Case File 11

Ashes to Ashes: Using evaporation rate to identify an unknown liquid

Measure and compare the cooling rates of unknown liquids, and identify the probable arsonist.

PROBABLE ARSON

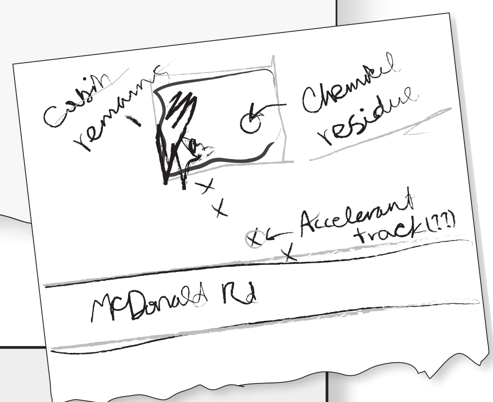
Investigator: James

Date: 10/05/05

- call in at 3:04 a.m.
- large fire on the East Side; historic log cabin of town founder, James McDonald
- first responders too late to save cabin
- traces of an unidentified chemical residue discovered in cabin remains
- drops of unidentified chemical found between cabin remains and main road

  (??accelerant used to spread the fire??)

  ARSON strongly suspected
- chemical evidence sent to lab for testing



McDonald Cabin Arson
Suspect List

The following four people were found within three blocks of the blaze in the early morning and were brought in for questioning. Each has access to flame accelerants for one reason or another. Chemicals collected from each of the suspects have been sent to the lab for identification and comparison with those collected at the scene.

Suspect 1: Barney Weber: member of school custodial staff
Weber was found cleaning out the back of his truck several blocks from the crime scene.

Suspect 2: Anna Appleby: local painter and muralist
Police found Appleby finishing a mural on a warehouse wall across the street from the fire.

Suspect 3: Virginia Lawson Smith: mechanic
Lawson Smith called the fire department. Police questioning her found chemicals on her work clothes.

Suspect 4: Dr. Martin Brown: university chemist
Brown was transporting a cart of chemicals to his college laboratory when police picked him up.

Forensics Objective

- identify the likely accelerant in an arson

Science and Mathematics Objectives

- identify a solution, based on evaporation rate
- understand that evaporation rate is a characteristic property of a liquid

Materials (for each group)

- TI-83/TI-84 Plus™ Family
- Vernier EasyTemp™ temperature probe
- Vernier EasyData™ application
- accelerant samples from 4 suspects
- accelerant sample from crime scene
- 5 small test tubes
- test-tube rack
- 6 pieces of filter paper cut into 2 × 2 cm squares
- 6 small rubber bands
- lint-free tissues or paper towels
- goggles (1 pair per student)

Procedure

In order to determine whether any of the accelerants found with the suspects matched the accelerant found at the crime scene, you will need to compare the evaporation rate of each suspect's sample with the evaporation rate of the sample from the crime scene. You will compare the samples by, first, graphing the temperature change of each sample as it evaporates and, second, comparing the graphs of each sample to look for a match. Because your calculator can display only three curves at a time on a graph, you will need to create two different graphs with three curves (two suspect samples and the crime scene sample) on each graph.

1. Connect the EasyTemp temperature probe to the USB port on your calculator.

2. To set up the EasyData App for data collection, select File from the Main screen, and then select New to reset the application. The Main screen should be displayed. You should see the current temperature reading at the top of the screen and **Mode: Time Graph: 180 (s)** near the bottom of the screen.

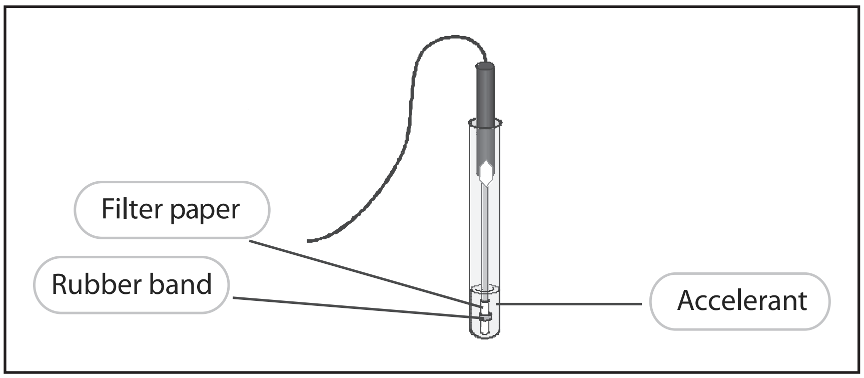
TIP! At the bottom of the Main screen are five options (File, Setup, Start, Graph, and Quit). Each of these options can be selected by pressing the calculator key located below it (Y=, WINDOW, ZOOM, TRACE, or GRAPH).

