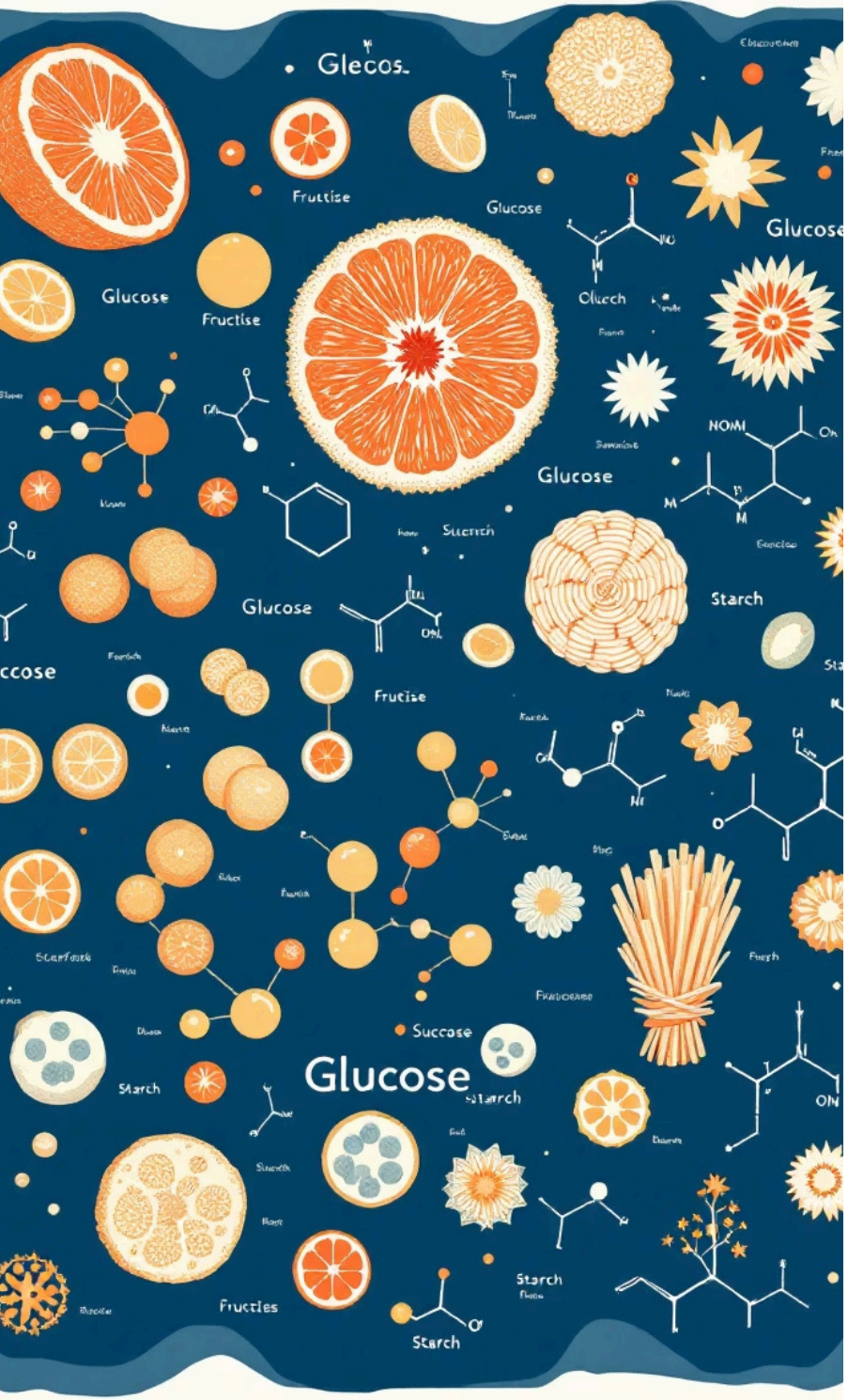
Carbohydrate Metabolism

A Journey Through Life's Energy

Carbohydrates are the body's primary energy source, powering every cellular process from thought to movement. This lecture explores how cells extract, transform, and utilise this vital fuel through an elegant cascade of biochemical reactions.



