#15 A Search for Automated Plastics Recycling Separation

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Introduction

Description

Recycling efforts of recent years have been hampered by the high cost of manually separating the materials. This is particularly true of plastics. Students will be challenged to investigate the physical and chemical properties of plastics and use them to design a system that could be used to separate them. In working with my students, first-year chemistry students were steered in the direction of using density for separation. They were directed to use information gathered from handbooks and the Internet to prepare a series of solutions with different densities which could be used to separate the plastics. A flow chart was developed to describe and outline this process. Second-year chemistry students were given the problem during a study of infrared spectroscopy. During discussion they were directed to search for absorption peaks unique to each plastic. Again a flow chart was used to summarize the process design. Third-year chemistry students with some limited experience in chemical instrumentation were given the problem as an independent study.

Student Audience

The general activity is designed to be used with different levels of students with appropriate degrees of complexity. First-year chemistry students could be challenged and guided to utilize the concept of density to perform the separation. Advanced-level chemistry students could be given less preparation and could use more advanced techniques including instrumentation, if available. This activity could serve as an introduction to infrared spectroscopy.

Goals for the Experiment/Activity

- The students will develop and apply concepts of physical and chemical properties such as density.
- The student will use critical-thinking skills to solve a real-world problem.

Recommended Placement in the Curriculum

These activities would fit into the typical first-year chemistry curriculum into the topics of density or chemical and physical properties. These occur in the textbook I use (Merrill) in chapters 4 and 5. My second-year chemistry curriculum consists of four quarters, each with its own theme. This project fits into the analytical chemistry quarter during the study of spectroscopy, particularly infrared.

Scenario Modification for Students

I plan to implement the problem-solving process into one aspect of this separation process; the separation of the various kinds of plastics. The identification of the materials by the manufacturer using the triangle symbols is used during manual sorting. This would need to be replaced with some type of automated identification. I plan to propose this problem to the students through the introduction of an unsorted bag of plastic trash. The students would need to collect information about the properties of plastics from both literature and experiments as well as currently available separation methods. The experiments I would propose for students would involve measuring chemical and physical properties of the seven commonly identified plastics. Data retrieved from literature and Internet would be discussed in class with my input into the discussion encouraging experimental investigation into density and infrared spectra properties in order to find differences among the plastics. The results of experimental and literature data gathering would then be the subject of a brainstorming session on separation process development. The results of the session would then be tested in laboratory. A final stage of the process would be a flow chart design for a system that would separate the plastics.

STUDENT HANDOUT

Identifying and Sorting Plastics

First-Year Chemistry Experiment Name______________________________
Option 1

Purposes

1. To develop a method to identify and sort plastics.
2. To use the method to identify an unknown plastic.
3. To learn how to draw a flow chart diagram.

Scenario/Industrial Applications

Plastics may release toxic or hazardous pollutants when burned and do not decompose in landfills. Therefore, the best way to dispose of plastic waste from your home is to recycle it. However, since each plastic has different properties, the plastic must be sorted into different kinds before it can be reused. This is very labor intensive and thus expensive. Many uses of plastics require the manufacturer to follow a standard code and label the object with the type of plastic used to make it. This is the familiar number inside a triangle symbol. (See Table 1 below for the meaning of the numbers.) However often the symbol is not easily read and this complicates sorting time. Also, not all plastic objects are labeled.

In this experiment we will try to develop a sorting method using the different properties of each type of plastic. We will use a chemical property (reaction with copper in a flame) and a physical property (density) to sort the plastic.

Table 1. Plastic Identification Numbers

#1	Polyethylene teraphthalate	(PET or PETE)
#2	High density polyethylene	(HDPE)
#3	Polyvinyl chloride	(PVC)
#4	Low density polyethylene	(LDPE)
#5	Polypropylene	(PP)
#6	Polystyrene	(PS)
	Plexiglas	(PG)

Safety, Handling, Disposal

None of the plastics themselves are toxic. Often they are used to store food. However, during the flame test some plastic will be heated and burned. This may produce irritating and perhaps toxic fumes. Hydrogen chloride gas is formed from burning polyvinyl chloride (PVC) plastics. Thus, this testing process should be done in a fume hood. The amounts of gases should be held to a minimum by using small pieces of plastic and short testing times. The solutions used to separate the plastics using their densities are quite harmless. The 10:7 ethyl alcohol solution would be flammable and could be disposed of by pouring down the drain followed by large amounts of water so that no flammable alcohol is left in the drain. The salt and Epson salt solutions can also be disposed of down the drain. Dispose of used reagent according to local ordinances.

Materials Needed

Small pieces (.5 x .5 cm) of plastic

#1	Polyethylene teraphthalate	(PET or PETE)
#2	High density polyethylene	(HDPE)
#3	Polyvinyl chloride	(PVC)
#4	Low density polyethylene	(LDPE)
#5	Polypropylene	(PP)
#6	Polystyrene	(PS)
	Plexiglas	(PG)

10-cm-long copper wire
cork
Bunsen burner
solutions (50 mL of each):

- 10:7 ethyl alcohol made by mixing 100 mL of ethanol with 70 mL of water
- 1:1 ethyl alcohol made by mixing 50 mL of ethanol with 50 mL of water
- 10% sodium chloride solution made by mixing 10 grams of sodium chloride with 90 mL of water
- 24% magnesium sulfate solution made by mixing 24 grams of common Epsom salt with 76 mL of water

6 100-mL beakers
paper towels

Procedure

1. Obtain one piece of each kind of plastic in Table 2 below and identify it by writing a number or initial on each piece with an indelible marker.

Table 2. Properties of Plastics

			flame color	density
#1	Polyethylene teraphthalate	(PET)	__________________	______
#2	High density polyethylene	(HDPE)	__________________	______
#3	Polyvinyl chloride	(PVC)	__________________	______
#4	Low density polyethylene	(LDPE)	__________________	______
#5	Polypropylene	(PP)	__________________	______
#6	Polystyrene	(PS)	__________________	______
	Plexiglas	(PG)	__________________	______

The numbers above coincide with the numbers which must be molded into every plastic item, usually on the bottom.

2. Push a piece of the heavy copper wire into a cork to serve as a handle. Heat the wire in the burner flame and while still hot touch it to one piece of plastic so that the plastic melts a little. Then put the wire back into the burner flame. Observe the color of the flame.

   Clean the wire by sanding. Repeat with each kind of plastic.

   What color flame does each kind of plastic produce? Record in Table 2 above. Do not include any plastic that forms a colored flame in the test in steps 3-5 below.

3. Label five CLEAN AND DRY 100-mL beakers with the following:

- 10:7
- 1:1
- H_2O
- NaCl
- $MgSO_4$
- Rinse

4. Pour about 50 mL of each of the solutions in Table 3 below into the appropriate beaker.

Table 3. Floating Plastics in Each Solution

			floating plastic
10:7	Ethyl alcohol in water	D = 0.91 g/mL	
1:1	Ethyl alcohol in water	D = 0.94 g/mL	
H_2O	Distilled water	D = 1.00 g/mL	
NaCl	10% sodium chloride	D = 1.1 g/mL	
$MgSO_4$	26% magnesium sulfate	D = 1.3 g/mL	
	sunk plastic		

5. Starting with the least dense solution put all plastic pieces into each solution. Gently shake the beaker. Note which plastics float and which sink. If a piece of plastic floats do NOT put it into the next higher density solutions. To remove the plastics from the beaker pour the solution into rinse beaker. Pat the plastic pieces dry with paper towel but do not rub off the identifying marks before putting them into the next higher density solution. Return each solution to its correct beaker. Only one piece of plastic should float in each solution. Record in Table 3 above.