3. The default experimental setup is to collect one sample every second for 180 seconds. For this experiment, you will need to collect one sample every second for 240 seconds. Change the length of the experiment to 240 seconds.
   a) Select Setup from the Main screen.
   b) Select **2: Time Graph**.
   c) Select Edit to change the values. The default sample interval is 1 second, which is what we want for this experiment. Select [Next] to move to the next option.
   d) Press CLEAR to remove the default number of samples (180), and type **240** as the number of samples.
   e) Select Next.

f) Confirm that the settings are correct (sample interval = 1 second, number of samples = 240, experiment length = 240 seconds) and then select **OK**.

Obtain and wear goggles! CAUTION: The compounds used in this experiment are flammable and poisonous. Avoid inhaling their vapors. Avoid touching them with your skin or clothing. Be sure there are no open flames, heat sources, or sparks in the lab during this experiment. Notify your teacher immediately if an accident occurs.

4. Wrap the probe with a square of filter paper, and secure the paper with a small rubber band, as shown in the figure.



5. Pour a small amount of the accelerant from Suspect 1 into a test tube. Place the test tube in a test-tube rack, and place the temperature probe into the test tube so that the filter paper is covered by the liquid.

6. After the probe has been in the liquid for at least 30 seconds, select **Start** to begin collecting temperature data. On the calculator screen, a real-time graph of temperature vs. time will be displayed. The temperature readings are displayed in the upper right corner of the graph.
   a) Leave the temperature probe in the test tube for 15 seconds to establish the initial temperature of the liquid.
   b) Remove the probe from the liquid, and tape it to the table so the tip of the probe extends over the edge of the tabletop.

7. Data collection will stop after 240 seconds. The graph of temperature vs. time will then be scaled and displayed. The time, **X**, and temperature, **Y**, values are displayed above the graph.
   a) Use the arrow keys to move along the graph and determine the maximum and minimum temperatures for this sample. Record the maximum temperature as the T_{max} in your Evidence Record, and record the minimum temperature as T_{min}.
   b) Subtract the minimum temperature from the maximum temperature to determine the temperature change during evaporation. Record this value in the Evidence Record.

8. To store the data that you collected during this run, select **Main** to return to the Main screen. Select **File** and choose option **5: Store Run....** If you get a message about overwriting stored data, select **OK**.

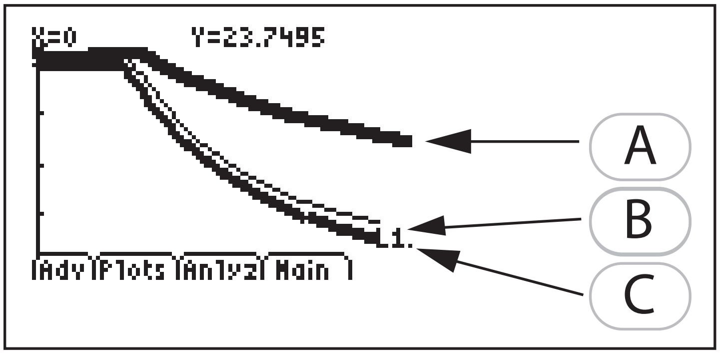
9. Remove the rubber band, dispose of the filter, and dry the probe thoroughly.

10. Repeat steps 4–9 with the accelerant from Suspect 2.

11. With the accelerant from the crime scene, repeat steps 4–7 *only*. (*Careful! Do not* store this run, or your data will be overwritten.)

12. Plot the data from all three accelerants on the same graph.
    a) Select Adv.
    b) Select **7↓L2, L3 and L4 vs L1**.

