Activity: Hot Air Balloon

FOR THE TEACHER

Summary
In this activity, students use their knowledge of Charles’ law to build a hot air balloon and evaluate its design.

Grade Level
Middle School, High School

NGSS Alignment
This lab will help prepare your students to meet the performance expectations in the following standards:

- **MS-PS1-4**: Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.
- **MS-ETS1-2**: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- **Scientific and Engineering Practices**:
  - Asking Questions and Defining Problems
  - Constructing Explanations and Designing Solutions

Objectives
By the end of this lesson, students should be able to

- Explain Charles’ law
- Build and evaluate a functioning hot air balloon

Chemistry Topics
This lesson supports students’ understanding of

- Gas laws
- Charles’ law

Time
**Teacher Preparation**: 30 minutes
**Lesson**: 40 minutes to construct, 20 minutes to launch (extension: 40-60 minutes)

Materials
- Thin plastic trash bags (1 per group, see Teacher Notes for important details)
- Aluminum foil
- Ruler
- Marker
- Straws
- Birthday candles (5 per group)
- Tape
- String/thread (for controlling the balloon after liftoff)
- Scissors
- Lighter/matches

Safety
- Always use caution around open flames. Keep flames away from flammable substances.
- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- When students complete the activity, instruct them how to clean up their materials.

Submitted by
Noreen Scarpitto
Reading Memorial High School
Reading, Massachusetts
Teacher Notes

- Prelab question #1 should be answered individually, but prelab question #2 must be answered as a class.
- Here is guide on balloon construction with pictures/videos to demonstrate each step: https://www.wikihow.com/Make-a-Mini-Flyable-Hot-Air-Balloon-with-Candles
- The trash bag is the trickiest thing to get – there are almost no bags that you can get at the grocery store that would work, as they are all too heavy (yes, even the most “bargain brand” ones you can find). Your best option is to get small trashcan liners from the school janitor. The plastic should be rated at about 6 microns (or 0.24 mil) thick. One size that has worked well is 24” x 33”, or about 12-16 gallons. You could order these yourself, but you usually can’t get less than 1000 at a time. Here I found them in a pack of 300: https://www.amazon.com/Office-Clear-Trash-Liners-Gallon/dp/B011QKA1JM
- Alternatives to the trash can liners are dry cleaning bags for shirts (shorter, not the kind the uses for longer garments) with the hole at the top taped closed (but the tape adds weight) or extra-large produce bags from the grocery store.
- Remind students to be very careful when lighting the candles. The flame should not come into contact with the trash bag or it will melt/shrivel up and be ruined. Groups of three may be advisable to have two students working with the bag for the launch.
- If you have trouble getting liftoff, you can cut the candles in half so there is less weight pulling down on the bag. Also make sure you are using as little tape as possible.
- If doing this activity with a middle school class, the teacher should be the constructor. It’s best done as a demo for safety reasons.
- This activity should be done outside if possible, but if it is raining or too windy, a large high-ceilinged room like the gym or auditorium will work well.
- After the balloons are launched, students should have a chance to discuss/compare results with other groups, or a whole-class discussion can be facilitated to allow students to compare data. They will need to do the same if you do the extension activity.
- If you do the extension activity, you can also meet the following standards:
  o **MS-ETS1-3**: Analyze data from tests to determine similarities and difference among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
  o **MS-ETS1-4**: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be reached.
- If you do the extension activity, the students will need to ask for your approval on what design feature they will change. You may want to make sure that different groups choose different features to modify. Alternatively, the class might brainstorm modifications as a group and then you can assign which ones will be made by which groups.

For the Student

Lesson

Hot Air Balloon

Background
Consider a hot air balloon. Gases expand when they are heated. Because the particles in the hot air move farther apart from one another than particles in the cool air, the hot air becomes less dense than the cool air. This difference in density allows the hot air balloon to rise. Jacques Charles (1746 – 1823) was a French scientist who studied gases. According to Charles’ law, the volume of a gas increases as the temperature of the gas increases, as long as the pressure remains constant. In equation form the law is written as:

\[ \frac{V_1}{T_1} = \frac{V_2}{T_2} \]
Charles’ law can be explained using the kinetic theory of matter. As a gas is heated, its particles move faster and faster and its temperature increases. Because the gas particles move faster, they begin to strike the walls of their container more often and with more force. In a hot air balloon, the walls have room to expand so instead of increasing in pressure, the volume of the balloon increases.

Since you are currently studying the gas laws, you will perform an activity that investigates Charles’ Law.

Prelab Questions
1. You will be building a hot air balloon and asked to evaluate how well it worked. What are at least two specific criteria you could measure (with numbers) “how well the balloon worked”?
2. Before building your balloon, share your answers to #1 with the class. Then, decide as a class which criterion you are going to use to determine whose balloon “worked best.” Write it below.

Purpose
To test Charles’ Law by constructing a hot air balloon from a plastic trash bag, and to evaluate the product and suggest improvements.

