Educational Innovations Inc.®

TEACHERS Serving TEACHERS!®

Microscale Vacuum Apparatus

VAC-10 / VAC-16

Students can now safely produce a vacuum in a small bell jar right at their lab stations. By reducing the pressure in our microscale bell jar, they can expand a balloon, boil warm water, and even transfer liquids from one pipet to another. They can watch a marshmallow or shaving cream increase in volume as the pressure is reduced and learn about how extremely low pressure affects the world around them. Instead of passively observing a demonstrator, students can actively experiment on their own and observe the results right before their eyes.

More advanced high school and college level students can study Boyle's and Raoult's Laws and finally understand the relationship between vapor pressure, temperature, and boiling point. Included with the full instructions and guide is a bonus set of Educational Innovations ideas to challenge you and your students. (See other side.)

Kit includes 8.5 cm (3.5") bell jar, base plate, vacuum pump syringe, suction cup, pipets, and instructions.

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NGSS Correlations

Our Microscale Vacuum Apparatus and these lesson ideas will support your students' understanding of these Next Generation Science Standards (NGSS):

Elementary

2-PS1-2
Students can use the Microscale Vacuum Apparatus to test a variety of materials; plan and conduct an investigation to describe and classify different kinds of materials by their observable properties.

3-PS2-1
Students can use the Microscale Vacuum Apparatus to plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

K-2-ETS1-2
Students can use the Microscale Vacuum Apparatus in an investigation and develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem.

3-5-ETS1-3
Students can use the Microscale Vacuum Apparatus to plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Middle School

MS-ETS1-2
Students can use the Microscale Vacuum Apparatus to test and evaluate design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

High School

HS-ETS1-2
Students can use the Microscale Vacuum Apparatus to test and design a solution to complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Suggested Science Idea(s)

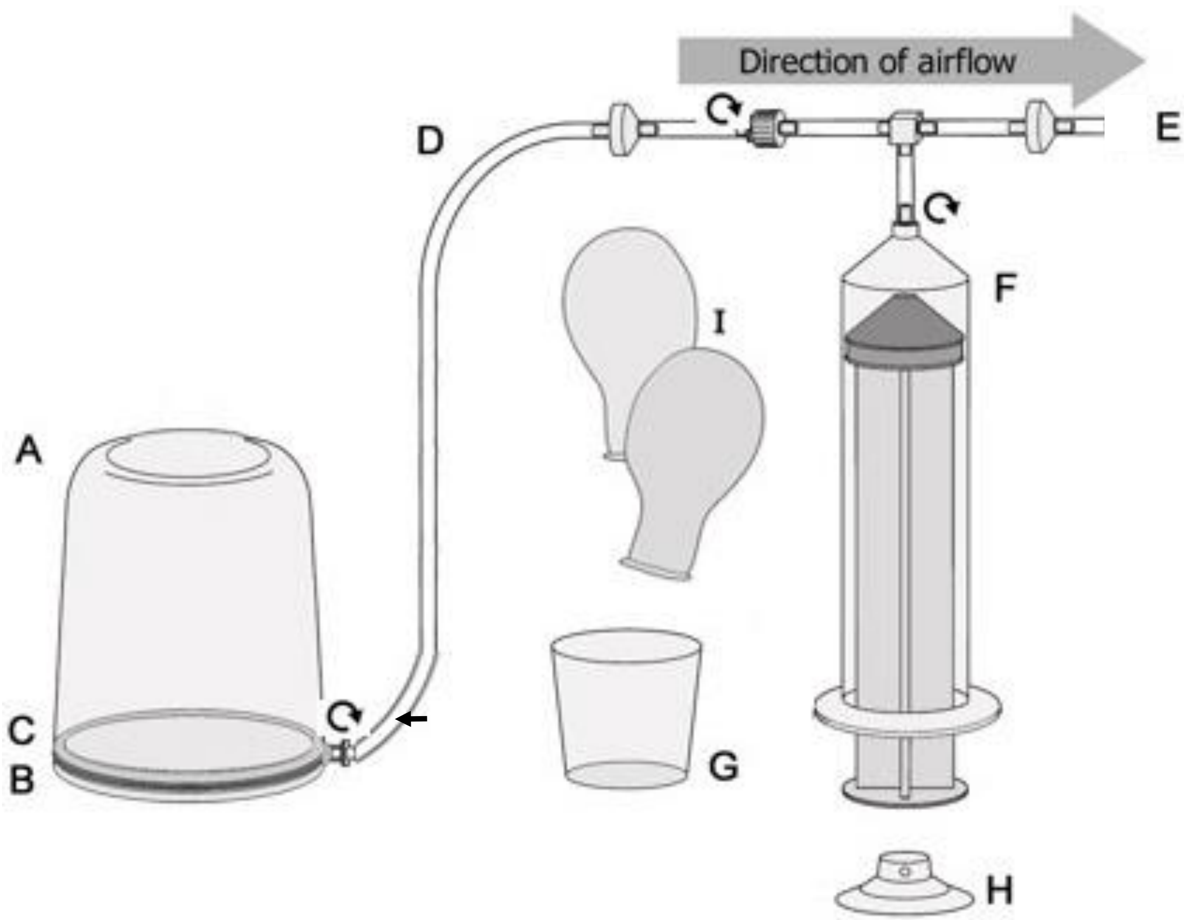
2-PS1-2 • 3-PS2-1 • K-2-ETS1-2
Students can use the Microscale Vacuum Apparatus to experiment and investigate the effects of the vacuum or fluctuations of air pressure on solids, liquids, and gases. Place shaving cream in the apparatus and evacuate the air. Then return the air and make observations. Use a variety of materials to classify them.

