

Sorting Trash with Static Electricity*

by

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Part I – Introduction and the Question

Americans love their trash. According to the United Nations Environment Program, the typical American generates 4.5 pounds of municipal solid waste a day, more than any other nation in the world. Fifty five percent is residential garbage, including household plastics. Many municipalities are running out of space for local landfills so they are looking for ways to reduce waste. Disposal by incineration decreases the volume of the waste material. But the incineration of polyvinylchloride (PVC), used frequently in plastic products, generates hydrogen chloride and other toxins. This leads to air pollution and shortens the life of incinerators. One of the best ways to reduce waste is by recycling.

Waste plastics are typically mixed together when sent for recycling. Many municipalities have residents use one plastic bin and all plastics are placed into the bin. Before these plastics can be recycled, however, they must be sorted. How best to do this? One way would be sorting the plastic by hand at the recycling center. Hand sorting can be difficult, impractical, and expensive. Another method involves separating plastic by their specific gravities. However, this process requires soaking and drying and creates wastewater, another potential problem. Also, this process cannot be used effectively to separate plastics of similar specific gravity.

Another solution to sorting the plastic involves the use of static electricity. Different plastics can be ground up into small pellets and then put together in a large drum. The drum is spun around for a while mixing the plastic pellets. This mixing involves the pellets rubbing around each other. Some types of pellets have electrons rubbed off, creating positive plastic pellets; other types of plastic gain electrons and become negatively charged. The process of rubbing different materials together to exchange electrons (charges) is called triboelectricity. When different combinations of plastic are rubbed together, the amount of charge transferred depends on the separation between the two plastics on the triboelectric series. If different types of plastics can

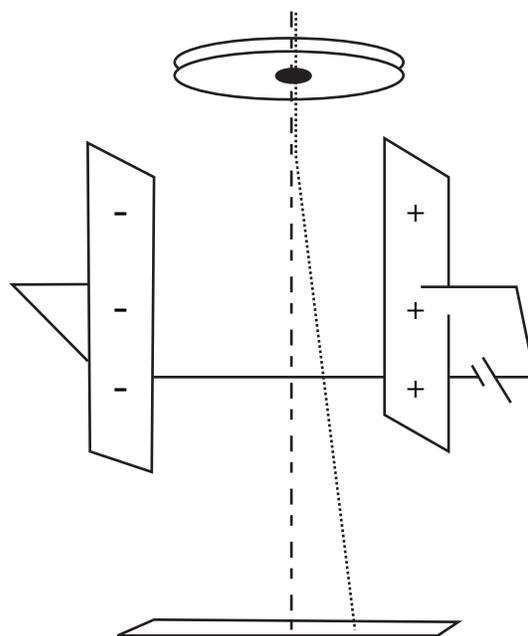


Figure 1: Two types of particles passing through an electric field. The more strongly negatively charged particles are deflected to the right, allowing them to be sorted from the less strongly charged particles. In this diagram, the right plate is positively charged and the left plate is negatively charged.

* This case study is based on a study by Matsushita, *et al.* (1999).

be ground up and differentially charged by rubbing together in a mixer, then allowed to fall through an electric field, it may be possible to sort them.

Additional Information

Here are some physics concepts to help you analyze the case:

- Electric fields (**E**) exert forces (**F**) on objects of charge q according to the formula $\mathbf{F}_{\text{on } q} = q\mathbf{E}$. In this experiment, we can treat the charged particles as point sources.
- According to Newton's 2nd Law of Motion, $\mathbf{F}_{\text{on } q} = m\mathbf{a}$. As particles fall as shown in Figure 1, they undergo a downward acceleration due to gravity and a horizontal acceleration due to the electric field. Thus, it is the horizontal electric field that causes the different charged particles to separate beneath the plates.
- The triboelectric series describes the sign and relative amount of charge picked up when two objects in the series rub against one another. One of the series consisting of different plastics is:
(positive end) PA-PS-PE-PP-PET-PVC (negative end)
where each of the terms represents a different type of plastic*. The farther apart two plastics are in the sequence, the more easily charges can move between them. When PS is rubbed against PE, for example, the PS is charged positively and the PE negatively. Moreover, PS rubbed against PP can be charged positively with more ease than PE rubbed against PP.

Questions

1. What is the basic question of this study and what are its applications for our town?
2. What specific and measurable hypotheses (at least two) can you develop that are supported by the information presented and that address the basic question of this study?
3. What specific and measurable predictions about sorting trash can you make if your hypotheses are correct?

* PA is polyamide, PS is polystyrene, PE is polyethylene, PP is polypropylene, PET is polyethyleneterephthalate, and PVC is polyvinylchloride.

