

MICROBIAL BIOCHEMISTRY
3rd Year Licence — Biotechnology and health

Chapter I

Definitions: Metabolism and Metabolic Pathways

Learning objectives

By the end of this chapter, students should be able to:

- Define metabolism, catabolism, anabolism and intermediary metabolism, and correctly relate these terms to one another.
- Explain why a non-growing (stationary-phase) cell still requires a continuous supply of energy.
- Describe the two functions of metabolic pathways (provision of precursors and provision of energy).
- Distinguish the three major stages of nutrient transformation into cell material.
- Explain the difference between a precursor metabolite and a building block, and give examples of each.
- Explain why catabolism and anabolism, although opposite in direction, are functionally and structurally integrated (amphibolic pathways).

1. Why do cells need a continuous supply of energy?

Vegetative (actively multiplying) cells clearly need energy to grow: to duplicate their DNA, synthesize new proteins, and build new membrane and wall material. What is less intuitive for many students is that **cells that are no longer growing still consume energy**. A culture that has entered the *stationary phase* (no net increase in cell number) is not a metabolically inactive population: it must continuously spend energy on

- maintaining the transmembrane ion gradients and membrane potential (proton motive force),
- repairing macromolecular damage (proteins, DNA) caused by normal cellular "wear",
- turning over (degrading and resynthesizing) RNA and some proteins,
- osmoregulation and motility, when applicable.

This baseline energy requirement, independent of growth, is called **maintenance energy** (sometimes: endogenous metabolism, when the cell degrades its own reserve or structural material to obtain it once external nutrients are exhausted). This is the biological justification, often missing from short definitions, for the statement that "energy is required not only during growth but also during the stationary phase".

Common confusion — Stationary phase does not mean "metabolically dormant". Cell number is constant because division rate $\approx$ death rate, but individual cells are still metabolically active

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and energy-dependent; only true dormant forms (e.g., bacterial endospores) approach a genuine metabolic standstill.

2. Definition of metabolism

Metabolism is the sum of all chemical (enzyme-catalysed) reactions occurring inside a living cell. It corresponds to the transformation of substances taken up from the external environment (nutrients) into the energy and molecular components the cell needs to maintain itself and to grow. Metabolism is organized as a network of **metabolic pathways**: ordered sequences of enzymatic reactions in which the product of one reaction becomes the substrate of the next.

3. The two functions of metabolic pathways

Every metabolic pathway, whatever the organism or the specific molecules involved, ultimately serves one (or both) of two purposes:

1. **Providing precursors** for the synthesis of cellular components (building blocks such as amino acids, nucleotides, sugars, fatty acids).
2. **Supplying energy** (in the chemical form of ATP, and reducing power such as NADH/NADPH) for biosynthesis and for other energy-requiring cellular processes (transport, motility, maintenance).

Common confusion — In reality, catabolic/central pathways (e.g. glycolysis, the TCA cycle) do both jobs simultaneously: several of their intermediates are drawn off as precursor metabolites for anabolism, while the rest of the flux continues on to generate ATP and NADH. Catabolism is therefore not "wasted" once energy is made — it is the same pathway that also feeds anabolism.

4. The three major stages in the transformation of nutrients

Starting from simple nutrients (glucose, fatty acids, amino acids, and even aromatic compounds in some bacteria), the transformation of matter inside the cell proceeds through three conceptually distinct stages:

1. **Stage I — Degradation (catabolism stricto sensu)**: large nutrient molecules (or polymers taken up and hydrolysed) are broken down into a limited number of simple fragments.
2. **Stage II — Intermediary metabolism**: these fragments are further converted, via central pathways (glycolysis, the pentose phosphate pathway, the TCA cycle...), into a small, common set of organic acids and phosphate esters — the *precursor metabolites* — while simultaneously releasing energy (ATP) and reducing power (NADH).
3. **Stage III — Biosynthesis (anabolism)**: the precursor metabolites are used, at the expense of ATP and NADPH, to build the monomeric "building blocks" of the cell, which are then polymerised into macromolecules.

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Stages I and II together correspond to **catabolism** (in the broad sense, including intermediary metabolism); the two are described as "completely integrated" because their reactions largely share the same central pathways and the same pool of intermediates. Stage III corresponds to **anabolism**.

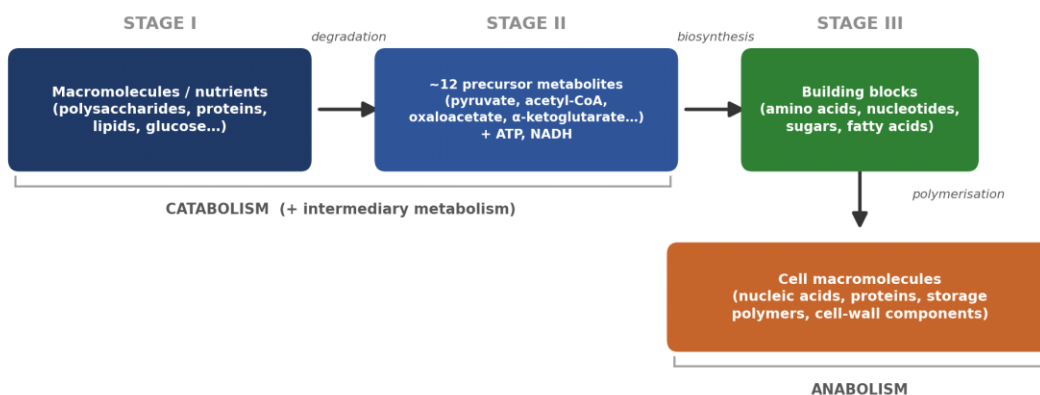


Figure 1. The three major stages in the transformation of nutrients into cell material.

