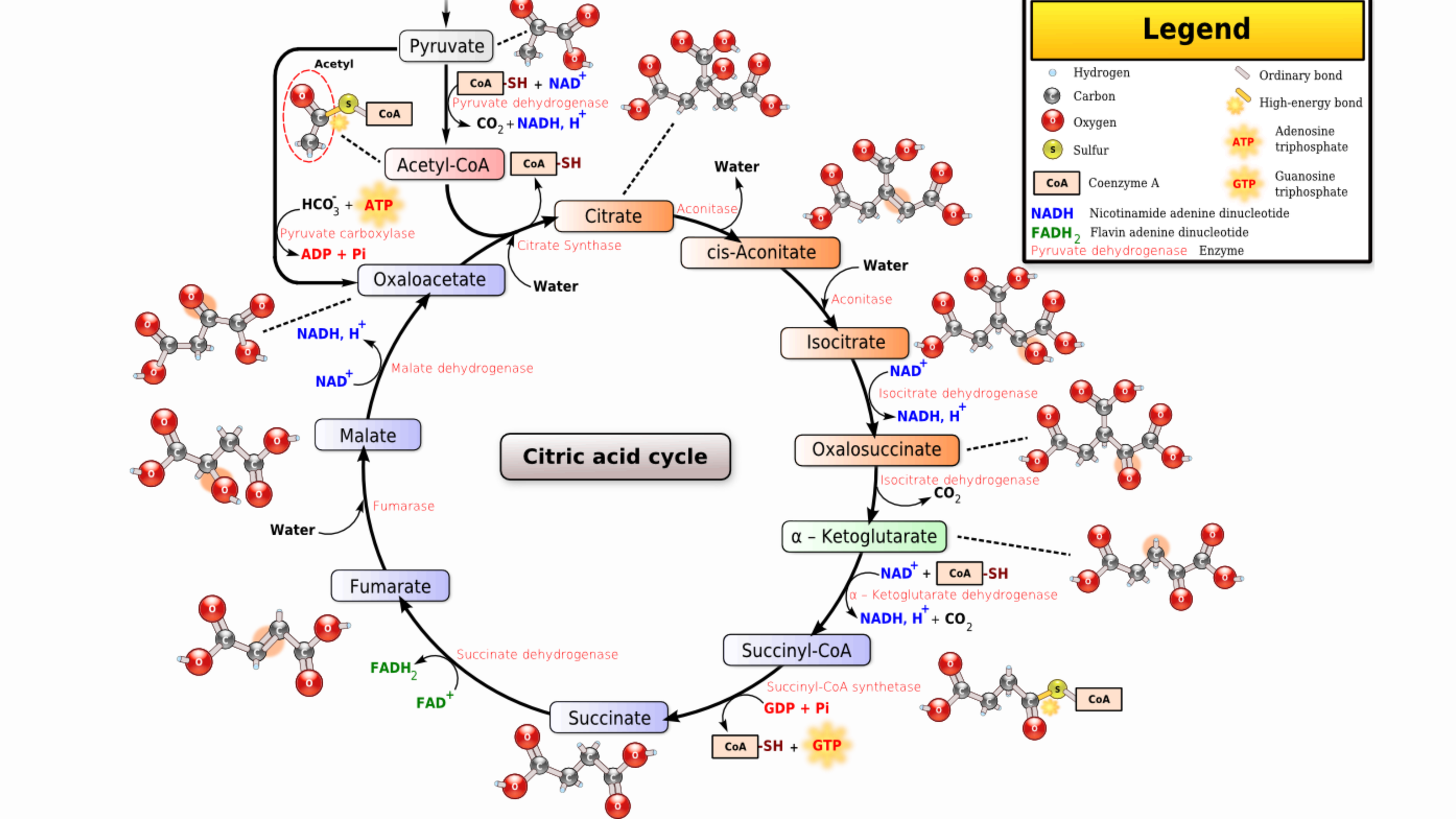
One intermediate can enter several pathways.

Example: amino acid metabolism.

Linear pathways

Substrate → Product

Example: glycolysis.