6. Obtain a piece of plastic of unknown type from the instructor. Perform the copper wire flame test and density test above to identify it.

Identity of unknown ______________________________

Proof:

Questions

1. What is the density range of each plastic? (Hint: See densities of solutions above. If a material floats, its density is less than that of the solution.)
2. Draw the molecular structure of each plastic used.
3. How could the density of a plastic be changed?
4. What other properties of plastics could be used to sort them?
5. Draw a flow chart diagram of this testing method.

Suggested Reading

Smoot, Robert C., Price, Jack S., and Smith, Richard G.; “Chemistry: A Modern Course”; Merrill: Columbus, Ohio, 1983, pp 34-37 and 50-53.

STUDENT HANDOUT

First-Year Chemistry Experiment Name____________________________
Option 2

Identifying and Sorting Plastics

Purposes:

1. To develop a method to identify and sort plastics.

2. To use the method to identify an unknown plastic.

3. To learn how to draw a flow chart diagram.

Scenario/Industrial Applications

Plastics may release toxic or hazardous pollutants when burned and do not decompose in landfills. Therefore, the best way to dispose of plastic waste from your home is to recycle it. However, since each plastic has different properties, the plastic must be sorted into different kinds before it can be reused. This is very labor intensive and thus expensive. Many uses of plastics require the manufacturer to follow a standard code and label the object with the type of plastic used to make it. This is the familiar number inside a triangle symbol. (See Table 4 below for the meaning of the numbers.) However often the symbol is not easily read and this complicates sorting time. Also, not all plastic objects are labeled.

In this experiment we will try to develop and sorting method using the different properties of each type of plastic. We will use a chemical property (reaction with copper in a flame) and a physical property (density) to sort the plastic.

Table 4. Plastic Identification Numbers

#1	Polyethylene teraphthalate	(PET or PETE)
#2	High density polyethylene	(HDPE)
#3	Polyvinyl chloride	(PVC)
#4	Low density polyethylene	(LDPE)
#5	Polypropylene	(PP)
#6	Polystyrene	(PS)
	Plexiglas	(PG)

Safety, Handling, Disposal

None of the plastics themselves are toxic. Often they are used to store food. However, during the flame test some plastic will be heated and burned. This may produce irritating and perhaps toxic fumes. Hydrogen chloride gas is formed from burning polyvinyl chloride(PVC) plastics. Thus this testing process should be done in a fume hood. The amounts of gases should be held to a minimum by using small pieces of plastic and short testing times. You will be mixing solutions of certain densities to separate the plastics. Be sure to check with your instructor as to the safety precautions to be used for each solution. For example, alcohol are flammable, acids are caustic, etc. Before disposing of the solution check with your instructor about the correct procedure to use. Dispose of used reagent according to local ordinances.

Materials Needed

Small pieces (.5 x .5 cm) of plastic

#1	Polyethylene teraphthalate	(PET or PETE)
#2	High density polyethylene	(HDPE)
#3	Polyvinyl chloride	(PVC)
#4	Low density polyethylene	(LDPE)
#5	Polypropylene	(PP)
#6	Polystyrene	(PS)
	Plexiglas	(PG)

10-cm-long copper wire
cork
Bunsen burner
6 100-mL beakers
paper towels
solutes to make solutions

Procedure

1. Obtain one piece of each kind of plastic and identify it by writing a number or initial on each piece using a magic marker. Use the references provided to find the densities and record in Table 5 below:

The types of plastics to be used are:

Table 5. Properties of Plastics

			flame color	density
#1	Polyethylene teraphthalate	(PET)		
#2	High density polyethylene	(HDPE)		
#3	Polyvinyl chloride	(PVC)		
#4	Low density polyethylene	(LDPE)		
#5	Polypropylene	(PP)		
#6	Polystyrene	(PS)		
	Plexiglas	(PG)		

The numbers above coincide with the numbers which must be molded into every plastic item, usually on the bottom.

2. Push a piece of the heavy copper wire into a cork to serve as a handle. Heat the wire in the burner flame and while still hot touch it to one piece of plastic so that the plastic melts a little. Then put the wire back into the burner flame. Observe the color of the flame.

3. Clean the wire by sanding. Repeat with each kind of plastic.

What color flame does each kind of plastic produce? Record in Table 5 above. Do not include any plastic that forms a colored flame in the further tests.

Identifying and Sorting Plastics Part 2

1. Find the densities of each kind of plastic using appropriate resources. Record in Table 5 above.

2. Use the references provided to find solutions which would separate each plastic one at a time from the rest. Remember, a substance will float in a liquid of higher density and sink in a liquid of lower density.

3. Make 100 mL of each solution in beakers according to the directions provided in the references. In Table 6 below write the density of each solution and how it is prepared. Also include the type of plastic it is intended to separate.

Table 6. Solutions of Known Densities Used to Separate Plastics

Solution preparation	Density	Plastic it separates

Testing the Separation Method

4. Starting with the least dense solution put all plastic pieces into each solution. Gently shake the beaker. Note which plastics float and which sink. If a piece of plastic floats do NOT put it into the next higher density solutions. To remove the plastics from the beaker pour the solution into another beaker. Pat the plastic pieces dry with paper towel but do not rub off the identifying marks before putting them into the next higher density solution. Return each solution to its correct beaker. Only one piece of plastic should float in each solution. Record in Table 6 above.

5. Obtain a piece of plastic of unknown type from the instructor. Perform the copper wire flame test and density test above to identify it.

Identity of unknown ______________________________

Explain your answer:

Questions

1. What is the density range of each plastic? (Hint: See densities of solutions in Table 6 above. If a material floats, its density is less than that of the solution.)
2. Draw the molecular structure of each plastic used.
3. How could the density of a plastic be changed?
4. What other properties of plastics could be used to sort them?
5. Draw a flow chart diagram of the order of your testing method.

Suggested Reading

Weast, R. C. Handbook of Chemistry and Physics, 47th Edition; The Chemical Rubber Company: Cleveland, 1968.

Stecher, P.G. The Merck Index, 8th Edition; Merck and Company, Inc: Rahway, 1968.

Smoot, Robert C., Price, Jack S., and Smith, Richard G., Chemistry: A Modern Course, Merrill: Columbus, 1983, DENSITY pp 34-37, and CHEMICAL AND PHYSICAL PROPERTIES pp 50-53.

STUDENT HANDOUT
Second-Year Chemistry

Sorting Plastic by Infrared Spectroscopy

Purposes

1. To learn the principles of infrared (IR) spectroscopy.
2. To learn how to identify unknown substances using IR spectroscopy.
3. To identify two unknown polymers (plastics).

