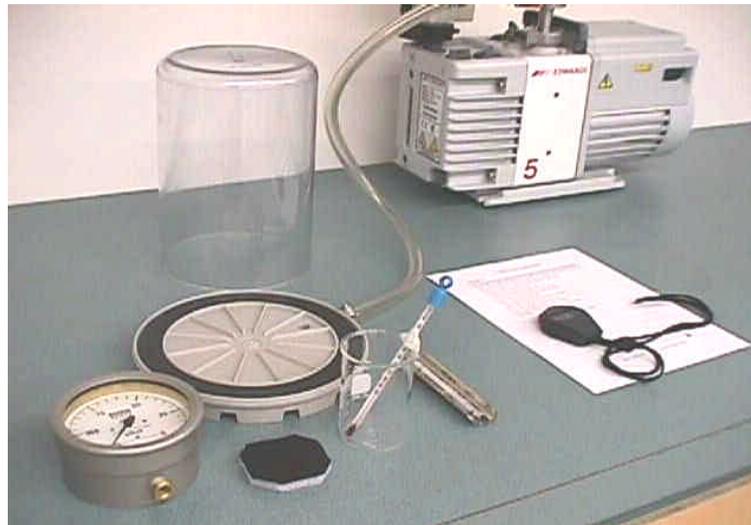


Triple Point Experiment

Equipment List

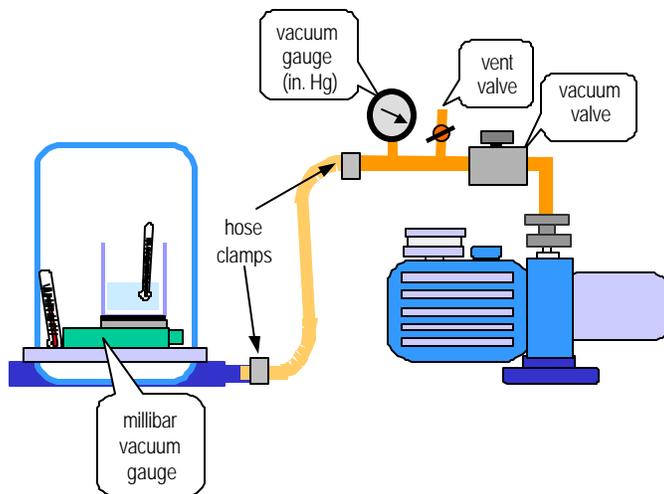
- Rotary vane vacuum pump – 2-stage, 2 to 7 CFM. For example, Edwards 2M2 (2 CFM), Edwards RV5 (3.5 CFM), Edwards E2M8 (6.7 CFM) or equivalent.
- Bell jar – Nalgene® polycarbonate plastic, 5-5/8 inch O.D., 9-1/2 inch high, nominal volume 0.162 cubic feet.
- Baseplate – with seal for bell jar and connection for vacuum connecting tubing.
- Connected together as manifold that attaches to vacuum pump: vacuum roughing valve, vent valve and dial vacuum gauge – in-line, Bourdon type, 0-30 inches Hg.
- Vacuum connecting tubing – Tygon® PVC plastic, 3/8 inch I.D., 30 inch long.
- Hose clamps (2).
- Vacuum gauge – Sealed diaphragm type, range: 0-125 millibar.
- Beaker – Pyrex® glass, graduated, 400 ml.
- Insulating foam disk – about 2-1/4 inch diameter, 1/4-inch thick.
- Black felt disk – about same diameter as foam disk.
- Thermometers (2) – Alcohol in glass, range: -20°C to 100°C.
- Safety glasses – *To be worn whenever vacuum pump is running.*
- Timer – 10 minutes by seconds (a stopwatch is best). *Not supplied.*
- Data sheets.



Triple Point Experiment

Preparation

1. The manifold consists of vacuum tubing, the vacuum roughing valve, vent valve and in-line vacuum gauge. Install the manifold on the roughing pump. Connect the vacuum tubing between the manifold and the bell jar baseplate according to the diagram below. For the leak test (step 5) omit the beaker and thermometers. All hose clamp connections must be leak-tight!