Legend
Hydrogen
Carbon
Oxygen
Sulfur
Coenzyme A
Ordinary bond
High-energy bond
ATP
Adenosine triphosphate
GTP
Guanosine triphosphate
NADH Nicotinamide adenine dinucleotide
FADH2 Flavin adenine dinucleotide
Pyruvate dehydrogenase Enzyme
Citric acid cycle
Pyruvate
Acetyl
CoA
Acetyl-CoA
CoA-SH + NAD+
Pyruvate dehydrogenase
CO2 + NADH, H+
HCO3- + ATP
Pyruvate carboxylase
ADP + Pi
Oxaloacetate
Citrate
Citrate Synthase
Water
Aconitase
cis-Aconitate
Water
Aconitase
Isocitrate
NAD+
Isocitrate dehydrogenase
NADH, H+
Oxalosuccinate
Isocitrate dehydrogenase
CO2
α – Ketoglutarate
NAD+ + CoA-SH
α – Ketoglutarate dehydrogenase
NADH, H+ + CO2
Succinyl-CoA
Succinyl-CoA synthetase
GDP + Pi
CoA-SH + GTP
Succinate
Succinate dehydrogenase
FADH2
FAD+
Fumarate
Fumarase
Water
Malate
Malate dehydrogenase
NADH, H+
NAD+

Major Metabolic Pathway

Carbohydrate pathways

- Glycolysis
- Gluconeogenesis
- Glycogen synthesis
- Glycogen breakdown

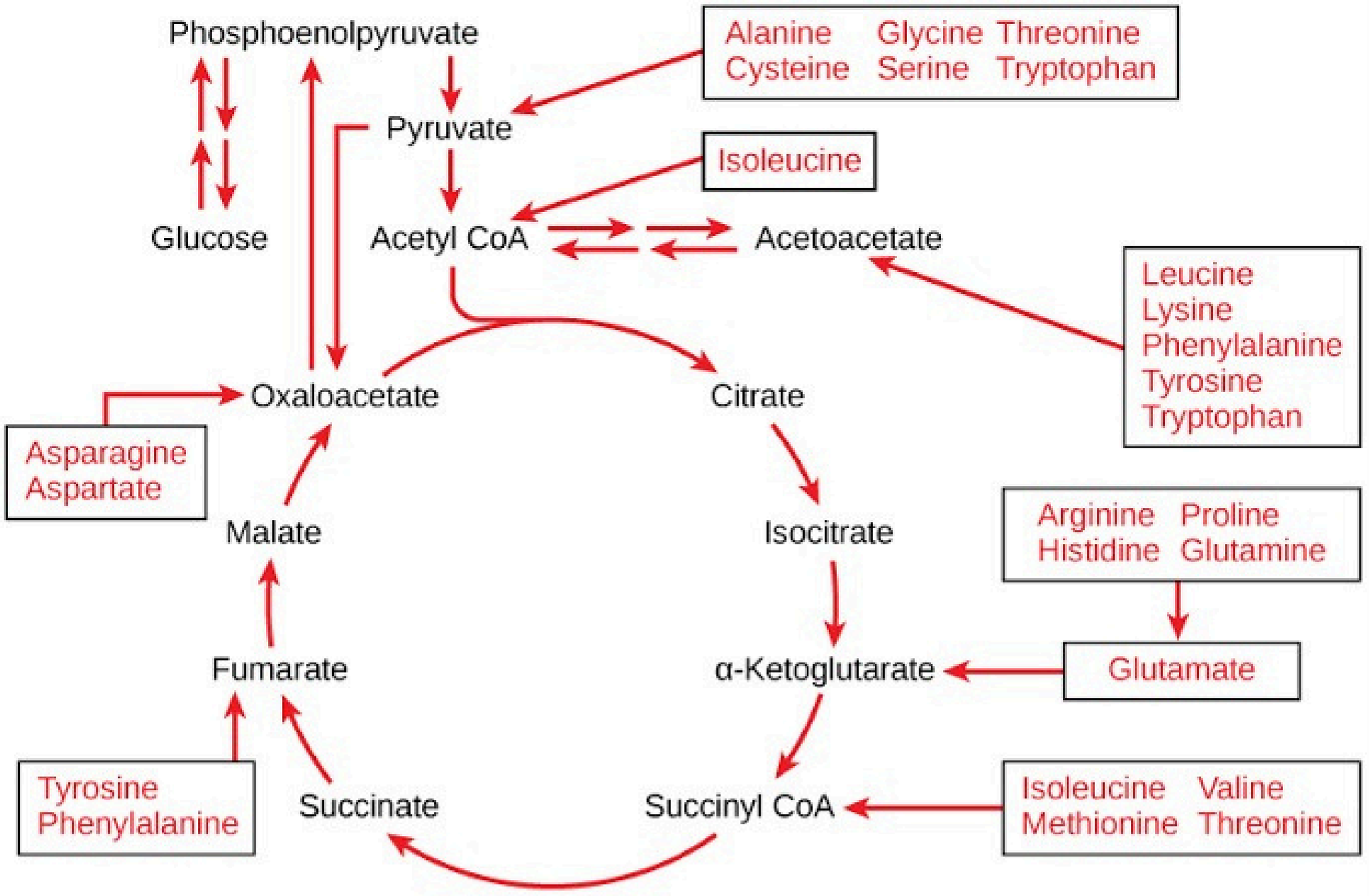
Protein pathways

- Amino acid degradation
- Urea cycle

Lipid pathways

- Lipolysis
- β-oxidation
- Fatty acid synthesis

These pathways are interconnected and contribute to ATP production.