3-5-ETS1-3 • MS-ETS1-2 • HS-ETS1-2
Observe the Microscale Vacuum Apparatus in action. What purpose does it serve? Design, construct and test your own apparatus that solves a real world problem.

Introduction

The Transparent Devices Bell Jar and Vacuum Pump Set is intended to be used as a replacement or an addition to a traditional large-scale bell jar apparatus used for demonstrations regarding the topic of air pressure. Because of its small size and ease of use, including the transparent nature of the included pumping mechanism itself, it is designed to be used in the hands of students and fits perfectly with the concept of inquiry based science education.

This manual includes instructions to teachers wishing to use a traditional worksheet-assisted experimental model of scientific investigation, including copy-ready student worksheets and answer key, as well as suggestions on how to use the apparatus with a more open-ended inquiry approach.



Contents of Set

This set includes the following items:

- Bell Jar, polycarbonate
- Base Plate
- "O" ring set in Base Plate
- Hose with check valve and fittings (coupling at one end connects to base (B) and the other end connects to the syringe assembly (E))
- Hose with tee, check valve, and fittings (connects (D) and (F))
- Syringe (60 ml)
- Clear plastic vial
- Suction cup
- Two balloons, (9 inch if fully inflated)
- This instruction manual

Recommended for some of the labs but not included:

1. A balance capable of reading to the hundredths place
2. A plastic bucket or tub capable of submerging the bell jar
3. Hot, but not scalding water
4. Towels for wiping up water spills
5. Marshmallows, shaving cream, or bubble wrap with large bubbles

Care of the Apparatus

The "O" ring, part (C), and the surfaces it contacts, should be kept clean and protected from abrasion or other abuse that might cause scratches.

(Scratches might provide paths for air leakage. If needed, vacuum grease may be used to overcome slow leaks caused by small scratches. However, grease attracts dirt, so should be used only if actually required.)

The rubber seal in the syringe does not normally require lubrication. If required, glycerol (glycerin) may be used as a lubricant. Pure <u>silicone</u> oil may also be used. Never use other oils or grease, which will quickly damage the seal.

If necessary, clean the bell jar and bottom plate with a soft cloth and a mild dishwashing soap. Do not use harsh agents such as organic solvents or abrasive cleansers.

Safety Considerations

This set is intended to be used by teachers, and their students while working under appropriate supervision.

Generally...

Please teach and expect safe behavior in your classroom and lab. Safety considerations call for supervision of students at all times, use of safety eyewear, no horseplay, no unauthorized experimentation, and the immediate reporting to the instructor of accidents or breakage, among others.

More Specifically...

Any liquids entering the pump are apt to be discharged as a mist or spray. Only safe liquids such as water should be used in association with the pump, and safety eyewear is definitely required.

Do not put items in the bell jar that would be damaged by, or cause damage as a result of, reduced pressure. Examples would include sealed containers, wristwatches, batteries, etc. Certainly animals should not be placed in the bell jar, for reasons of law and human decency.

Do not use the apparatus if the bell jar or bottom plate have become cracked or otherwise damaged.

Teacher Instructions for Experiment 1: Action of a Vacuum Pump and the Nature of Air Pressure

1. Be sure to read the student worksheet and answer key below BEFORE attempting the lab with students. It is even suggested that you work through the lab yourself to note any difficulties your students may encounter as they work their way through the lab.

2. The lab experience is designed to be completed in groups of two or three students. Single students will physically have trouble completing some of the tasks, and groups of more than three will likely have too many students to be fully engaged with each task.

3. **EXTENSIONS:** Try having students predict and design a test for what would happen if they placed a marshmallow, shaving cream, or a piece of bubble wrap in the bell jar. Note that these will increase in volume when the pressure is decreased around them, but will decrease in volume from their original volume when air is let back into the bell jar because all three are made up of small, individual cells of air that break or leak when expanded under low pressures. Bubbles of bubble wrap may break if the bubbles are large, or merely expand and leak somewhat.

Answer Key to Experiment 1: Action of a Vacuum Pump and the Nature of Air Pressure

1. Air
2. From the bell jar
3. Out of the unattached end of part E
4. Not much force
5. Friction and atmospheric pressure pushing in on the piston
6. The force needed increased.
7. There was less and less air pressure inside trying to push the piston out.
8. Nothing or at least very little air (vacuum, partial vacuum)
9. Air entered the bell jar
10. It grows larger.
11. The pump removed air surrounding the balloon that had been pressing inward. The air inside the balloon is still pressing outward, so it expanded.
12. Air moves back into the bell jar and crushes the balloon back to its original size.
13. Students may give a variety of explanations involving suction. A better explanation is that there is reduced pressure inside the suction cup, but greater pressure outside the suction cup.
14. The suction cup falls off. The pump has removed the outside pressure that held the suction cup on the surface.