Introduction to Carbohydrates: Structure and Function

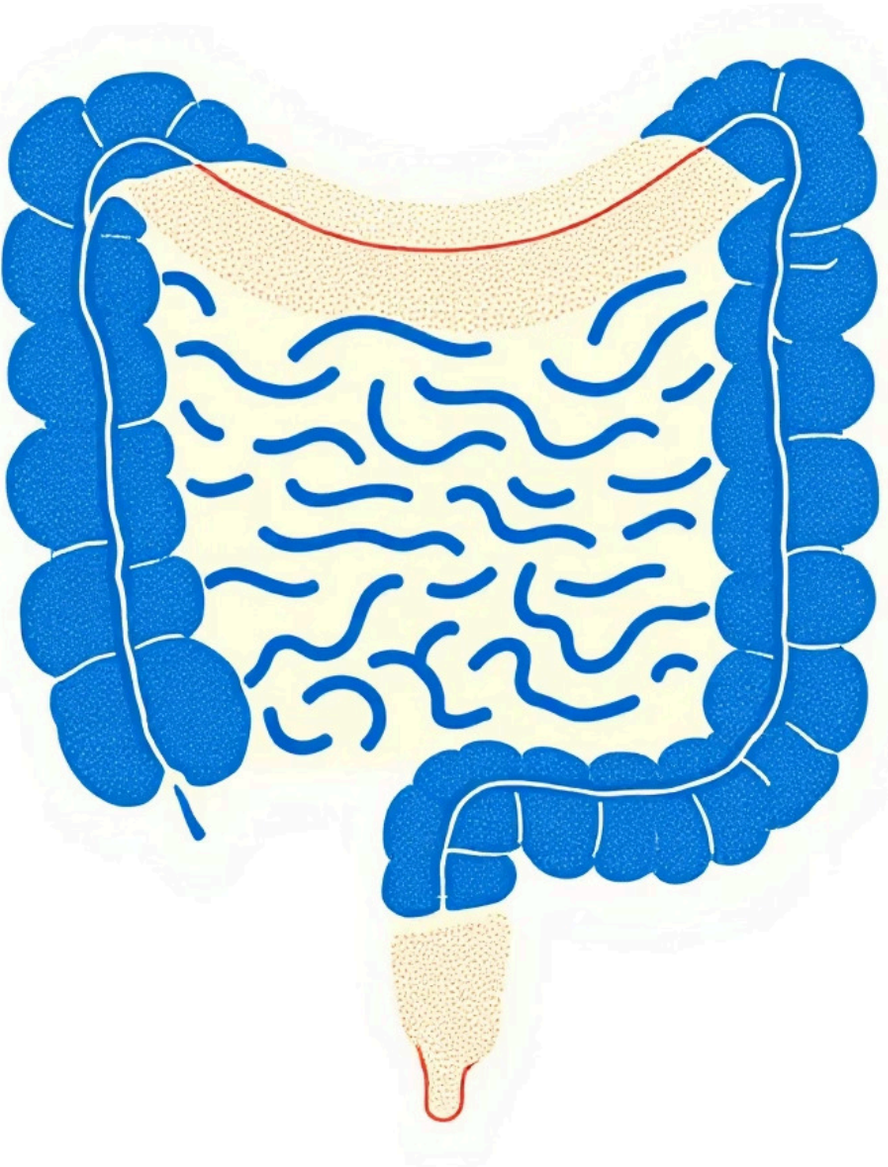
Carbohydrates are organic compounds composed of carbon, hydrogen, and oxygen. They serve as the body's preferred energy currency and structural components, ranging from simple monosaccharides to complex polysaccharides.

