I don't know how far away the moon lies but here is how I rediscovered the value of absolute zero

Absolute zero

Absolute zero is the lowest temperature theoretically possible, it is the limit of the thermodynamic temperature scale where a system's energy reaches its minimum value.[1] During the 18th century many scientists began to notice patterns between the variables volume, pressure and temperature including: Jaques Charles who realised that at a constant pressure, ideal gases expanded or contracted their volume linearly[2] and Jaques Gay-Lussac who discovered the relationship between temperature and pressure.[3]

Therefore, I hypothesise that there is a relationship between pressure temperature and volume, and that there is a minimum temperature at which all movement of a gas ceases. I will create instruments such as a thermometer to measure temperature changes in different environments; and a manometer which can be used to measure the relationship between temperature and pressure, or the relationship between pressure and volume. Boyle himself who discovered Boyles law $P_{gas}V = k$ (where P is pressure, V is volume and k is a constant) used a similar apparatus to this which involved pouring mercury into a j-shaped tube to vary pressure.[4,5] I will also use the formula $\Delta p = \rho g h$ (where p is pressure difference, ρ is density of a liquid, g is acceleration due to gravity and h is the height of a fluid) the principle formed by Pascal and published in 1663.[6] By using all the data collected and discovering patterns in the relationships between variables I will plot my data on graphs and use them to extrapolate data found to rediscover the value for absolute zero like Lord Kelvin did in 1848.[7,8]

Making equipment

Firstly, in order to calculate a value for absolute zero I had to ensure I had all the equipment necessary, the manometer was simple to make. Plastic tubing filled with coloured water and blue tack stuck to one end to ensure it was airtight.[9] And finally I attached it to a plank of wood along with a tape measure to help increase the accuracy of my measurements. However, the thermometer proved more difficult to make.

Figure 1 - manometer

The original plan was to use a plastic bottle with a hole drilled in the lid and a straw,[10] however the plastic of the bottle very quickly deformed at high and low temperatures. So I then tried a glass bottle which was able to keep its shape but due to the large amount of air inside the liquid rose far too much.

Figure 2 – thermometer 1 (plastic bottle)

I then planned to use a smaller glass jar with a hole drilled into its metal lid for a plastic straw to fit into, and some blue tack as a sealant however the first problem I faced was finding a sealant that could withstand 100°C, I soon discovered that blue tack melts in boiling water along with candle wax and sealing wax. Next, I tried silicone glue which does in fact withstand high temperatures [11] however it was unable to stick the metal lid of the jar and the plastic straw together, so liquid could still leak out of the thermometer from the join. Finally, I tried gorilla glue which was able to stick the materials together and keep the liquid inside the thermometer.

Another problem was what to use as the liquid inside the thermometer – sadly I did not have any access to mercury, so I at first tried ethanol, before realising this has a boiling point lower than 100°C. I then decided to try ethylene glycol – otherwise known as car antifreeze, this has a boiling point of 198°C[12] when pure. This worked well, although it is quite viscous and so did not pour easily.

Figure 3 – thermometer in boiling water

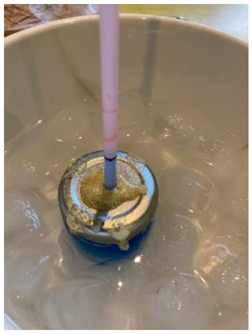


Figure 4 – thermometer in freezing water

The third class of problem I faced was too much expansion occurring, the thermometer in *Figure 2* was filled with very little liquid and therefore almost all the expansion which occurred was due to the air in the bottle, this meant that the liquid went up the plastic straw extremely quickly. So I decided to use a smaller glass jar (*Figures 3* and *4*), meaning there would be less air inside, however this still caused too much expansion. I then tried filling the jar with stones to reduce the space further, but this still did not work. Next I attempted using a small nail varnish bottle, however too much expansion still occurred so I realised there must have still been air trapped under the lid of the smaller jar. Therefore, I went back to the small jar but ensured there was as little air inside as possible, this finally worked. (*Figure 5*)

Figure 5 – final thermometer

In order to create a scale for the thermometer I put it in freezing water for 30 minutes (*Figure 4*) until the liquid did not move down any further and marked this on, I then placed it in boiling water (*Figure 3*) and marked the highest point reached, after this I split the distance between the 2 lines into 10 equal parts and split sections in half to make a centigrade scale.