Experiment 1 Worksheet
Action of a Vacuum Pump and the Nature of Air Pressure

Name(s): ___________________________ ___________________________ ___________________________

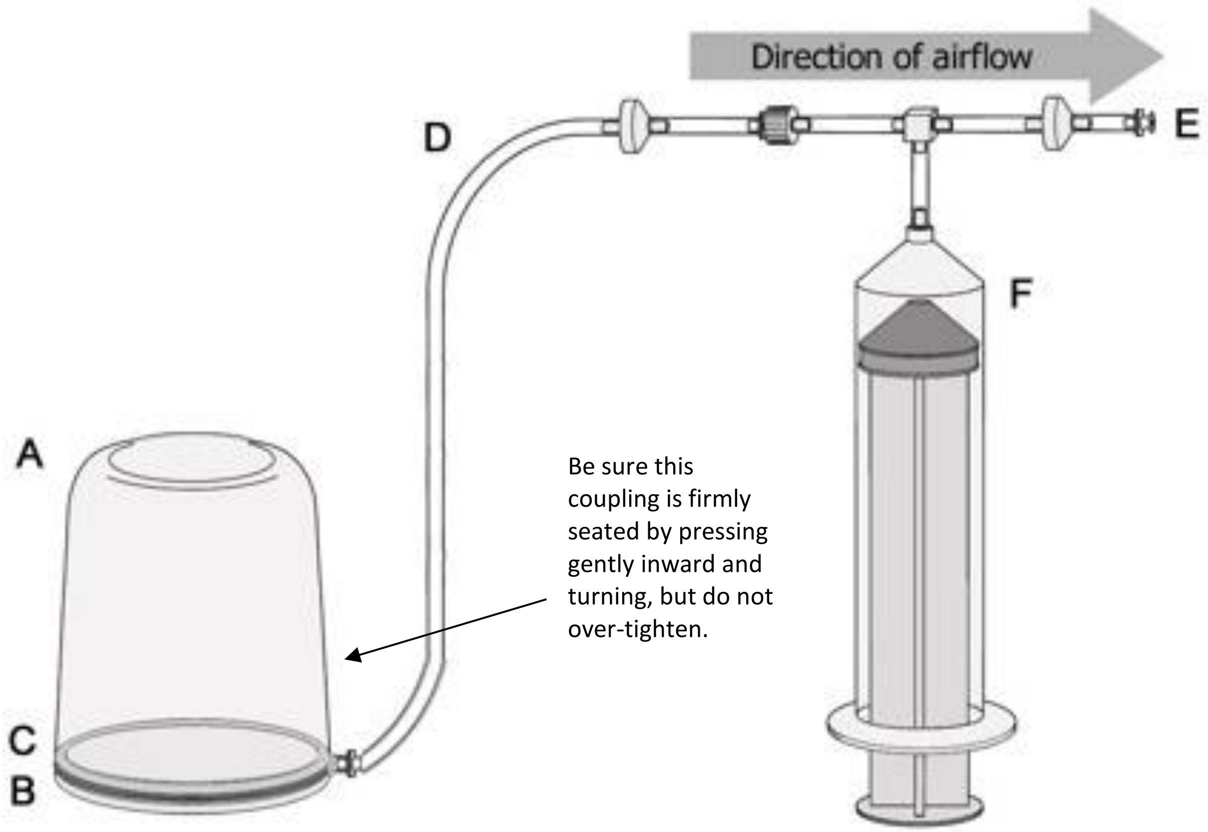


Figure 1.

1. Assemble the apparatus as shown in Figure 1. The check valves will easily allow air to flow in the direction shown by the arrows, but not in the other direction. Also check to make sure that the coupling at the end of hose D is inserted into the hole in the base and is secure, but not so tight that it cannot be easily removed. What is inside the bell jar now? (Hint: "Nothing" is not the correct answer.)

   ____

2. Have a partner push down on the bell jar to make certain that the bell jar is pressing against the "O" ring. While they are doing this, pull the piston of the syringe out to the 60 mark. Where does the air come from that fills the syringe?

   ____

3. Let go of the piston, and watch what happens. Now quickly push the piston all the way back into the syringe. Listen for the sound of moving air at the open end of the tube. Where did the air go that was in the syringe?

   ____

Experiment 1 Worksheet

continued

4. Describe, in words, the amount of force that was required to pull out the piston. How hard was it to pull out the piston?

5. There were two forces that resisted your pulling on the piston; what were they?

6. Repeat the following steps five times in rapid succession:
    a) -pull the piston out to the 60 ml mark;
    b) -let go of the piston, and see what happens;
    c) -push the piston all the way back in.

    As you followed the steps above, what happened to the amount of force required to pull out the piston?