Scenario/Industrial Applications

Plastics are very polluting when burned and do not decompose in landfills. Therefore, the best way to dispose of plastic waste from your home is to recycle it. However, since each plastic has different properties, the plastic must be sorted into different kinds before it can be reused. This is very labor intensive and thus expensive. Many uses of plastics require the manufacturer to follow a standard code and label the object with the type of plastic used to make it. This is the familiar number inside a triangle symbol. (See Table 7 below for the meaning of the numbers.) However often the symbol is not easily read and this complicates sorting time. Also, not all plastic objects are labeled.

Table 7. Plastic Identification Numbers

#1	Polyethylene teraphthalate	(PET or PETE)
#2	High density polyethylene	(HDPE)
#3	Polyvinyl chloride	(PVC)
#4	Low density polyethylene	(LDPE)
#5	Polypropylene	(PP)
#6	Polystyrene	(PS)
	Plexiglas	(PG)

In this experiment we will develop a sorting method using different properties of each type of plastic. We will use the property of how the plastic sheets interact with infrared light. When electromagnetic radiation, such as infrared light, encounters a material, the energy of the radiation determined by its frequency ($E=hf$) may be absorbed by various types of chemical bonds in the substance. Each type of bond has a different vibrational energy level and will absorb different energies (frequencies) of infrared radiation. A material will be placed into a beam of infrared light. The instrument will scan through a spectrum of different frequencies. Some of the frequency's energy will match the energy needed for a bond to change vibrational energy levels and will be absorbed. The instrument will indicate this by a valley (called a peak) in a graph of relative amount of infrared energy passing through the sample at each frequency. We will use this graph to find a peak at a frequency unique to each plastic which can be used to identify an unknown plastic. The bonds in Table 8 produce absorption peaks at the indicated wavenumbers (frequencies):

Table 8. Wavenumbers of Chemical Bonds

Bond			Wavenumber (cm-1)
C-H	Alkane	bend	2850-3000
	CH_3	bend	1375 & 1400
	CH_2	bend	1465
	Alkene	stretch	3000-3100
		bend	1000-1700
	Aromatic	stretch	3050-3150
		bend	700-1000
	Alkyne	stretch	3300
	Aldehyde		2800-2900 & 2700-2800
C=C	Alkene		1600-1680
	Aromatic		1400-1600
C≡C	Alkyne		2100-2250
C=O	Aldehyde		1720-1740
	Ketone		1705-1725
	Carboxylic acid		1700-1725
	Ester		1730-1750
	Amide		1810
	Anhydride		1760
C-O	Alcohol, ether, ester, acids		1000-1300
O-H	Alcohol, phenol (free)		3600-3650
	H-bonded		3200-3400
	Carboxylic acids		2500-3300
N-H	Amines		3500
C≡N	Nitriles		2240-2260
N=O	Nitro		1500-1600
			1300-1400
C-X	Fluoride		1000-1400
	Chloride		600-800
	Bromide & iodide		<600

Safety, Handling, Disposal

This activity will be restricted to the use of an infrared spectrophotometer. Be aware of any caution or warning notes in the instrument's operating manual.

Materials Needed

Infrared spectrophotometer (The instrument available to the writer was a Beckman IR10 donated from a local college. The plotting mechanism was no longer operable, so the output was sent to an Apple IIe computer using Vernier Voltage Input Unit (VIU) hardware and Voltage Plotter software to produce hard copy spectra. A time to wavenumber conversion was necessary. See appendix for Tables 14 and 15 to do the conversions.)

Cardboard slide holders for mounting one's own slides
3 x 3 cm sheets of the plastic samples:

#1	Polyethylene teraphthalate	(PET or PETE)
#2	High density polyethylene	(HDPE)

#3 Polyvinyl chloride (PVC)
#4 Low density polyethylene (LDPE)
#5 Polypropylene (PP)
#6 Polystyrene (PS)
Plexiglas (PG)

Procedure

The following instrument directions are specific to the Beckman IR10. A similar list of instructions would be appropriate for other instruments.

Instrument

The instrument has the following control knob and variables:

a. FUNCTION switch (bottom of the left side of the instrument). Turn on the knob to the STOP position to allow the instrument to warm up. To start a scan turn the switch to the START position. It will automatically turn back to the SCAN position.

b. Single beam (SB) or double beam (DB). A single-beam instrument sends light through the sample and measures how much is transmitted. A double-beam instrument sends light through the sample and compares it to a second beam of light which is not sent through the sample (reference beam). All samples are to be placed in the front beam of the sample cavity. The back beam is the reference beam.

c. Scan speed: fast or slow

These two variables are selected by the MODE knob of the middle of the left side of the instrument. Most commonly we will use the instrument as a single beam at the fast scan speed.

d. 100% TRANSMITTANCE (top of the left side of the instrument). Used to set the transmittance of the instrument to near 100% (3.0 volts) when the sample is not absorbing light.

e. BALANCE (bottom of the right side of the instrument). Turn this on to turn on the electronic detection system. For normal operation set it at zero (at the 12 o'clock position).

f. GAIN (top of the right side of the instrument) Set it at 5 (at the 12 o'clock position) for normal operation.

g. ZERO (middle of the right side of the instrument). Used to set the pen recorder to zero. We will not be using this control since we will be using a computer as the recording instrument.

h. Wavenumber selector. The wavenumbers are set by the position of the moving arm which moves from left to right across the front of the instrument. The arm is connected to the diffraction gratings inside the instrument which select the wavelength of the light passed through the sample. The arms can only be moved manually to the left. The wavenumber the arm it is set on is directly under the left line on the plastic scale attached to the left side of the arm. We will begin our scans at a wavenumber of 2000.

Recorder

We will be using the Voltage Plotter program of the computer as a recorder.
Hook up the hardware as follows:

a. Plug the Voltage Input Unit (VIU) into the game port of the computer.

b. Plug two banana alligator plugs into the left side of the instrument.

c. Plug two banana alligator plugs into the Voltage Input Unit.

d. Connect the two leads from a digital volt meter to the instrument and to the VIU, making sure that the polarity is observed. Black is negative and red is positive. Set voltmeter to 20 V DC.

Set up the software as follows:

a. A startup program is on one side of the disk. When it asks for the Voltage plotter "program" turn the disk over and push return.

b. Select "Voltage Input Unit."

c. On the main menu select "Graph in Real Time."

d. On the Graph Style menu use the up and down arrows and the space bar to select "line connecting points" and "specific graph title."

e. Respond to save data with "No."

f. Minimum anticipated voltage is "0."

g. Maximum anticipated voltage is "1.5."

h. Length of time change to 00:04:30. This will be changed to 00:06:30 for a scan from 4000 to 2000.

i. Enter graph heading "IR and name of your sample."

j. After the graph is set up, the computer is ready to collect data when the space bar is pushed.

Procedure

Collecting Spectra from Solid Polymer Samples

1. Most of our samples are mounted in photographic slide mounts. Place a sample in the front sample holder.

2. Start the scan and start collecting data simultaneously by turning the function switch to start and pushing the space bar on the computer. When the scan finishes, turn the function switch to STOP and gently push the wavenumber arm back to 2000.