Measuring atmospheric pressure

In order to calculate absolute zero I decided I would measure the relationship between temperature and volume and temperature and pressure, because when volume is zero or pressure is zero that is when absolute zero is theoretically achieved.[13,14]

However, I used an open-ended manometer in order to complete my investigation meaning I needed to consider atmospheric pressure because the formula $\Delta p = \rho g h$ would give me the pressure difference rather than the actual pressure of the gas.

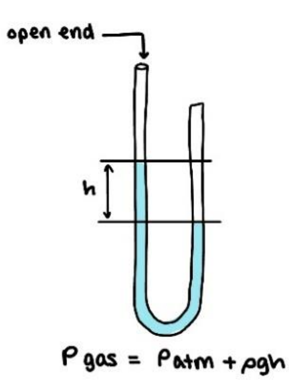


Figure 6

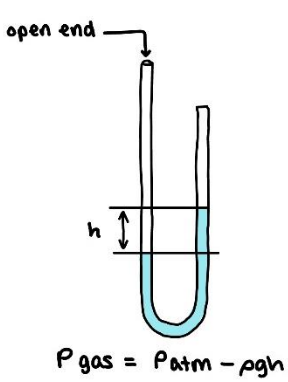


Figure 7

In *Figure 6* the height of the liquid on the side of the enclosed gas is lower showing that it has a larger pressure than atmospheric pressure, so you must add the pressure difference to atmospheric pressure to calculate overall pressure. In comparison *Figure 7* shows the height of the liquid on the open end of the manometer being lower showing that there is a larger pressure acting on the liquid from the atmosphere. Therefore, to find the pressure of the enclosed gas you must subtract the pressure difference from atmospheric pressure.[15]

So, in order to find a value for atmospheric pressure I began an investigation comparing pressure and volume using the manometer I had made.

Method

In this experiment I varied the height difference between the liquids in the two sides of the manometer and using this measurement (in meters) I calculated the pressure difference ($\Delta p = \rho g h$). I assumed the density of water to be 1000 kg/m3[16]and g to be 9.81 N[17]. The varying of height difference changed the pressure in the manometer and therefore changed the volume, so I measured the height of air in the closed end of the manometer. From this to find the volume of air I multiplied the height measured by the radius of the plastic tube squared and pi ($V = \pi r^2 h$). Overall I repeated the experiment 4 times and calculated an average of 93,600 Pascals (3sf) for atmospheric pressure.