7. Explain why the amount of force changed in this manner.

8. Pull the piston of the syringe out to the 60 ml mark and push it all the way back in. Do this 24 times in rapid succession while listening to the air exiting the open end of the tubing. Over time you should not notice any sound of air movement by the end of this step. What is in the bell jar now?

9. Now disconnect the hose at the base of the bell jar (D) from the base. Note any sound you may hear. What does this sound indicate?

10. A rubber balloon has been included with this kit. It was designed to be blown up to a 20 cm diameter round shape, but in this experiment it will just barely be inflated. Blow into it until the rubber is tight, but not stretched. Then tie it. It should be about 7 cm long, and 3 or 4 cm in diameter. This step may have already been done for you. Place the balloon inside the bell jar, and assemble the apparatus as shown in Figure 1. Start pumping the piston. What happens to the balloon?

11. Why did the balloon change in the way it did? Why didn't it do this before you started pumping?

12. Loosen the connection between hose (D) and the base until you hear the movement of air. What happens to the balloon? Why does this change occur?

13. Open the apparatus and take out the balloon. Save it for the next students who will be using the apparatus. Now stick the suction cup firmly to the center of the bottom plate as in Figure 2, and put the bell jar over it, so the suction cup is inside. Turn the bell jar upside down such that the base is on the top. Why does the suction cup stick tightly to the bottom plate instead of falling off?

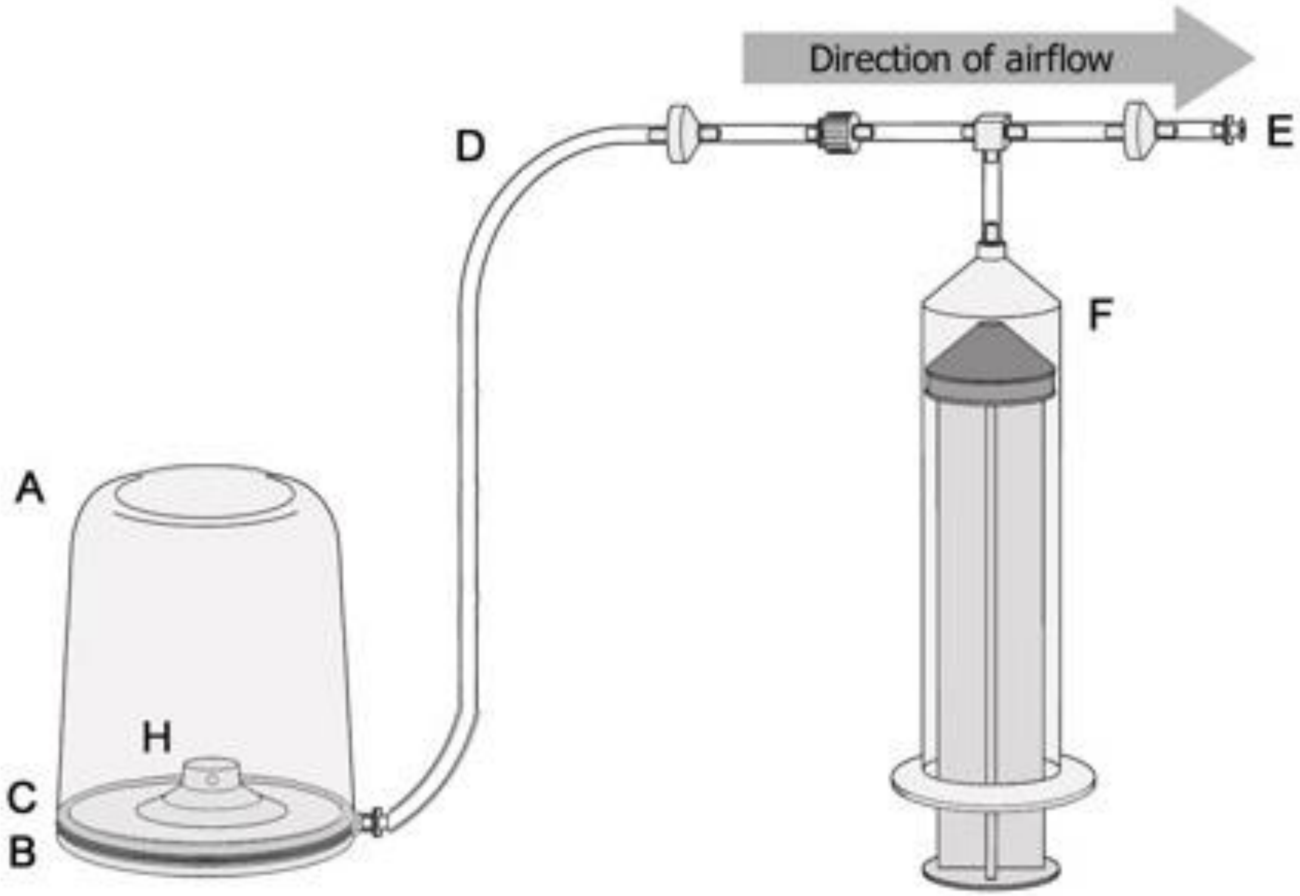


Figure 2.

