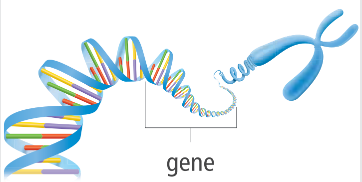
Regulating Gene Expression

Most of the cells that make up your body have the same DNA. Red blood cells are one of the exceptions. Mature red blood cells do not contain DNA. However, the rest of your body cells, such as all the different cell types that make up each of your organs, have the same DNA. If they have the same DNA, how can these cells be so different from each other? The answer lies in the fact that some genes, and the proteins they encode, control the expression of other genes.

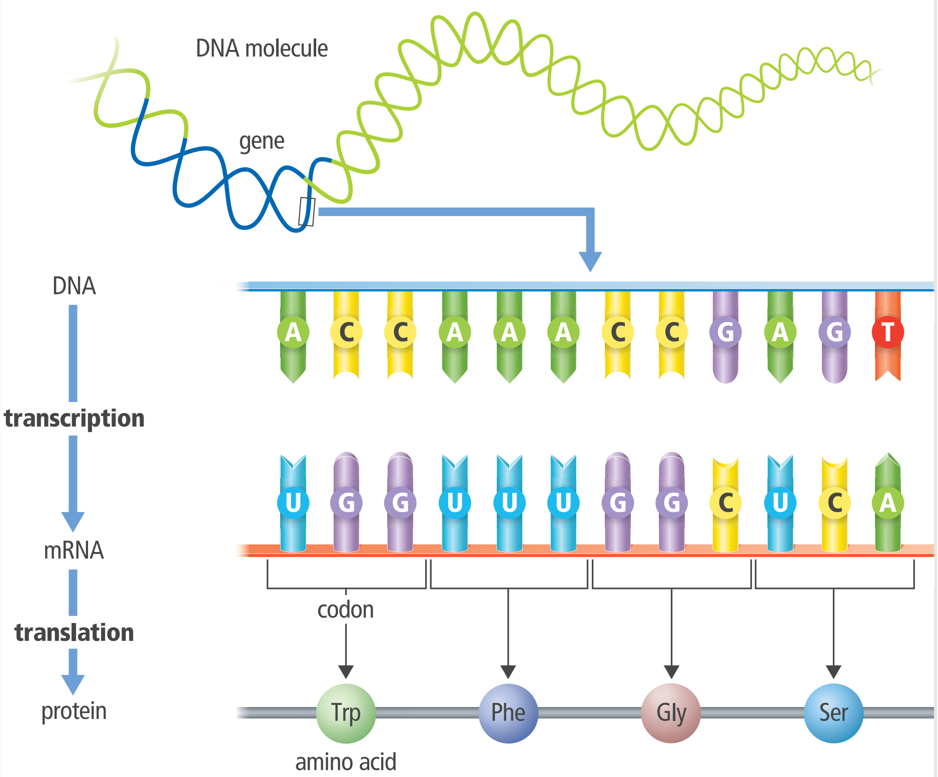
FIGURE 2: Every gene has a locus, or specific position on a chromosome.



Gene Expression

Typically, a gene is considered "expressed" if transcription of mRNA occurs. However, the mRNA can undergo modification or be broken down before it is translated into a protein. Gene expression is the process by which the nucleotide sequence of a gene directs protein synthesis. In this way, cells use protein synthesis to respond to particular needs and react to changes in their environment.

FIGURE 3: Protein Synthesis in Prokaryotes and Eukaryotes



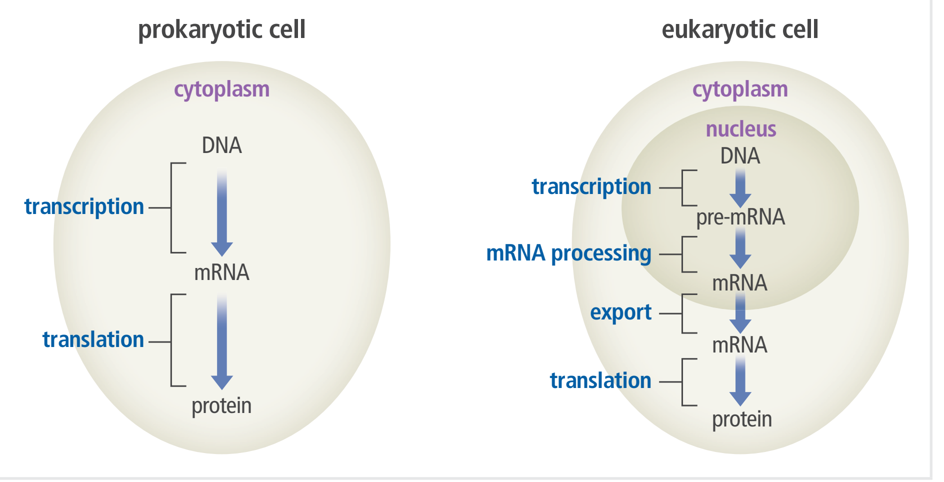
Explain How are genes, proteins, and cell processes related?

Collaborate With a partner, discuss these questions: What does the term "expression" mean in everyday language? How does the meaning of this word relate to the concept of gene expression?