Figure 8 - manometer

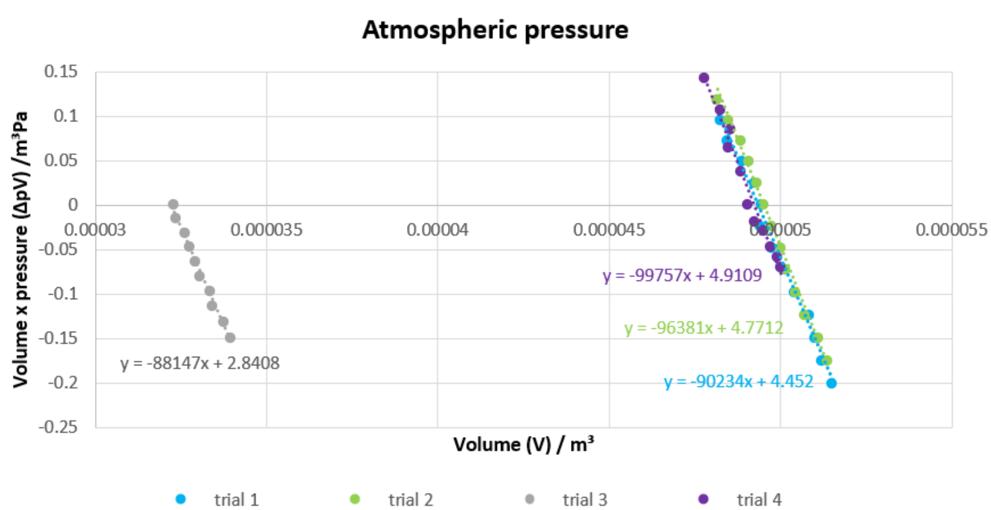
Results

In order to plot my results I assumed that there was an inversely proportional relationship between the pressure of the gas in the closed end of the manometer (P_{gas}) and volume (V), so as P_{gas} decreases V increases. This can be written as $P_{gas}V = k$ (where k is a constant) . I also decided to record all height difference readings where the height in the open tube was lower than the height in the closed tube as negative so the only equation needed to calculate pressure was $P_{gas} = P_{atm} + \rho g h$. I then substituted $\Delta p = \rho g h$ and $P_{gas} = P_{atm} + \rho g h$ into $P_{gas}V = k$.

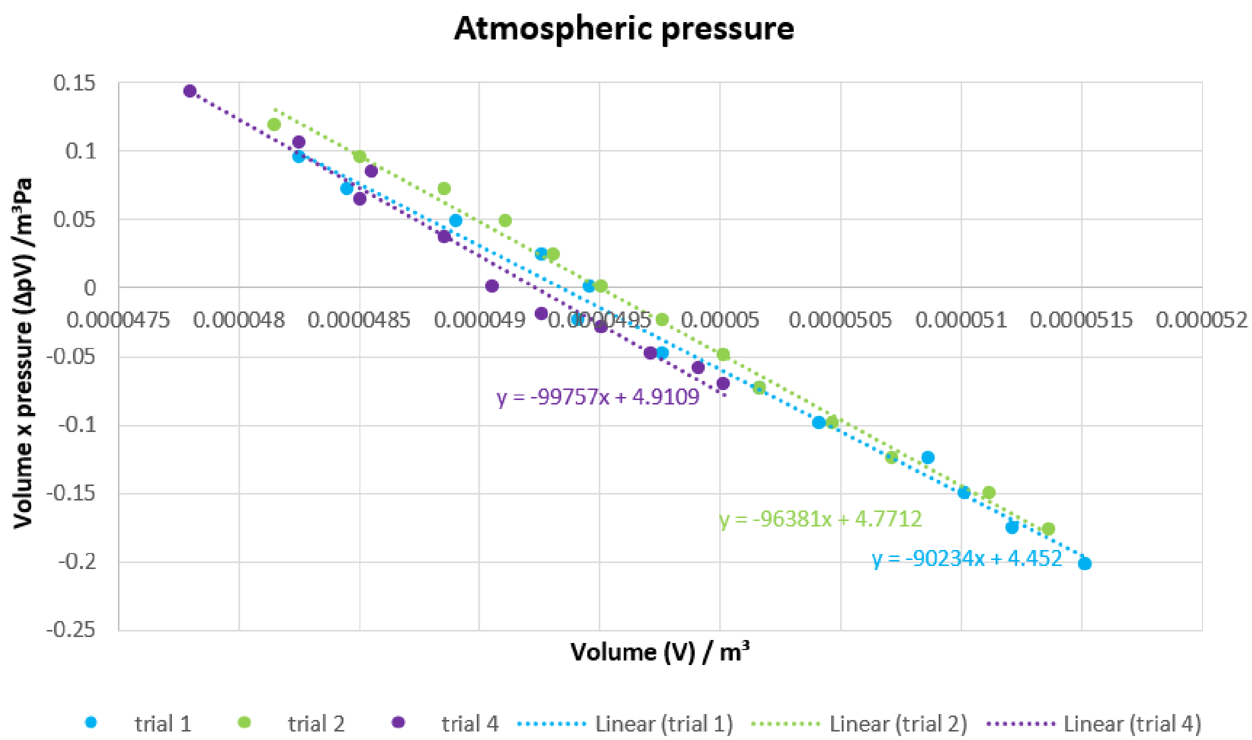
$P_{gas} = P_{atm} + \rho g h$ and so,
$\Delta p = \rho g h$ therefore,

$$P_{gas}V = (P_{atm} + \rho g h)V = k$$
$$(P_{atm} + \Delta p)V = k$$
$$P_{atm}V + \Delta p V = k$$
$$\Delta p V = -P_{atm}V + k$$
$$y = mx + c$$