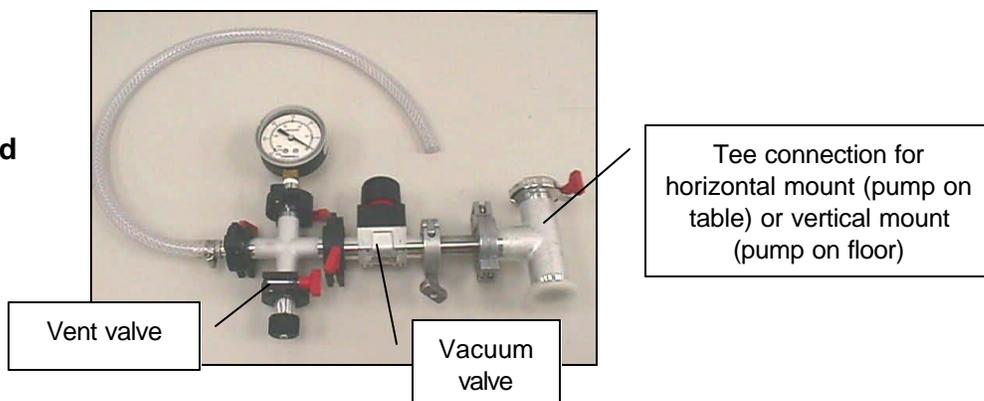


Experiment Set-Up

2. Plug the vacuum pump into 110V AC circuit. Open gas ballast valve part way.
3. Close vacuum valve between pump and vacuum line. Start the vacuum pump.
4. Check oil level. If it is low, add oil. If the oil foams, it indicates that the oil has water in it. If this is the case, turn off the pump and change the oil. Low oil or moisture in the oil will compromise the success of the experiment.
5. Allow pump to warm up for about 30 minutes with vacuum valve closed and ballast valve open.
6. Leak Check – Time the pumpdown of the empty bell jar containing only the millibar vacuum gauge. The bell jar should pump down to 5 mbar in about 30 seconds and bottom out at about 3 mbar within 2 minutes. If not, you have a leak that must be corrected or the experiment will not succeed.

General – Between experiments, run the vacuum pump with the vacuum valve closed and the ballast valve open. For pumps that have a ballast valve with settings 0, I, II, use setting II. With other pumps that have a continuous screw-type valve, open valve $1\frac{1}{2}$ turns.

Vacuum Manifold



Triple Point Experiment

Experimental Procedure

It takes five people to perform this experiment. Assign a beaker watcher, a time reader, a temperature reader, a pressure gauge reader and a data recorder. The readers call out the values and the data recorder writes them down. The watcher observes the water in the beaker and notes the times when it bubbles, boils and freezes.

Set up the data sheet with columns for time (seconds), temperature ($^{\circ}\text{C}$), and observations.

1. Place the diaphragm vacuum gauge face up on bell jar baseplate.
2. Place the black felt disk on top of the insulating foam disk and place both on top of the diaphragm vacuum gauge. Make sure that the 0-25 mbar range of the gauge is visible.
3. Fill the 400 ml beaker with 20 ml of tap water (about $\frac{1}{4}$ inch deep) from the cold water faucet. Place the beaker on the black felt disk. The black felt under the beaker makes it easier to see the water freezing. Place one thermometer in the beaker.
4. Place one of the thermometers next to the beaker on the baseplate. Make sure that it will be visible from outside the bell jar.
5. Record the room temperature.
6. Place the bell jar on the baseplate, making sure there is a good seal between the bell jar and the baseplate.
7. Close the ballast valve on the vacuum pump.
8. Close the vent valve on the vacuum manifold.
9. Open the vacuum valve to the bell jar and start the timer at the same time.
10. Record the time, the in-line Bourdon gauge reading (inch Hg) and water temperature ($^{\circ}\text{C}$) every 10 seconds for one minute. Observe that during this time the water starts to bubble (the dissolved air *outgasses*) and then boil (the water vaporizes).
11. At 30-second intervals, continue to record the time, the diaphragm vacuum gauge reading (mbar), and the water temperature until the water freezes (typically in less than 4 minutes but it may take as long as 10 minutes).
12. Close the vacuum valve.
13. Open vent valve. Wait until gauge reads atmospheric pressure.
14. Remove belljar from baseplate. Observe that the water has frozen to ice.
15. Open ballast valve.
16. Optional. Plot a graph of the data (see example).



