PLASTICS RECYCLING EXPERIMENT

Introduction

The purpose of this unit is to introduce science students to plastics and their properties and how these relate to recycling issues. The unit starts by introducing polymers, their structure, and their properties. The discussion extends into the assorted types of commonly used plastics and the general properties of each. After introducing polymers, the focus turns to the recycling process. The various plastic recycling codes are related to the earlier polymer discussion. Finally, an activity for students is included in which they get to test different plastic types and see how the properties relate to the recycling process.

Polymers Background

Soda bottles, food containers, garbage and grocery bags, bullet proof vests, golf balls, glue, pantyhose, and computers are very different in their appearance, feel, and shape, but all belong to the same class of materials—polymers. Most often, materials made of polymers are referred to as plastics and are found in a wide range of applications.

What is it that makes plastics so useful? Many factors play an important role in making plastics the "wave of the future". They are recyclable, lightweight, strong, easily manufactured into many shapes, and cheap.

So, what is a polymer? In short, a polymer is a large collection of many individual molecular chains. These chains are made of many repeating units that have mostly carbon as their backbone. If you were able to look at a section of a plastic bottle zoomed in many times, it would look like a large bowl of cooked spaghetti (without the sauce). Below are two pictures that hopefully will help you visualize what a polymer looks like on a molecular level.

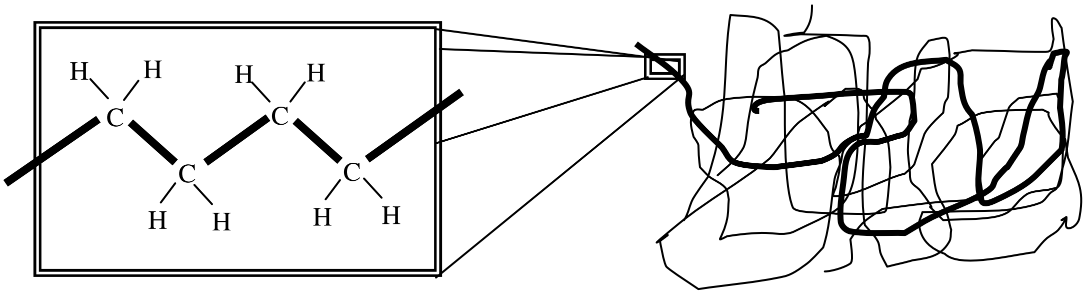


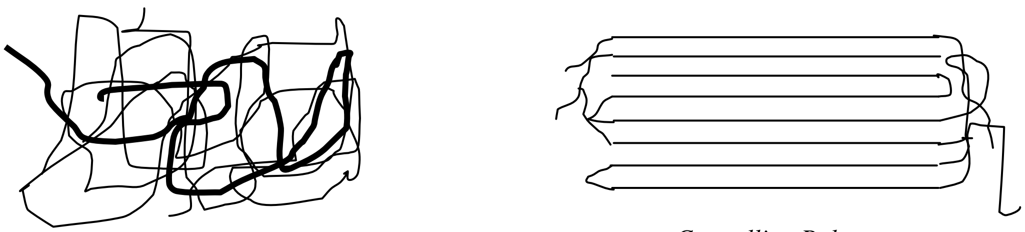
Figure 1. Magnified view of a polymer chain. **Figure 2. A collection of many polymer chains.**

Figure 1, above, shows a highly magnified view of a polymer chain complete with carbon ("C") and hydrogen ("H") atoms. The sticks (or lines) represent the single bonds connecting each atom.

Figure 2, on the other hand, represents a collection of chains that are made from the polymer unit that you see in Figure 1. As you can see from the darkened line, each polymer chain is intertwined with others. Although each chain is made from the same units as seen in Figure 1, each chain is not necessarily the same length.

Because polymers are made of many interconnected chains of varying lengths they are able to exhibit many unique properties. The chemical structure of the repeat unit (Figure 1.), the length of the chain, and the number of chains determine the properties that a piece of plastic will have. Additionally, it is the chains that allow the plastic to be flexible. For instance, when you bend or pull a piece of plastic, you are actually pulling the chains in the polymer past one another, but the chains are entangled enough so that the thing you are pulling does not fall apart.

