Signal Transduction Pathways

What happens inside of a cell when a signal has been received?

Why?

When cells release signal molecules (ligands) to send a message, and the message is received, a whole host of events take place inside the cell. The ultimate goal is a response—a gene is turned on, a protein is manufactured, an enzyme is activated, the cell divides or dies, etc. There are many responses that could occur, but the pathways to those responses are very similar.

Model 1 – Basic Signal Transduction Pathway

1. According to Model 1, does the signal transduction pathway occur inside or outside of a cell?
   *Inside.*

2. Compare the shape of the ligand in Model 1 to the shape of the receptor protein.
   *The shapes of the ligand and receptor proteins are compatible so the ligand will fit into the active site on the receptor protein.*

3. The four steps in the signal transduction pathway are listed below. Label the diagram above with the Roman numerals to indicate where on the diagram each step is taking place.
   - I. Signaling
   - II. Reception
   - III. Transduction
   - IV. Response

   *See Model 1.*
4. Based on the diagram in Model 1 and your labels, propose a definition for “transduction” in the context of the signal transduction pathway.

*The signal gets moved through the cell to the location where the response will occur.*

5. Amplification often occurs during the transduction step in the signal transduction pathway.
   a. Define “amplification” as it is used in everyday language.
   
   *Amplification is to make larger.*
   
   b. Explain how the signal in Model 1 was amplified.
   
   *One relay protein was able to activate several relay proteins, each of which caused a response.*

6. List several possible responses that could occur due to a signal being received by a cell. *(Hint: There are several listed in the Why? box.)*

   *A protein is produced, a gene is turned on, a protein channel is opened, a cell divides or dies.*

7. Once the response is achieved in a cell, what would need to occur to stop the response?

   *The activated relay proteins would need to be deactivated.*

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**Read This!**

Signal transduction pathways are as varied as the species on Earth, but each of them follow the same basic steps. Reception may occur by the ligand attaching to a receptor protein or the ligand may travel through the cell membrane by diffusion. Transduction may occur by one protein or by several proteins activating each other in a cascade. Keep this in mind as you continue working through this activity.
8. Refer to Model 2. Describe the event that sets off a phosphorylation cascade inside of a cell.

*A ligand attached to an active site in a receptor protein in a cell membrane.*

9. **Phosphorylation** is a process that adds a phosphate group onto a protein to "activate" it—that is, to change its shape enough that it can function properly.

   a. Which step(s) in the phosphorylation cascade illustrated in Model 2 include phosphorylation?

      *Steps 4, 5, and 7.*

   b. Where do the phosphate groups come from that are added to the proteins during phosphorylation?

      *The phosphate group comes from an ATP molecule that converts to ADP.*

10. According to Model 2, what class of enzymes performs phosphorylation?

    *Kinases.*

11. Identify the steps in Model 2 that represent reception, transduction, and response for the phosphorylation pathway.

    **Reception**
    
    *Step 1*
    
    **Transduction**
    
    *Steps 2, 3, 4, 5, and 6*
    
    **Response**
    
    *Step 7*
12. What is the cell's response to the signal received in Model 2?

*Transcription of a segment of DNA is started.*

13. In Model 2, steps 3, 4, and 5 are shown as amplification steps. Describe what that means in terms of this signal transduction pathway example.

*Each kinase can activate more than one of the next kinase enzymes in the sequence.*

14. What advantage would there be to an organism if the signal transduction pathway had several amplification steps?

*Amplification would allow the reception of a single ligand to cause a response in several places in the cell. This allows an organism to respond to a stimulus faster.*

15. Describe what would occur in the cell if the activated protein kinase enzymes continued to be active for a long period of time.

*The transcription factor would continue to transcribe the DNA strand as long as the protein kinases were active.*

16. What would need to occur in the cell to deactivate the protein kinase enzymes?

*The phosphate groups would need to be removed.*

17. Protein phosphatases are enzymes that remove phosphate groups from proteins. Complete the illustration in Model 2 by adding at least two protein phosphatases (PP) to show how the cell is returned to inactive status.

*See Model 2. Answers may vary, but students should show arrows from an active kinase 2 or active kinase 3 to an inactive kinase 2 or 3 (respectively).*

18. Although signal transduction pathways vary among species, there are several common elements. Explain how a biologist might use details about signal transduction pathways used in different species as evidence for evolutionary relatedness.

*Species that use the same ligands, receptor proteins, and relay proteins are probably closely related by evolution.*
19. Consider the signal transduction pathway in Model 3. What event begins the process of producing a cellular response?

A ligand attached to the active site of a receptor protein molecule.

20. Locate the secondary messenger molecules in Model 3.

a. Describe the type of diffusion that is used to get the secondary messengers into the cell.

Facilitated diffusion.

b. What activates or opens the transport protein channel that allows the secondary messengers to enter the cell?

The membrane channel is opened by the activated relay protein, which attaches to an active site on the transport protein.
Read This!

Relay molecules and secondary messengers have essentially the same jobs in signal transduction pathways. However, relay molecules are almost always proteins that require activation. They are large and do not diffuse through the cell quickly. Secondary messengers on the other hand are small, water soluble molecules that can diffuse quickly. They may or may not need activation before they are able to move the signal on to the next step in the process. Cyclic AMP (cAMP) and calcium ions (Ca^{2+}) are common secondary messengers in human systems.

21. Within an organism it is critical that signals between cells are very specific. For example, if ligand A is meant to activate immune system cells to reproduce in response to an infection, it should not also cause other cells to grow as if they had received a growth hormone. When a ligand is released, what prevents all of the cells in the body from being affected?

The corresponding shape of the ligand and the receptor allows for specificity. For example, receptors for ligand A would only be found on the target immune system cells and not on cardiac muscle cells or skin epithelial cells. Thus, even though the cardiac muscle cells or skin epithelial cells would be exposed to ligand A, they would not be able to bind to it and therefore could not react to it.