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Heat engines

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Abstract

In this experiment we studied a very important effect by verifying the Heat engine functioning. Using a sufficiently sensible set-up, our purpose was at first to study the Watt (P-V) diagram for different strokes.Then we computed the adiabatic coefficient γ and the change of internal energy and entropy. This experiment allowed us to verify the the concept of a Heat Pump, which takes work to give heat back. Our experimental measurements allowed us to have quite consistent results.

1 Introduction

In thermodynamics a thermal engine is a physical or theoretical device capable of exchanging heat and work with the surrounding environment or with other physical systems. Thermal engines are typically cyclical and are therefore physically described by a thermodynamic cycle. The name of a thermal engine is usually that of the associated thermodynamic cycle. Sometimes instead they have names such as diesel engines, gasoline, turbine engines, steam engines. The work is produced by exploiting the thermal gradient between a hot source and a cold source. The heat is transferred from the hot source to the cold one usually through a fluid. An example of such machines are refrigeration machines and heat pumps.

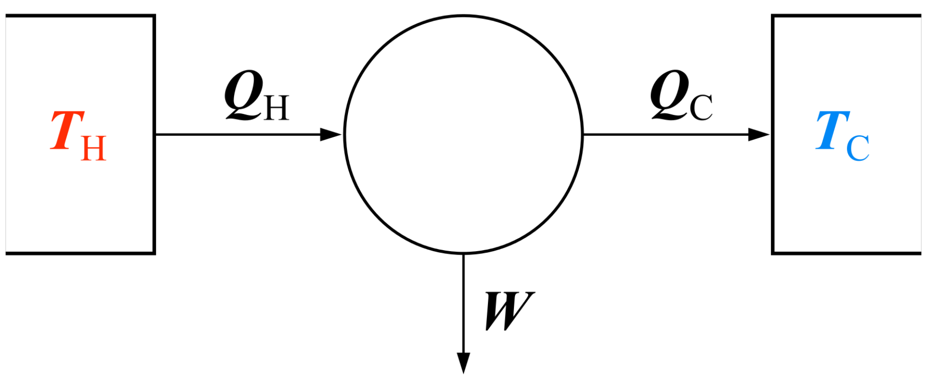


Figure 1: Example of a Carnot heat engine.

□

2 Dissertation of the theory

2.1 4 strokes cycle

The Carnot cycle of a perfect gas consists of two isotherms (1-2) and (3-4) at temperatures respectively T 1> T 2 and two adiabatic (2-3) and (4-1) Reversible isothermal expansion (1-2): the gas draws in the amount of heat Q 1 from the hottest source T 1 and this causes the volume of the gas to increase and the pressure to decrease. The tendency of the gas temperature to drop is counteracted, limited to the first part of the stroke, by the effect of the heater (heat source). As a result, it remains constant.

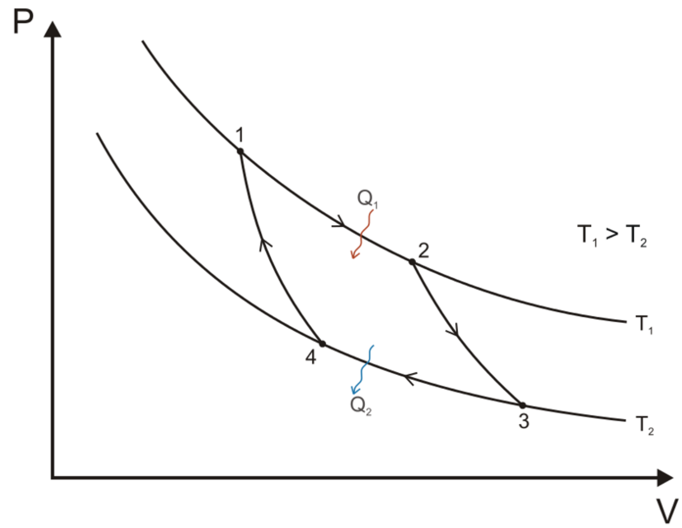


Figure 2: Example of a 4 strokes Watt diagram.

