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The Calculation of Heat Capacity Ratios of Nitrogen and Argon Using Adiabatic Expansion

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# Introduction:

The heat capacity of a substance tells us how much heat must be put into a system to get a certain amount of change in the temperature: . There

: and .

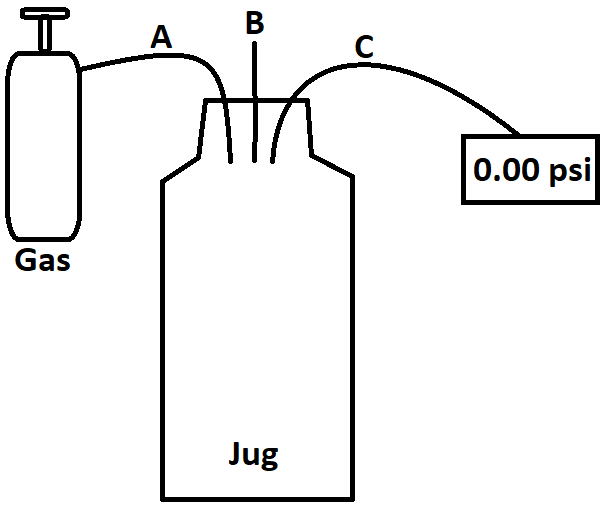
There are different attributes a system may have which yield large simplifications. Adiabatic means no heat transfer between the system and the surroundings (and using equation 1: ).

|  |  |
| --- | --- |
|  | (2) |

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

# Experimental Methods:

The apparatus consists of a 5-gallon jug connected to a pressure gauge and gas cylinder. The 5-gallon glass jug was used as a vessel to contain argon and nitrogen for the process. It was defined as the system. Before beginning the experiment, the vessel was filled with either argon or nitrogen. The procedure for both was identical: the vessel was lowered upside down into a water bath with a tube allowing air in the vessel to be displaced by the water. The same tube was plugged into a regulator on the gas cylinder and the gas was allowed to displace the water in vessel until gas flowed freely out the surface of the water. The vessel was quickly raised out of the water bath and capped with the 3-holed rubber stopper. All tubes were connected as shown in figure 1. Tube C was attached to a digital pressure gauge to determine the difference between ambient atmospheric pressure and the pressure in the vessel. Tube A was attached to the gas canister and tube B was clamped closed. Temperature T1 was recorded.

**Figure 1.** Vessel with a gas canister to the left and pressure gauge to the right. The system is closed by a rubber stopper.

The vessel was pressurized to around 1.6 psi above atmospheric and allowed to return to room temperature. The pressure was checked again to ensure 1.6 psi after thermal contraction and to ensure there were no leaks in the system. The pressure P1 was recorded. The gas was allowed to adiabatically expand by quickly unclamping tube C and reclamping it. After thermal equilibrium was achieved, the pressure P3 was measured. Two trials of nitrogen and two of Argon were completed. Between trials 2 and 3, the atmospheric pressure P2 was measured along with ambient room temperature T1 for later calculations.

# Data and Results:

**Table 1.** Data and calculations for gamma with uncertainty.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | P1, gauge (psi) | P3, gauge (psi) | P1 (psi) | P3 (psi) | γ |
| N2 trial 1 | 1.66±0.01 | 0.45±0.01 | 16.409±0.006 | 15.20±0.02 | 1.39±0.08 |
| N2 trial 2 | 1.64±0.01 | 0.43±0.01 | 16.389±0.006 | 15.18±0.02 | 1.37±0.08 |
| Ar trial 1 | 1.63±0.01 | 0.41±0.01 | 16.379±0.006 | 15.16±0.02 | 1.35±0.08 |
| Ar trial 2 | 1.71±0.01 | 0.58±0.01 | 16.459±0.006 | 15.33±0.02 | 1.5±0.1 |

The calculation of P1 and P3 are relative to the measurement of P2. This value was acquired from IBM’s Weather Data API on August 31, 2022 as 30.03±0.01inHg. [1] The conversion from inHg to psi went as follows:

Next, the uncertainty must be propagated to P1 and P3. For example:

Now we can calculate gamma using equation 4:

Partial derivatives of gamma with respect to various pressures were calculated using Mathematica.

Graphical user interface, text, application, email

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**Figure 2.** The calculation of the uncertainty of gamma values using Mathematica. In[1] shows the definition of the gamma function followed by the data points. In[4] shows the calculation of gammas for each trial. In[5] shows an example calculation of the partial derivative of gamma. In[6-8] is the partial derivatives with respect to P1, P2 and P3 respectively. In[9] is an example calculation of the uncertainty of gamma for trial 1. In[10] is all gamma values and uncertainties

and for all trials. Error on these measurements originates from the instrumentation. Each uncertainty is half the incremental value for the instrument.