Primary Functions

- Energy production through oxidation
- Storage in glycogen and fat reserves
- Structural support in cell walls and connective tissue
- Recognition and signalling between cells

Classification by Structure

- **Monosaccharides:** Simple sugars like glucose, fructose, and galactose
- **Disaccharides:** Pairs of sugars—sucrose, lactose, maltose
- **Polysaccharides:** Chains including starch, glycogen, and cellulose



Digestion and Absorption: Breaking Down the Fuel

Carbohydrate digestion begins in the mouth and continues through the small intestine. Enzymes progressively break complex carbohydrates into glucose, which is then absorbed into the bloodstream for distribution throughout the body.

01

Mechanical Breakdown (Mouth)

Mastication and salivary amylase initiate carbohydrate hydrolysis, creating smaller polysaccharide fragments.

02

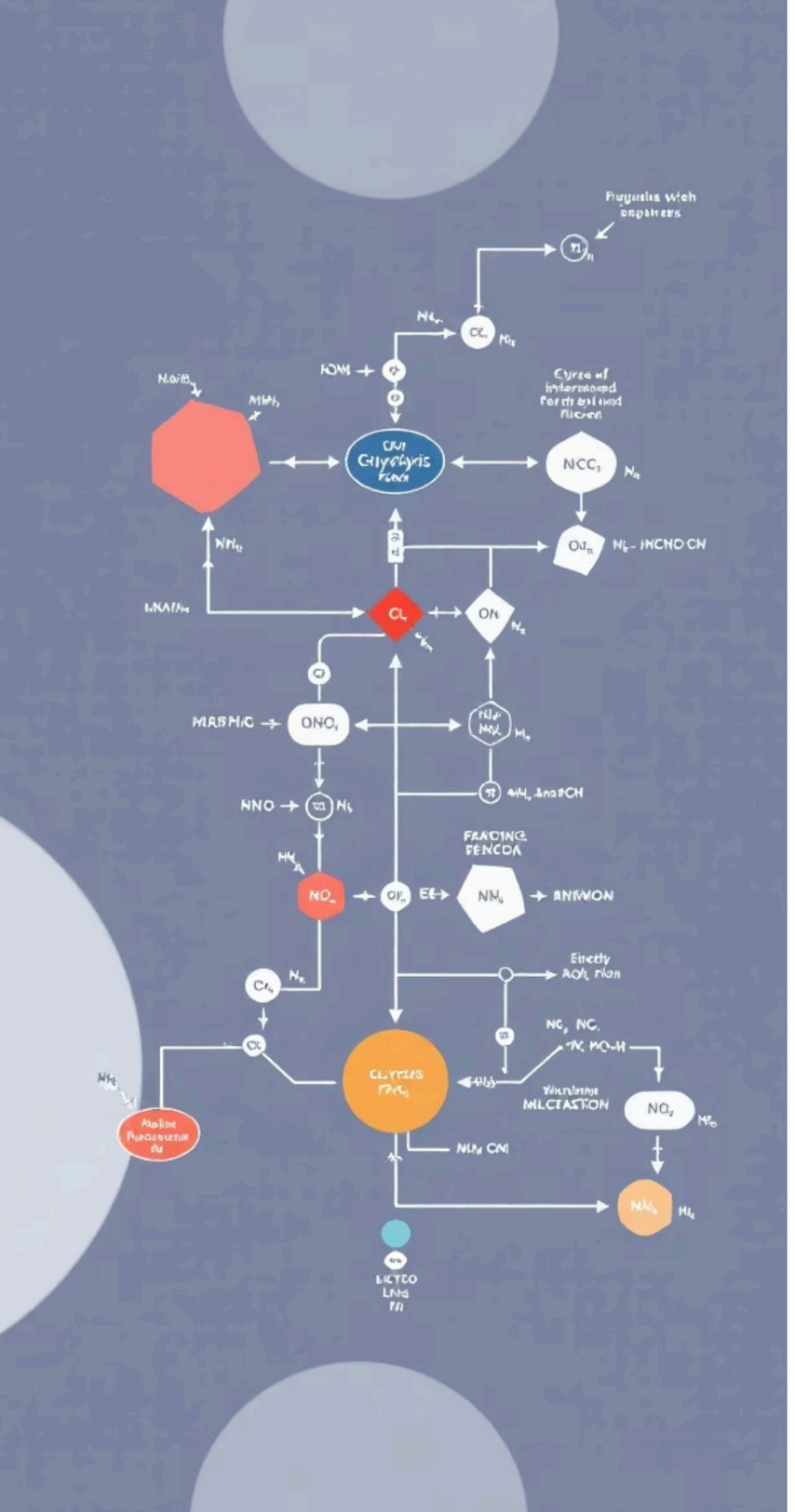
Chemical Digestion (Stomach & Small Intestine)