According to the central dogma of molecular biology, information flows in one direction from DNA to RNA to proteins. This means there are multiple steps along the way where protein synthesis can be regulated, or controlled.

Both prokaryotic cells and eukaryotic cells regulate gene expression, though they do so differently. In eukaryotes, gene expression is regulated at many different steps. In contrast, the ability of prokaryotes to regulate gene expression is much simpler.

FIGURE 4: In prokaryotic cells, transcription and translation both occur in the cytoplasm at about the same time. In eukaryotic cells, where DNA is located inside the nucleus, these processes are separated both in location and time.



Structure and Function Use the model in Figure 4 to write an explanation for how differences in cell structure are related to the differences in the ways gene expression is regulated in prokaryotic and eukaryotic cells.

Gene Regulation in Prokaryotes

Because transcription and translation occur at the same time in prokaryotic cells, gene expression in these cells is mainly regulated at the start of transcription. Prokaryotic cells control gene expression using operons to turn genes "on" or "off" during transcription. An operon is a region of DNA that includes a promoter, an operator, and one or more structural genes that code for all the proteins needed to do a specific task. The promoter is a segment of DNA that helps the enzyme RNA polymerase locate the starting point for transcription.

Analyze What might be the benefit of turning genes on and off?

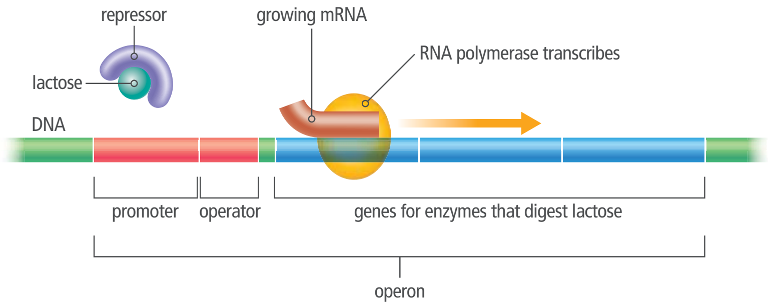
The DNA segment that actually turns genes on or off is the operator. It interacts with proteins that increase the rate of transcription or block transcription from occurring. Bacteria have much less DNA than do eukaryotes, and their genes tend to be organized into operons. The *lac* operon was one of the earliest examples of gene regulation discovered in bacteria. The *lac* operon has three genes, which all code for enzymes that play a role in breaking down the sugar lactose.

Gather Evidence As you read, record information to help you construct an explanation for how prokaryotes respond to changes in their environment by controlling gene expression.

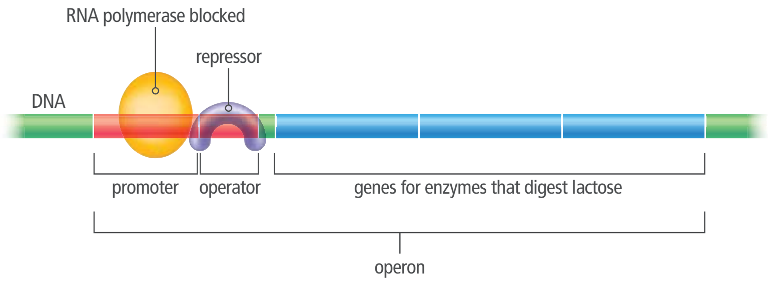
The ability of a cell to switch certain genes on or off was first discovered in 1961 by French scientists François Jacob and Jacques Monod. This major advance in our understanding of how genes work began with a study of how genes control lactose metabolism in the bacterium *Escherichia coli*. Jacob and Monod observed that the genes responsible for lactose metabolism were expressed only in the presence of lactose. When lactose was not present, the genes were shut off. Their questioning of how this happened led to the discovery of the *lac* operon. Scientists now had a basis for understanding how specific genes can be turned on when needed and turned off when not needed.

FIGURE 5: Gene Regulation in Prokaryotes

Explore Online



a When lactose is present, the lactose molecules strip away the repressor, which lets RNA polymerase attach to the promoter and complete the transcription process.



b When lactose is absent, the repressor protein binds to the operator and prevents RNA polymerase from transcribing the structural genes that code for proteins.

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Hands-On Activity

Modeling Prokaryotic Operons Build a model of the *lac* operon. Then use your model to show how gene expression is regulated in prokaryotes.

The *lac* operon acts like a switch. When lactose is present, the *lac* operon is switched on to allow transcription. The lactose binds to the repressor, which makes the repressor change shape and fall off the *lac* operon. RNA polymerase is able to transcribe the DNA into RNA. This RNA is translated to form enzymes that work together to break down the lactose.

When lactose is absent, the *lac* operon is switched off to prevent transcription of the *lac* genes, thus saving the cell's resources. Bacteria have a protein that can bind specifically to the operator. When lactose is absent, the protein binds to the operator, which blocks RNA polymerase from transcribing the genes. Because the protein blocks—or represses—transcription, it is called a repressor protein.

Language Arts Connection Make an informational guide explaining how the *lac* operon helps prokaryotes respond to changes in their environment. In your guide, explain the functions of the gene, promoter, operator, repressor, and RNA polymerase.

Model Imagine a bacterium has a mutated gene which codes for a malformed repressor protein. Draw a flow chart to show how this mutation would affect the bacterium's ability to digest lactose.