So by plotting a graph with volume on the x axis and pressure difference multiplied by volume on the y axis the gradient of the line of best fit would be a negative value of atmospheric pressure.



Graph 1



Graph 2

Analysis

Graph 1 shows the 3rd trial was the least accurate, this may be because I tried varying the initial volume of air in the tube in comparison to other experiments. In trial 3 the initial height of air was 0.643m whereas in the others trials the initial height of air was always in the range of 0.95-0.96. The larger volume of air may have led to more accurate results as increasing the measurement would have reduced uncertainty.

Interestingly my final result was the most accurate, this may be because for the final reading rather than measuring the height difference between the two sides of the manometer with a ruler and then separately measuring the height of air in the tube (making 4 measurements in total) I only made 3 - this would have decreased the uncertainty in my measurements and may be the reason my final result was the most accurate.

In addition, my values for atmospheric pressure were always lower than the true value – 101.325 Pascals[18], atmospheric pressure does decrease as altitude increases due to air becoming less dense the higher up you go however, this would have had a very very small impact on the results of my experiment.

Measuring the value of absolute zero

Now that I had a value for atmospheric pressure and my thermometer was ready, I could begin to investigate the relationship between temperature, and pressure/volume.

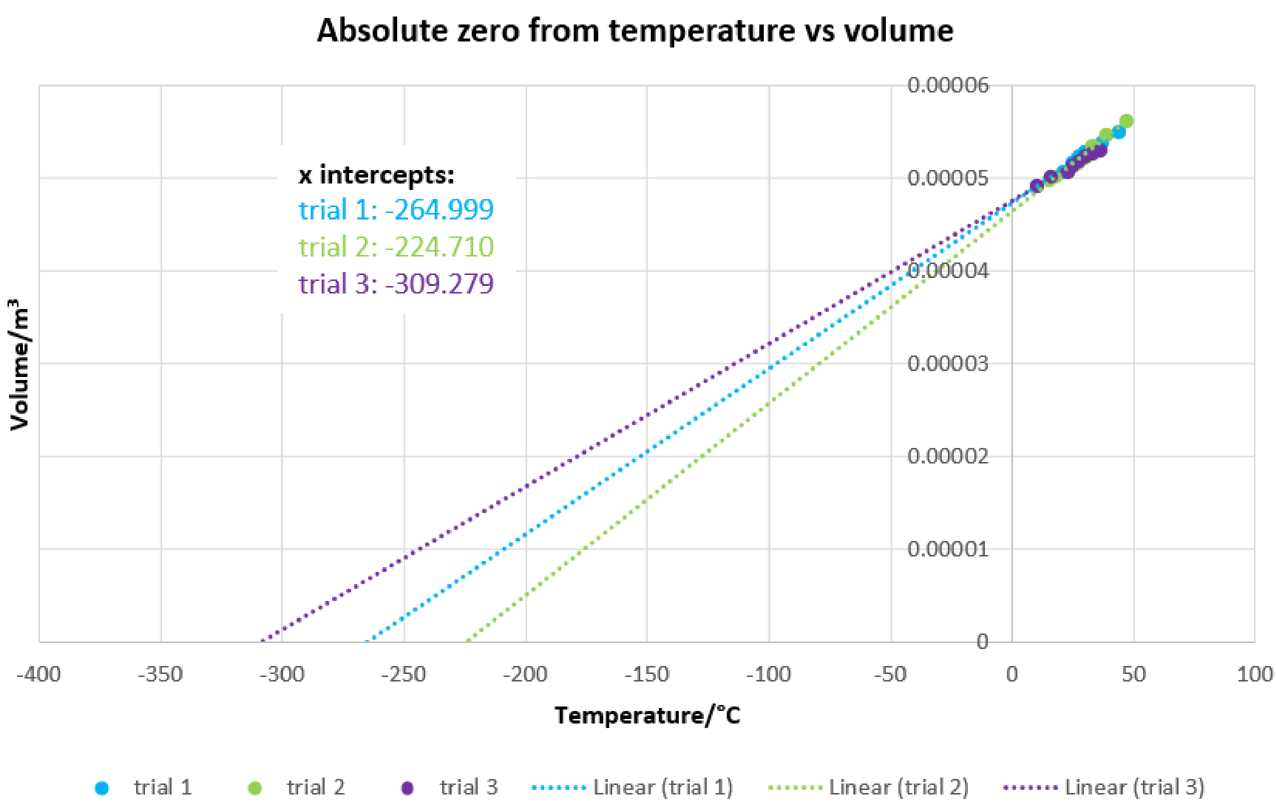
Method

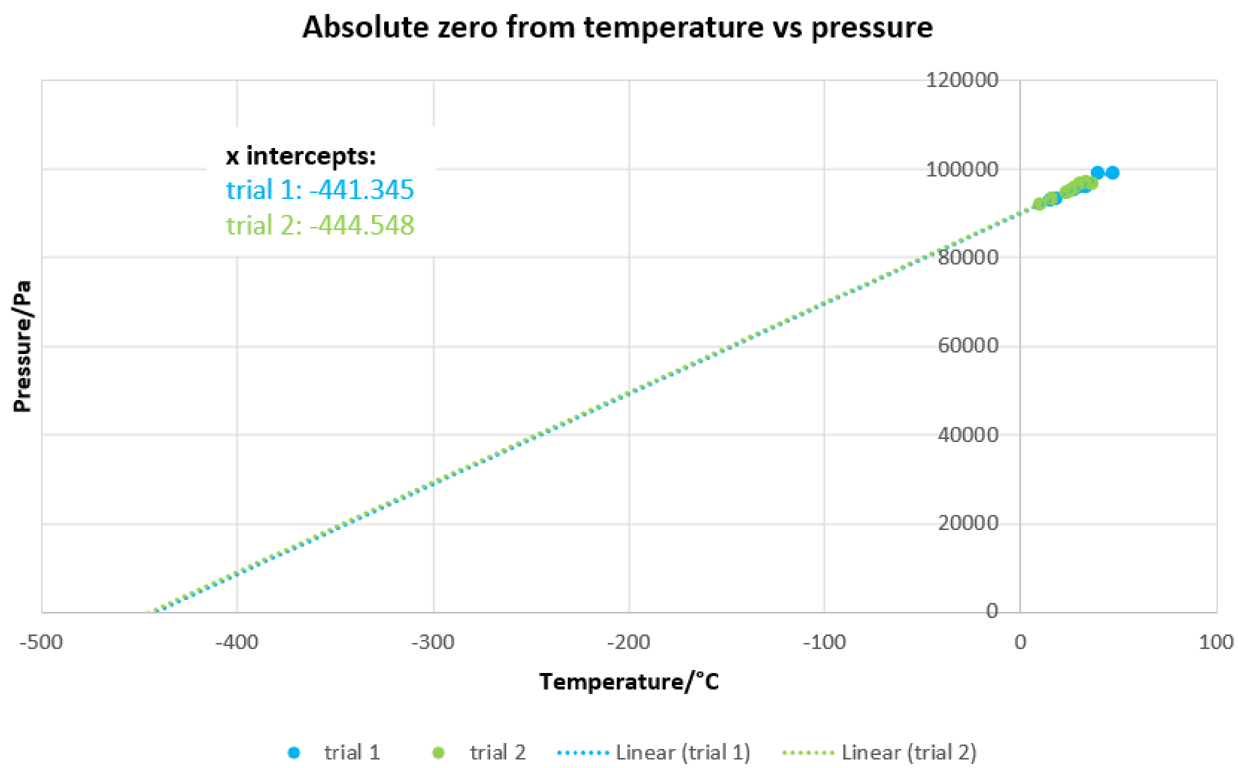
For both experiments I first measured the initial height of gas in the manometer when the pressure was 0 (when the liquid in both sides of the manometer were level). I then placed the manometer in a tub of hot water and waited 20 minutes for the water in the manometer and for the thermometer, to adjust to the new temperature before taking a reading. I then took readings every 15 minutes until the water had cooled back to room temperature, recording the temperature of the water and the height of gas/ the height difference in both sides of the manometer.