Pancreatic amylase continues breakdown in the duodenum; brush border enzymes complete conversion to monosaccharides.

03

Active Absorption (Small Intestine)

Glucose and galactose are actively transported; fructose uses facilitated diffusion. Absorbed sugars enter portal blood to the liver.



Glycolysis: The Universal Energy Pathway

Glycolysis is the metabolic foundation—a ten-step cytoplasmic pathway converting one glucose molecule into two pyruvate molecules whilst generating ATP and NADH. This process occurs in all living cells and requires no oxygen.

Energy Investment Phase (Steps 1–5)

Two ATP molecules are consumed to phosphorylate glucose and fructose-6-phosphate, preparing them for breakdown and creating fructose-1,6-bisphosphate.

Energy Payoff Phase (Steps 6–10)

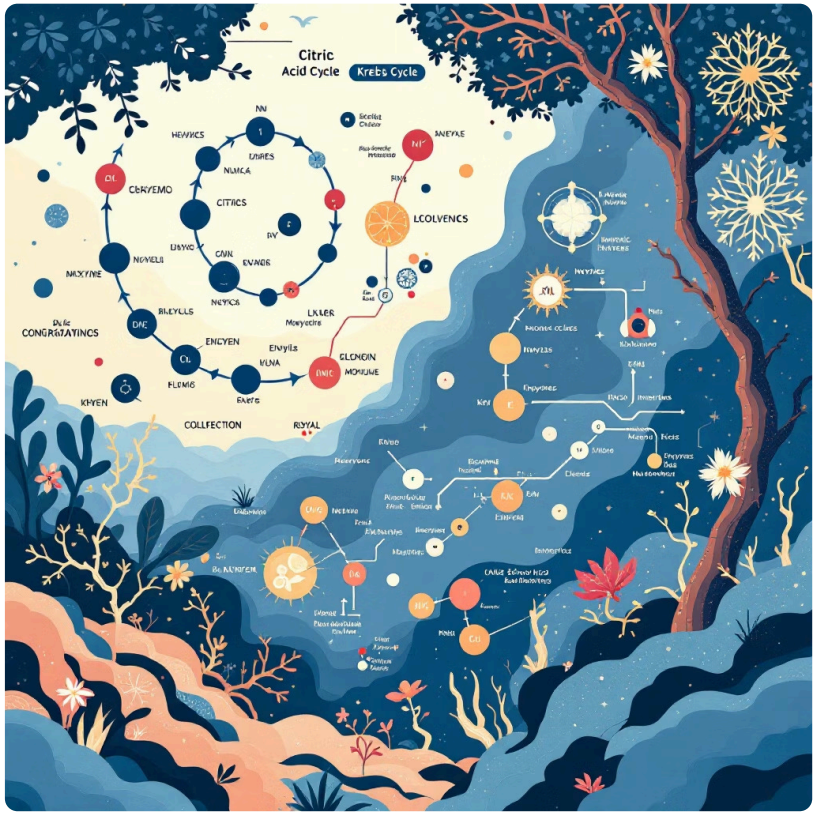
Four ATP molecules are generated and two NADH molecules are produced through oxidation and phosphorylation reactions, yielding two pyruvate molecules.

