16.2C: The lac Operon: An Inducer Operon

The lac operon is an inducible operon that utilizes lactose as an energy source and is activated when glucose is low and lactose is present.

Learning Objectives

• Describe the components of the lac operon and their role in its function

Key Points

• The lac operon contains an operator, promoter, and structural genes that are transcribed together and are under the control of the catabolite activator protein (CAP) or repressor.
• The lac operon is not activated and transcription remains off when the level of glucose is low or non-existent, but lactose is absent.
• The lac operon encodes for the genes needed to utilize lactose as an energy source.

Key Terms

• **operator**: a segment of DNA to which a transcription factor protein binds
• **repressor**: any protein that binds to DNA and thus regulates the expression of genes by decreasing the rate of transcription
The lac Operon: An Inducer Operon

A major type of gene regulation that occurs in prokaryotic cells utilizes and occurs through inducible operons. Inducible operons have proteins that can bind to either activate or repress transcription depending on the local environment and the needs of the cell. The lac operon is a typical inducible operon. As mentioned previously, *E. coli* is able to use other sugars as energy sources when glucose concentrations are low. To do so, the cAMP–CAP protein complex serves as a positive regulator to induce transcription. One such sugar source is lactose. The lac operon encodes the genes necessary to acquire and process the lactose from the local environment, which includes the structural genes lacZ, lacY, and lacA. lacZ encodes β-galactosidase (LacZ), an intracellular enzyme that cleaves the disaccharide lactose into glucose and galactose. lacY encodes β-galactoside permease (LacY), a membrane-bound transport protein that pumps lactose into the cell. lacA encodes β-galactoside transacetylase (LacA), an enzyme that transfers an acetyl group from acetyl-CoA to β-galactosides. Only lacZ and lacY appear to be necessary for lactose catabolism.

CAP binds to the operator sequence upstream of the promoter that initiates transcription of the lac operon. The lac operon uses a two-part control mechanism to ensure that the cell expends energy producing β-galactosidase, β-galactoside permease, and thiogalactoside transacetylase (also known as galactoside O-acetyltransferase) only when necessary. However, for the lac operon to be activated, two conditions must be met. First, the level of glucose must be very low or non-existent. Second, lactose must be present. If glucose is absent, then CAP can bind to the operator sequence to activate transcription. If lactose is absent, then the repressor binds to the operator to prevent transcription. If either of these requirements is met, then transcription remains off. The cell can use lactose as an energy source by producing the enzyme β-galactosidase to digest that lactose into glucose and galactose. Only when both conditions are satisfied is the lac operon transcribed, such as when glucose is absent and lactose is present. This process is beneficial and makes most sense for the cell as it would be energetically wasteful to create the proteins to process lactose if glucose were plentiful or if lactose were not available.
In the absence of lactose, the lac repressor binds the operator, and transcription is blocked.

In the presence of lactose, the lac repressor is released from the operator, and transcription proceeds at a slow rate.

cAMP-CAP complex stimulates RNA polymerase activity and increases RNA synthesis.

However, even in the presence of cAMP-CAP complex, RNA synthesis is blocked when repressor is bound to the operator.

Figure 1\PageIndex{1}: The lac Operon: Transcription of the lac operon is carefully regulated so that its expression only occurs when glucose is limited and lactose is present to serve as an alternative fuel source.

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