RADIANT HEATING

Which Prius is the coolest? Listen to your mother.

INTRODUCTION

Lucky you! You are getting ready to buy a new car. Needless to say, everyone you know has important advice for you, like make sure you get the stereo with the integrated iPod dock. When it comes to choosing a color, you have narrowed it down: white, silver, or black. Your practical mother suggests that a white car will remain cooler in the summer sun, but your hipster brother claims that this is an urban myth, and that a black car is just plain cooler, period. Then your mom sends you and your brother out to mow the lawn. You're in a white t-shirt and his is, of course, black. *Now who's cooler?*

Instead of spending an hour sweltering in the parking lot looking for light and dark cars to compare, or comparing the sweat stains on our t-shirts, we can stay in the lab and test the idea that the color of an object is related to how much and how quickly it heats up. All we need are three equivalent objects whose only difference is their color. We also want to examine cooling rates, and discover if these are related to color as well. And finally, does an object cool down as quickly as it absorbed heat in the first place?

OBJECTIVES

- Investigate radiant heating
- Determine the rate at which different colored objects absorb energy
- Compare the total amounts of energy absorbed by equivalent objects of different colors
- Construct and analyze a graph of heating rates
- Consider qualitatively the rates of cooling
- Apply specific observations to general situations

EQUIPMENT

- Black, white, and silver aluminum bottles
- LabQuest unit
- Temperature probes
- Beakers
- Heat lamp

Start with a full liter of water in the biggest beaker, then measure out 300 ml into each bottle. That way, each bottle will have the same initial temperature.

PROCEDURE

- Add 300ml of tap water to each of the three bottles.
- Stopper the bottles, then insert a temperature probe into each. Place the bottles side by side, very close (but not touching).
- Adjust the heat lamp so that it is close to the bottles (a few cm away), and centered so that each bottle receives equal light.
- Connect each temperature probe to the LabQuest. Make sure to keep track of which color bottle is plugged in to which channel. Under the **Sensor** menu of the **Meter** tab, select **Data Collection.** Make the collection **Length** = **35 minutes**, and the **Rate** = **6 samples per minute**.
- Record the initial temperature of each bottle, then switch on the lamp. Tap the **GO** button to start data collection.
- Continue to collect data for **20 minutes**. *Do not stop the data collection*, but switch the lamp off and slide it away from the bottles. As the bottles cool, continue data collection for another **15 minutes**. Make sure to tap the **File Cabinet** icon to save the completed data set.
- When the data collection is complete, tap the **Table** tab to view the raw data. Record the values in your notebook, using 5 minute intervals (see the example table below).

DATA & ANALYSIS

If you have not already, construct and fill in your data table.

TIME (MIN)	TEMPERATURE (°C)			TIME (MIN)	TEMPERATURE (°C)		
	BLACK	WHITE	SILVER		BLACK	WHITE	SILVER
0				20			
5				25			
10				30			
15				35			

1. Make a neat sketch of the graphs in your notebook. You should make sure to reproduce the relationships accurately, and label each curve with the correct color of the bottle.
2. Fit the data with best-fit lines. Drag the stylus to highlight the region of the graph between 0 and 20 minutes, being careful not to highlight the cool-down part of the data. Under the **Analyze** menu, select **Curve Fit**, and the data you want to fit. Choose the **Linear** fit, and record the slope of the line. Fit a line for each of the three bottles.
3. Now highlight the cool-down portion of the data (from 20 to 35 minutes), and repeat the curve fitting for each bottle. If you have not already, make a neat table to record the slope data in your notebook.

SLOPE (°C/MIN)	BLACK BOTTLE	WHITE BOTTLE	SILVER BOTTLE
HEATING UP			
COOLING DOWN			

4. After 20 minutes, which bottle had the highest temperature? Is this the bottle you expected?
5. So if these are cars and not bottles, which car stays coolest? Assume you have parked the car in a lot without shade for about 4 or five hours.
6. Compare the *rates* of heating: use the slopes of the graphs you drew (think about what the slope of the graph means physically). Use your graph to determine how much time it takes each bottle to heat up by 5°C.
7. After 35 minutes, which bottle had the *lowest* temperature? Is this the bottle that actually cooled down the most? Compare the total amount of cooling by calculating the temperature change from 20 to 35 minutes for each bottle:
$$\Delta T = T_{35} - T_{20}$$
Which bottle actually released the most energy? Is it the bottle with the lowest temperature? Comment on this.
8. Examining your data and the slopes of the graphs without doing any calculations, compare the *rate* of cooling with the *rate* of heating. Regardless of color, what can you say about the time to heat up compared to the time to cool back down?
9. Use your graphs and slopes to make some predictions: What would the approximate temperature of each bottle be at time t = 40 minutes, if you had kept collecting data? Show your reasoning and work here.
10. Extend your analysis to other situations: How would your results in this experiment affect other choices you have to make? For example, if you have to replace the roof of your house (black asphalt shingles or light tan cedar shakes?), or maybe you just have to choose what to wear to mow the lawn on a cloudless summer afternoon (black t-shirt or white t-shirt?). Think of at least one more example of how this principle shows up in your daily life.
11. It's reasonable to assume that the same amount of energy from the lamp strikes each can. However, you have just seen that the cans do not absorb the same amount of energy in the same amount of time. If the can reflects the energy that it does not absorb, which can *reflects* the most energy? Relate this observation to the urban heat island effect, and why it's always a few degrees warmer in the city than in the undeveloped areas surrounding it.