Net Yield

2 ATP + 2 NADH per glucose under anaerobic conditions. Under aerobic conditions, NADH feeds into the electron transport chain for additional ATP synthesis.

The Citric Acid Cycle (Krebs Cycle): Unlocking More Energy

The citric acid cycle is the cell's central metabolic hub, occurring in the mitochondrial matrix. Acetyl-CoA enters the cycle and is completely oxidised, releasing carbon dioxide whilst generating energy-rich electron carriers and GTP.



This eight-step cycle regenerates oxaloacetate whilst capturing energy in:

- **3 NADH molecules** (feeding the electron transport chain)
- **1 $FADH_2$ molecule** (also entering the ETC)
- **1 GTP molecule** (directly used as energy)

The cycle's intermediates also serve as building blocks for amino acids, fatty acids, and other biosynthetic pathways, making it central to cellular metabolism.

Electron Transport Chain and Oxidative Phosphorylation: The Energy Factory

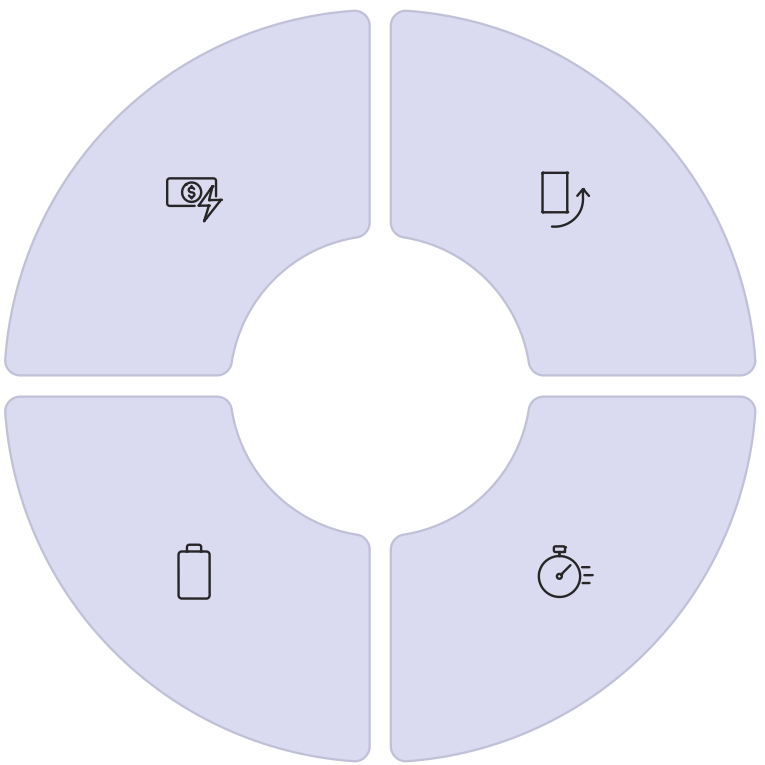
The inner mitochondrial membrane hosts the electron transport chain, where NADH and $FADH_2$ transfer electrons through protein complexes. This process pumps protons, creating an electrochemical gradient that powers ATP synthase to produce the majority of cellular ATP.

Complex I

NADH oxidation begins; electrons pass through iron-sulphur clusters.

ATP Synthase

Proton gradient drives ADP phosphorylation, producing ~32–34 ATP per glucose.



Complex III

Cytochrome bc_1 complex transfers electrons; proton pumping continues.

Complex IV

Cytochrome c oxidase reduces oxygen to water, completing electron transfer.

Gluconeogenesis: Building New Glucose

Gluconeogenesis synthesises glucose from non-carbohydrate precursors when dietary carbohydrates are depleted. This pathway occurs primarily in the liver and kidney, maintaining blood glucose during fasting and exercise.