3. Usually the first spectra will have problems. Correct them as follows:

a. If the line falls to zero for long parts of the spectrum, turn up the BALANCE clockwise. Thicker plastic samples will typically have this problem.

b. If the line does not show significant absorbances, turn up the GAIN clockwise.

c. Adjust the line at the top of the graph by using the 100% transmittance knob. The line should be near the top of the graph but not go above it.

4. You will need to collect GOOD spectra for:

a. one standard polymer sample from 2000 to 600

b. one standard polymer sample from 4000 to 2000

c. one unknown polymer sample from 2000 to 600

d. one unknown polymer sample from 4000 to 2000

Each student needs to collect spectra for only one standard polymer. We will share the spectra with one another so that each student has a complete set of spectra for the six types of recycled plastics. Please write the name or number of the plastic you chose on the sign-in sheet taped to the spectrophotometer.

Data Manipulations

1. Use a ruler to approximate the wavenumbers of the major absorption peaks of your spectra.

2. Compare your spectra to the standards from a handbook and calculate the % error.

3. Use Table 8 to identify the structural features that caused these absorption peaks. Relate these to the structures shown with the standard spectra

Questions

1. How does a molecule absorb infrared radiation? What does this have to do with the concept of resonance?

2. Infrared radiation does not pass through air easily; it is absorbed after short distances. Why?

3. Does it take more energy to stretch, bend, or rotate a bond? Explain.

4. What is the difference between a single- and a double-beam IR spectrophotometer? What is an advantage of each?

5. Choose a wavenumber which is present in each spectrum that is not present in any other. This could be used to distinguish each type of plastic from others.

6. Design a process which could differentiate the six kinds of plastic from one another using the unique wavenumbers for each found in question 5 above. Summarize the process in the form of a flow chart.

Suggested Reading

Pavia, Donald L.; Lampman, Gary M.; Kriz, George S. “Introduction to Organic laboratory Techniques, A Contemporary Approach”; Harcourt Brace: Fort Worth, 1988, pp 695-714.

Durst, H. DuPont; Gokel, George; W. “Experimental Organic Chemistry”; McGraw-Hill: New York, 1987, pp177-184.

INSTRUCTOR NOTES

Identifying and Sorting Plastics

Time Required

The first-year activity exists as two options. The first option, which gives the most explicit directions, should take about one period (45 min). The second option in which the students must research resources to find the densities of plastics and then consult reference manuals to make solutions with specific densities would take considerably longer. Part of the research could be assigned as homework. Estimated time is three periods (each 45 min).

Group Size

This activity has been successfully performed in a class of 20 students. In another application, groups of 2 or 3 students performed the activity as an individual research project.

Materials Needed

Small pieces (.5 x .5 cm) of plastic should be cut from large pieces of waste plastic. Each piece should be numbered with a mark that will not be washed off by alcohol solutions (pen, pencil, or scratches with a sharp knife.)

#1	Polyethylene teraphthalate	(PET)	2-liter soda bottles
#2	High density polyethylene	(HDPE)	translucent milk jugs, plastic bags
#3	Polyvinyl chloride	(PVC)	some food containers
#4	Low density polyethylene	(LDPE)	plastic lids
#5	Polypropylene	(PP)	ketchup bottles
#6	Polystyrene	(PS)	clear plastic fast food salad containers
	Plexiglas		plastic windows

Note: Some food containers are composed of multiple layers which may have different densities.

Copper wire can be obtained as electrical wiring pieces. Twelve-gauge wire from which the plastic insulation has been stripped works well. Cut the wire into 10-cm-long pieces. Push into corks as holders to prevent fingers from getting burned by heat conduction through the wire.

Safety, Handling, Disposal

None of the plastics themselves are toxic. Often they are used to store food. However, during the flame test some plastic will be heated and burned. This may produce irritating and perhaps toxic fumes. Hydrogen chloride gas is formed from burning polyvinyl chloride (PVC) plastics. Thus this testing process should be done in a fume hood. The amounts of gases should be held to a minimum by using small pieces of plastic and short testing times. The solutions used to separate the plastics using their densities are quite harmless. The 10:7 ethyl alcohol solution would be flammable and could be disposed of by pouring down the drain followed by large amounts of water so that no flammable alcohol is left in the drain. The salt and Epson salt solutions can also be disposed of using the drain. In using the second option, discourage the students from using solutions made from acids or strong bases. To make solutions of densities less than 1 g/mL, use alcohols. For solutions with densities greater than 1 g/mL, use nontoxic common substances such as salt (NaCl) and Epsom Salt. Dispose of used reagent according to local ordinances.

Points to Cover in the Pre-Lab Discussion

Introduce the project to the students after the study of chemical and physical properties through the use of an unsorted bag of plastic trash. Encourage the students to approach the project first by discussing what properties could most easily be used to separate the plastics. After data has been collected from various sources, steer the classroom discussion in the direction of density. For option 1, the students do not need to know the densities of the plastics, only the densities of the test solutions. For option two, the students need to know the densities of the plastics in order to find what density solutions are needed to separate them.

The concept of the effect of density of an object on its floating and sinking ability should be reviewed. If a material floats, its density is less than that of the solution. Students next need to find how to prepare solutions with densities between the densities of the plastics. Chemical handbooks such as the Handbook of Chemistry and Physics and The Merck Handbook can be used to find this information. The Internet could also be used to find this information, especially the densities of the plastics. I found this information in the Journal of Chemical Education articles in the reference section. In the first option of the laboratory activities, the solutions are already made for the students and they need only find how the solutions interact with the plastics. Thus solution making is not necessary for the students.

A discussion on how to prepare solutions based on percentage by weight is necessary. The Merck Index does a good job of this by calculating all necessary amounts, but only for certain percentage solutions. Their calculations include provisions for any volume change during the dissolving process. Since the densities of the solutions need not be known exactly, the solutions can be made without taking this volume change into account. For example, a 10% by weight salt solution can be made by dissolving 10 g of sodium chloride in 90 mL of water. The Handbook of Chemistry and Physics in the section entitled Concentrative Properties of Aqueous Solutions lists the amount of solute and water needed to make the solution to make a number of different percentage solutions for a large number of solutes.

Safety precautions include those normally necessary for dealing with nontoxic solutions. However, the alcohol solutions would be flammable and must be disposed of carefully so that flammable alcohol fumes do not accumulate in the drains. The fumes from the melting, burning plastic did not present a problem in my laboratory even without a fume hood since such small amounts are placed into the flame. Do not allow students to make solutions from highly acidic or alkaline materials.

The solutions are then tested in lab using the prepared activity sheet. Finally, the students present their process design in the form of a flow diagram.

Procedural Tips and Suggestions

See sample results Table 9.

A difficulty encountered in my classes involved mixing up the different kinds of plastics during the testing, especially the density testing. The samples must be marked with something that does NOT wash off with alcohol. This could be pencil, pen, or even scratches with a sharp object. Surface tension also presented a problem by making some plastic samples float that should have sunk. Make sure that the students shake or stir the solutions. Also the solutions must be completely removed from the samples before proceeding on to the next solution. This must be done without removing the labels.