Safety
- Always use caution around open flames. Keep flames away from flammable substances.
- Always wear safety goggles when handling chemicals in the lab.
- Wash hands thoroughly before leaving the lab.

Materials
- Thin plastic trash bags (1 per group)
- Aluminum foil
- Ruler
- Marker
- Straws
- Birthday candles (5 per group)
- Tape
- String/thread (for controlling the balloon after liftoff)
- Scissors
- Lighter/matches

Procedure
1. Measure, in centimeters, the opening of the bag when laid flat on a surface. This is the diameter of the opening. Multiply it by 0.7. For example, if the bag measured 40.0 cm, the calculation is 40.0 cm x 0.7 = 28.0 cm. This will be the length of one of the straw pieces.
2. Cut off the flexible end of the straw, close to the ridges. Compress one end of the straw piece and insert it into another straw piece. Secure with a small piece of tape. Continue to combine straws until you reach the length you need. Make another straw piece of the same length.
3. Mark the center of each straw piece. Attach the straws together in a “plus sign” by lining up the marked centers. Secure the + with a piece of tape. Use tape sparingly. For the balloon to lift, it cannot be too heavy!
4. Cut a square piece of aluminum foil measuring 10.5 cm x 10.5 cm.
5. From the center of each of the four sides, measure in 2.5 cm and make a mark. These points will be the positions of the candles.
6. Fold up the edges of the foil so there is a lip of about 1 cm on each side. This will catch melted wax before it drips off the edge of the foil.
7. Using one of the candles as your flame source, heat the bottom of another candle, allowing the wax to drip on a point marked on the foil. Press a candle into the wax and hold for 30 seconds. Repeat this process to attach all four candles to the foil. Wait a minute in between attaching each candle so the wax can harden. Be careful not to burn yourself. At this point, no candles should be lit.
8. Attach the foil and candles to the center of the straw construction. Secure each corner of the foil to a straw using a small piece of tape. Wait a few minutes to be sure the wax has hardened.
9. One person should hold the plastic trash bag open. The other person should invert the straw/candle base and attach the end of each straw to the edge of the bag by folding over a small amount and using a small piece of tape.
10. Securely tape or tie one end of a spool of fishing line/thread/string to the cross section of the straws. This tether is needed so the balloon can be retrieved if it flies very high and so you can maintain control of the balloon.
11. Be sure all pieces are secure. Now you are ready to launch!

Launching the Balloon
1. One person will hold the plastic bag vertically, from the top, while the other person carefully lights each of the candles. **Do not light the plastic bag on fire!** If this happens, it will shrivel, create a hole, and will not fly.
2. Lower the bag to the floor, gently hold the bag vertically. Be patient as the bag will begin to expand. The bag may begin to move horizontally across the floor at first but will eventually rise. When you start to get lift, let the balloon go on its own. Give the balloon plenty of slack as it rises. Guide the balloon as it flies to keep it away from any flammable materials and in the designated area.
3. Do not jerk the tether as it will cause the wax to roll off of the foil. After a few minutes of observing your creation, begin to gently reel in the balloon. The birthday candles burn quickly, and you do not want the candles to burn down and catch the foil or straws on fire.

You are responsible for controlling the flight of your hot air balloon. Maintain control of it at all times!

Results
Record any data regarding your balloon’s flight that will help you evaluate how well it flew based on your answers to the prelab questions. Organize and label it clearly in the space below.

Analysis
1. Why does a hot air balloon float? (Think about the difference between the air inside the balloon and the air outside the balloon.)
2. According to the criterion for balloon quality your class selected in your answer to Prelab Question #2, how well did your balloon work compared to those of your classmates? Whose balloon was best?

3. Provide at least two suggestions for ways you might improve your balloon’s performance.

**Conclusion**

Explain in your own words how this activity exhibits Charles’ Law. Draw a diagram of the air particles in the balloon before and after lighting the candles to accompany your explanation.

**Extension Activity**

**A Better Hot Air Balloon!**

**Background**

You have built a hot air balloon and evaluated its performance compared to certain standards/criteria. Now you are going to determine how to improve the design of your balloon!

**Problem**

How can you improve the design of your hot air balloon?

**Procedure**

Choose one feature of the construction of your balloon to change to try to make it perform better according to the criterion set by the class in the prelab questions. Get approval from your teacher *before you start making your changes!* Once you have approval, take apart/rebuild the balloon with these changes, relaunch your (hopefully) new and improved balloon, and record the results.

**Results**

Record any data regarding your balloon’s flight that will help you evaluate how well it flew based on your answers to the prelab questions. Organize and label it clearly in the space below.

**Analysis**

1. What change did you make in your balloon’s design? Why did you choose to change that feature?
2. Did the change you made actually improve your balloon’s performance? If so, by how much?
3. Compare the design adjustment you made to one of your classmate’s. Whose adjustment made more of a difference? Why do you think that is?