Triple Point Experiment

MAKING ICE BY BOILING WATER

Heat is energy due to molecular motion. When a liquid boils, molecules from the liquid leave the surface and in the process change from a liquid to a vapor. This is called a *change of state*. When a molecule evaporates from the liquid surface it takes some energy with it. The amount of thermal energy removed equals the heat that is required to reach the boiling point of the liquid plus the *latent heat of vaporization*. The latent heat of vaporization is the quantity of heat required to change unit mass of liquid into vapor at the boiling point. For water this is about 539 calories per gram (a cubic centimeter of water weighs approximately one gram).

Normally the thermal energy necessary to reach and sustain boiling is supplied to the liquid from an external heat source. It requires one calorie of energy to increase the temperature of one gram of water by one degree Celsius ($^{\circ}\text{C}$). This is called the *specific heat* of water. We can make it easier for a molecule to evaporate by reducing the pressure above the liquid surface. If no external heat is supplied, the process is reversed and the heat of vaporization must be extracted from the liquid itself. The molecules that leave the liquid surface and enter the vapor state still require energy to evaporate, but since no heat is being supplied, the thermal energy is removed from molecules in the liquid. This reduces the speed (the kinetic energy) of the molecules in the liquid. This causes the temperature of the liquid to drop. The liquid can get very cold – cold enough to freeze.

To demonstrate this effect, a glass beaker containing a small volume of water is placed in the vacuum enclosure. The bulb of a thermometer is immersed in the water. As the pressure in the vacuum enclosure is reduced, the air that is dissolved in the water will come out as bubbles. The water *effervesces*. More violent bubbling quickly follows as the water begins to boil. The temperature of the water will decrease due to this forced boiling.

After the temperature has been reduced to 0.01°C , and the *latent heat of fusion* is removed, the water freezes. The heat of fusion is the heat required to change a unit mass of solid into a liquid at the melting point; for water this is about 80 calories/gram. We now have a curious occurrence—making ice by boiling water. The temperature at which all three forms of water: solid, liquid and gas, can exist simultaneously is 0.01°C (273.16 Kelvin), and is called *the triple-point* of water. The vapor pressure of water at the triple point is 6 mbar.

Questions to ponder:

What temperature does the thermometer on the baseplate (outside of the beaker) indicate? Did this temperature change during the experiment?

Why is an insulating pad placed under the beaker?

Are the calories mentioned above the same as the Calories listed on food packages?

Why does the water take so long to freeze after the water temperature reaches 0°C ?

The vapor pressure of water at the triple point is 6 mbar. How low did the pressure get during the experiment?

Can you guess how a liquid changing to a vapor makes a refrigerator or air conditioner work?