Phosphoenolpyruvate
Alanine Glycine Threonine
Cysteine Serine Tryptophan
Pyruvate
Isoleucine
Glucose
Acetyl CoA
Acetoacetate
Leucine
Lysine
Phenylalanine
Tyrosine
Tryptophan
Oxaloacetate
Citrate
Asparagine
Aspartate
Malate
Isocitrate
Arginine Proline
Histidine Glutamine
Fumarate
α-Ketoglutarate
Glutamate
Tyrosine
Phenylalanine
Succinate
Succinyl CoA
Isoleucine Valine
Methionine Threonine

Major metabolic fuels

Metabolic fuels aremolecules thatcanbeoxidized to provide energy for cellular processes. The majorfuelsare carbohydrates,fatty acids, and amino acids.

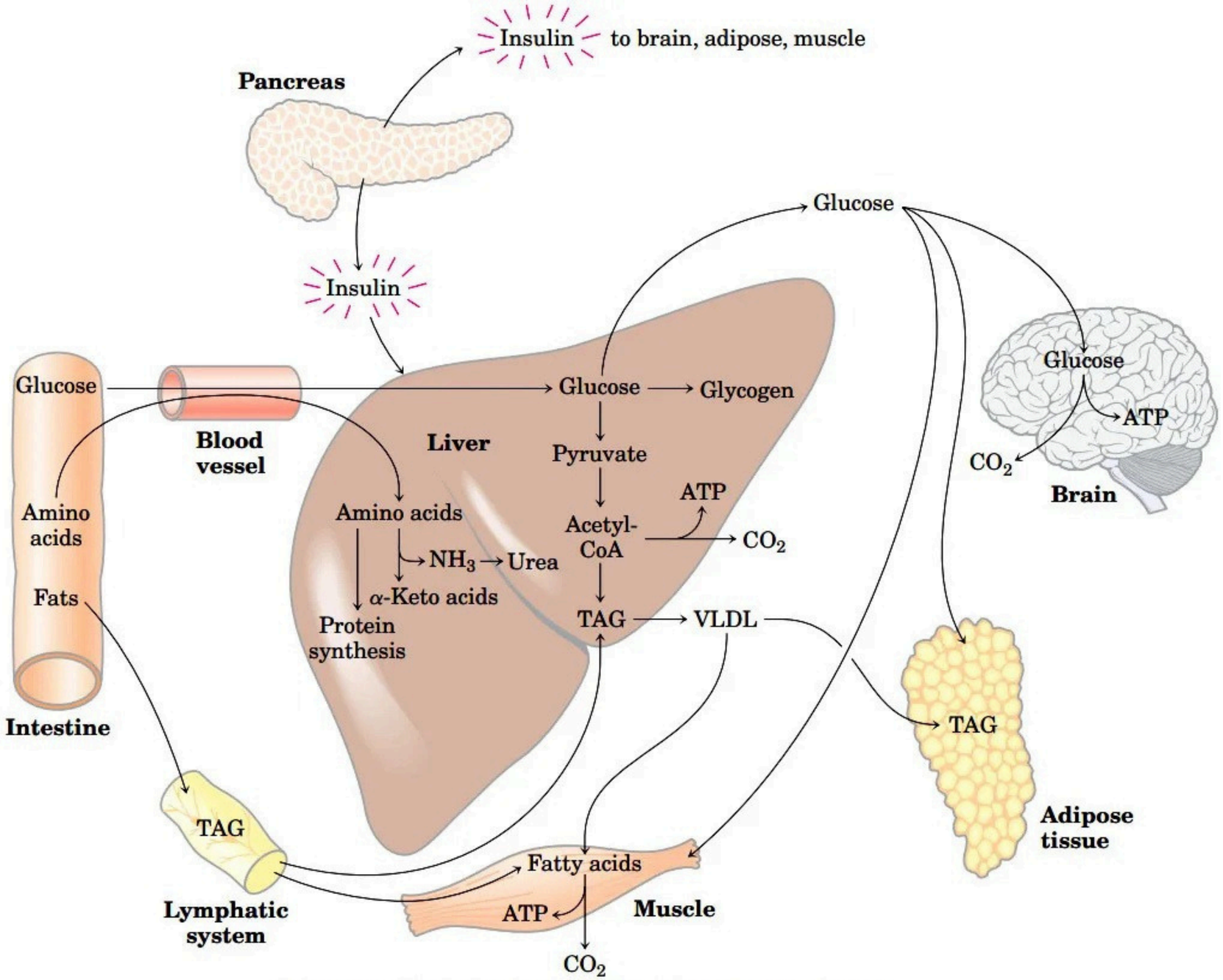
Fuel	Main source	Main role
Glucose	Carbohydrates	Rapid source of ATP; important for brain and red blood cells
Fatty acids	Dietary fat, adipose tissue	Major long-term energy source, especially during fasting
Amino acid	Dietary and body proteins	Used mainly for protein synthesis, but can provide energy when necessary
Ketone bodies	Produced from fatty acids in the liver	Alternative fuel during prolonged fasting