Reversible adiabatic expansion (2-3): when the gas finishes drawing up thermal energy, it is maintained so that it does not exchange energy with the outside world through an adiabatic, even though it continues to expand: the result is a lowering of the temperature. Reversible isothermal compression (3-4): the gas is compressed keeping the temperature constant and the heat generated by the work done in this phase is removed from the contact with the source at the lowest temperature. T 2 <T 1 . The gas is released to the source by the amount of heat Q 2 . Reversible adiabatic compression (4-1): when the gas finishes to release heat to the chiller, it continues to compress but is maintained so that it does not exchange energy with the outside. The result of this cycle is to show that, having an ideal Carnot machine, a perfect gas and two sources at different temperatures at your disposal, you can get work done by bringing the system back to its original condition. The efficiency of a thermal machine is, in general, the ratio between the useful work that the machine can do and the total heat absorbed by the system. In the case of the Carnot cycle, the efficiency will be equal to:

$$\nu = \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{T2}{T1}$$

2.2 3 strokes cycle

During this Tp we will study a three strokes heat pump. An heat pump works like a heat engine, only having the inverse sequence of strokes (cfr. Introduction).

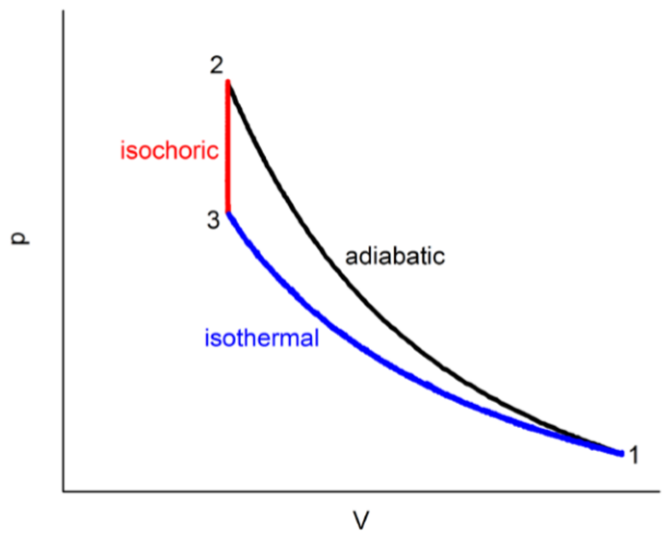


Figure 3: Example of a cycle that we will perform today.

2.3 Theoretical work to be done BEFORE the lab session

We compute the expressions for the change of internal energy and for the change of entropy! We have that :

$$dU = \eth W + \eth Q$$

and :

$$dS_n = \Delta S - \int \eth Q dx$$

When all the transformations are reversible :

$$dU = 0 \qquad dS = 0.$$

So in the first part from 1 to 2 of our experiment we consider an adiabatic process : dQ=0, dU=dW

$$dU = \eth W = -\int_{V1}^{V2} pdV = \int_{T1}^{T2} nC_v dT$$

for ideal gases :

$$W = nRTln\frac{V1}{V2} = C_v(T2 - T1)$$

$$dS = \int \frac{1}{T} dQ.$$

In the second tract from 2 to 3 we consider an isochoric process : dW=0.

$$dU = nC_v(T3 - T2)$$

$$dS = nC_v ln\frac{T3}{T2}$$

For the last section back to 1 we consider an isothermal process :

$$dU = 0$$

$$dS = \int \frac{1}{T} dQ = nRln\frac{V2}{V1}.$$

$\square$

3 Setup

All the measurements were recorded using an Adiabatic Gas Law apparatus following the procedure suggested in the TP handout. □

Figure 4: Experimental apparatus used for this session.