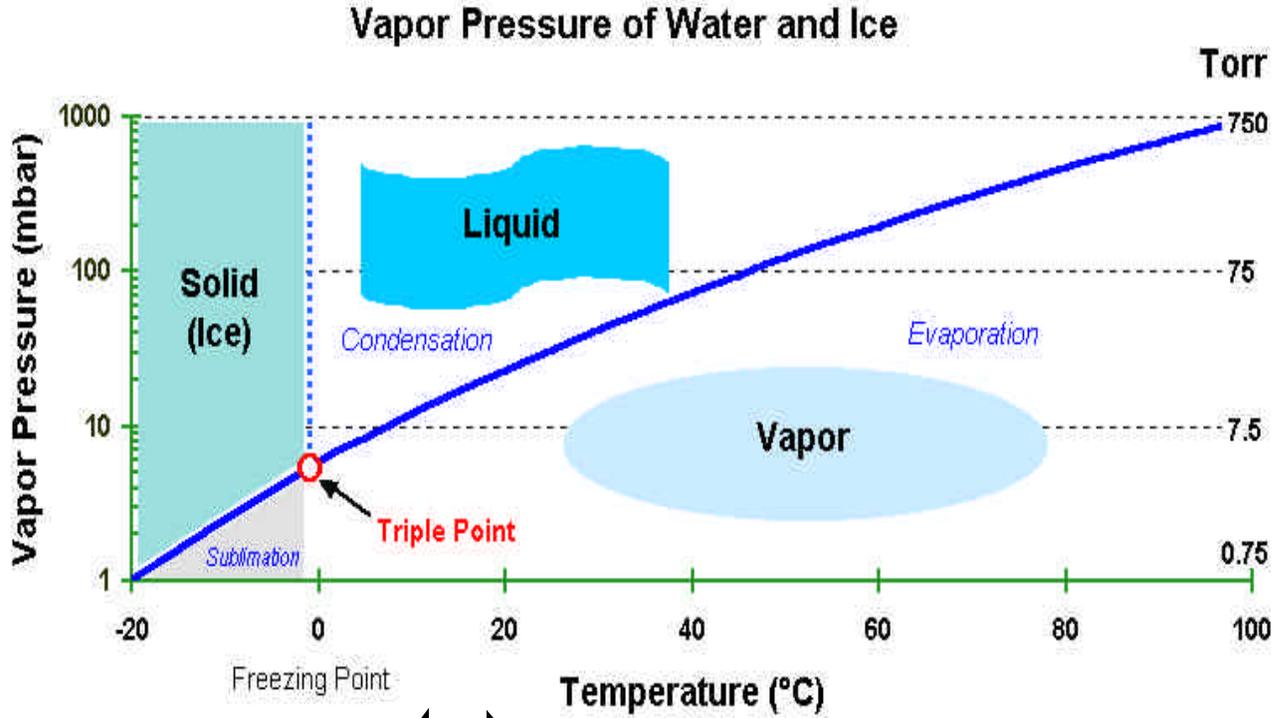
Triple Point Experiment

Data Sheet – Triple Point Experiment

Time (min:sec)	Pressure (mbar)	Temperature (°C)	Observations
Start			
00:10			
00:20			
00:30			
00:40			
00:50			
01:00			
01:30			
02:00			
02:30			
03:00			
03:30			
04:00			
04:30			
05:00			
06:00			
07:00			
08:00			
09:00			
10:00			

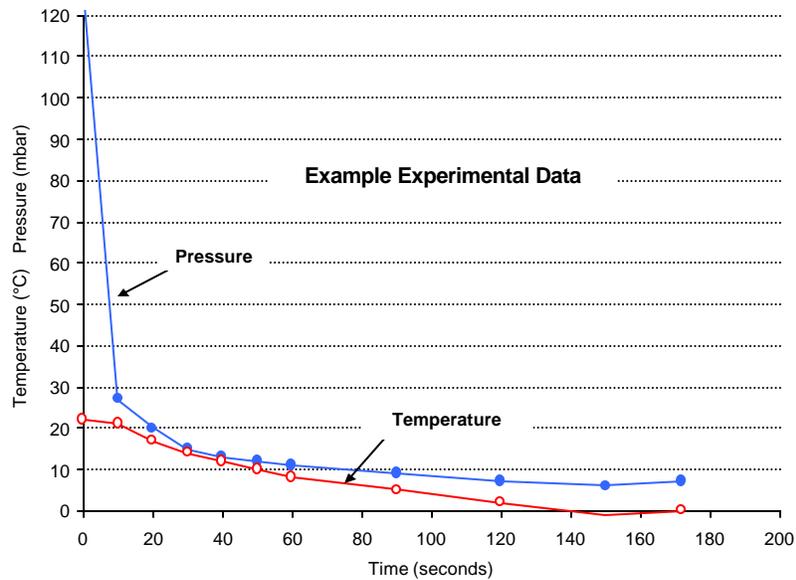


Triple Point Experiment



Elapsed time during experiment. The triple point is 0.01°C at 6 mbar pressure.

Example Data Plot



Triple Point Experiment

Background Information

The Physics of Skiing : Skiing at the Triple Point, by David Lind, Scott P. Sanders
Paperback, 268 pages (Springer Verlag, 1996) ISBN: 1563963191:

The earliest record of skiing is a 2,000-year-old pictograph from Rodoy, Norway. Only in the past 50 years, however, have the greatest advances been made in skiing technology. *The Physics of Skiing* reveals what really happens when a skier hits the slopes, where the snow is always near the triple point – the temperature at which the solid, liquid, and vapor phases co-exist.

More technical information on the uses of the triple point is available at the following web sites:

- The National Institute of Standards and Technology (NIST):
<http://physics.nist.gov/cuu/Units/kelvin.html>
- *Scientific American*: www.sciam.com – search for Triple Point
- A commercial site: www.pondengineering.com/tripplept.html

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