13. Compare the graphs to decide whether either Suspect 1 or Suspect 2 had an accelerant that is likely to be the same as the accelerant used at the crime scene.
    a) If one of the suspects' accelerants produces a plot that matches the shape of the plot from the crime scene accelerant, it could be the accelerant that was used.
    b) To identify which plot corresponds to which accelerant, use ▼ and ▲ to move the cursor from plot to plot and match the T_{max} and T_{min} values to those in your Evidence Record. See the example.



You can see that curves B and C are nearly identical in shape. Curve B is from the crime scene. Accelerant C is most likely to have been the accelerant used at the crime scene.

14. Even if you got a match in step 13, you need to test and compare the other two accelerants; two of the accelerants could be the same. Select Main to return to the Main screen. Repeat steps 4–13 for the accelerants from Suspect 3 and Suspect 4 and the accelerant from the crime scene. (Remember, *do not* perform a **Store As** for the crime scene run.)

NAME: ______________________________________

DATE: ______________________________________

Evidence Record

Substance	T_{max} (°C)	T_{min} (°C)	T_{max} – T_{min} (°C)	Cooling-Rate Graph Match?
Suspect 1				
Suspect 2				
Suspect 3				
Suspect 4				
Crime Scene				NA

Case Analysis

1. Which of the suspects' accelerants best matches the accelerant from the crime scene?
2. Did any of the suspects' accelerants appear to be the same liquid? If so, which ones?
3. Why may the graphs of the crime scene accelerant and primary suspect's accelerant not match exactly?
4. In what other ways can you examine the accelerants to determine which one was used in the crime?

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Teacher Notes

Teaching time: one to two class periods

This lab introduces the concept of evaporation rate and teaches students how to plot more than one curve on a graph.

Tips

Have students work in groups. You may want to use a different "crime scene accelerant" for each group.

Lab Preparation

Materials (accelerants) per group
- 10 mL methanol
- 10 mL acetone
- 10 mL isopropanol
- 10 mL *tert*-butyl alcohol

Setup notes
- The filter paper is necessary to slow down the evaporation process.
- Small rubber bands used for braces work very well. Small hair ties are another possibility.
- Put out the smallest test tubes you have. There is no reason for each group to have much of these solutions.
- Label test tubes with suspect numbers or names from the investigation report.

Background Information

In this lab, students use the evaporation rate as a characteristic property with which to distinguish different liquids from one another. The evaporation rate of a liquid depends primarily upon the volatility of the liquid, the temperature of the surrounding air, and the air pressure. Temperature change is a good proxy for evaporation rate because the evaporation of each liquid causes a decrease in its temperature; the faster the liquid evaporates, the faster the temperature drops.

In real arson investigations, gas chromatography, rather than tests of evaporation rates, is usually used to identify accelerants. This is necessary for several reasons: 1) many accelerants are nonvolatile or solid substances; 2) it is rare to find unadulterated accelerant samples near the site of an arson; and 3) trace impurities are often present in different accelerants. Identifying and matching these impurities to other samples can help investigators tie a suspect or a particular batch of accelerant to a particular fire. Many of these impurities do not significantly change evaporation rate, so they could not be detected by the method used in this lab.

Differences in evaporation rate can be difficult to measure and are not as accurate in establishing the identity of an accelerant as is gas chromatography. However, many of the factors that affect evaporation rate also produce distinctive patterns in gas chromatograms. Gas chromatography, like other forms of chromatography, separates the components of a mixture according to their affinities for a particular substrate. These affinities are often related to the same molecular characteristics that cause a substance to be highly volatile or relatively stable. For example, a substance with highly polar bonds will probably have a low evaporation rate; the polar bonds will probably also affect its relationship to the gas chromatography substrate. Therefore, even though the students are not necessarily using the same *method* to identify accelerants in this lab, the method they are using is based upon the same chemical principles.

Resources

http://www.firearson.com/
This Web site for the International Association of Arson Investigators contains many links and a great deal of interesting information.