4 Procedure

In this session we have succeded in analyzing the following gases: Helium, Carbon dioxide and finally Argon. We have started with Helium because it the low molecular weight and it was the easiest to compress and so the time required to record the isothermal stroke would be a little smaller in comparison with the other two heavier gases. Here is the figure of the curve that we obtained for He : As one can notice the region more complicated to evaluate

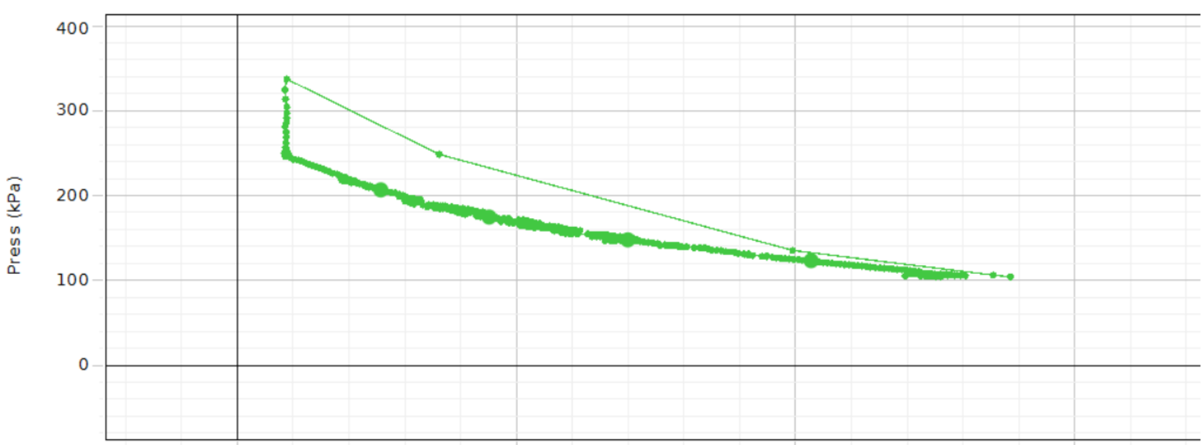


Figure 5: Three strokes cycle of Helium.

during this tp has been the isothermal process since we cannot be sure that the temperature

doesn't vary all along the recording procedure.
Then we were interested in plotting a graph to understand how the volume changes with respect to time. In the right side of the plot one can see the brusque decreasing of the volume

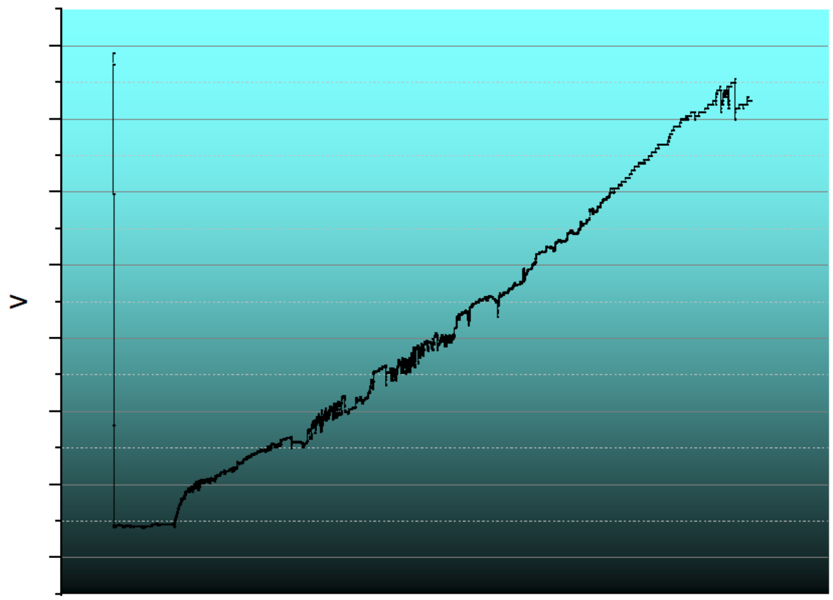


Figure 6: Evolution of the volume in time.

