Do it yourself: Properties of air

Motivation. You can find out the properties of air and the atmosphere with equipment available to the Greeks. We will use modern scales rather than goldsmith's balances and soft drink bottles rather than sealed goatskins. The Greeks often had ice but not freezers. The first objective is to weigh air. Then you will find some of its other properties.

You will need: 20 oz plastic soft drift bottles (or another size), freezer, scale precise to at least 0.1 gram, and graduated cylinder or kitchen volume measurer in which the drink bottle fits. We will meet in a laboratory in the Mitchell Building.

The physics is simply that

pressure * volume = (number of molecules) * constant * (absolute temperature)

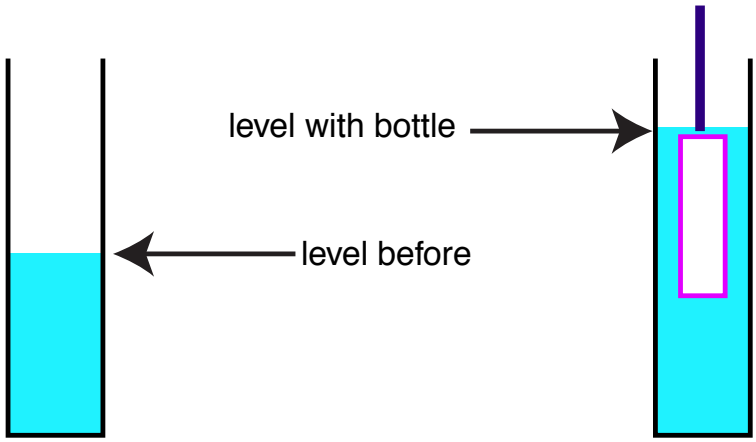
density = (number of molecules) * (mass of 1 molecules) / volume

The formulas use these relationships but we have done the algebra already

Measuring volume change

You will use graduated cylinder to measure the volume of crushed and filled soft drift bottles. From the label the volume on the inside of drink is about 600 milliliters. You will need to set your initial water level in the graduated cylinder so that there is room for this much more displaced water. Record the before level.

You will do two pairs of measurements. One with the bottles from the freezer and one with the bottle filled at the hill top. You will record the crushed and the filled filled displacement. Their difference is the change in volume. Use prod to push bottle cap first until it is just below the surface of the water and record water level in cylinder



Freezer bottles

Displaced volume = level with bottle - level before

Crushed volume=_____ = _____ - _____

Filled volume= _____= _____ - _____

Hill bottles

Displaced volume = level with bottle - level before

Crushed volume=_____ = _____ - _____

Filled volume= _____= _____ - _____

Step 1. Fill a bottle with water. Pore into measured cylinder.

Record **Filled volume** = _____

Place empty bottles in freezer. Record **temperature in freezer** = _____

Leave one bottle open and one bottle sealed with cap. Wait a while for the bottles to cool. The sealed bottle will collapse. From the formula, cold air has less volume than room temperature air. The number of molecules of air does not change because the bottle is capped. Cap the open bottle when you remove it from the freezer. Work quickly with collapsed bottle while it is still cold.

Step 2. We need the volume inside the collapsed bottle. It is easiest to measure this indirectly. Measure the volume the crushed bottle displaces in the graduated cylinder. This includes both the volume of the air and the plastic.

Crushed volume displaced = _____

Open the bottle and let inflate. You will hear air rush in. Cap bottle so water will not get in. Measure the volume that it now displaces. This again includes both plastic and air.

Filled volume displaced = _____

These volumes include both the bottle and the air so you will need to do some calculations to get volume of air in crushed bottle.

The change in volume when the air rushed in is

Change = **Filled volume displaced - Crushed volume displaced**

_____ = _____ - _____

The actual crushed volume is

Crushed volume = filled volume - change

_____ = _____ - _____.

The ratio of the volumes is

ratio = filled volume / crushed volume

_____ = _____/_____

Step 3. Wait for the other bottle that you capped to heat up to room temperature. It should feel quite full when you squeeze it. The air cannot expand because the volume within the bottle stays constant. The air pressure is now higher inside than out. Soft drink bottles are designed to withstand inside pressure but collapse if the pressure inside is low.

Weigh the bottle on the scale and record the result. Your scale gives grams so we record it as mass

Filled mass = _____

Uncap the bottle. You will hear the high-pressure air rush out. The air is now back to room pressure. Weight the bottle with cap back on.

Vented mass = _____

The masses include both air and plastic. We eliminate the plastic by using the difference of the masses.

The density (with "weights" in units of mass) is

density = (filled mass - vented mass) / (ratio - 1) / (filled volume)

_____ = (_____ - _____) (_____ - 1) / _____

You now have the density of the air in grams per milliliter or equivalently grams per cubic centimeter. You can multiply by 1000 to get kilograms per cubic meter or ~10,000 to get specific weight as Newtons per cubic meter.

