Gene Switches

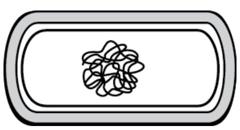
Introduction

Bacteria need to be very efficient and only produce specific proteins when they are needed. Making proteins that are not needed for "everyday" cell metabolism wastes energy and raw materials. Bacteria prevent resources (energy and raw materials) from being wasted by switching genes off when the proteins they produce are not needed. Genes for proteins that are only needed under certain conditions are regulated by "on-off switches."

Genes are switched ON when the proteins that they produce are needed

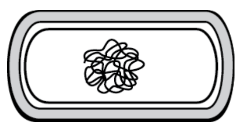
Genes are switched OFF when the proteins that they produce are not needed.

The diagrams below show three different types of bacteria (A, B, and C):



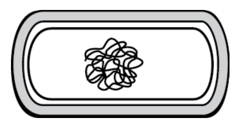
A

All genes are turned on to make all proteins



B

All genes are turned off to prevent protein production



C

Some genes are turned on and others are turned off

1. Which of the three types of bacteria cells in the diagram above (A, B, or C) is most likely to survive and reproduce efficiently? Provide an explanation for your answer.

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2. Some genes are <u>not</u> regulated by gene switches. These genes are expressed constantly. What kinds of genes would be expressed constantly?

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3. Other genes are regulated by gene switches that turn them on or off. What kinds of genes would be regulated by gene switches?

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Part 1: Modeling a Gene Switch in Bacteria

Use the information in the **Operons: Gene Switches in Bacteria** sheet and materials in your kit to make a model of a bacterial chromosome with an operon that regulates the production of enzymes.

1. Apply labels to the straw pieces to represent DNA segments in an operon. The labels should be applied so they wrap around the straws as shown in the diagram below.

   - Black straw piece – **Promoter** label
   - Red straw piece – **Operator** label
   - 4 Clear straw pieces
     - **Lactase Gene** label
     - **Permease Gene** label
     - **Transacetylase Gene** label
     - **Regulator Gene** label

2. Use information in the **Operons: Gene Switches in Bacteria** sheet to make a model of an operon. Thread the chenille stem through the labeled straw pieces to arrange them in the proper order to represent the DNA segments in an operon.

3. What genes are included in an operon?

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4. What is the function of an operon?

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5. Briefly describe the role of the following structures in gene regulation:

- Regulator Gene

- Operator

- Promoter

- Structural Genes

Part 2: Modeling the Function of the Lac Operon

One example of an operon is the **lac operon** that regulates genes that produce enzymes involved in lactose metabolism. Bacteria normally rely on glucose in their environment as a food source. However, if glucose is not available and lactose (a disaccharide) is present in the environment, bacteria can survive by switching on the genes that allow them to use lactose as a food source. The structural genes in the lac operon contain the DNA code that produces three proteins. These three proteins are enzymes involved in lactose metabolism:

- Lactase (also called beta-galactosidase) - This enzyme digests lactose to form glucose and galactose
- Permease - This enzyme allows lactose to enter the cell.
- Transacetylase - The function of this enzyme is not known.

<u>When lactose is absent:</u>
A repressor protein attaches to the operator to block the transcription of the lac operon's structural genes. This switches genes in the lac operon OFF. The structural genes that produce the three enzymes (lactase, permease, and transacetylase) which enable bacteria to use lactose as a food source are not produced.

<u>When lactose is present:</u>
The lactose molecule acts as inducer that changes the shape of the repressor protein so that it cannot bind to the operator. This switches genes in the lac operon ON. The three enzymes (lactase, permease, and transacetylase) are produced, which enable bacteria to use lactose as a food source.

1. In the lac operon, a repressor protein has the proper shape that allows it to attach to the operator. Place the repressor protein (hair clip) over the operator gene to represent an active repressor protein that blocks the movement of the RNA polymerase.

2. Apply the **RNA polymerase** label to the yellow plastic car.
   Hint: To make the label fit the car, you will need to cut out just the yellow part of the label and apply it to the top of the car, or you can wrap the entire label around the top of the car.

3. Place the RNA polymerase (yellow plastic car) on the promoter to represent the action of RNA polymerase.

4. Note that the repressor protein blocks the movement of the RNA polymerase (yellow car) along the DNA strand. The operon is turned off and the structural genes cannot be expressed.

5. In the space below, draw your model to show what happens when the lac operon is turned OFF. Include and label a regulator gene, a promoter, an operator, three structural genes (lactase gene, permease gene, transacetylase gene), an RNA polymerase, and a repressor protein in your diagram.

6. Explain how the lac operon is turned OFF when lactose is <u>not</u> present.

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7. When lactose is present, it acts as an <u>inducer</u> by attaching to the repressor protein. This changes the shape of the repressor protein so that it cannot bind to the operator.
   - Attach a "Lactose" label to your hand. Lactose changes the shape of the repressor protein so that it cannot attach to the operator. Use your fingers to open the hair clip and remove it from the operator.

8. Place the RNA polymerase (yellow car) on the operator.

9. With the repressor protein removed, the RNA polymerase can move along the structural genes and transcribe them to make a messenger RNA molecule. Move the RNA polymerase (yellow car) along the structural genes to transcribe them.

10. Transcription creates a long messenger RNA molecule. Place a yellow twist tie below the structural genes to represent the messenger RNA produced by transcription of the structural genes.

11. Ribosomes then use the coded information in the messenger RNA to create proteins. Attach three ribosomes (black beads) to the messenger RNA (twist tie).

12. Place three plastic objects below the messenger RNA to represent the enzymes produced when the ribosomes translate the messenger RNA.

- Sword = Lactase—digests lactose to form glucose and galactose
- Ring = Permease—allows lactose to enter the cell
- Cube = Transacetylase—function not known

13. In the space below, draw your model to show what happens when the lac operon is turned ON. Include and label a regulator gene, a promoter, an operator, three structural genes (lactase gene, permease gene, transacetylase gene), an RNA polymerase, and a repressor protein in your diagram. Also include and label a lactose molecule, an RNA molecule, ribosomes, a lactase enzyme, a permease enzyme, and a transacetylase enzyme.

14. Explain how the lac operon is turned ON when lactose molecules are present.

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15. One weakness of this model is the fact that it does not represent the action of the lactase molecule. If the model was more accurate, the lactase (sword) would ____________________ the lactose (your hand).

16. What is the advantage to having one promoter and one operator associated with three structural genes that produce lactose metabolizing enzymes?

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17. What would happen if the positions of the promoter and operator were reversed?

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18. How might the following mutations in the lac operon affect bacterial metabolism? Be specific and explain your answer.

- A mutation in the promoter

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- A mutation in the operator

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- A mutation in one of the structural genes

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- A mutation in the regulator gene that produces the repressor protein

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