Not only are polymers able to exhibit flexibility (because of their interconnected chains), but they can come in both clear and opaque (unclear) states. For instance, what is it that makes plexi-glass and soda bottles clear, but computers and plastic chairs not clear? Well, polymers can be classified into two groups: 1. crystalline (semi-crystalline) and 2. amorphous (or non-crystalline). Above, Figure 2 describes a non-crystalline, or amorphous, arrangement of the polymer chains. Below, Figure 3 shows a crystalline polymer. Notice the difference in the arrangement of the chains.



Amorphous Polymer *Crystalline Polymer*

Figure 3. Amorphous vs. Crystalline Polymer

The chains that are lined up are made of the same repeat units as shown in Figure 1, but because the part was manufactured differently, the chains were allowed to align and form a crystalline structure. The regular crystalline structure shown in Figure 3 does not allow light to pass through it. Instead light is reflected and you are unable to see through the piece of plastic. Amorphous polymers (Figure 3) on the other hand, allow light to pass through them and thus, the plastic is clear.

Separate from being able to be clear or opaque, plastics are also easily colored before being manufactured. The next time that you are in a grocery store, take a look at the dairy section. Notice that some plastic milk jugs are clear, while others are yellow. Both are made from the same type of polymer, both are amorphous, yet one is yellow, while the other is clear. The reason for this is because scientists wanted to use the properties of the clear milk jug, but at the same time block out the harmful UV light that spoils milk. So they decided to color the jug—and it works!!

In addition to the different arrangements that the polymer chains may take to give different properties, different polymers are also used to gain desired properties. The example given in Figure 1 is that of polyethylene, a common plastic. Figure 4 is a table that describes some common polymers along with their corresponding names, abbreviations and uses.

Name	Abbreviation	Common Uses	Properties
Poly(ethylene teraphthalate)	PET	Soda (Pop) Bottles	Amorphous, Rigid
High Density Polyethylene	HDPE	Food Containers	Crystalline, Rigid
Polystyrene	PS	Styrofoam Cups	Brittle
Polyvinyl Chloride	PVC	Piping	Hard
Poly(methyl methacrylate)	PMMA	Plexiglass	Rigid, Transparent
Polybutadiene	PB	Automobile Tires	Flexible, Soft
Low Density Polyethylene	LDPE	Garbage Bags	Non-Crystalline, Rigid
Poly(tetrafluoroethylene)	Teflon	Coating in Frying Pans	Non-stick
Polypropylene	PP	Plastic Drinking Straws	Flexible, Tough
Kevlar	Kevlar	Bullet-proof Vests	Stronger than Steel

Figure 4. Table of Common Polymers

In addition to their fabulous properties, plastics are also able to be recycled. Have you ever noticed the little numbers inside a triangle on the bottom of a plastic bottle? This is a code for the recyclers to use. Although plastics are able to be recycled, they are not *easily* recycled. The reason for this is quite complicated and related to thermodynamics.

In order to recycle plastics, they must be melted and then reshaped. However, there is a slight problem. When melted, one plastic does not mix with another type of plastic—this makes recycling difficult and separation necessary. Think of what happens when Italian salad dressing has been sitting around for a while and the oil and vinegar has separated. This is basically what happens when different polymers are mixed together.

Plastic Recycling Codes

As previously mentioned, polymer structure determines the properties of each type of plastic. Polymer structures affect properties such as density, brittleness, and boiling point. In order to separate plastics for recycling, numbers have been assigned to each type of plastic.

NOTE: Numbers 1 and 2 make up the majority of recycled plastics.

1. **PET (Polyethlene Terephthalate)**
   - Ability to contain carbon dioxide makes it ideal for soft-drink containers

   Properties
   - Clear
   - Tough
   - Resistant to Gases
   - Resistant to Moisture
   - Resistant to High Temperatures

   Examples
   - Beverage containers
   - Food containers

2. **HDPE (High Density Polyethylene)**
   - Protective barrier properties make it ideal for liquid containers

   Properties
   - Excellent moisture barrier
   - High chemical resistance

   Examples
   - Milk, orange juice, and water containers
   - Deli food containers
   - Detergents
   - Acid containers

3. **PVC (Polyvinyl Chloride)**
   - Broken up into two categories

   Properties
   - Excellent transparency
   - Excellent chemical resistance
   - Good stability (puncture resistance)
   - Tough

   Examples
   - **Rigid**
     Pipe and fittings
     Siding
     Carpet Backing
   - **Flexible**
     Meat packaging
     Synthetic leathers
     Insulation

