

## Cooling Rates

ID: 8546

Name \_\_\_\_\_

Class \_\_\_\_\_

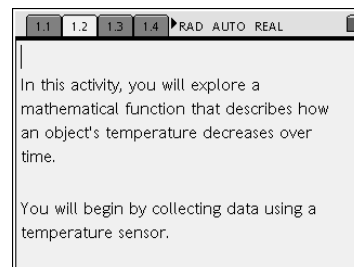
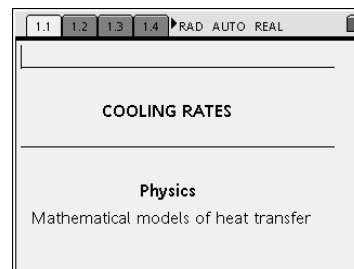
In this activity, you will explore the following:

- how the temperature of an object decreases with time
- how to make a mathematical model of a physical phenomenon

Open the file **PhyAct01\_cooling\_EN.tns** on your handheld or computer and follow along with your teacher for the first two pages. Move to page 1.2 and wait for further instructions from your teacher.

You know that a hot object will cool off if you place it in a cool place. Eventually, the object and the room reach thermal equilibrium—that is, their temperatures become equal. The rate at which an object cools off is related to the difference in temperature between the object and the room; the greater the temperature difference, the faster the object will cool.

In this activity, you will collect temperature data for a cooling metal sensor. Then, you will attempt to fit an equation to the data you collect. Finally, you will explore the relationship between cooling rate and temperature difference.



### Part 1: Collecting temperature data

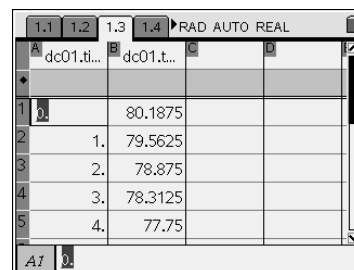
**Step 1:** Move to page 1.3. Put on a pair of safety goggles. Connect a Vernier EasyTemp™ or Go!™Temp temperature sensor to your handheld or computer. The light on the sensor should come on, and a data collection display should appear on the screen. Wait until the temperature reading stabilizes. This is the ambient (room) temperature.

**Q1.** What is the ambient temperature?

**Step 2:** Your teacher will give you a container of boiling water.

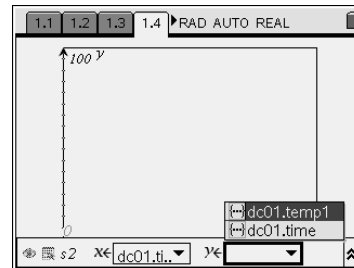
**CAUTION:** Be very careful handling the boiling water. Make sure your work area is clear, and be careful not to spill the water. Place the end of the temperature sensor into the boiling water. Watch the temperature readout until it has stabilized. (Note: The temperature will probably not reach 100°C.)

**Step 3:** Remove the sensor from the boiling water and wipe it off with a paper towel. Immediately after you wipe the water off the sensor, click the ► button to start the data collection. Data collection will continue for three minutes. During this time, the sensor will record one data point each second. After three minutes, close the temperature-reading box to stop the data collection. (Note: The temperature reading in the box will continue to change even after data collection has stopped. The ► symbol will reappear when data collection has finished.)



**Step 4:** After you have closed the data collection box, you can disconnect the temperature sensor. Your teacher will collect the boiling water. Move to page 1.4, which contains a *Graphs & Geometry* application. Make a scatter plot of the data you just collected. Use the time data for your x-values and the temperature data for your y-values.

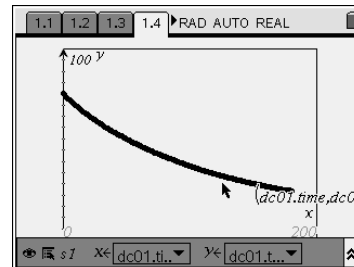
**Q2.** Describe the shape of the graph.



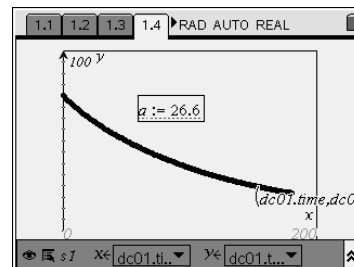
### Part 2: Fitting a curve to the data

**Step 1:** The shape of the graph should be consistent with an exponential function of the form  $y = a + b \cdot c^x$ . In this case,  $y$  is temperature and  $x$  is time. Next, you will attempt to find the values of  $a$ ,  $b$ , and  $c$  that produce a curve that best fits your recorded data.

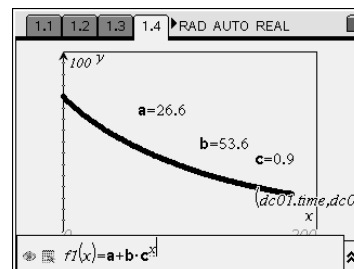
- Q3.** Should  $c$  be greater than, less than, or equal to 1? Explain your answer and give your prediction for the value of  $c$ .
- Q4.** What value should  $a$  have? (Hint: What will happen to the temperature of the sensor as time approaches infinity?)
- Q5.** What value should  $b$  have?



**Step 2:** Next, you will define three variables,  $a$ ,  $b$ , and  $c$ , to represent each of the values in the equation. Add a text box (**Menu > Actions > Text**) somewhere on page 1.4. Type in the value you determined for  $a$  above, and press  $\text{enter}$ . Then, press  $\text{esc}$  and move the cursor so that it is hovering above the value you just typed. Click once to select the text box, and then press  $\text{store var}$ . Select **Store Var**, and then type  $a$  in the text box when it becomes highlighted. Press  $\text{enter}$  to define the variable. Repeat this process for  $b$  and  $c$ .