Part II – Hypotheses

Separation Hypothesis

Different plastic bits can be separated into different piles with at least 95% purity when these plastics are charged by rubbing against an appropriate plastic in a mixer. (*Note:* 95% purity means that at least 95% of the plastic bits in a pile are of the same type and of the type predicted to be there.)

Duration Hypothesis

The longer the plastic bits are mixed together in a mixer, the greater the purity after mixing.

Questions

1. Rewrite the two hypotheses of this study in your own words using the “If (some manipulation of the independent variable), then (some response with the dependent variable), because (some scientific reason)” format, making sure any vague aspects are clarified. If the hypotheses you wrote in Part I address the ideas stated above, you may use them again here.
2. Describe how you could use the concepts of electric force and kinematics (displacement, velocity, and acceleration) to analyze the separation of pieces of plastic in an electric field. List the specific relationships (formulas) that can be used in the analysis.
3. How can you use the triboelectric series to determine the sign and relative charge on different objects?
4. Design an experiment to test each of the hypotheses in Question 1 above. Be specific, describing what you would do, number of trials, devices needed, and method of analysis for each experiment.

Part III – The Experiments/Observations

Different plastics are ground up into pellets and put into a mixer. The plastic pellets become charged by rubbing against each other and the mixer parts during this process. The mixed plastics are poured into the separator unit, pass through a horizontal electric field, and are separated according to their properties (Figure 2). A DC power source produces a horizontal electric field ($4.0 \times 10^5 \text{ N/C}$) between parallel plate electrodes. A recovery receptacle with three sections is placed under the parallel plate electrodes. Negatively charged plastic pellets end up in the ground-electrode zone (GZ). (For the purposes of this case study, you may consider this electrode positively charged in comparison to the negative electrode.) Neutral pellets end up in the intermediate zone (IZ). Positively charged pellets end up in the negative-electrode zone (NZ). While the mixture falls from the top to the bottom of the partition plate (24 cm), the plastic pellets in the mixture are subject to an attractive force from either the ground/positive electrode or negative electrode depending on the polarity of the pellet's charge. Plastic pellets with a sufficient negative charge are attracted to the ground electrode and fall into GZ, and those with sufficient positive charge fall into NZ. Plastic pellets not charged at all or insufficiently charged fall into IZ. The intensity of the electric field and the height of the partition plate are adjusted to appropriate values in accordance with the amount of charge and the weight of a plastic pellet.