in an adiabatic compression. Next the volume is kept constant and the pressure diminishes. This is the isocoric process. In the end we performed a reversible isothermal expansion, which is described by the steep slope in the plot. □

5 Results

In this section we will verify the corresponding conditions, adiabatic and isotherm, by plotting p(V) together with a calculated curve using pV=constant or pV^{γ}=constant respectively. We will not be interested in studying the isochoric process since there the volume is only a constant. In the end we will plot the relation of T as a function of V. To do this we proceed on Origin by fitting the adiabatic curve with an user defined fit:

$$p = \frac{c}{V^h}$$

where h=γ and c a constant.

We obtain the following result:

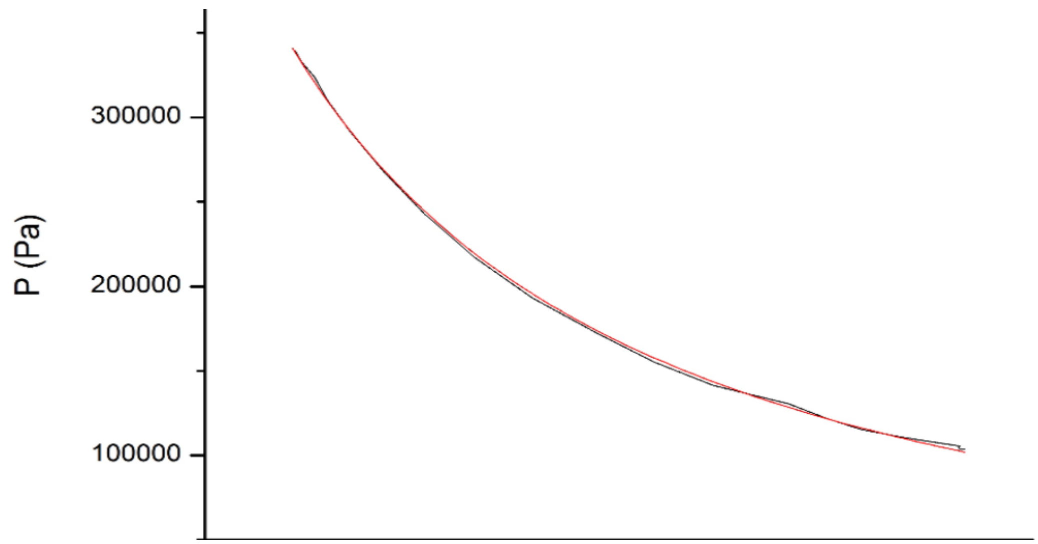


Figure 7: Fitting of the adiabatic stroke to find gamma.

here :

$$p = \frac{1.05}{V^{1.57}}$$

]so :

$$\gamma_{He} = 1.55.$$

with 5% error from the expected value of 1.63.

When we fit the same function for the isotherm process we expect to find the value h=1 because pV=constant.

We fit again on the software :