4. LDPE (Low Density Polyethylene)

- Used to make bottles that require flexibility
- Used to make grocery bags (due to strength in film form)

Properties

- Toughness
- Flexibility
- Low melting point

Examples

- Film
- Grocery/garbage bags

5. PP (Polypropylene)

- High strength good for making caps and lids
- Can be filled with hot substances (due to high melting point)
- Used for products that are designed to cool in bottles

Properties

- Excellent chemical resistance
- High melting point
- Excellent tensile strength

Examples

- Ketchup bottles
- Medicine bottles
- Automobile battery casings

6. PS (Polystyrene)

- Insulation properties

Properties

- Brittle
- Clear
- Hard
- Insulator (keeps heat from escaping)

Examples

- Restaurant take-out containers
- Egg crates
- Packaging appliances
- Coffee cups

Recycling Background

Plastic recycling has made great gains in the past 20 years. The majority of individuals associate recycling with collection bins and trucks carting away their discarded plastic containers and other recyclables. But what happens to your plastic containers after you drop them off to be recycled? The most common type of plastics recycling in the United States is mechanical recycling. The mechanical recycling process refers to the direct recycling and conversion of plastics, from discarded materials to plastic pellets. These recycled pellets are then reintroduced into the plastic production process to form new products.

Soda bottles, detergent bottles and other household items end up in the recycling stream when consumers place these items in their recycling bins. Plastics, along with other recyclables, first go to a Material Recovery Facility (MRF) where they are sorted, either mechanically or manually (Figure 5), from the other materials such as glass and metals. The mixed plastics are then sorted by type. This occurs at the MRF or at a "handler" who only sorts plastics. These generically separated plastics are separately baled and shipped to a reclaimer.

Figure 5. Manual plastic sorting process

The reclaimer receives bales (Figure 6) of the specific plastic processed at that facility. Most community recyclers process clear and pigmented PET or natural and pigmented HDPE. Upon entering the recycling process, these bales are put through the "Bale Breaker." This machine breaks down the compressed bales into a stream of loose recyclable materials.

Figure 6. The sorted plastics are baled and shipped to recycling reclaimers.

The plastic material is then moved across a shaker screen. This specialized screen filters out small pieces of trash and dirt, which pass into the trash hopper — this constitutes the first contaminant removal step (Figure 7).

Figure 7. The trash hopper cleans out contaminants.

The recyclable plastic materials are then put through a grinding and washing process. They are first cut into small pieces. This liberates labels and other container attachments and facilitates washing. This is then followed by the addition of water to soften and remove contaminants from the newly formed plastic flakes.

The flakes are conveyed into a washing system. Some systems utilize warm water and a cleaning agent. Other systems use water, which is heated by the mechanical action of the wash process. Here residual contents, dirt, and labels are removed (Figure 8).

Figure 8. The flakes are cleaned using water and a cleaning agent.

Mixed plastics and contaminants are then separated utilizing a flotation tank (Figure 9). Different types of plastics have different densities. HDPE is less dense than water and therefore floats. Dirt and denser plastics will sink and be removed. For PET processing the opposite occurs. PET is denser than water and sinks while less dense contaminants are floated away.

In most plastic recycling facilities process water is filtered to remove contaminants and reused.

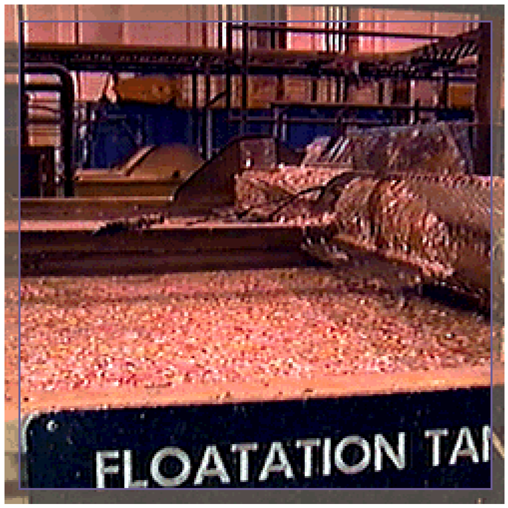


Figure 9. Float tanks are used to separate the different plastic types.

The cleaned separated flakes are then dried by a flow of heated air. An air classifier (Figure 10) is then used to separate film and labels from the plastic flakes. In this process step the flakes fall through an air stream that blows the lighter film particles away from the heavier plastic flakes.