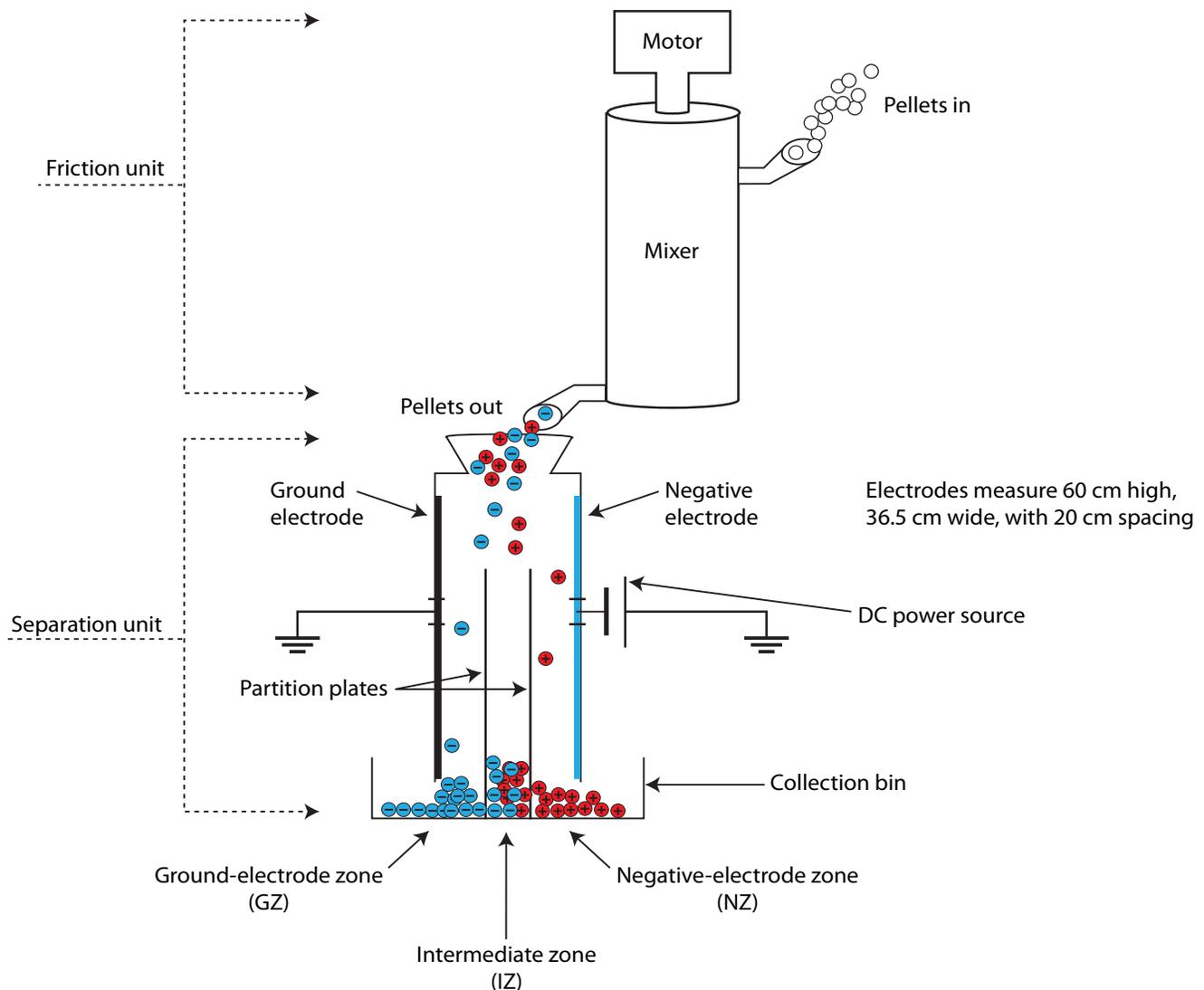


Figure 2: The experimental set-up. When analyzing this case, consider the ground electrode to be positively charged.

In the first experiment, the separation of a mixture of PS (polystyrene) and PE (polyethylene) was compared with a mixture of PP (polypropylene) and PVC (polyvinylchloride) to determine how the separation purities compared. Each mixture was stirred for 10 minutes and the relative purities of plastic in each zone were compared.

Summary of Experiment 1 – Separation of two plastic mixtures

Independent variable: PS + PE vs. PP + PVC

Dependent variable: Purity level

Constant variable: Each mixture stirred for 10 minutes

In the second experiment, separate PE and PP mixtures were stirred for 10 minutes, 20 minutes, or 30 minutes. The relative purities of plastic in each zone were compared. Each of the three mixtures described above consisted of 50% of each type of plastic.

Summary of Experiment 2 – Separation of one plastic mixture PE + PP

Independent variable: Stirred for three different timing durations (10 vs. 20 vs. 30 minutes)

Dependent variable: Purity level

Constant variable: Same two plastics

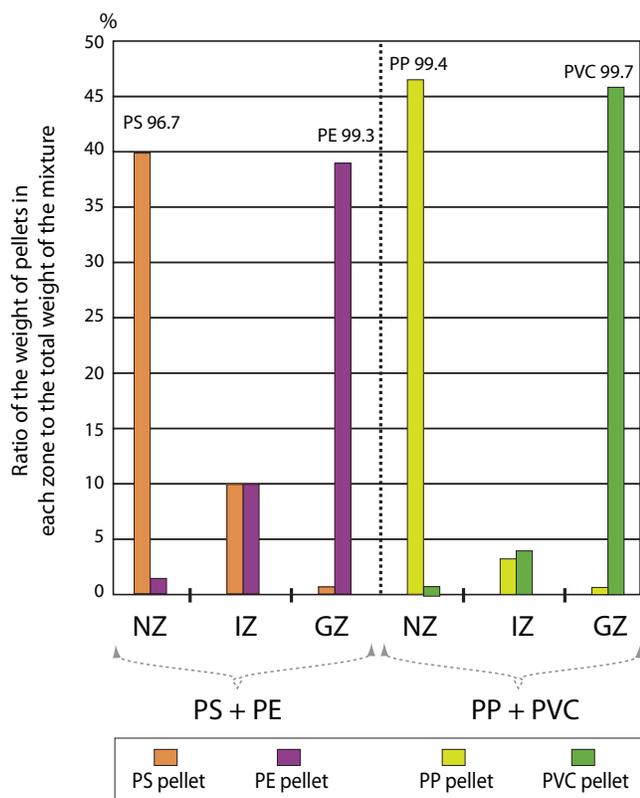
Questions

1. Given the experimental set-up and the triboelectric series listed earlier, sketch a graph of what the data would look like if the separation hypothesis you wrote in Part II is true. Please explain your reasons for saying the data would look like this. (*Note:* when sketching your graphs in this section, put whatever parameter you listed in your hypothesis after the word “If” on the x-axis and whatever parameter you listed in your hypothesis after the word “then” on the y-axis.)
2. Given the experimental set-up and the triboelectric series listed earlier, sketch a graph of what the data would look like if the separation hypothesis you wrote in Part II is false. Please explain your reasons for saying the data would look like this.
3. Given the experimental set-up and the triboelectric series listed earlier, sketch a graph of what the data would look like if the duration hypothesis you wrote in Part II is true. Please explain your reasons for saying the data would look like this.
4. Given the experimental set-up and the triboelectric series listed earlier, sketch a graph of what the data would look like if the duration hypothesis you wrote in Part II is false. Please explain your reasons for saying the data would look like this.