14. Continue to hold the apparatus upside-down while someone pumps the piston several times, until something happens to the suction cup. What happens? What is the explanation?

Teacher Instructions for Experiment 2: Demonstrating that Air Has Mass and Determining Density of Air

1. Be sure to read the student worksheet and answer key below BEFORE attempting the lab with students. It is even suggested that you work through the lab yourself to note any difficulties your students may encounter as they work their way through the lab.

2. The lab experience is designed to be completed in groups of two or three students. Single students will physically have trouble completing some of the tasks, and groups of more than three will likely have too many students to be fully engaged with each task.

3. Note that the use of a fairly precise balance is recommended for this experiment. A balance capable of measuring with an accuracy of one-hundredth of a gram (0.01 g) is necessary. Even if a less accurate balance is used, it may at least still be possible to show that air has mass.

4. Note that a plastic bucket, tub, or plugged sink is required for this experiment. The bucket, tub, or plugged sink must be large enough to completely submerge the vacuum apparatus and allow for manipulation of hose D such that it can be removed from the base while under water.

5. **EXTENSIONS:** How would the density of air differ in locations of greatly different altitudes? How could you find out? How could you find the density of a gas such as helium or carbon dioxide?

Answers to Experiment 2:

3. Students have no basis for answering this question at this time, but the actual answer is that the apparatus contains a partial vacuum at this point. (The purpose of the question is simply to get them thinking about possible answers).
4. The mass without air is approximately 112 grams. This will be slightly different for different bell jars. The answer should be given to the nearest 0.01g if possible.
5. The sound of air rushing into the bell jar could be heard.
6. The mass should be about two tenths of a gram more than #4.
10. About 0.2 g
11. Water rushes in due to a higher pressure outside of the bell jar and a lower one inside of the bell jar.
12. Answers will vary depending on the student's original prediction to question #3 but they should note that after water went into the bell jar, it contains mostly water **and some air**. The pump had not removed all of the air.
13. Perhaps 5%, or 1/20, of the air is left.
14. Perhaps 210 ml. This will vary from one bell jar to another and will depend on how completely the student pumped the bell jar.

15. A typical result might be:

Density = mass / volume
= 0.23g / 210 ml
= 0.0011 g / ml

Experiment 2 Worksheet
Demonstrating that Air Has Mass and Determining Density of Air

Name(s): ___________________________ ___________________________ ___________________________

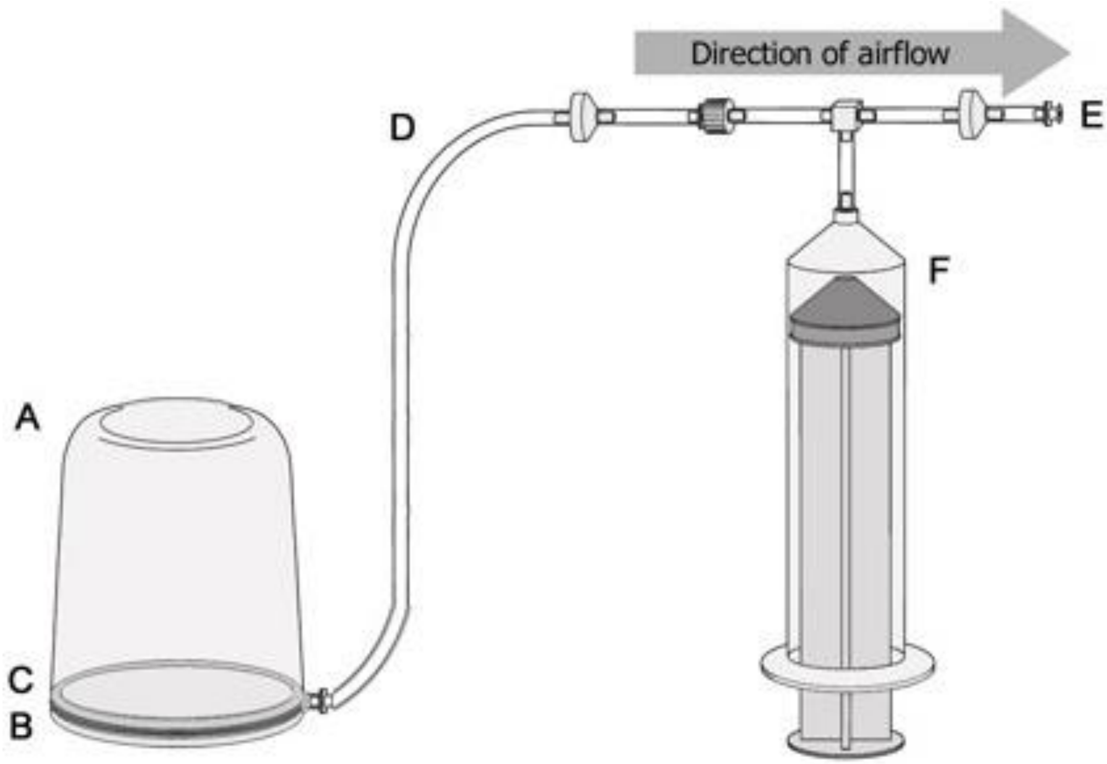


Figure 1.