The **integration** of metabolism is the coordinated regulation of biochemical pathways across different tissues and organs. It maintains energy balance and stable blood sugar levels through shifting hormone levels, mainly insulin and glucagon, during fed and fasting states.

Key Metabolic States

Fasting state: High glucagon and low insulin trigger the breakdown of glycogen, release of stored fat, and creation of new glucose (gluconeogenesis) to fuel the brain and body.

Fedstate (absorptive): High insulin promotes storage. Glucose is stored as glycogen or fat, and amino acids build proteins.



The well-fed state: the lipogenic liver

Lehninger Principles of Biochemistry, (5E, 2008), Nelson & Cox, W.H. Freeman and Company, New-York

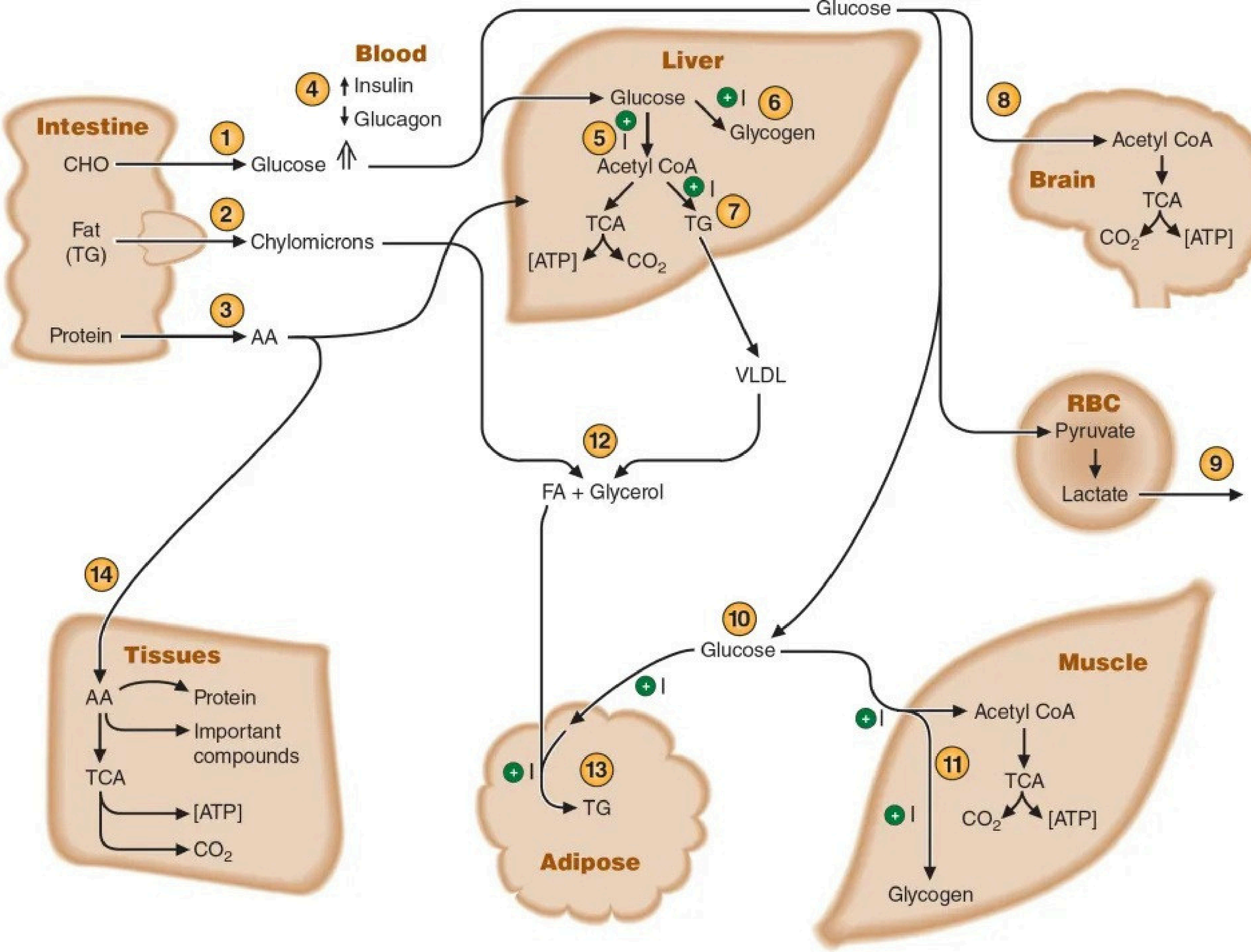
The **fed state** occurs after eating, when nutrients are readily available in the bloodstream.