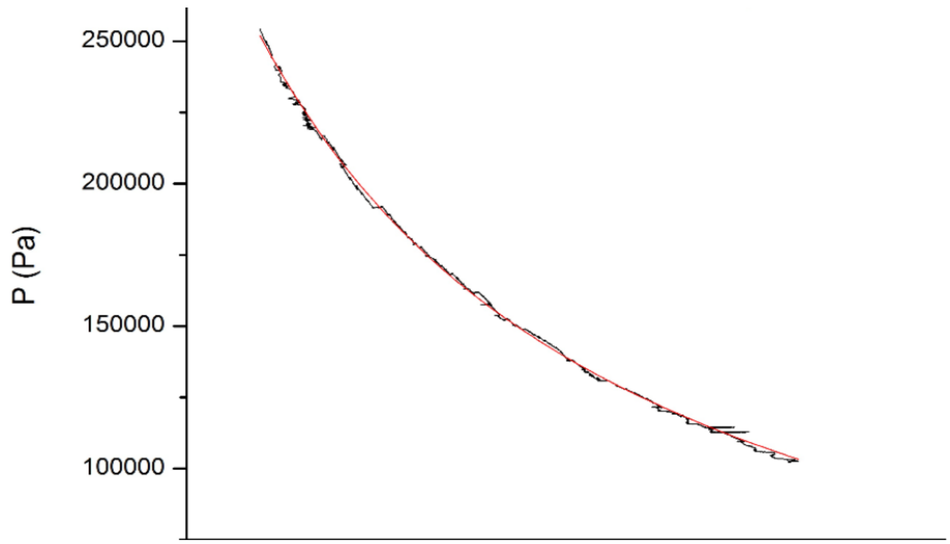


Figure 8: Fitting of the isotherm stroke to confirm here that gamma=1.

we have then :

$$p = \frac{18.37}{V^{1.03}}$$

so here :

$$\gamma = 1.03$$

with 3% error from the expected value of 1.

Now we do the same for T(V). We study how the temperature varies as a function of the volume during the adiabatic stroke. We expect to have a plot satisfying the relation $TV^{\gamma-1} = constant$. So we have defined on Origin a new fit:

$$T = \frac{c}{V^h}$$

where h=$\gamma - 1$

We obtain the following result : the fit reads :

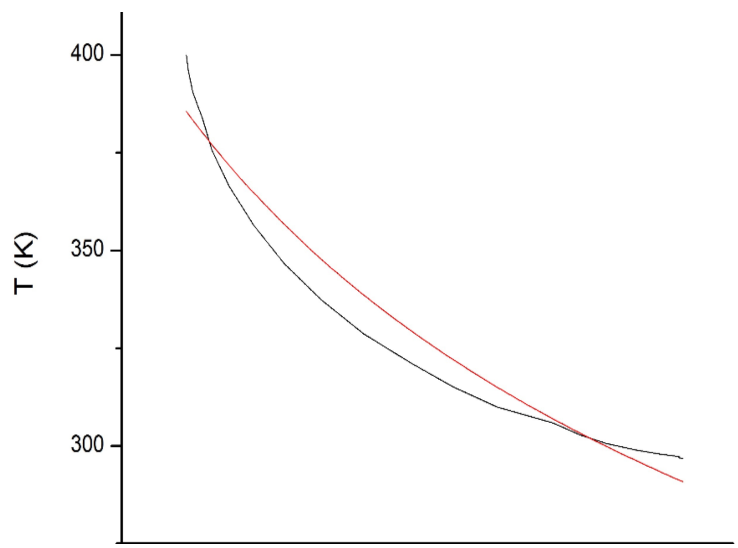


Figure 9: Fitting of the temperature to find gamma.

$$T = \frac{17.64}{V^{0.54}}$$

so here :

$$\gamma = 0.54 + 1 = 1.54$$

with 6% error from the expected value of 1.63.

5.1 Internal energy and entropy change

To compute the internal energy and entropy change we establish C_v and C_p by knowing that helium is a monoatomic gas so it has only three translational degrees of freedom and no vibration or rotation as Docteur Bhalawane told us. So $C_v = \frac{3R}{2}$, and by Mayer's rule $C_p - C_v = R$ we can find $C_p = \frac{5R}{2}$. We will normalize this to the mass. By using the equation discussed in the theoretical paragraph for the change of entropy and of internal energy we find :

	adiabate	***isochore***	***isotherme***	***sum***
dU	19.02	-19.17	0	-0.15 J
dS	0	0.49	-0.58	-0.09 J/K

These results are in accordance with the theory discussed at the beginning : For a reversible cycle the change in entropy and internal energy amounts to 0. Of course we had some losses which is why we end up with negative values. But all in all we are satisfied.

