AP BIOLOGY · UNIT 4 · TOPIC 4.3

Signal Transduction Pathways

Learning objective 4.3.A Explain how signal transduction pathways amplify cellular responses.

Name: Date: Period:

Use the tool **One Signal, Many Copies**. Parts 1 and 2 use **The cascade**, Part 3 uses **What a phosphate does** and Part 4 uses **Break it two ways**. This topic includes calculations, so show your work each time a question asks for a number.

Part 1 · Count the cascade

Set the Each step activates and Number of steps sliders to each combination below. Write the calculation in the third column, and record the Molecules at the end readout in the fourth.

Each step activates	Steps	Calculation	Molecules at the end
10	2		
10	4		
10	6		
20	4		
100	4		

1. Using the Part 1 table, determine an equation for the number of molecules activated at the end of a cascade, in terms of the number that each step activates and the number of steps.

2. In the cascade diagram, the top two rows show one signaling molecule and one activated receptor. Explain why no amplification occurs at the receptor.

Part 2 · Which slider matters more?

Before you press anything, predict which change will give the larger response. Then press Reset, press **Double what each step activates** and record the result. Press Reset again, press **Add two steps instead**, and record that result.

Change	Each step activates	Steps	Molecules at the end	How many times the starting value
Starting point	10	4		1×
Double what each step activates				
Add two steps				

3. (a) Identify the change that produced the larger response.

(b) Explain why this change has the larger effect. In your answer, refer to where each number appears in the equation from question 1.

4. Hormones circulate in the blood at very low concentrations. Explain why amplification is important for a cell's response to a hormone.

Part 3 · What a phosphate does

Switch to **What a phosphate does**. It opens on the first step, Inactive protein. Press Next step to move through the other three steps, and record all four readouts at each step.

Step	Phosphate attached?	Protein active?	Protein molecules	Back where it started?
Inactive protein				
A kinase adds a phosphate				
The active protein does its job				
A phosphatase removes the phosphate				

5. (a) Identify the column of the Part 3 table that is the same in all four rows.

(b) Explain what this result shows about how a cell amplifies a signal.

6. (a) Describe what a kinase does to a protein.

(b) Explain how this changes the activity of the protein.

7. A phosphatase removes the phosphate group from a protein. Explain why a cell needs phosphatases as well as kinases.

Part 4 · Two ways to break a pathway

Switch to **Break it two ways**. Before you start, go back to The cascade tab and press Reset, because this tab uses the cascade's settings (each step activates 10 molecules, over 4 steps). Then select each of the three cells in turn and record the Response with signal, Response with no signal and Behaving correctly? readouts.

Cell	Response with the signal	Response with no signal	Behaving correctly?
Working normally			
A relay enzyme cannot be activated			
A relay enzyme is stuck in its active shape			

8. Two of the cells in the Part 4 table are faulty, in opposite directions.
(a) Describe the effect of the fault in the cell in which a relay enzyme cannot be activated.

(b) Describe the effect of the fault in the cell in which a relay enzyme is stuck in its active shape.

9. A patient produces a normal amount of a hormone, but the patient's cells do not respond to it. Explain why giving the patient more of the hormone might not restore the response.

10. A mutation locks a relay protein in a pathway that signals cell division permanently in its active form.
(a) Predict the effect of the mutation on the cell when no signal is present.

(b) Explain how this mutation could contribute to the formation of a tumor.

What the model simplifies

Every step is given the same gain. In a real cascade the gain differs from step to step, and some steps have a gain close to one and exist to regulate rather than to amplify.

The horizontal axis of the cascade diagram is logarithmic, because a linear axis cannot show one molecule and a hundred million on the same picture. Each equal step along it is a ten-fold increase, so the bars are shorter than the numbers feel.

The course framework does not require the individual enzymes or intermediates of any named pathway, so this tool counts molecules and tests dependencies rather than naming them. Phosphorylation is the mechanism the framework does expect you to be able to describe.

Activation is drawn as instantaneous and complete. Real cascades take seconds, do not activate every available molecule, and are being switched off by phosphatases the whole time they are switching on, so the final number is a ceiling rather than a measurement.