Main hormone:Insulin↑

After a meal:

- Blood glucose increases.
- Glucose uptake by many tissues increases.
- Glucose is used for immediate energy production.
- Excess glucose is stored as glycogen.
- Excess energy can be converted into fatty acids and triglycerides.
- Protein synthesis increases using available amino acids.
- Breakdown of stored fuels is generally inhibited.

Glucose → ATP production / Glycogen / Fat storage


Glucose
Blood
4
Insulin
Glucagon
Liver
Glucose
I
6
Glycogen
5
I
Acetyl CoA
I
TCA
TG
7
[ATP]
CO_2
Intestine
1
CHO
Glucose
2
Fat
(TG)
Chylomicrons
3
Protein
AA
VLDL
8
Acetyl CoA
Brain
TCA
CO_2
[ATP]
RBC
Pyruvate
Lactate
9
12
FA + Glycerol
14
Tissues
AA
Protein
Important
compounds
TCA
[ATP]
CO_2
10
Glucose
I
I
13
TG
Adipose
Muscle
I
Acetyl CoA
11
TCA
I
CO_2
[ATP]
Glycogen

The **fasting state** occurs when nutrients are no longer being absorbed from the intestine and blood glucose begins to fall.

Mainhormone: Glucagon↑

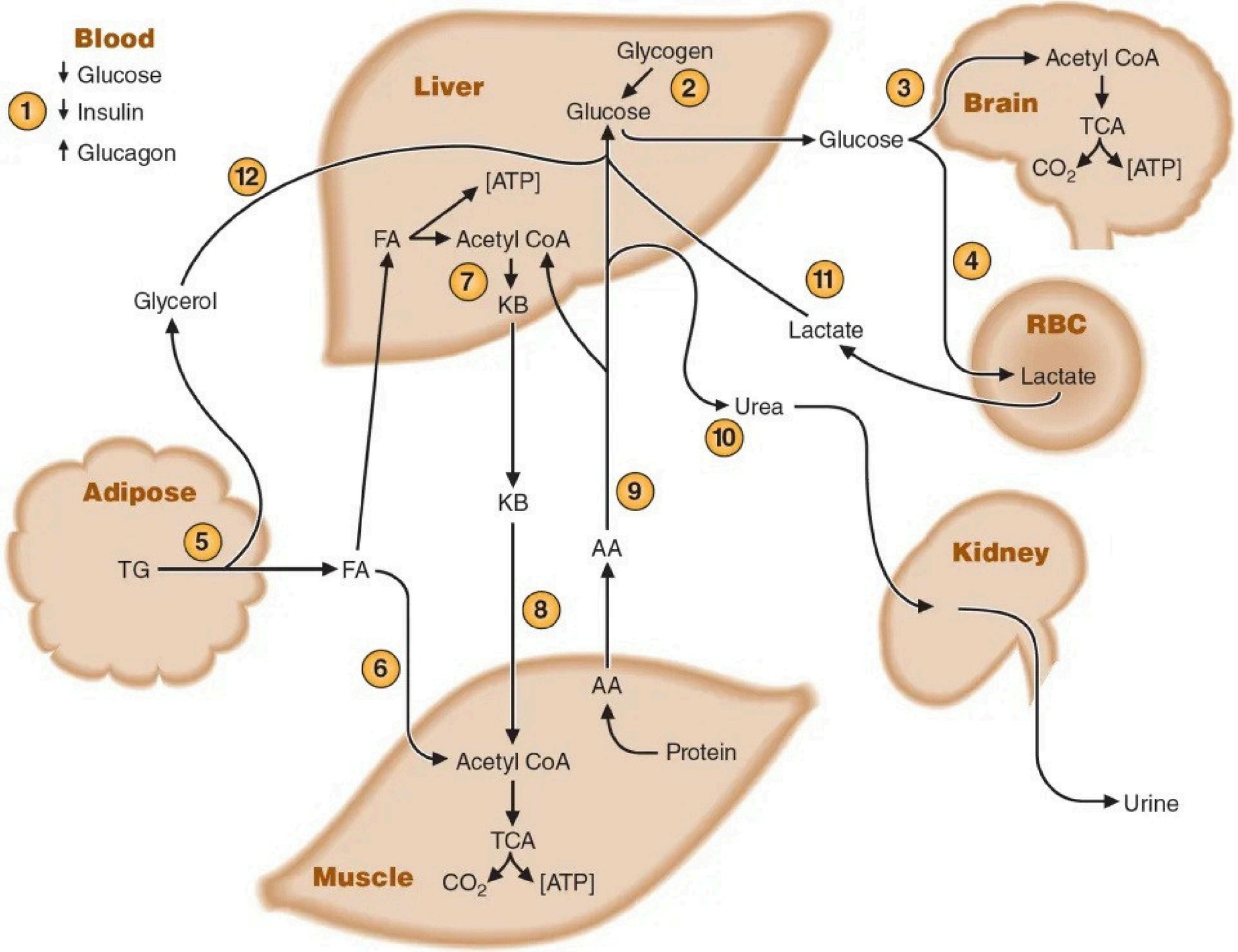
During fasting:

- Glycogen is broken down to maintain blood glucose.
- Adipose tissue releases fatty acids.
- Fatty acids are oxidized to produce ATP.
- The liver increases gluconeogenesis to produce glucose.
- During prolonged fasting, the liver produces ketone bodies from fatty acids.
- Protein breakdown may contribute amino acids for gluconeogenesis, especially when fasting is prolonged.

Glycogen→ Glucose

Triglycerides → Fatty acids → ATP

Fatty acids → Ketone bodies


Blood
Glucose
Insulin
Glucagon
1
Liver
Glycogen
2
Glucose
3
Brain
Acetyl CoA
TCA
CO_2
[ATP]
Glucose
12
[ATP]
FA
Acetyl CoA
7
KB
Glycerol
4
11
Lactate
RBC
Lactate