The formation and use of a dichotomous key may be discussed. The plastic samples could first be put in water and then separated into two groups; those with density greater than 1 g/mL and those with density less than 1 g/mL. Other solutions could then be used to separate each group further.

SAMPLE RESULTS

Table 9. Plastic’s Densities and Reactions with Copper in Flame

Densities of plastics from Journal articles in reference section:

			density	flame
#1	Polyethylene teraphthalate	(PET)	1.39	______
#2	High density polyethylene	(HDPE)	.94-.97	______
#3	Polyvinyl chloride	(PVC)	varies	green
#4	Low density polyethylene	(LDPE)	.91-.94	______
#5	Polypropylene	(PP)	.90-.91	______
#6	Polystyrene	(PS)	1.05-1.07	______
	Plexiglas	(PG)	1.24	______

The numbers above coincide with the numbers which must be molded into every plastic item, usually on the bottom.

PVC is separated by the color flame test. This is necessary since most PVC has considerable fillers added and thus a large range of densities exist.

Table 10. Solutions of Known Densities and Plastics That Float in Each

Solutions which can be used are:

			floating plastic
10-7	Ethyl alcohol in water	D = 0.91 g/mL	#5
1-1	Ethyl alcohol in water	D = 0.94 g/mL	#4
HOH	Distilled Water	D = 1.00 g/mL	#2
NaCl	10% Sodium chloride	D = 1.1 g/mL	#6
$MgSO_4$	26% Magnesium sulfate	D = 1.3 g/mL	Plexiglas
	sunk plastic		#1

See also Figure 4 in Appendix for student flow charts.

Plausible Answers to Student Questions

Question 1. What is the density range of each plastic? (Hint: See densities of solutions above. If a material floats, its density is less than that of the solution.)
Answer 1. See Table 9 above.

Question 2. Draw the structure of each plastic used.
Answer 2. See Appendix, Table 13.

Question 3. How could the density of a plastic be changed?
Answer 3. Fillers are added to plastics to make them opaque, add strength and weight, make them more flexible, etc. This is often done with polyvinyl chloride, so it must be identified by flame test and not density.

Question 4. What other properties of plastics could be used to sort them?
Answer 4. Other properties could include solubility or melting point.

Question 5. Draw a flow chart diagram of the order of your testing method.
Answer 5. See student results in Appendix, Figure 4.

References

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Weast, R. C. Handbook of Chemistry and Physics,47th Edition; The Chemical Rubber Company: Cleveland, 1968, pp D144-D182.

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INSTRUCTOR NOTES

Sorting Plastics by Infrared Spectroscopy

Time Required

The second-year activity is based on the availability of an infrared spectrophotometer. Access to the instrument by several groups at different times is also required. The activity could perhaps require a week of time, with each group or individual using the instrument for about one hour.

Group Size

The activity was performed as a week-long experiment in a second-year chemistry class. The students used the instrument individually but shared data with one another. One student was assigned to each plastic sample as well as one unknown plastic of their own choice.

Materials Needed

Infrared spectrophotometer (The instrument available to the writer was a Beckman IR10 donated from a local college. The plotting mechanism was no longer operable, so the output was sent to an Apple IIe computer using Vernier Voltage Plotter to produce hard copy spectra. A time to wavenumber conversion was necessary. See Appendix for Tables 14 and 15 to do the conversions.) For schools that don't have an infrared spectrophotometer, an instrument or access to an instrument may be obtained from a local college.

Cardboard slide holders for mounting one's own slides
3 x 3 cm sheets of the plastic samples:

#1	Polyethylene teraphthalate	(PET or PETE)
#2	High density polyethylene	(HDPE)
#3	Polyvinyl chloride	(PVC)
#4	Low density polyethylene	(LDPE)
#5	Polypropylene	(PP)
#6	Polystyrene	(PS)
	Plexiglas	(PG)

Safety, Handling, Disposal

Since no expensive and fragile salt plates are needed for this project there is little hazard of harm to the instrument if each student is give sufficient instruction. There is no wet chemistry so no safety precautions are necessary. Be aware of any caution or warning instructions in the instrument operation manual.

Points to Cover in the Pre-Lab Discussion

The theory of infrared radiation interacting with chemical bonds by exciting them to higher energy levels needs to be discussed. Bonds between different kinds of atoms are held together by different amounts of energy. The energy of most bonds coincides with the energy of infrared radiation. Therefore, each bond will absorb infrared radiation of different energy and thus frequency. When the energy is absorbed, the bond's energy is increased to a higher energy level analogous to the interaction between electron energy levels and visible light. The instrument simply scans through a range of infrared energies described by their wavenumber (reciprocal frequency) and produces a graphical presentation of this information called a spectrum. The instrument records the relative amount of infrared passing through the sample. Reference books can be used to interpret the type of bond by the wavenumber of energy absorbed. The spectra produced can be compared to reference spectra. Students should look for absorption peaks which are unique to that type of compound and not to those peaks commonly found in most organic compounds, i.e., those caused by carbon-to-carbon single bonds. An unknown is to be identified by comparison to spectra of known materials, both those produced by the students with known plastic samples and those available in reference books.

We will use the property of how the plastic sheets interact with infrared light. When electromagnetic radiation, such as infrared light, encounters a material, the energy of the radiation determined by its frequency (E=hf)may be absorbed by various types of chemical bonds in the substance. Each type of bond has a different vibrational energy level and will absorb different energies (frequencies) of infrared radiation. A material will be placed into a beam of infrared light. The instrument will scan through a spectrum of different frequencies. Some of the frequency's energy will match the energy needed for a bond to change vibrational energy levels and will be absorbed. The instrument will indicate this by a valley (called a peak) in a graph of relative amount of infrared energy passing through the sample at each frequency. We will use this graph to find a peak at a unique frequency to each plastic which can be used to identify an unknown plastic. The bonds in the Table 11 below produce absorption peaks at the indicated wavenumbers (frequencies):

Table 11. Chemical Bonds and Their Characteristic Wavenumbers.

Bond			Wavenumber (cm-1)
C-H	Alkane	bend	2850-3000
	CH_3	bend	1375 & 1400
	CH_2	bend	1465
	Alkene	stretch	3000-3100
		bend	1000-1700
	Aromatic	stretch	3050-3150
		bend	700-1000
	Alkyne	stretch	3300
	Aldehyde		2800-2900 & 2700-2800
C=C	Alkene		1600-1680
	Aromatic		1400-1600
C≡C	Alkyne		2100-2250
C=O	Aldehyde		1720-1740
	Ketone		1705-1725
	Carboxylic acid		1700-1725
	Ester		1730-1750
	Amide		1810
	Anhydride		1760
C-O	Alcohol, ether, ester, acids		1000-1300
O-H	Alcohol, phenol (free)		3600-3650
	H-bonded		3200-3400
	Carboxylic acids		2500-3300
N-H	Amines		3500
C≡N	Nitriles		2240-2260
N=O	Nitro		1500-1600
			1300-1400
C-X	Fluoride		1000-1400
	Chloride		600-800
	Bromide & iodide		<600

Procedural Tips and Suggestions

See instrumentation instructions specific for the Beckman IR 10 in the student handout.