1. Assemble the apparatus as shown in Figure 1.
2. Pull the piston of the syringe out to the 60 ml mark and push it all the way back in. Do this 30 times.
3. Do you think that the contents of the bell jar now represents a vacuum, a partial vacuum, or normal atmospheric pressure? _________________________. We will now have you to test this prediction.
4. **Without allowing air back into the bell jar**, disconnect the base hosing (D) from the syringe and exit hosing (E and F) but NOT the bell jar base. Place the bell jar, bottom plate (with "O" ring) and base hosing (D) on a balance. Make certain that hose (D) is not touching anything. Carefully find the mass and record it here:

   ____

5. Now, loosen the connection between hose (D) and the base, remove the hose, and then reconnect it. Did you hear the movement of air? What was the air doing?

   ____

6. Again place the bell jar, the bottom plate (with "O" ring) and hose (D)\ on the balance pan. Again, make certain that hose (D) is not touching anything. Find the mass and record it.

Experiment 2 Worksheet

continued

7. Calculate the difference between the balance readings in steps 4 and 6. This represents the mass of the air that you had removed from the bell jar in step #2. Record the mass of air you removed here: ________________________

8. Reassemble the apparatus as in Figure 1. Pump the piston 30 times, as before.

9. Disconnect hose (D) from hose (E) but **NOT from the base**. In other words, do NOT let any air in the bell jar yet.

10. Obtain water in a pail or other convenient container. With one hand, carefully hold the whole bell jar apparatus under the water with the right side up (base plate on the bottom and the bell on the top). Now, carefully reach into the bucket with your other hand and while still holding the base plate firmly in place against the bell jar, undo the fitting holding hose (D) to the base. Describe what happened, and explain why.

    ____

11. Put your fingers over the base **and** the hose fitting on the bell jar. Now lift it out of the water. Keep your finger over the hose fitting. Note that there is both water and some air in the bell jar. What does this tell you about your prediction in question #3.

    ____

12. What fraction (or percentage) of the air was left? (Estimate) _______________ What fraction (or percentage) of the air was removed?

    ____

13. Use a graduated cylinder to measure the volume of water in the bell jar. This is equal to the volume of air removed. Record this volume.

    ____

14. Now you know the mass and the volume of the air that you removed. Calculate the density of air. Show your calculations. Remember to include units of measurement in your answer.

    ____

15. Dry out the apparatus, including tubing assembly "D," as well as you can with a towel.

Teacher Instructions for Experiment 3: The Effects of Air Pressure on Boiling Water

1. Be sure to read the student worksheet and answer key below BEFORE attempting the lab with students. It is even suggested that you work through the lab yourself to note any difficulties your students may encounter as they work their way through the lab.

2. The lab experience is designed to be completed in groups of two or three students. Single students will physically have trouble completing some of the tasks, and groups of more than three will likely have too many students to be fully engaged with each task.

3. Note that hot tap water is required for use in this lab experience. The water should be as hot as possible without being scalding. If your classroom lacks running water, it is a good idea to have a thermos of hot water set aside.

4. You will also want towels (for cleanup of water spills), a sink or container for used water, and thermometers for each group if available.

Answers to Experiment 3

1. Invariably your students will likely say that the water is not hot enough to boil. (By the end of the experiment they will have learned that external air pressure is also a factor.)

2. Students should predict that external pressure would make the boiling process more difficult.

3. Responses will vary. But those with high reasoning skills may note that it should allow the water to boil at lower temperatures.

4. Temperature should be 45 to 50° C. It should be quite uncomfortable to leave one's finger in the water for more than a few seconds.

6. The water boils!

7. Most students will say that the water has become hotter. Step 8 shows this is not correct.

8. The water temperature has fallen substantially. Here are two explanations:

   (a) At any given instant, different molecules have different amounts of energy. During the boiling process, the more energetic molecules left as steam, and the less energetic ones remained behind. Thus the average energy of the molecules in the liquid decreases and the liquid becomes cooler.

   (b) Because boiling is an endothermic process, the temperature of the water drops.

Experiment 3 Worksheet: The Effects of Air Pressure on Boiling Water

Name(s): ___________________________ ___________________________ ___________________________

1. Imagine some very hot water in a cup that came from the hot water tap of a faucet. Why is the water not boiling in the cup?

   ____

2. Think about the boiling process for a moment. When a liquid is heated to a high enough temperature, water molecules will have enough energy to overcome the forces holding them to each other. They will then separate to form a gas, which we see as bubbles. Because gases occupy more space than liquids, the water molecules also require energy to push outward against any pressure trying to push them back together.

   Based on what you have already learned about air pressure, do you think that the presence of atmospheric pressure helps the boiling process or makes it more difficult?