Part IV – Results

Separation Hypothesis

Figure 3: The distribution of the component pellets in the PS + PE and PP + PVC mixture after the 10 minute separating process.



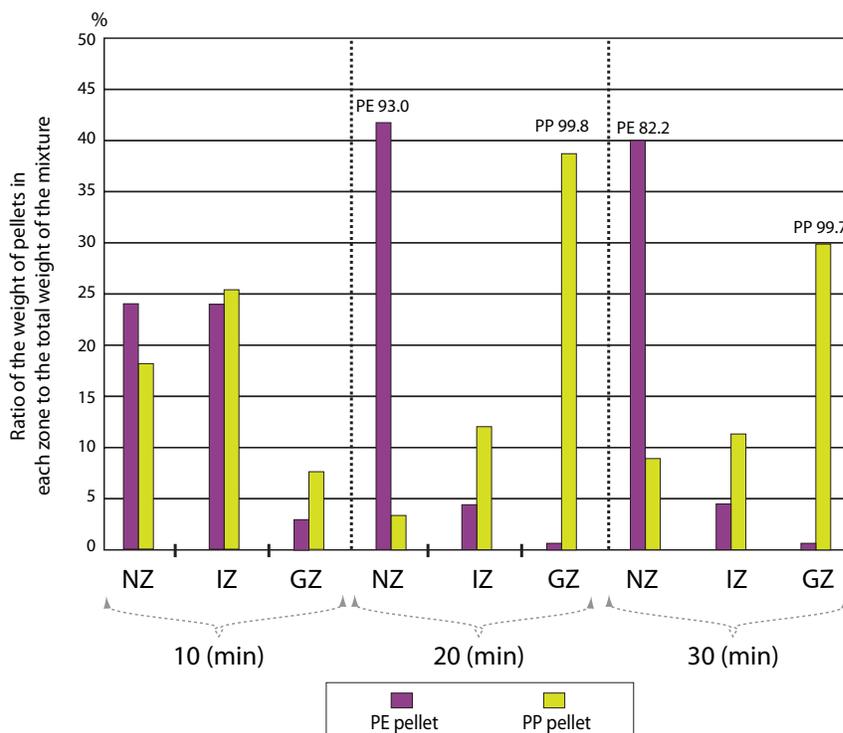
The x-axis shows the three zones and the y-axis shows the ratio of the weight of pellets separated into each zone to the total weight (300 g) of the mixture of pellets. The sum of the heights of the six bars (two bars for each zone) is 100% because each pellet must be accounted for in one of the zones. A notation such as “PS 96.7” indicates the purity. In this example, 96.7% of the material in that zone is PS.

When fewer pellets fall into IZ and the purities in NZ and GZ are high, the mixture of pellets is said to be effectively separated. If pellets are sufficiently charged in the mixing process, the horizontal displacement of each falling pellet increases and the fraction of pellets falling into IZ decreases.

Duration Hypothesis

Figure 4: The results of separation of PE + PP after different mixing times.

Both the PE and the PP pellets fall into NZ and IZ and are not separated when the mixing time is 10 minutes. This indicates that both PE and PP pellets are charged positively, not by contact with each other, but by contact with the same thing—the mixer. When the mixing time is 20 minutes, the particles are much more separated and the purity increases. When the mixing time is lengthened to 30 minutes, more PP pellets appear to be undergoing increased friction with the mixer and gain a positive charge, while the charging of PE pellets by friction levels off. Thus, the purity appears to decrease after 20 minutes. Since PS and PE in Figure 3 are separated even when the mixing time is 10 minutes, the optimal mixing time depends on types of materials being mixed.



Questions

1. Summarize what Figure 3 tells you about the validity of the separation hypothesis in Part II.
2. Summarize what Figure 4 tells you about the validity of the duration hypothesis in Part II.
3. How do your hypotheses compare with the experimental results?
4. Use the triboelectric series to explain the results of Figure 3 and 4. Specifically, why are more particles in the intermediate zone in the PS+PE mixture than in the PP+PVC mixture? Why did the purity of the PE+PP mixture increase from 10 to 20 minutes?
5. Summarize how we can apply these results to making recycling more efficient. Be sure to list both pros and cons to this method.

References

Matsushita, Y., Mori, N., and Sometani, T. (1999). Electrostatic separation of plastics by friction. *Electrical Engineering in Japan* 127(3): 33–39.



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