**Step 3:** Next, set the function  $f1(x)$  equal to  $a + b \cdot c^x$ . Change the graph type to **Function**. In the function line, type in the expression above and press  $\text{enter}$ . A graph of the function should now be displayed on your screen. It will probably not fit your data very well. Press  $\text{esc}$  to exit out of the function line. Adjust the value of  $c$  by clicking on the  $c =$  text box and typing in new values. Vary  $c$  until the curve fits your data reasonably well.



**Q6.** What value of  $c$  gave you the best fit to your data?

### Part 3: Exploring the relationship between cooling rate and temperature difference

In the previous steps, you determined the function that describes the cooling of the sensor. The slope of this curve at any point is the cooling rate at that time, as shown by the following equation:

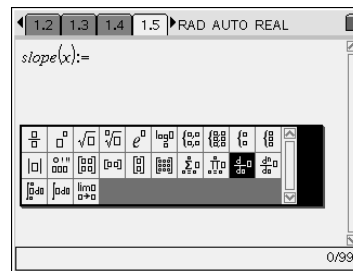
$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{\Delta(\text{temperature})}{\Delta(\text{time})} = \text{cooling rate}$$

To find the slope algebraically, you would find the differences in temperature of the sensor and the time at two points and divide them.

When you calculate slope in this way, you are limited by how close together your data points are. A tool of calculus, the derivative, allows you to take the difference between two points that are infinitesimally close together. Therefore, the derivative allows you to find the slope of the curve at any single point.

In this part of the activity, you will plot the slope of the curve (the cooling rate) versus the difference in temperature between the sensor and the room to learn how temperature difference affects cooling rate.

**Step 1:** First, you must define the *slope* function. Move to page 1.5, which contains a *Calculator* application. Type **slope(x):=**. (Note: Make sure you type :=, not just =). Then, press  $\text{ctrl}$   $\left(\frac{d}{dx}\right)$  to open the templates menu, and select the  $\frac{d}{dx}$  template. Enter **x** in the box in the denominator of the template and **f1(x)** in the large box to the right of the template. Then, press  $\text{enter}$ . This command defines the function **slope(x)** as the derivative of **f1(x)**.



**Step 2:** Move to page 1.6, which contains a *Lists & Spreadsheet* application. The data you collected will probably already be present in the application. If they are not, in the formula bar (gray square) of Column A, press  $\text{enter}$ , then press  $\text{ctrl}$   $\left(\frac{\text{store}}{\text{var}}$ ) and choose **dc01.time**. Repeat this process for Column B, but set it equal to the temperature readings.

	A	B	C	D
dc01.time				
1	0.	80.1875		
2	1.	79.5625		
3	2.	78.875		
4	3.	78.3125		
5	4.	77.75		

**Step 3:** Next, make Column C equal to the slope of the curve at each point. In the formula bar for Column C, type **=slope(a[])** and press  $\text{enter}$ . (To insert the brackets after **a**, press  $\text{ctrl}$   $\left(\frac{[ ]}{\text{insert}}$ ) and then press  $\blacktriangleright$  (right) on the NavPad.) Assign this series to the variable **sl** by typing **sl** in the title bar of Column C (the white box next to the C label) and pressing  $\text{enter}$ .

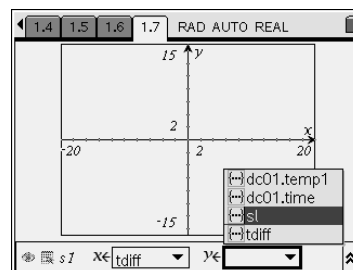
	A	B	C	D
dc01.time			sl	
1	0.	80.1875	-0.484584	
2	1.	79.5625	-0.480223	
3	2.	78.875	-0.475901	
4	3.	78.3125	-0.471618	
5	4.	77.75	-0.467373	

**Q7.** Why is the variable for the slope function in Column C time, not temperature? (That is, why do you have to type **a[]** and not **b[]** into the function?)

**Step 4:** Now, set Column D equal to the difference in temperature between the probe and the room. In the formula bar for Column D, type **=b[]-temp**, but substitute the ambient temperature you recorded in part 1 for *temp*. (For example, if your ambient temperature was 19°C, you would type **=b[]-19**.) Press  $\text{enter}$  to populate the list. Assign this series to the variable **tdiff** by typing **tdiff** in the title bar of Column D and pressing  $\text{enter}$ .

	A	B	C	D
dc01.time			sl	tdiff
1	0.	80.1875	-0.484584	53.5875
2	1.	79.5625	-0.480223	52.9625
3	2.	78.875	-0.475901	52.275
4	3.	78.3125	-0.471618	51.7125
5	4.	77.75	-0.467373	51.15

**Step 5:** Next, move to page 1.7. Create a scatter plot of slope (**sl**) versus difference in temperature (**tdiff**). You may need to resize the window (**Menu > Window > Zoom-Data**) to see the points.



- Q8.** Describe the shape of the graph.
- Q9.** What does the shape of the graph tell you about the relationship between cooling rate and temperature difference?
- Q10.** If the graph were extended, what would its x- and y-intercepts be? What does this tell you about the relationship between cooling rate and temperature difference?
- Q11.** Which would you expect to cool more quickly, a 90°C sensor in a 10°C room, or a 50°C sensor in a 20°C room? Explain your answer.