5.2 Results for Co2 and Argon

For the other two gases we will give a summarizing overview table :

gas	γ ***pV***	γ ***TV***	γ ***literature***
CO2	1.25	1.24	1.29
Argon	1.58	1.56	1.67

The value we have for CO2 is more close to the literature value. The value for argon is not satisfactory. Maybe we were not sufficiently careful by voiding the apparatus from the previous gas and so it could have been contaminated with some amount of Helium.

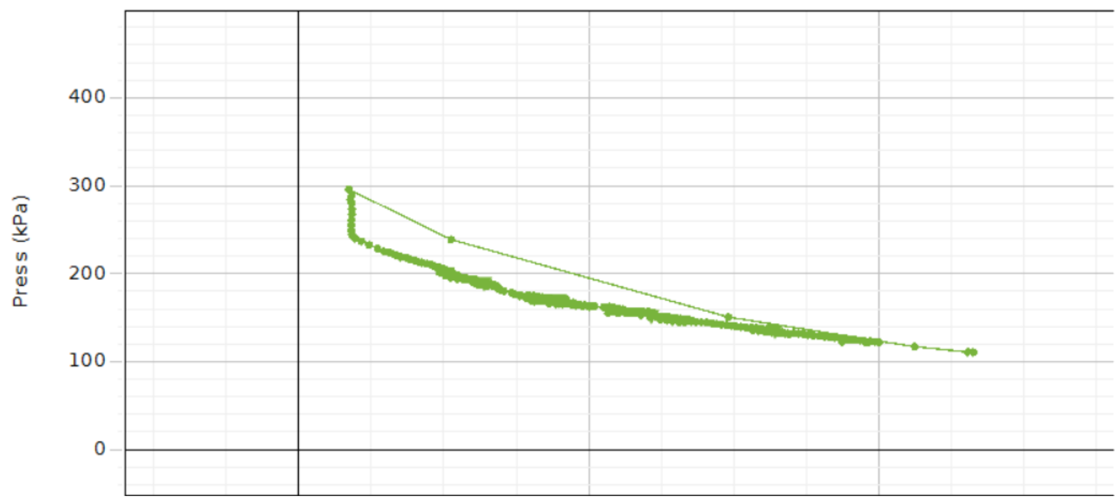


Figure 10: Three strokes cycle of Carbon Dioxide.

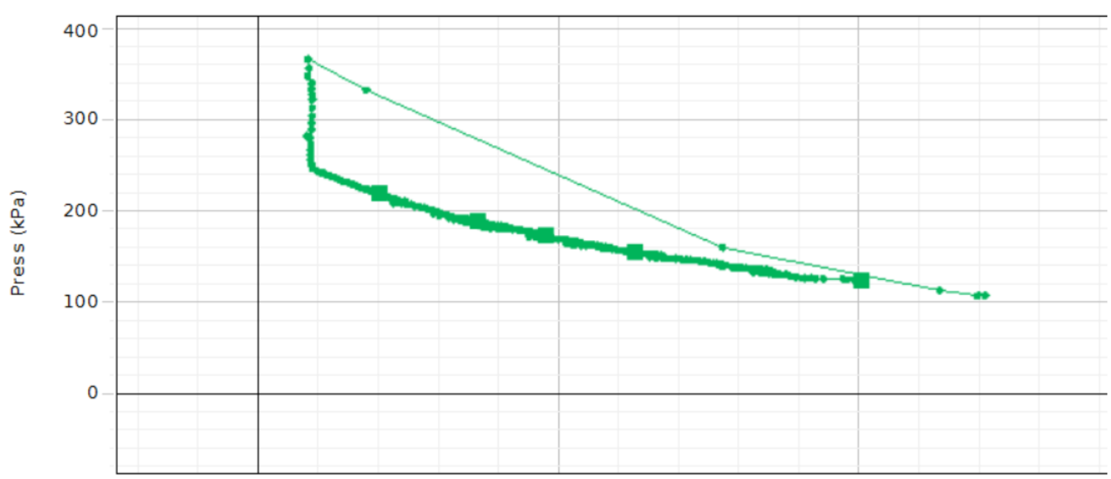


Figure 11: Three strokes cycle of Argon.

