

Review on the Lactose Operon

Microorganisms are capable of controlling the expression of their genes. This regulation allows the cell to adjust its synthesis activities according to its nutritional needs in a changing environment, in order to ensure growth and cell division.

The control of enzyme expression allows for a rapid adjustment of metabolic activities in response to fluctuations in intracellular levels of sugars, amino acids, or nucleotides.

✓ Some enzymes are synthesized **only when their substrates are present** in the cell — these are called **inducible enzymes**.

✓ Other enzymes are synthesized **only when their final product is absent** — these are **repressible enzymes**.

✓ Finally, some enzymes are produced by genes that are **not regulated** and are therefore synthesized continuously, whether their substrate is present or not. These are **constitutive enzymes**. Constitutive enzymes are generally those that the cell constantly needs, such as those involved in glucose metabolism.

In prokaryotes, genes are grouped into functional units called **operons**.

1. Definition of an Operon

An **operon** is a regulatory unit consisting of a group of adjacent genes that are transcribed from a single promoter as a **single (polycistronic) mRNA**, and then translated into several different proteins.

This unit includes:

- **Structural genes (cistrons)**
- One or more **regulatory genes** coding for regulatory proteins
- And **control elements** within the DNA sequence.

There are two main types of operons:

✓ **Inducible operons** – code for enzymes of **catabolic pathways** (breakdown processes).

→ Example: the **lactose operon**.

✓ **Repressible operons** – code for enzymes of **anabolic pathways** (biosynthesis processes).

→ Example: the **tryptophan operon**.

The most illustrative examples of transcriptional regulation are:

- **The lactose operon (inducible enzymes)**
- **The tryptophan operon (repressible enzymes)**

2. Definition of the Lactose Operon

The **lactose operon** (or **lac operon**) is a classical model in bacterial genetics illustrating gene expression regulation.

It is used to study how bacterial cells control protein production in response to environmental conditions — particularly the use of **lactose as an energy source** in *Escherichia coli*.

Below is an explanation of its structure and functioning.

2.1. Structure of the Lactose Operon

The **lac operon** consists of several components:

Structural Genes

These code for enzymes necessary for the breakdown of lactose:

- **lacZ**: codes for **β -galactosidase**, an enzyme that breaks lactose into glucose and galactose.
- **lacY**: codes for **permease**, a membrane protein that facilitates lactose entry into the cell.
- **lacA**: codes for **transacetylase**, an enzyme whose function is less well defined but seems involved in detoxification.

Regulatory Sites

DNA sequences that control the expression of structural genes:

- **Promoter (P)**: binding site for **RNA polymerase** to initiate transcription.
- **Operator (O)**: binding site for the **lac repressor**, a protein that blocks transcription when attached here.

Regulatory Gene (*lacI*)

This gene, located outside the operon, codes for the **lac repressor**, which regulates operon activity.

<https://youtu.be/Eekp-ZPObIg?si=e51skEMDRReBAjt9K>

2.2. Functioning of the Lactose Operon

The **lac operon** functions as an **induction system** that responds to the **presence or absence of lactose**.

a) In the absence of lactose

- The **lac repressor** (encoded by *lacI*) binds to the **operator (O)**.
- This binding blocks **RNA polymerase** from accessing the promoter, preventing transcription of *lacZ*, *lacY*, and *lacA*.
- Consequently, lactose-degrading enzymes are not produced, saving cellular energy and resources.

b) In the presence of lactose

- When lactose is available, a derivative called **allolactose** binds to the **repressor**.
- This binding changes the repressor's shape, preventing it from attaching to the operator.
- **RNA polymerase** can then bind to the promoter and initiate transcription of *lacZ*, *lacY*, and *lacA*.

- The resulting enzymes break down lactose into glucose and galactose, which are used as energy sources.

2.3. Role of Cyclic AMP (cAMP) and the CAP Protein

The **lac operon** is also influenced by the presence of **glucose**, the preferred sugar of bacteria.

When glucose levels are low, **cyclic AMP (cAMP)** levels increase. cAMP binds to a protein called **CAP (Catabolite Activator Protein)**, forming a complex that attaches near the promoter of the lac operon, enhancing transcription.

Thus, when **lactose is present** and **glucose is absent**, the lac operon is activated **optimally**.