Sample Results

See Figures 1-3 in the Appendix for typical spectra. Figures 1 and 2 are spectra from handbooks, and Figure 3 is a student-produced spectrum.

Plausible Answers to Student Questions

Question 1. How does a molecule absorb infrared radiation? What does this have to do with the concept of resonance?
Answer 1. The bonds between individual atoms absorb infrared energy by vibrating, rotating, twisting, or bending at higher energy levels. The energy is absorbed when its frequency matches that natural frequency of the bond motion.

Question 2. Infrared radiation does not pass through air easily; it is absorbed after short distances. Why?
Answer 2. The bonds in carbon dioxide and water vapor in air especially absorb in the infrared spectrum.

Question 3. Does it take more energy to stretch, bend, or rotate a bond? Explain.
Answer 3. Whatever motion absorbs at a lowest wavenumber (highest frequency) is the highest energy. Thus in the above table, bending occurs at a lower wavenumber than stretching and therefore requires more energy.

Question 4. What is the difference between a single- and a double-beam IR spectrophotometer? What is an advantage of each?
Answer 4. A double-beam instrument has two identical infrared beams, only one of which passes through the sample. The radiation passing through the sample is compared to the beam which does not pass through the sample and the output spectrum is the difference between them. This is advantageous because different energies are produced by the instrument and absorbed by the sample in different amounts. A single-beam instrument of course does not have this advantage but avoids the complications of making the two beams exactly identical.

Question 5. Choose a wavenumber which is present in each spectrum that is not present in any other. This could be used to distinguish each type of plastic from others.
Answer 5. See Table 12 below.

Table 12. Wavenumbers Specific for Each Plastic

#1	Polyethylene teraphthalate	(PET)	C-O	1000-1300
			C=O	1730-1750
			C=C	1400-1600
#2	High density polyethylene	(HDPE)	C-H	2850-3000, 1375, 1450, 1465
#3	Polyvinyl chloride	(PVC)	C-Cl	600-800
#4	Low density polyethylene	(LDPE)	C-H	2850-3000, 1375, 1450, 1465
#5	Polypropylene	(PP)	C-H	2850-3000, 1375, 1450, 1465
#6	Polystyrene	(PS)	C=C	1400-1600
	Plexiglas	(PG)	C-O	1000-1300
			C=O	1730-1750

Notice that the absorption peaks of plastic numbers 2, 4, and 5 are similar. Small differences in spectra will have to be used to separate them.

Question 6. Design a process which could differentiate the six kinds of plastic from one another using the unique wavenumbers for each found in question 5 above. Summarize the process in the form of a flow chart.
Answer 6. See Appendix, Figure 5.

References

Pavia, Donald L.; Lampman, Gary M.; Kriz, George S. "Introduction to Organic laboratory Techniques, A Contemporary Approach"; Harcourt Brace: Fort Worth, 1988, pp 695-714.

Durst, H. DuPont; Gokel, George; W. "Experimental Organic Chemistry"; McGraw-Hill: New York, 1987, pp 177-184.

APPENDIX

Figure 1. High Density Polyethylene from literature

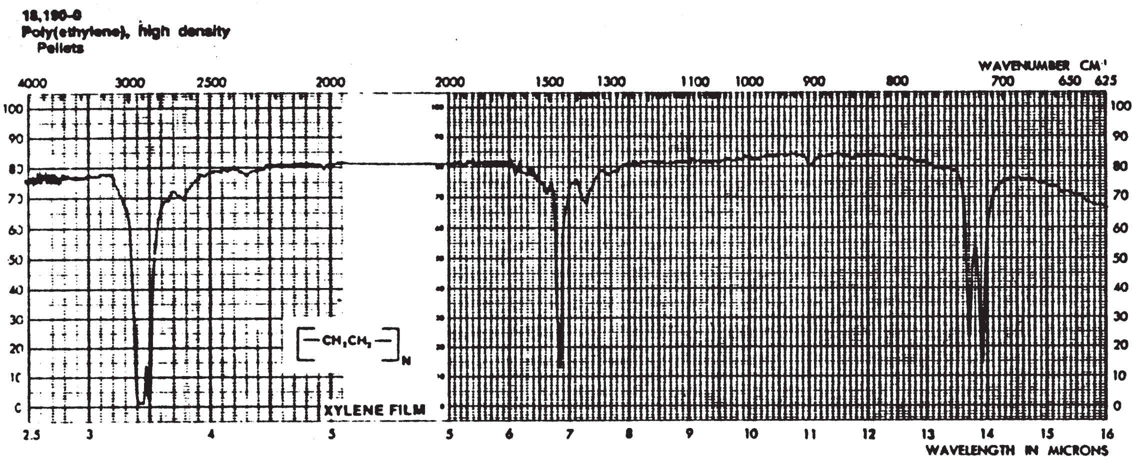

Figure 2. Polystyrene Spectrum from literature

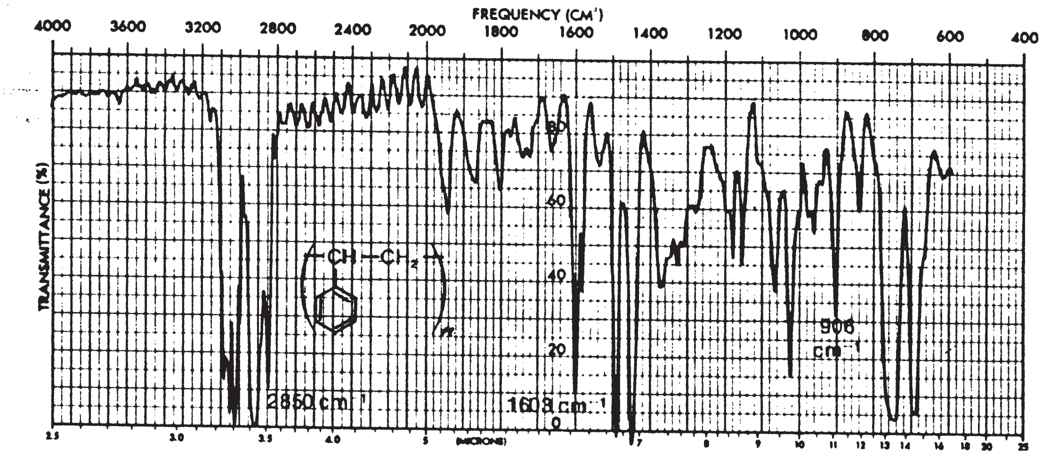

FIGURE 17-8. Infrared spectrum of polystyrene (thin film)