Modifications

- It may be difficult to complete this lab in one period. If time is an issue, have students investigate only two of the suspects (delete step 14).
- If a computer with TI Connect™ software is available, the accelerant samples can be compared all at the same time using the following set of procedures. This set of procedures requires a working knowledge of opening files and making graphs in Microsoft Excel®. If you or your students are unfamiliar with making graphs, refer to the Help menu in Excel.
- If you choose to use the computer to display the data, use the following steps after step 6:

7. Data collection will stop after 240 seconds. The graph of temperature vs. time will then be scaled and displayed.

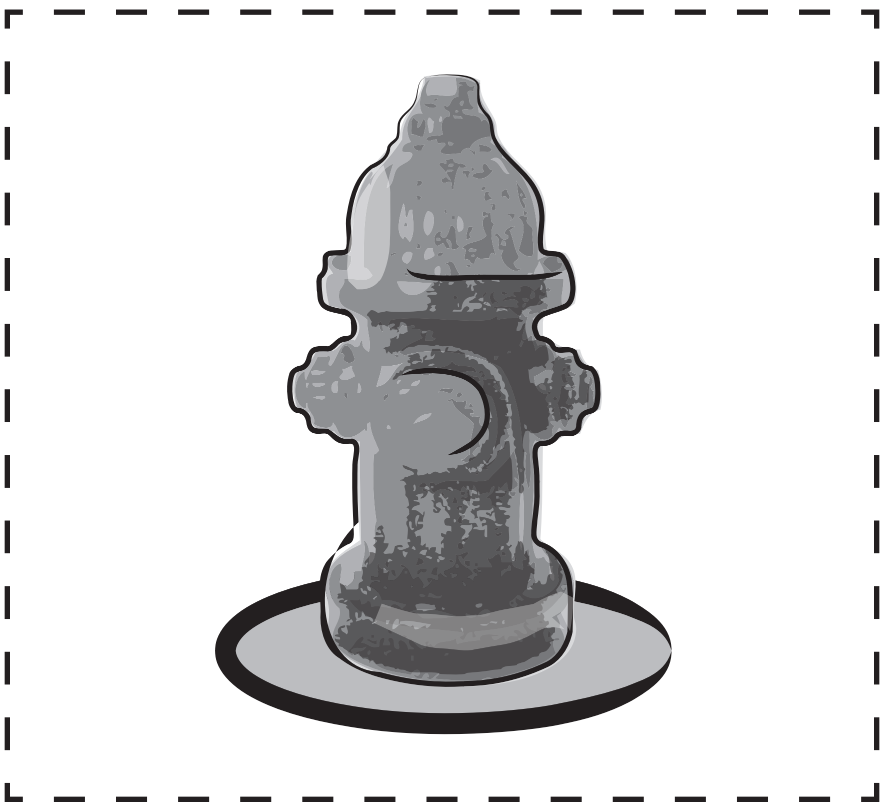
8. Remove the rubber band, dispose of the filter, and dry the probe thoroughly.

9. To store the data you collected during this run, select Main to return to the Main screen. Select File and choose option **5: Store Run...**. If you get a message about overwriting stored data, select OK.

10. In order to compare many different accelerants at the same time, you will transfer your temperature data from your calculator to a computer, using TI Connect. Transfer the temperature data from the first run.
    a) From the Main screen, select Quit then OK. This will return you to the Home screen.
    b) Disconnect the temperature probe from the calculator.
    c) Connect the calculator to the computer with the USB cable by plugging the cable into the USB port on the computer *before* plugging the other end into the calculator.
    d) Start TI Connect by double-clicking the desktop icon.
    e) Once you have opened TI Connect, select TI DeviceExplorer. (Note: Make sure your calculator is turned on *before* selecting TI DeviceExplorer.)
    f) The DeviceExplorer screen will display a list of the different files in your calculator. Double-click on List (Real) to open the data lists. (Note: It may take a few seconds for the computer to talk to your calculator. Be patient!)
    g) You will need to transfer the data in the lists to the TI DataEditor. On the DeviceExplorer menu bar, select Tools and then TI DataEditor.
    h) The time data for the first run are stored in list L1. Click and drag “L1” from the DeviceExplorer to the DataEditor. (Note: You may need to move the windows around on your computer screen until you can see both the DeviceExplorer and the DataEditor windows.)
    i) When the time data have finished transferring, transfer the temperature data for the first run (stored in list L2) by clicking and dragging “L2” from the DeviceExplorer to the DataEditor.
    j) Right-click on the L1 column label in the DataEditor and select Properties. Under Variable Name, click the radio button at the very bottom and type “TIME” in the box.
    k) Repeat step 10j for the L2 column, but type the name “TEMP1.”
    l) From the DataEditor menu bar, select File, then select Special List Export. Type a name for your data file and click Save. (Note: Be sure to select Special List Export, not just Export; Export will save *only* the first column of your data!)
    m) Disconnect the USB cable from your calculator. Leave the cable connected to your computer for the next run.
    n) Reconnect the EasyTemp probe to the USB port on your calculator. The EasyData screen should come up and display the ambient temperature. You are now ready to collect data for the next accelerant.