5. Precursor metabolites versus building blocks — a key distinction

These two terms are frequently confused because both are "small molecules", but they belong to two different stages of metabolism:

	Precursor metabolites	Building blocks
Origin	Direct products of central catabolic/intermediary pathways	Synthesized FROM precursor metabolites, using ATP and NADPH.
Examples	Glucose-6-P, pyruvate, acetyl-CoA, oxaloacetate, α-ketoglutarate, succinyl-CoA, phosphoenolpyruvate...	Amino acids, nucleotides, monosaccharides, fatty acids
Role	Branch points feeding anabolic pathways (or continuing to be oxidised for energy)	Monomers polymerised into macromolecules
Number	A small, conserved set (about 12 in most bacteria)	Dozens of distinct molecules (20 amino acids, several nucleotides, sugars, fatty acids...)

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6. From building blocks to cellular macromolecules

The building blocks produced in Stage III are polymerised into the macromolecules that give the cell its structure and its catalytic and genetic machinery:

- **Nucleic acids** (DNA, RNA) — built from nucleotides;
- **Proteins** — built from amino acids;
- **Storage compounds** (e.g., glycogen, poly- β -hydroxybutyrate) — built from sugars or acyl units;
- **Cell-wall and membrane components** (peptidoglycan, phospholipids, lipopolysaccharides) — built from sugars, amino acids and fatty acids.

This synthesis of building blocks (Stage III, first phase) followed by their polymerisation into macromolecules (second phase) together constitute **biosynthetic metabolism**, or **anabolism**.

7. Integration between catabolism and anabolism

Although catabolism and anabolism run in opposite chemical directions (degradation versus synthesis), they are not two separate, independent networks. They are tightly coupled through:

- **Shared intermediates:** several central pathways (most notably the TCA cycle) are used simultaneously for energy production and for supplying biosynthetic precursors — such dual-purpose pathways are called *amphibolic* pathways.
- **Energy transfer:** ATP and reducing power generated by catabolism are consumed by anabolism; the cell maintains a dynamic balance between the two.
- **Distinct reducing cofactors:** catabolism typically generates NADH (channelled toward ATP synthesis via the respiratory chain), whereas anabolism typically consumes NADPH (a distinct cofactor pool dedicated to biosynthesis). This NADH/NADPH separation is a frequent point of confusion, since both are "reduced cofactors" but are largely used in opposite metabolic directions.

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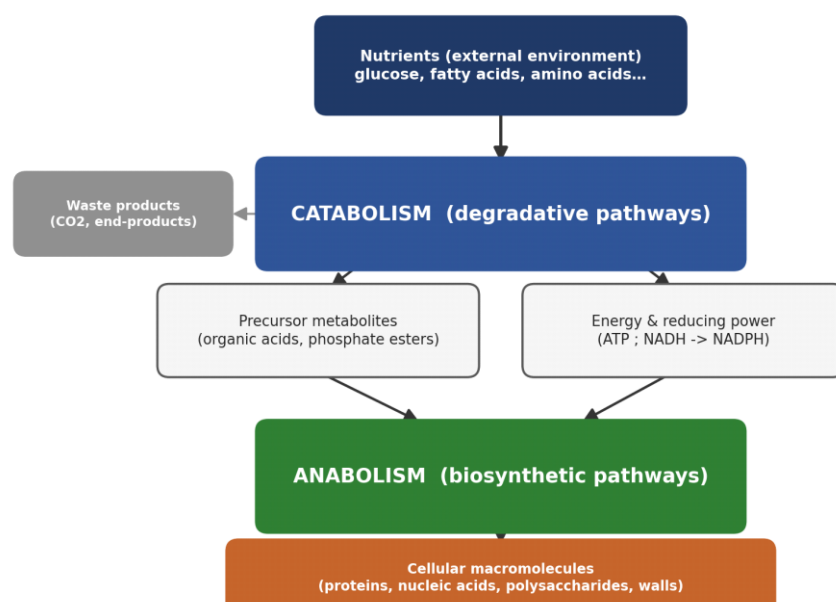


Figure 2. Integration between catabolism and anabolism in the bacterial cell.

Common confusion — Catabolism and anabolism are sometimes taught as if they were simply "the reverse of each other" (like combustion versus photosynthesis). In practice, the enzymes and even some of the intermediate steps differ between the catabolic and anabolic versions of a pathway (e.g., glycolysis versus gluconeogenesis), specifically so that the cell can regulate the two directions independently and avoid a wasteful "futile cycle".

Term	Definition	Key example(s)
Metabolism	Sum of all enzymatic reactions transforming matter and energy in the cell	—
Catabolism	Degradative pathways releasing energy and producing precursor metabolites	Glycolysis, TCA cycle, β -oxidation
Intermediary metabolism	Central pathways converting simple fragments into the common pool of precursor metabolites	TCA cycle, pentose phosphate pathway
Anabolism	Biosynthetic pathways building monomers then polymers, consuming ATP and NADPH	Amino acid synthesis, gluconeogenesis, fatty acid synthesis
Maintenance energy	Baseline energy expenditure independent of growth (membrane potential, repair, turnover)	Stationary-phase cells

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