Figure 3. Student High Density Polyethylene Spectrum

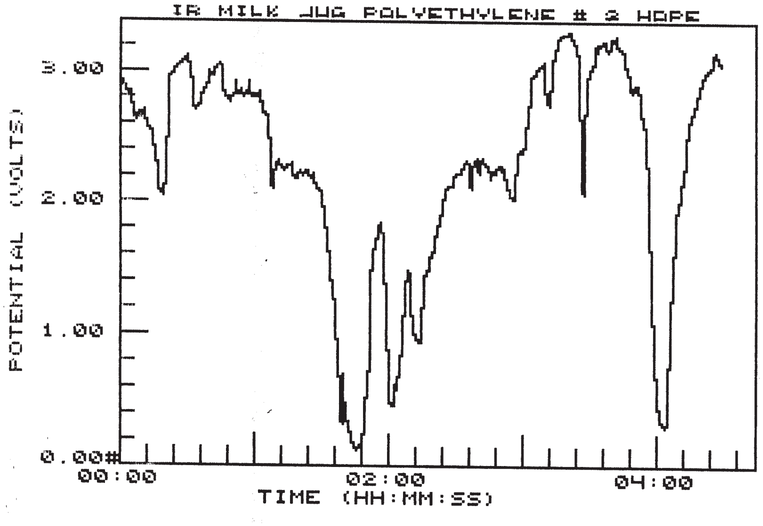

Figure 4. Flow Chart of Separating Plastics by Infrared Spectra

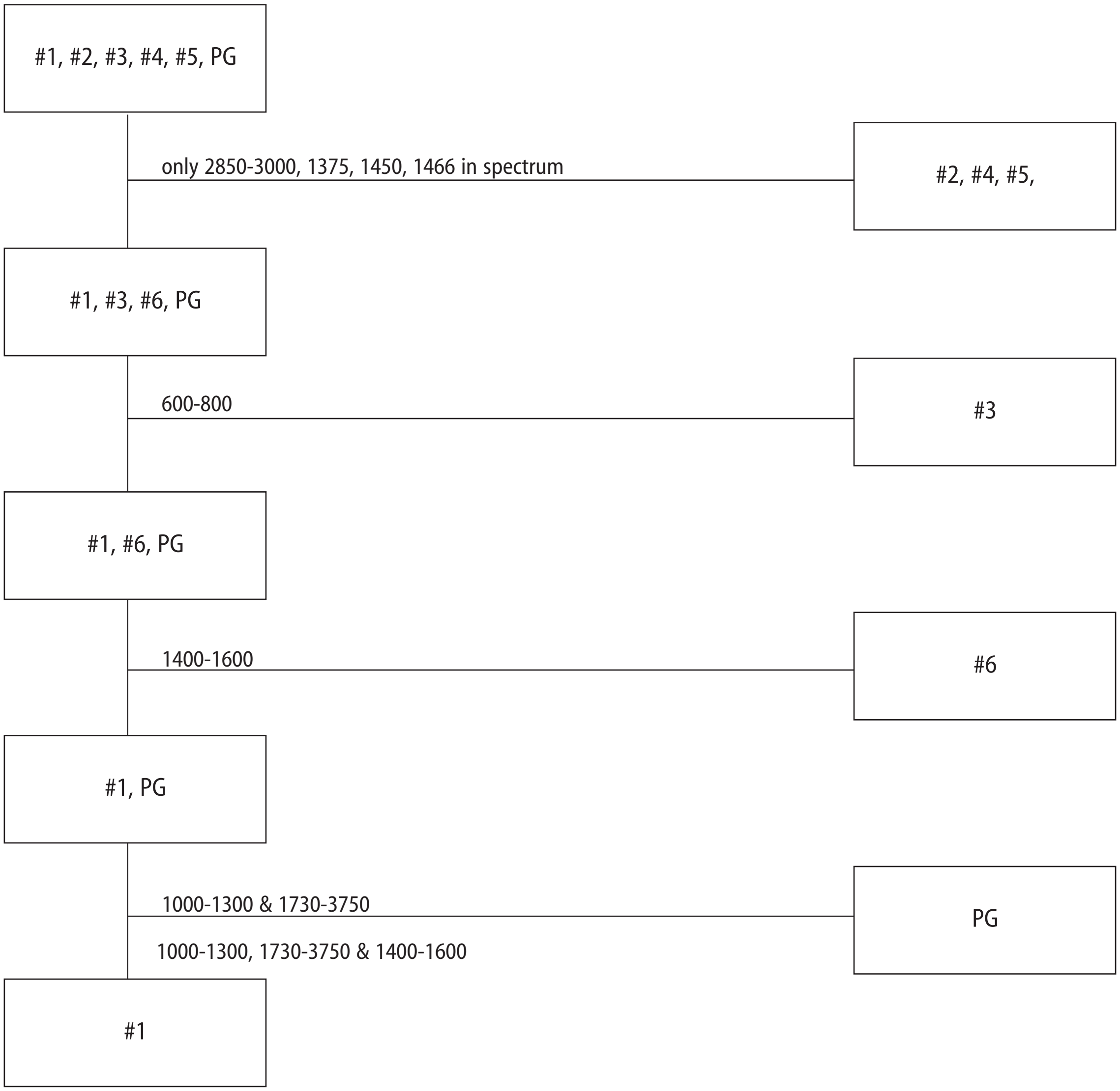

Table 13. Structures of Plastics
(All are polymers; the unit inside the parentheses is repeated a large number of times (n).)

# 1	PET	$(\text{-CH}_2\text{-CH}_2\text{-O-CO-C}_6\text{H}_4\text{-CO-O-})\text{n}$	polyethylene teraphthalate
#2	HDPE	$(\text{-CH}_2\text{-CH}_2\text{-})\text{n}$	high density polyethylene
#3	PVC	$(\text{-CH}_2\text{-CHCl-})\text{n}$	polyvinyl chloride
#4	LDPE	$(\text{-CH}_2\text{-CH}_2\text{-})\text{n}$	low density polyethylene
#5	PP	$(\text{-CH}_2\text{-CHCH}_3\text{-})\text{n}$	polypropylene
#6	PS	$(\text{-CH}_2\text{-CHC}_6\text{H}_5\text{-})\text{n}$	polystyrene
	PG	$(\text{-CH}_2\text{-CCH}_3\text{COOCH}_3\text{-})\text{n}$	polymethylmethacrylate

Note: C_6 in PET and PS in above table are benzene rings.