Figure 10. Air Classifier separates labels and film from the plastic flakes.

Plastic flakes are then melted, filtered and formed into pellets through the extrusion process. Then, the plastic flakes are blended in large hoppers to minimize product quality variation. The uniform flakes are fed into an extruder - a rotating screw conveyer inside of a heated barrel. Here the flakes are melted. At the end of the extruder the molten plastic passes through a fire mesh screen where unmelted particle contaminants are removed. The clear melt is forced through a plate drilled with numerous holes (called a "die") forming spaghetti-like strands. As the plastic cools it is rapidly chopped into small pellets (Figure 11).

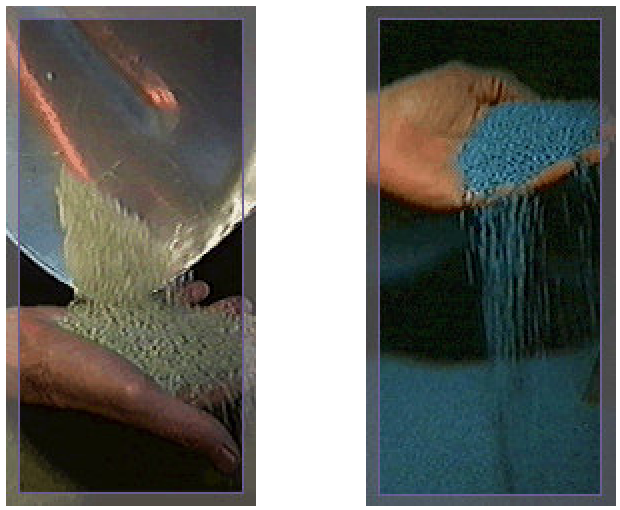


Figure 11. The end result of the recycling process is plastic pellets that can be used in new plastic production.

The pellets are boxed and shipped to product manufacturing plants. The recycled pellets are either mixed with virgin resin, or used in the plastic manufacturing process directly. The resultant recycled materials are found in many applications, such as merchandise packages, drink containers, grocery bags, garbage bags, and house siding.

Plastics Melting Experiment

*Name*________________________

Materials

1 plastic article per student (representing each of the recycling codes)
Hot plate
Properties table (included)
Scissors

Purpose

The purpose of this experiment is to allow you to become more familiar with the properties of plastics. Additionally, you will see how plastics do not mix when melted (as in recycling).

Procedure

1. Prior to the classroom experiment, you should have been assigned to bring into class an article of plastic representing one of the recycling codes.

2. Observe the properties of your piece of plastic and fill in the attached table based on your observations.

3. Exchange your plastic article with another student (or group) and record your observations for that piece of plastic.

4. Keep exchanging pieces of plastic until you have observed pieces of plastic representing all of the recycling codes.

5. After the properties have been observed for each piece of plastic, obtain your original piece of plastic and cut a small piece from it (1”x1”).

6. Give your small piece of cut plastic (done with scissors) to your teacher.

7. The teacher will now demonstrate the difficulty involved in recycling by melting the plastic pieces together and trying to mix them.

PLASTICS MELTING EXPERIMENT WORKSHEET

***Name*_______________________________**

Directions: Using the information that you have read thus far, complete the table below by describing a piece of plastic from each recycling category.

Plastic Article (bottle, bowl, etc.)	**Recycling Code**	**Flexibility (1-10) 1-most flexible 10-least flexible**	**Texture (smooth, bumpy, etc.)**	**Degree of Clarity (1-10) 1-"see through" 10-"not see through"**	**Additional Observations**
	1				
	2				
	4				
	5				
	6				

QUESTIONS

***Name*_________________________**

1. What was the piece of plastic that you had originally?____________________________

2. With the plastic article that you brought into class in mind, do you think that the material used was crystalline or amorphous? What do you base your claim on?
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3. Do you believe that your piece of plastic was colored? If so, why do you think it is colored? (Think about the milk carton).
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4. Why do you believe that your plastic part has the degree of flexibility that it does?
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5. Think of as many things that you can that could be made better if they were made of plastic and explain why you think so.
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6. Based on what you know from this experiment, what type of plastic do you think your article is made of? Why?
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7. Did the plastics mix when the teacher melted them together? Any ideas why or why not?
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