Urea
10
Adipose
5
TG
FA
KB
9
AA
Kidney
8
6
AA
Protein
Acetyl CoA
TCA
Muscle
CO_2
[ATP]
Urine

Task for Students

Case study: Compareaperson1hour afterameal with the same person after an overnight fast.

1. Create a table comparing insulin and glucagon levels, major fuels, and active pathways in the liver and adipose tissue.

2. Classify glycolysis, glycogen synthesis, lipolysis and gluconeogenesis as catabolic or anabolic. Justify each choice.

3. Explain how ATP links catabolism and anabolism. Include one example of cellular work that requires ATP.

Submit: one comparison table and a 150-200 word explanation. Use at least one textbook reference.

Conclusion

Metabolism includes the reactionsthat supply energy and build cellular components.

Catabolism breaks down fuels. Anabolism uses energy to synthesize complex molecules.

ATP hydrolysis helps drive biosynthesis, active transport and other cellular processes.

Enzymes organize reactions into pathways that connect carbohydrate, lipid and amino acid metabolism.

Insulin and glucagon coordinate fuel use and storage as the body shifts between fed and fasting states.

References

1. Doktyrbay, G. Introduction to Metabolism. Lecture 1. Al-Farabi Kazakh National University. Supplied lecture material.

2. Nelson, D. L., Cox, M. M., & Hoskins, A. A. (2021). Lehninger Principles of Biochemistry (8th ed.). Macmillan Learning.

3. Abali, E. E., Cline, S. D., Franklin, D. S., & Viselli, S. M. Lippincott Illustrated Reviews: Biochemistry (8th ed.). Wolters Kluwer.

Recommended reading: bioenergetics and ATP, regulation of metabolic pathways, and integration of metabolism.