Key Precursors

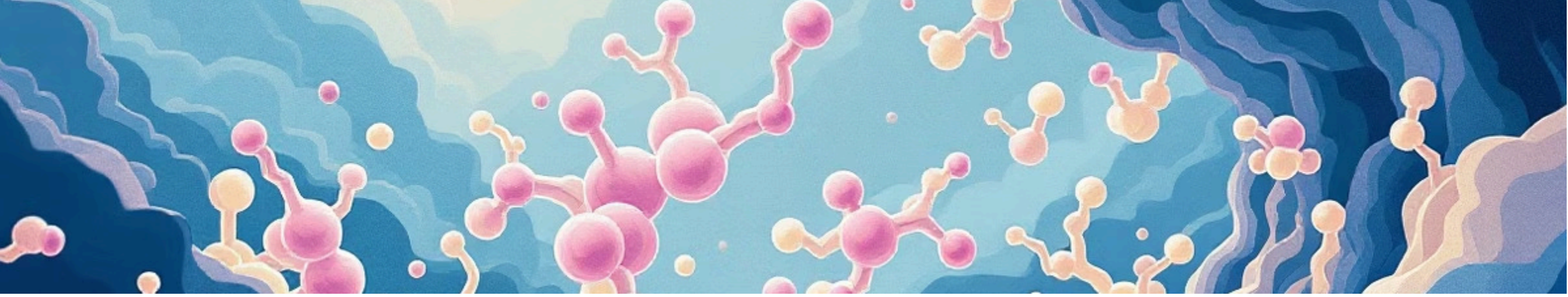
Pyruvate (from amino acid deamination and lactate), glycerol (from triglyceride breakdown), and certain amino acids feed into the pathway.

Reverse Glycolysis (Mostly)

Seven of ten glycolytic steps are reversed; three key gluconeogenic enzymes bypass irreversible glycolytic steps.

Energy Cost

Synthesis requires 4 ATP and 2 GTP per glucose—more expensive than glycolysis but essential for maintaining glucose homeostasis.



Glycogen Metabolism: Storage and Release

Glycogen serves as the body's carbohydrate reservoir, providing rapid glucose access during fasting or intense activity. The liver maintains blood glucose; muscle glycogen fuels local contraction.

Glycogenolysis (Release)

Phosphorylase cleaves glucose units from branch points; debranching enzyme removes α-1,6 branches. Glucose-1-phosphate is converted to free glucose (liver) or used directly (muscle).

Glycogenesis (Storage)

Glucose-6-phosphate is converted through multiple enzymatic steps into glucose units, which are linked by α-1,4 and α-1,6 glycosidic bonds, forming a highly branched polymer optimised for rapid mobilisation.

Regulation of Carbohydrate Metabolism: Hormonal Control

Hormones orchestrate carbohydrate metabolism, matching energy supply with cellular demand. Insulin favours storage and oxidation; glucagon and adrenaline mobilise glucose during stress or fasting.

Insulin (Fed State)

