9.3B: Cell Signaling and Gene Expression

Gene expression, vital for cells to function properly, is the process of turning on a gene to produce RNA and protein.

Learning Objectives

• Describe the regulation of gene expression

Key Points

• Each cell controls when and how its genes are expressed.
• Malfunctions in the control of gene expression are detrimental to the cell and can lead to the development of many diseases, such as cancer.
• In prokaryotic cells, the control of gene expression is mostly at the transcriptional level.
• In eukaryotic cells, the control of gene expression is at the epigenetic, transcriptional, post-transcriptional, translational, and post-translational levels.

Key Terms

• translation: a process occurring in the ribosome in which a strand of messenger RNA (mRNA) guides assembly of a sequence of amino acids to make a protein
• gene expression: the transcription and translation of a gene into messenger RNA and, thus, into a protein
• transcription: the synthesis of RNA under the direction of DNA
Gene Expression

For a cell to function properly, necessary proteins must be synthesized at the proper time. All cells control or regulate the synthesis of proteins from information encoded in their DNA. The process of turning on a gene to produce RNA and protein is called gene expression.

Whether in a simple unicellular organism or a complex multi-cellular organism, each cell controls when and how its genes are expressed. For this to occur, there must be a mechanism to control when a gene is expressed to make RNA and protein; how much of the protein is made; and when it is time to stop making that protein because it is no longer needed. The regulation of gene expression conserves energy and space. It would require a significant amount of energy for an organism to express every gene at all times, so it is more energy efficient to turn on the genes only when they are required. In addition, only expressing a subset of genes in each cell saves space because DNA must be unwound from its tightly-coiled structure to transcribe and translate the DNA. Cells would have to be enormous if every protein were expressed in every cell all the time. The control of gene expression is extremely complex. Malfunctions in this process are detrimental to the cell and can lead to the development of many diseases, including cancer.

Prokaryotic versus Eukaryotic Gene Expression

To understand how gene expression is regulated, we must first understand how a gene codes for a functional protein in a cell. The process occurs in both prokaryotic and eukaryotic cells, just in slightly different manners. Prokaryotic organisms are single-celled organisms that lack a cell nucleus; their DNA floats freely in the cell cytoplasm. To synthesize a protein, the processes of transcription and translation occur almost simultaneously. When the resulting protein is no longer needed, transcription stops. As a result, the primary method to control what type of protein and how much of each protein is expressed in a prokaryotic cell is the regulation of DNA transcription. All of the subsequent steps occur automatically. When more protein is required, more transcription occurs. Therefore, in prokaryotic cells, the control of gene expression is mostly at the transcriptional level.

Eukaryotic cells, in contrast, have intracellular organelles that add to their complexity. In eukaryotic cells, the DNA is contained inside the cell’s nucleus where it is transcribed into RNA. The newly-synthesized RNA is then transported out of the nucleus into the cytoplasm where ribosomes translate the RNA into protein. The processes of transcription and translation are physically separated by the nuclear membrane: transcription occurs only within the nucleus, and translation occurs only outside the nucleus in the cytoplasm. The regulation of gene expression can occur at all stages.
of the process. Regulation may occur when the DNA is uncoiled and loosened from nucleosomes to bind transcription factors (epigenetic level); when the RNA is transcribed (transcriptional level); when the RNA is processed and exported to the cytoplasm after it is transcribed (post-transcriptional level); when the RNA is translated into protein (translational level); or after the protein has been made (post-translational level).