11. Repeat steps 4–10 with the remaining accelerants, but make the following changes:
    a) Skip step 10j.
    b) In step 10k, type the name “TEMPX” for the L2 column, where X is the number representing which sample the data are from (TEMP1 for Suspect 1, TEMP2 for Suspect 2, TEMP3 for Suspect 3, TEMP4 for Suspect 4, and TEMP5 for the crime scene).
    c) Do not type a new name for the file in the next step (10l). Use the same name you used before. When the computer asks if you want to overwrite the file, click Yes.

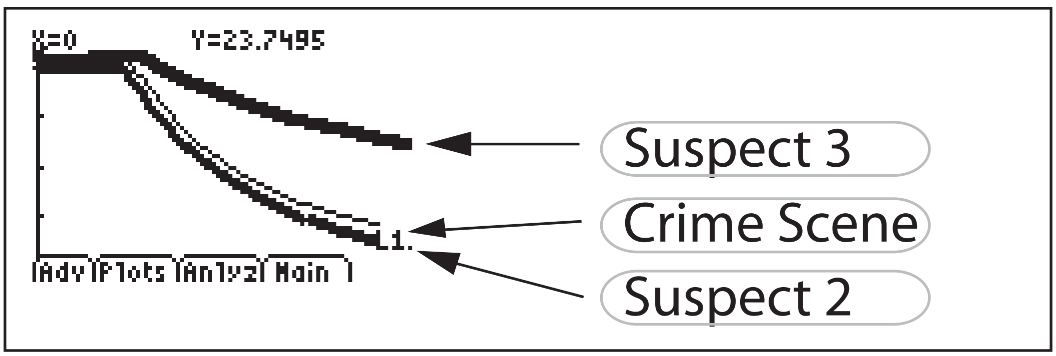
12. Use Microsoft Excel to compare the cooling graphs of the data.
    a) Open Excel. From the menu bar, choose File > Open. Open the file containing your temperature data. (Note: In order to see the file that you created, you may need to select Files of Type: All files (*.*). The DataEditor saves the data as a .csv file.)
    b) Using Excel, create a line graph of the cooling curves for each accelerant. Plot time on the *x*-axis and temperature on the *y*-axis. Compare the curves of the four accelerants to the curve of the accelerant from the crime scene.
    c) Decide which suspect is most likely to be guilty.



Sample Data

(Note: This Evidence Record is not necessary if the students use TI Connect™ software and Microsoft Excel™ to analyze their data.)

Substance	T_{max} (°C)	T_{min} (°C)	$T_{max} - T_{min}$ (°C)	Cooling-Rate Graph Match?
Suspect 1 (Methanol)	25.4	8.1	17.3	No
Suspect 2 (Acetone)	22.6	6.3	16.3	Yes
Suspect 3 (Isopropanol)	23.8	16.8	7	No
Suspect 4 (*tert*-Butyl Alcohol)	24.6	19.9	4.7	No
Crime Scene (Acetone)	23.7	9.6	14.1	NA



Guilty suspect: Suspect 2

Case Analysis Answers

1. Which of the suspects' accelerants best matches the accelerant from the crime scene?
   Answers will vary.
2. Did any of the suspects' accelerants appear to be the same liquid? If so, which ones?
   Answers will vary.
3. Why may the graphs of the crime scene accelerant and primary suspect's accelerant not match exactly?
   There may be differences in the amount of liquid on the probe, impurities in one or both of the samples, variations in ambient temperature or humidity, or differences in the starting temperature of the samples.
4. In what other ways can you examine the accelerants to determine which one was used in the crime?
   Answers may vary. (Boiling point is probably the most useful.)