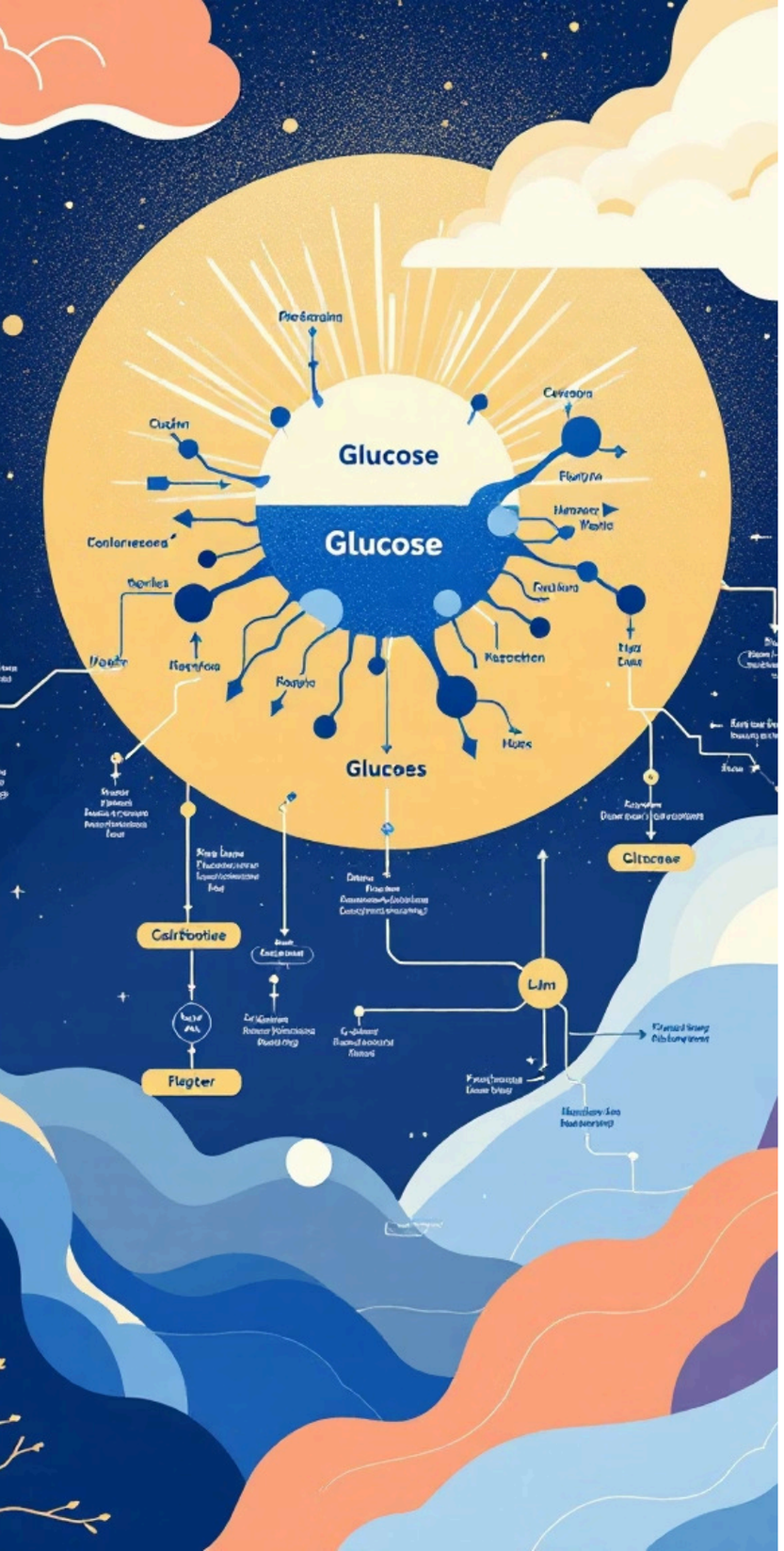
Promotes glucose uptake, glycolysis, and glycogenesis. Inhibits gluconeogenesis and glycogenolysis. Signals cellular abundance.

Glucagon (Fasting)

Stimulates glycogenolysis and gluconeogenesis. Raises blood glucose. Counters insulin's effects.

Adrenaline (Stress)

Rapidly mobilises glucose and fatty acids. Activates muscle glycogenolysis and hepatic glucose release for fight-or-flight response.



Conclusion: Carbohydrate Metabolism in Health and Disease

Carbohydrate metabolism is fundamental to life, seamlessly integrating energy production, storage, and biosynthesis. Dysregulation of these pathways underlies metabolic diseases including diabetes and obesity, whilst optimising metabolism is essential for athletic performance and longevity.

Clinical Relevance

Type 2 diabetes involves impaired insulin signalling and gluconeogenesis dysregulation. Understanding these mechanisms informs therapeutic strategies.

Future Directions

Research into metabolic flexibility, mitochondrial biogenesis, and epigenetic regulation continues to reveal therapeutic opportunities for metabolic disease.

Key Takeaway

Carbohydrate metabolism represents evolution's elegant solution to energy management—from glucose's first phosphorylation to ATP synthesis, every step is optimised for cellular survival.