Figure 5. Flow Chart of Plastic Sorting by Density

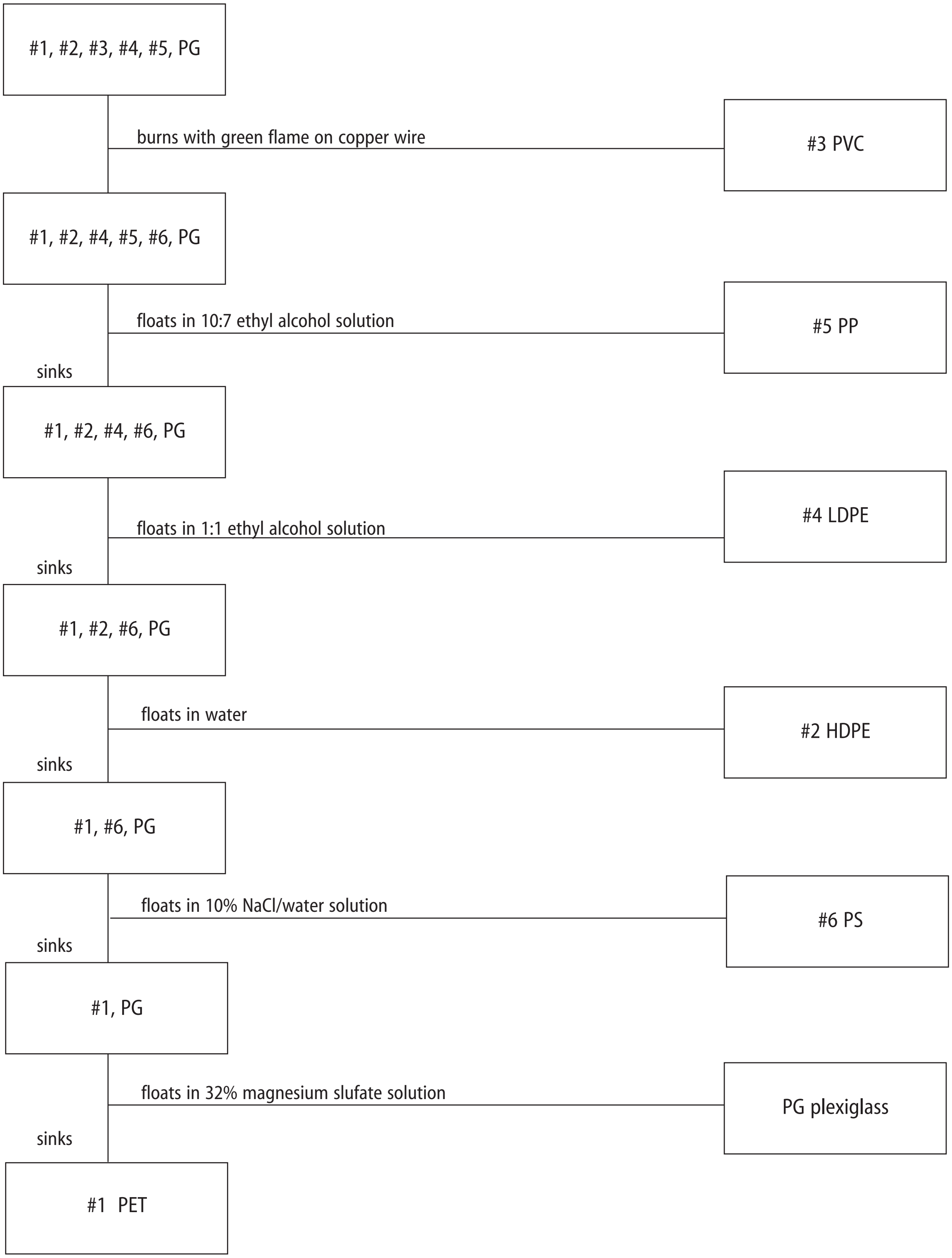

Table 14. Distance to Wavenumber Conversion

2000 to 600 cm-1

Time sec	Wavenumber cm-1	distance cm
0	2000	0
5	1974.075	0.28705
10	1948.15	0.5741
15	1922.225	0.86115
20	1896.3	1.1482
25	1870.375	1.43525
30	1844.45	1.7223
35	1818.525	2.00935
40	1792.6	2.2964
45	1766.675	2.58345
50	1740.75	2.8705
55	1714.825	3.15755
60	1688.9	3.4446
65	1662.975	3.73165
70	1637.05	4.0187
75	1611.125	4.30575
80	1585.2	4.5928
85	1559.275	4.87985
90	1533.35	5.1669
95	1507.425	5.45395
100	1481.5	5.741
105	1455.575	6.02805
110	1429.65	6.3151
115	1403.725	6.60215
120	1377.8	6.8892
125	1351.875	7.17625
130	1325.95	7.4633
135	1300.025	7.75035
140	1274.1	8.0374
145	1248.175	8.32445
150	1222.25	8.6115
155	1196.325	8.89855
160	1170.4	9.1856
165	1144.475	9.47265
170	1118.55	9.7597
175	1092.625	10.04675
180	1066.7	10.3338
185	1040.775	10.62085
190	1014.85	10.9079
195	988.925	11.19495

200	963	11.482
205	937.075	11.76905
210	911.15	12.0561
215	885.225	12.34315
220	859.3	12.6302
225	833.375	12.91725
230	807.45	13.2043
235	781.525	13.49135
240	755.6	13.7784
245	729.675	14.06545
250	703.75	14.3525
255	677.825	14.63955
260	651.9	14.9266
265	625.975	15.21365
270	600.05	15.5007
275	574.125	15.78775
280	548.2	16.0748
285	522.275	16.36185

Table 15. Distance to Wavenumber Conversion

4000 to 2000 cm-1

Time sec	Wavenumber cm-1	distance cm
0	4000	0
5	3974.359	0.203846
10	3948.718	0.407692
15	3923.077	0.611538
20	3897.436	0.815384
25	3871.795	1.01923
30	3846.154	1.223076
35	3820.513	1.426922
40	3794.872	1.630768
45	3769.231	1.834614
50	3743.59	2.03846
55	3717.949	2.242306
60	3692.308	2.446152
65	3666.667	2.649998
70	3641.026	2.853844
75	3615.385	3.05769
80	3589.744	3.261536
85	3564.103	3.465382
90	3538.462	3.669228
95	3512.821	3.873074
100	3487.18	4.07692

105	3461.539	4.280766
110	3435.898	4.484612
115	3410.257	4.688458
120	3384.616	4.892304
125	3358.975	5.09615
130	3333.334	5.299996
135	3307.693	5.503842
140	3282.052	5.707688
145	3256.411	5.911534
150	3230.77	6.11538
155	3205.129	6.319226
160	3179.488	6.523072
165	3153.847	6.726918
170	3128.206	6.930764
175	3102.565	7.13461
180	3076.924	7.338456
185	3051.283	7.542302
190	3025.642	7.746148
195	3000.001	7.949994
200	2974.36	8.15384
205	2948.719	8.357686
210	2923.078	8.561532
215	2897.437	8.765378
220	2871.796	8.969224
225	2846.155	9.17307
230	2820.514	9.376916
235	2794.873	9.580762
240	2769.232	9.784608
245	2743.591	9.988454
250	2717.95	10.1923
255	2692.309	10.396146
260	2666.668	10.599992
265	2641.027	10.803838
270	2615.386	11.007684
275	2589.745	11.21153
280	2564.104	11.415376
285	2538.463	11.619222
290	2512.822	11.823068
295	2487.181	12.026914
300	2461.54	12.23076
305	2435.899	12.434606
310	2410.258	12.638452
315	2384.617	12.842298
320	2358.976	13.046144
325	2333.335	13.24999
330	2307.694	13.453836
335	2282.053	13.657682

340	2256.412	13.861528
345	2230.771	14.065374
350	2205.13	14.26922
355	2179.489	14.473066
360	2153.848	14.676912
365	2128.207	14.880758
370	2102.566	15.084604
375	2076.925	15.28845
380	2051.284	15.492296
385	2025.643	15.696142
390	2000.002	15.899988