   ____

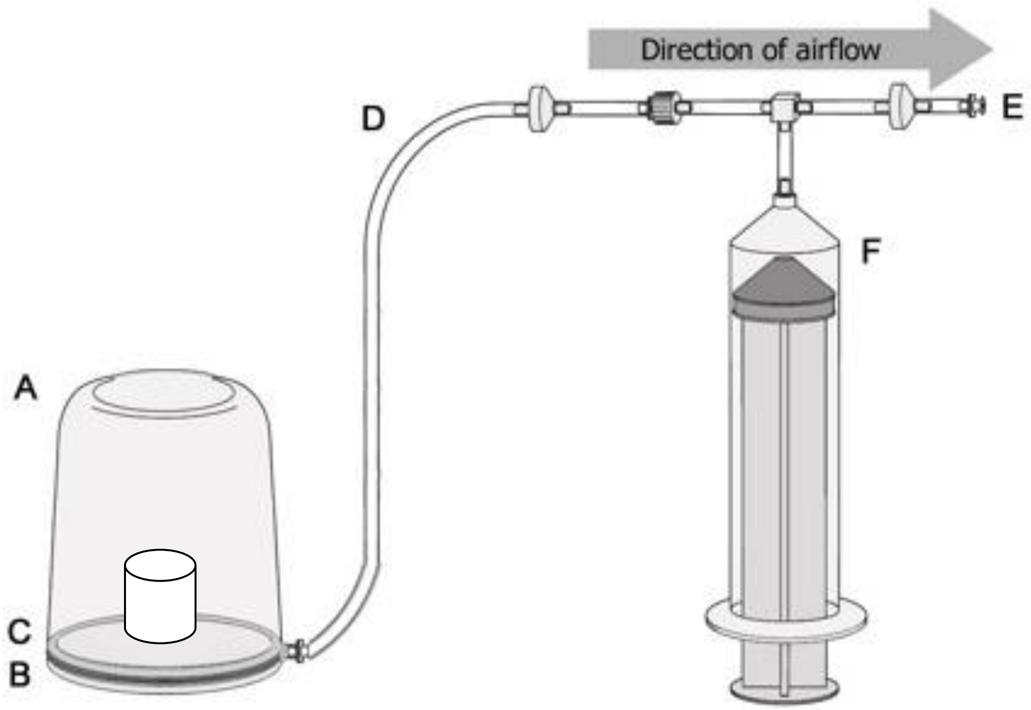
3. Can you predict what would happen if we put a container of hot tap water into the bell jar and pump the air out?

   ____

4. A small clear transparent vial has been included in this kit. Fill it about halfway with hot tap water. Use water that is not hot enough to burn you. If a thermometer is available, measure the temperature of the water. Do this quickly so the water does not cool appreciably. If the water temperature is safe and you don't have a thermometer, you might judge its temperature by dipping your finger briefly into the water.

   Note the temperature or your finger observations about the temperature: ___________

5. Carefully place the vial of hot water on the bottom plate, inside the bell jar, and assemble the apparatus, shown in the figure below. Have someone hold the bell jar in position so it does not tip over.



6. Start pumping the piston as vigorously as possible, and watch the vial of water. Something should happen after several strokes of the piston. What happens?

____

7. What do you think has happened to the temperature of the water?

____

8. Keep pumping until there is no further effect. Then **slowly** loosen the connection between hose (D) and the bell jar such that the water does not spill from the container. Now open the bell jar and check the temperature of the water. What has happened? Can you explain the change?

____

Teacher instructions for using the apparatus with a more open ended inquiry approach:

While we have provided sets of detailed step-by step worksheets for you to use in your classroom, we are aware that students often learn better when simply challenged with a question and allowed to determine their own methodology for meeting that challenge.

If you chose this approach, we still recommend that you, the teacher, work through the experimental worksheets for each of the labs to first familiarize yourself with the equipment. We have found that, for the most part, the apparatus is so easy to operate that students rarely need instruction beyond one basic demonstration. We find the most helpful aspect to note about the device is that the one-way air locks are triangular in shape on one side and that that triangle "points" in the direction of airflow. After doing so, you may wish to choose from one or more of the following challenge questions to engage your students.

1. How does this apparatus work to create an area of low pressure in the bell jar?

2. What happens to a balloon (marshmallow, shaving cream, or bubble wrap) when placed in an evacuated bell jar, and why does it happen? What happens to each substance when air is let back into the bell jar and why?

3. How does lowering air pressure affect the boiling point of water? Why?

4. Even at the point of greatest evacuation, there is still air remaining in the bell jar. What is the volume of this air at atmospheric pressure?

5. What is the density of air? (requires precision balance)

13 Microscale Vacuum Challenges

by Ron Perkins (retired), Greenwich High School

The following are challenges (with possible solutions) to use with students.

1) Can you increase the volume of a marshmallow or small capful of shaving cream? Solution: Place the marshmallow or capful of shaving cream in the bell jar and evacuate.

2) Can you fill a small plastic pipet with water without squeezing the bulb or using heat? Solution: Set the open end of the pipet into a small container of water and place inside the bell jar. As you evacuate the bell jar, air in the pipet will expand, causing bubbles of air to escape. When air returns to the bell jar, water will be forced into the pipet, thus filling it.