□

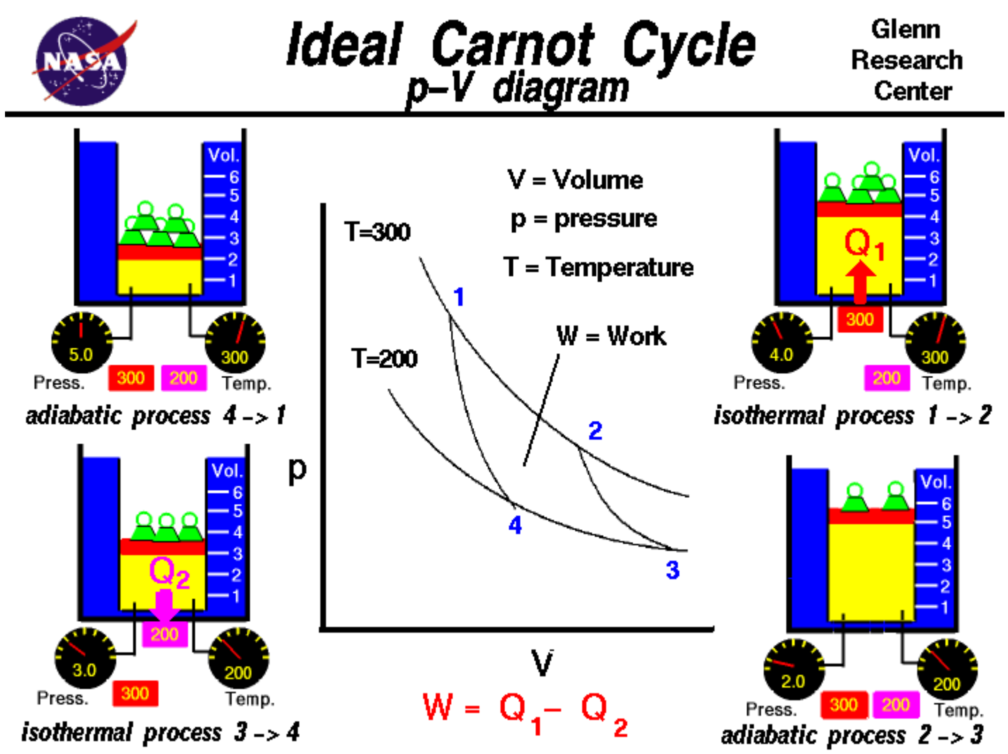
6 Conclusions

One could say that we reached satisfying results, but the entire procedure presented some difficulties and sources of mistakes. We can clearly compute that the work done received by the system during the all cycle is positive, this can be seen by the fact that we had to do lots of muscle exercice while pushing the piston in order to produce heat. The precision required was high and the patience to collect the isothermal part was daunting. But all in all we could exploit all the data we collected, such that the quality of our work was not negative influenced. We were able to verify with this experiment the pV= constant law, the pV^{γ}=constant law and the $TV^{\gamma-1}$=constant law law were applicable.

This method is interesting above all, because it made us visualize practically the topics which we will encounter in the lectures of thermodynamics during this semester. □

7 Appendix

We want to share this picture describing an ideal Carnot engine by the NASA. We find it really explanatory :



7.1 Acknowledgements

We would like to express our special thanks of gratitude to our supervisor ***Mr.Youri Nouchokgwe*** as ***Doctor Bahlawane*** who gave us the opportunity to do this wonderful lab experiment on the topic Heat engines, and we came to know so many new things we are really thankful to them.

□□

References

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