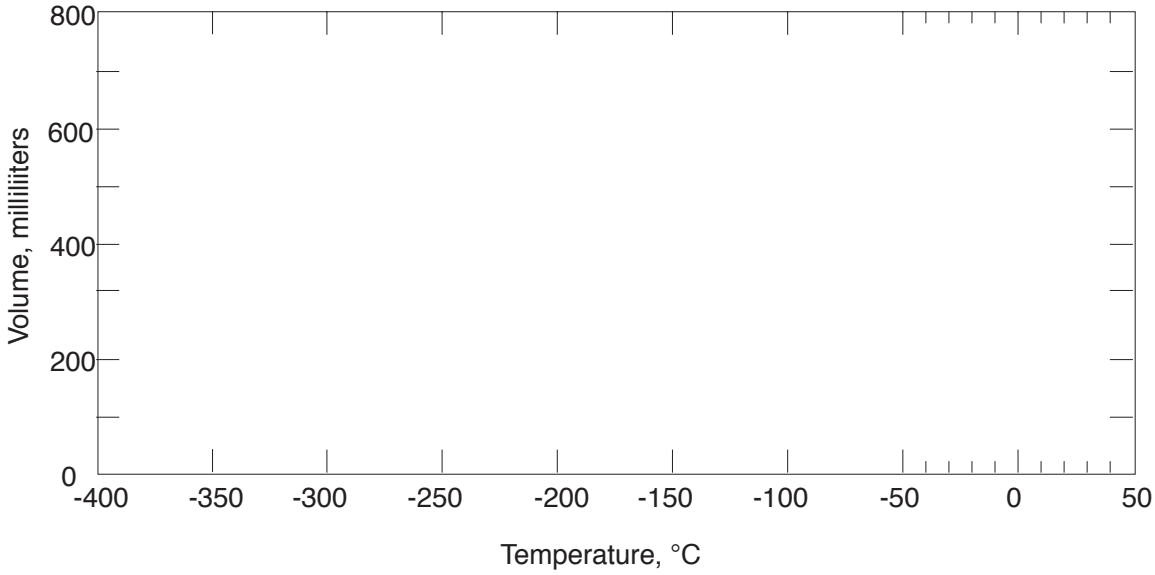
Step 4. You are now ready to determine the behavior of air with temperature. You do not yet know from your information what the relationship is between absolute temperature in the formula and the Celsius temperature that you measured.

Measure and record **room temperature** = _____

Plot **filled volume** and **room temperature** as one pair of points on graph paper. Plot **crushed volume** and **freezer temperature**. Connect the points with a line on the graph paper. Record the temperature where the line indicates the volume is zero.

_____

This is an estimate of absolute zero in degrees Celsius. You would get several more temperature volume pairs if you were doing a full experiment.



Step 5. This is an additional activity. Drive up to the top of a local hill and fill the bottles and cap them. We will collect extra bottles far everyone. We will have car for this. The people will also examine acorns and look at part of the San Andreas Fault to see the Earth is geologically active.

Record **hill elevation** = _____

Drive down to the base of the hill to the lab. Measure the filled and crushed volumes as before in steps 1 and 2.

Look at map and record **elevation difference** between the hill and the lab

_____

Fill a bottle with water when you are done if you did not already do it in Step 1. Pore into measured cylinder.

Record **Filled volume** = _____

The collapsed bottle has less air because you filled it on the hill where there was low air pressure.

We need the volume inside the collapsed bottle. It is easiest to measure this indirectly as before. Measure the volume the crushed bottle displaces in the graduated cylinder. This includes both the volume of the air and the plastic.

Crushed volume displaced = _____

Open the bottle and let inflate. You will here the air rush in. Cap bottle so water will not get in. Measure the volume that it now displaces. This again includes both plastic and air.

Filled volume displaced = _____

These volumes include both the bottle and the air so you will need to do some calculations to get volume of air in crushed bottle.

The change in volume when the air rushed in is again

Change = **Filled volume displaced - Crushed volume displaced**

_____ = _____ - _____

The actual crushed volume is

Crushed volume = filled volume - change

_____ = _____ - _____.

You can now the information from the formulas to get the scale height of the atmosphere. With some algebra it is

scale height = **elevation difference** / [1 - (**crushed volume - filled volume**)]

_____ = _____ / [1 - (_____ / _____]

Step 6. You can also get the scale height from the ground pressure and the weight of the air.

Multiple by 10,000 to convert the density of air in gram per milliliter to specific weight Newtons per cubic meter _____

The scale height is the surface pressure divided by the specific weight. Measure the pressure with the barometer or use 100,000 Newtons per meter squared if you do not have one

Air pressure = _____

Scale height = **Air pressure** / **specific weight**

_____ = _____ / _____

You can also get scale height by measuring the pressure at two different elevations

Scale height =
Air pressure (down)* elevation difference / (pressure (down)-pressure (up))
_____*_____/(_____-_____)
To do this, record the pressure in the sub-basement and the 4th floor. The elevation difference is X meter.
Pressure (down)= _____

Pressure (up) = _____

You now know that the atmosphere is a weighty matter.