3) Can you transfer water from one pipet to another without squeezing the bulb or using heat? Solution: Set the open end of an "empty" pipet at the bottom of a small "empty" vial. With tape, suspend a pipet almost totally filled with water above the bottom of the vial. Place in the bell jar. As the vacuum chamber is evacuated, water will leave the filled pipet and accumulate at the bottom of the vial. When air returns to the bell jar, water will be forced into the second pipet.

4) Can you start with two pipets, one containing colorless water and one containing water colored blue, and end with both containing green-colored water? Solution: Place the open end of both pipets at the bottom of an empty vial containing a few drops of yellow food coloring. Place in the bell jar, evacuate, and allow the air to return.

5) Can you boil water from the tap without using heat? Solution: Add a boiling chip (a piece of broken glass or pottery) to a container of hot water from the tap. Place in your vacuum chamber and evacuate.

6) Can you demonstrate the reduced pressure obtained by the vacuum pump using two different methods?

    a. First Solution: Open the evacuated bell jar under water. Compare the mass of the water entering the jar to the mass of water when the jar is filled. Knowing the atmospheric pressure, you can calculate the reduced pressure in the vacuum chamber.

    b. Second Solution: Boil hot water from the tap in your vacuum chamber. Allow air to return and measure the temperature of the water. By referring to a vapor pressure vs. temperature table, you can determine the pressure inside the chamber when the water started to boil.

    c. Third Solution: Estimate how much shaving cream expanded in Challenge #1 and use the inverse relationship between pressure and volume.

7) Can you place a small tied off balloon filled with water (ca. 4 cm dia.) into a plastic vial without touching the balloon? Solution: Rub cooking oil over the outside of the filled balloon and set on top of the open end of the vial. Place in the bell jar, evacuate, and allow the air to return.

8) Starting with two containers of hot tap water (at the same temperature) labeled "A" and "B," can you add something to the water in container "B" so that only it boils when both are placed in the bell jar and evacuated? Solution: Add a few drops of a lower boiling substance, such as ethyl alcohol, to the water.

9) Starting with two containers of hot tap water, as in Challenge #8, can you add something to the water in container "B" so that only the pure water boils when both are placed in the bell jar and evacuated? Solution: Add a few drops of a higher boiling substance, such as corn syrup, to the water.

10) Can you float something on the surface of water in a vial so that when the vial is placed in the bell jar and evacuated, the object will sink? Solution: Crumple a small piece of aluminum foil so that it floats on water or set the bulb of a plastic pipet open end down on the surface of the water.

11) Can you sink an object in the water of a vial so that when the vial is placed in the bell jar and evacuated, the object will rise to the top? Solution: Find something that is slightly denser than water, containing a gas sealed in a flexible membrane. A weighted, sealed, compressed plastic pipet bulb works well.

12) Can you design and build a microbalance that demonstrates the buoyancy effect of air when placed in a bell jar and evacuated? Solution: One arm of the balance should have a larger object, such as a sealed plastic pipet bulb, and the other arm should be weighted with a very dense material, such as a lead mass.

13) Given three vials with different concentrations of water and ethanol, can you place them in order of concentration? Solution: Place the three vials in the bell jar and evacuate. The one seen boiling is the one with the greater concentration of alcohol. Remove the most concentrated, and evacuate again.

Take Your Lesson Further

As science teachers ourselves, we know how much effort goes into preparing lessons.
For us, "*Teachers Serving Teachers*" isn't just a slogan—it's our promise to you!

Please visit our website for more lesson ideas:

TeacherSource.com/lessons

Check our blog for classroom-tested teaching plans on dozens of topics:

http://blog.TeacherSource.com

To extend your lesson, consider these Educational Innovations products:

Atmospheric Mat (AIR-280)

Our Atmospheric Mat offers a dramatic introduction to the concept of air pressure. Invite your students to pick up the mat. No matter how hard they pull on its sturdy metal hook, this mat will not budge! Is it some kind of suction trick? Nope! It's just air pressure. The room's air pressure is so much greater than the pressure under the mat that - in effect - the air itself is holding the mat in place.

Milk Bottle & Egg Demo (BOT-800)

Use this sturdy glass milk bottle for an egg-cellent demonstration of air pressure. All you need is a hardboiled egg and a little bit of fire. If you drop some lit paper inside the milk bottle and then place the egg on top, the fire goes out and the egg is mysteriously pushed into the bottle, intact! Warm air expands, cool air contracts—it's the cooling of the heated air inside the bottle that allows the atmosphere to "push" the egg inside.

Pressure Pullers (SC-300)

What keeps these cups together? Suction or air pressure? These cups are very simple to use: no vacuum pump—just two levers—yet they are incredibly difficult to pull apart. A great way to illustrate the concept that air pressure, not suction, is forcing the cups together. Have your students calculate, based on the area of the cup and the standard air pressure, just how much force is required to pull the cups apart.

Harbottle Differential Pressure Demonstration (AIR-275)

Use this beautiful glass globe to teach your students about the amazing properties of air pressure. Simply stretch the neck of the balloon over the mouth of the bottle and blow into the balloon. Once it's inflated, insert the rubber stopper into the hole at the bottom of the bottle. The balloon remains inflated though nothing seems to be stopping the air from escaping! A great starter for atmospheric pressure discussions.