For the temperature volume experiment, in order to keep pressure the same when I measured the height of gas I ensured that the water in the closed and open side of the manometer were level so that there was no pressure difference and therefore no pressure in the gas.

In order to keep volume constant in the temperature pressure experiment I kept the initial height of gas recorded the same and then measured the height difference.

Results





Graph 4

Having recorded results for both experiments I then plotted the data onto graphs with temperature along the x axis and volume/pressure on the y axis. By extrapolating the line of best fit on the data and seeing where it crossed the x axis (seeing where volume or pressure is 0) I was then able to rediscover the value absolute zero.

Analysis

Between the two experiments I found it much harder to keep the height of gas the same in comparison to keeping the two sides of water level, and this may be one of the reasons that the temperature volume results were more accurate.

In addition, at first I thought that by using my own value for atmospheric pressure (the average of the 4 trials I did which was 93,600 Pascals (3sf)) rather than 101,325 Pascals – I would calculate an less accurate result for absolute zero. However, using my own value for atmospheric pressure I calculated an average of -443°C for the value of absolute zero whereas using the actual value for atmospheric pressure I calculated an average of -481°C.

In comparison my results from the relationship between pressure and volume were much more accurate, the average of the results -266 °C. Therefore, my overall average across both experiments and their results was -337°C.

And that is how I rediscovered the value for absolute zero.

Bibliography

[1] https://en.wikipedia.org/wiki/Absolute_zero

[2] http://chemed.chem.purdue.edu/genchem/history/charles.html

[3] https://www.carolina.com/teacher-resources/Interactive/gay-lussacs-law-temperaturepressure-relationship-in-gases-determination-absolute-zero/tr10730.tr

[4] http://chemed.chem.purdue.edu/genchem/history/boyle.html

[5] https://www.chemedx.org/video/boyles-law-j-tube

[6] https://en.m.wikipedia.org/wiki/Pascal%27s_law

[7] https://www.askamathematician.com/2010/05/q-how-did-lord-kelvin-come-up-with-the-absolute-temperature-i-mean-how-could-he-say-surely-that-it-was-273-15-c-below-zero/

[8] https://www.nist.gov/si-redefinition/kelvin-history

[9] https://www.youtube.com/watch?v=gsI6wOeqRlI

[10] https://www.youtube.com/watch?v=6Vofzv5Ogx0

[11] https://jehbco.com.au/improving-extreme-temperature-degradation-silicone-rubber-using-flame-retardant-additives/

[12] https://www.pearson.com/channels/general-chemistry/asset/2ba1fd36/ethylene-glycol-hoch2ch2oh-the-major-substance-in-antifreeze-has-a-normal-boilin

[13] https://www.infoplease.com/encyclopedia/science/physics/concepts/absolute-zero

[14] http://chemed.chem.purdue.edu/demos/main_pages/4.13.html

[15] https://chem.libretexts.org/Courses/Louisville_Collegiate_School/General_Chemistry/LibreTexts_Louisville_Collegiate_School_Chapters%2F%2F09%3A_Gases/LibreTexts%2F%2FLouisville_Collegiate_School%2F%2FChapters%2F%2F09%3A_Gases%2F%2F9.1%3A_Gas_Pressure

[16] https://byjus.com/physics/density-of-water/

[17] https://physics.nist.gov/cgi-bin/cuu/Value?gn

[18] https://en.wikipedia.org/wiki/Atmospheric_pressure