Now we can calculate the mean of each gas using the student-t distribution. With 95% confidence and 1 degree of freedom using a two tailed distribution, the critical value is 12.71.

|  |  |  |
| --- | --- | --- |
|  |  | (5)  (6) |

Equation 5 gives the squared variance of a set x with n elements. Using equations 5 we calculate the variance of our nitrogen data:

Using equation 6 we can find the 95% confidence interval:

**Table 2.** 95% confidence intervals for gamma values of nitrogen and argon.

|  |  |  |
| --- | --- | --- |
|  | Nitrogen | Argon |
| γ |  |  |

When compared to literature values we find for nitrogen and for argon both with two standard deviations of uncertainty. [2] We determine if zero falls within the range of the difference of the values the uncertainties added in quadrature. For nitrogen we find 0 within the range:

Thus, our experimental nitrogen value agrees with the literature value. For argon we find 0 inside the range as well, so our values also agree. Unfortunately, there was a relatively large variance of 0.95 within our set of data for argon, compared to 0.0125 for nitrogen. More experimental data is needed to get a more precise value of gamma for argon.

There were two main differences during the trials of argon. The jug was capped more quickly in the second trial, and the capping and uncapping process was faster in the second trial. We originally thought the low gamma value was due to air entering the system during the first trial. This is likely not the case because the calculated gamma value would not have been lower than the gamma of the atmosphere (1.44 [2] compared to 1.35 for the first argon trial). If the air theory is true, the entire volume of argon would have had to been displaced within a few seconds, which likely did not happen.

Comparing values: the measurement for is consistent within 0.5% between the two trials, but is larger in trial 2 by 1.1%. When we look at the actual gauge values, the difference becomes 5% for and 41% for . With a smaller we expect a smaller , although the difference here seems significant. There are multiple possibilities for such a low value: there may have been a leak after capping and before measuring which could have been sealed before the measurement. It is also possible the uncapping and capping procedure took too long and the gas was allowed to escape during thermal expansion. Pressure differentials do not take long to equilibrate in the absence of a barrier, so both answers seem reasonable. If we find what of the first trial should have been to achieve the same gamma value in the second, we rearrange the equation of gamma to get:

Which means should be compared to the measured value of to achieve a gamma of 1.5. Such a difference in pressure results in a volume of gas small enough to have escaped through a small leak. This same small volume of gas could have also escaped before the thermal expansion.

# Conclusion:

In this experiment, the heat capacity ratio is calculated from the pressures before adiabatic expansion and after thermal expansion of nitrogen and argon. Our ratios were calculated to be and with 95% confidence. These values agree with the literature values, and even the theoretical and , although our values are not very precise. This is due to both a small sample size resulting in a large variance and discrepancies in the argon trials. We concluded that for argon trial 1 is too small and it would need to be compared to the measured to obtain the same gamma value as trial 2. This lower pressure was likely caused by gas escaping before the measurement of , either before the capping process during thermal expansion, or through a leak after capping.

Regardless of the error, the trend in heat capacity ratios for both gasses is clear. Monoatomic gasses have lower molecular degrees of freedom.

Safety:

Despite being quite abundant in our atmosphere, argon and nitrogen pose risks within a lab environment and safety measures must still be taken. When working around high pressure gas cylinders it is always necessary to ensure they will not tip over. When using regulators, close the main valve when not in use and always open it slowly to begin. Experiments should be done in a well-ventilated area as not to displace a large amount of oxygen in the room. [3,4] Argon has a specific vapor density of 1.66: greater than that of air, increasing risk of asphyxiation. [4] When left in the lungs, argon may settle to the bottom, replacing oxygen.

# References:

1. *Site-Based Observations - v1*; The Weather Company: Atlanta, GA, 2022. <https://ibm.co/v1cSBO> (accessed August 31, 2022)
2. Branca M.; Soletta I., “CP / CV Ratios Measured by the Sound Velocity Method W Using Calculator-Based Laboratory Technology”, *J. Chem. Educ.* **84**, 3, 462 (2007). doi: 10.1021/ed084p462
3. *Nitrogen;* MSDS No. 001040; Airgas: Radnor, PA, August, 31, 2021. <https://www.airgas.com/msds/001040.pdf> (accessed 9/27/22)
4. *Argon;* MSDS No. 001004; Airgas: Radnor, PA, January, 5, 2021. <https://www.airgas.com/msds/001004.pdf> (accessed 9/27/22)

# Calculations:

To propagate errors for P1 and P3:

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Comparing literature values with experimental values for argon: