Determination of Absolute Zero

#### Introduction

#### Purpose

To experimentally determine the relationship between the temperature and pressure of a fixed mass of gas at constant volume and to determine absolute zero by extrapolating an experimentally derived temperature-pressure curve.

# Discussion

When a gas is heated, the speed and average kinetic energy of the molecules are increased. Consequently, they strike the sides of a container more frequently and more vigorously. If the container is flexible, like a rubber balloon, it will expand. When the temperature is reduced, the balloon will shrink. If we assume the pressure is constant, we can say that as the temperature of a given mass of gas is increased, the volume of the gas will increase (Charles’ Law).

If the container is rigid, like a metal ball, the increased frequency of molecular impacts with the side of the container and the greater “push” exerted by each impact causes an increase in pressure. Similarly, as the temperature of the system decreases in pressure, the pressure decreases (Gay-Lussac’s Law). Continued lowering of the temperature will result in a decrease in pressure. A graph may be plotted to show how the pressure of a given mass of gas varies as the temperature is changed. The temperature at which the pressure of the gas, in theory, becomes zero can be determined by extrapolating (extending) the curve of the graph to zero pressure. The temperature is known as ***absolute zero.***

In this experiment we will vary the temperature of a metal bulb having a fixed volume and containing a fixed volume of air. You will record the pressure changes and then plot the temperature in \*C versus pressure in psi (lbs/in2). By extrapolating the graph to zero pressure, you will obtain a value for absolute zero.

**Hypothesis**

If the volume of a gas is held constant and the temperature is increased, then the pressure of the gas will also increase.

#### Materials

Gay-Lussac apparatus Four Battery Jars Thermometer Water Samples

<http://somup.com/cZnl2gpbtr> Charles' Law & Gay-Lussac's Law (3:50)

#### Procedures

Use the video link. Scroll to 1:47 minute point. Collect data for the ice-water and the boiling water. You will need to extrapolate the room temperature and 50°C pressures.

Immerse the bulb of the Gay-Lussac Apparatus into battery jars containing water at different temperatures. Record the temperature and pressure of each water sample in the Data table.

**Calculations and Data**

1. Complete the data table and the table of calculations on the Calculations and Data sheet.
2. Plot the temperature in Celsius on the x-axis (*independent variable*) versus the pressure in PSI on the y-axis [each line is 1 psi] (*dependent variable*).
3. You will need to allow for extrapolation into the negative x quadrant.
4. Draw a Straight-line slope representing your plotted points.
5. Extrapolate the slope line to “zero pressure” to determine an experimental value for “Absolute Zero”

##### Temperature and Pressure of Various Sample of Water Temperature

|  |  |  |
| --- | --- | --- |
| Water Sample | Temperature  (°C) | Pressure  (psi) |
| Ice-water |  |  |
| Room Temperature |  |  |
| 50 °C |  |  |
| Boiling |  |  |

##### Calculations based on the Data Table

|  |  |  |  |
| --- | --- | --- | --- |
| Water Sample | T  in K | P / T  (T in °C) | P **/** T  (T in K) |
| Ice-water |  |  |  |
| Room Temp |  |  |  |
| 50 C |  |  |  |
| Boiling |  |  |  |

# Assumptions

1. Normally when materials are heated they expand and when cooled they contract. Because metals are good conductors of heat, we can assume the temperature of the gas inside the bulb is the same as the temperature of the water surrounding the bulb.
2. Also, we are assuming that air is an ideal gas, i.e., that as the temperature continues to drop the air would continue to contract.

**Conclusions and Questions**

1. What value did you obtain for absolute zero based on extrapolating your slope of Pressure versus temperature? Determine the percent difference between your experimental value and the correct value of –273 °C
2. When your graphed slope line intersects the x-axis, what is the value of the pressure? Explain.
3. Explain how, using Gay-Lussac apparatus and your graph, you could measure temperature without a thermometer.
4. After completing the calculations in the table, determine
5. If the relationship between pressure and temperature (in °C) is direct or indirect.
6. If the relationship between pressure and temperature (in Kelvin) is direct or indirect.
7. Write a general equation including the actual value of the constant.
8. Derive a general equation that eliminates the need for the constant in part (c).

5. A metal ball is filled with air at 20 °C has a pressure of 3 atmospheres. At what Celsius temperature would the pressure be 5 atmospheres.

**Temperature and Pressure of Various Sample of Water Temperature**

|  |  |  |
| --- | --- | --- |
| Water Sample | Temperature  (°C) | Pressure  (psi) |
| Ice-water |  |  |
| Room Temperature |  |  |
| ~50 °C |  |  |
| Boiling |  |  |

##### Calculations based on the Data Table

|  |  |  |  |
| --- | --- | --- | --- |
| Water Sample | T  in K | P / T  (T in °C) | P **/** T  (T in K) |
| Ice-water |  |  |  |
| Room Temp |  |  |  |
| ~50 C |  |  |  |
| Boiling |  |  |  |

Pressure Versus Temperature

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Temperature °C

100

70

40

10

-20

-50

-80

-170

-200

-230

-273

**Conclusions and Questions**

1. What value did you obtain for absolute zero based on extrapolating your slope of Pressure versus temperature? Determine the percent error between your experimental value and the actual value of –273 °C
2. When your graphed slope line intersects the x-axis, what is the value of the pressure? Explain.
3. Explain how, using the Gay-Lussac apparatus and your graph, you could measure temperature without a thermometer.
4. After completing the calculations in the table, determine:
5. If the relationship between pressure and temperature (in °C) is direct or inverse.
6. If the relationship between pressure and temperature (in Kelvin) is direct or indirect.
7. Write a general equation including the actual value of the constant.
8. Derive a general equation that eliminates the need for the constant in part (c).
9. A metal ball is filled with air at 20° C has a pressure of 3 atmospheres. At what Celsius temperature would the pressure be 5 atmospheres?

**Temperature and Pressure of Various Sample of Water Temperature**

|  |  |  |
| --- | --- | --- |
| Water Sample | Temperature  (°C) | Pressure  (psi) |
| Ice-water | -2 | 13.8 |
| Room Temperature | 24 | 14.9 |
| ~50 °C | 52 | 16.2 |
| Boiling | 91 | 18.0 |

##### Calculations based on the Data Table

|  |  |  |  |
| --- | --- | --- | --- |
| Water Sample | T  in K | P / T  (T in °C) | P **/** T  (T in K) |
| Ice-water | 271 | -6.90 | 0.051 |
| Room Temp | 297 | 0.62 | 0.050 |
| ~50 C | 325 | 0.31 | 0.050 |
| Boiling | 364 | 0.20 | 0.049 |

Pressure Versus Temperature

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Temperature °C

100

70

40

10

-20

-50

-80

-170

-200

-230

-273

**Conclusions and Questions**

1. What value did you obtain for absolute zero based on extrapolating your slope of Pressure versus temperature? Determine is the percent error between your experimental value and the actual value of –273 °C

***(A – O) / A x 100% (-273 - -305) / -273 x 100% = 12 % Error***

2. When your graphed slope line intersects the x-axis, what is the value of the pressure? Explain.

***The x intercept value for pressure is 0 kPa, meaning that at absolute zero (-273 C or 0K), nothing exists. Absolute Zero would require NO volume and NO motion of molecules, making it a theoretical value.***

3. Explain how, using the Gay-Lussac apparatus and your graph, you could measure temperature without a thermometer.

***One can extrapolate values by extending the straight line (best fit) of the plotted values***

4. After completing the calculations in the table, determine:

a. If the relationship between pressure and temperature (in °C) is direct or indirect.

***Guy Lussac’s law shows a direct relationship between P and T (in °C)*** ***at constant Volume.***

b. If the relationship between pressure and temperature (in Kelvin) is direct or indirect.

***Guy Lussac’s law shows a direct relationship between P and T (in Kelvin)*** ***at constant Volume.***

c. Write a general equation including the actual value of the constant.

***P / T = k 🡪 P / T = 0.05 but one must use K rather than C temperature***

d. Derive a general equation that eliminates the need for the constant in part (c).

***P1 / T1 = P2 / T2 but one must use K rather than C temperature***

5. A metal ball is filled with air at 20° C has a pressure of 3 atmospheres. At what Celsius temperature would the pressure be 5 atmospheres?

***P1 = 3 atm T1 =* 20° C *= 293 K P2 = 5 atm***

***P1 / T1 = P2 / T2 T2 = P2 T1 / P1 T2 = (5 atm)(293 K) / (3 atm) = 488 K***

***T2 =* 215** ° C **Only Kelvin yields a constant in the P/T relationship (see chart)**