Thermolabs

Freek Pols
Science Education and Communication, Delft University of Technology, Delft, The Netherlands

Tom Haanstra
ImPhys, Delft University of Technology, Delft, The Netherlands

Roel Smit
Quantum Nanoscience, Delft University of Technology, Delft, The Netherlands
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Here we describe our project related to the topic of thermodynamics as devised for a renewed curriculum.

1. *Introduction*

- New curriculum
- Projects in which simulations, project work and labs are central and serve as link between courses and thereby aim at conceptual development / strengthening
- Here describe thermodynamics
- expensive experiments, single setup - or engineer it
- ...

2. *Physics background*

We here utilize the method devised by Clément and Desormes {see e.g. [ref]} which makes use of an adiabatic process where a pressured gas (**state1:** $P_1, T_1 = T_{atm}$) in a cylinder with volume V is suddenly released. In our case we use a fire extinguisher where the gas is released by opening the valve. As the pressure suddenly drops the temperature in the cylinder decreases as the gas is doing work. When the pressure inside the cylinder equals the atmospheric pressure (**state 2:** $P_2 = P_{atm}, T_2$) we close the valve. The temperature of the gas inside the cylinder increases and hence the pressure increases until equilibrium is reached (**state 3:** $P_3, T_3 = T_{atm}$), and hence the pressure increases to a value - no work is being done and here we make the assumption that the heat capacity of the cylinder is much larger than the heat capacity of the gas. The venting (state 1 → state 2) is adiabatic; the reheating (state 2 → state 3) is isochoric with heat from the vessel; overall, the vessel acts as a large reservoir returning the gas to T_{atm}.

The first part of the process can be described by the Poisson equations for an adiabatic process:

$$T_1^{\gamma} P_1^{1-\gamma} = T_2^{\gamma} P_2^{1-\gamma} \tag{1}$$

where γ is the specific heat ratio given by $\gamma = \frac{C_p}{C_V}$. We note that $T_1 = T_{atm}$ and $P_2 = P_{atm}$. The second part of the process can be described using Gay-Lussac's relation:

$$\frac{P_2}{T_2} = \frac{P_3}{T_3} \tag{2}$$

where we consider (again) that $P_2 = P_b$ and $T_3 = T_{atm}$. Rearranging these equations (see Appendix) yields:

$$\gamma = \frac{\ln P_1 - \ln P_b}{\ln P_1 - \ln P_3} \tag{3}$$

3. *Methods & Materials*

We use an 'old' fire 2L fire extinguisher as vessel and a an Arduino MKR Zero with onboard sd-card module as data logger, see {numref}'fig_experimental_setup_1'. An Adafruit MPL3115A2 is used to measure both temperature and pressure. The sensor is able to detect small pressure changes (+/- 0.05kPa) but is limited in range. We repeat the measurements with the XXX sensor which allows to measure at higher pressures.

The sensor and a LiPo battery are mounted to the Arduino. The entire instrument was then mounted on a regular pvc-tube which is in return mounted on the valve.

To ensure that minimal water vapor is present in the vessel, we blow nitrogen gas into the vessel before closing it. Interval... To obtain proper results, we waited half an hour before filling the vessel with nitrogen gas up to a pressure of 1400hPa. Again, for the best results, we waited half an hour before opening the valve. After 2s the pressure inside the vessel reaches atmospheric pressure. We kept recording pressure and temperature for half an hour.

Using equation (3) we calculate the specific heat ratio.

4. *Results*

Figure 2 shows the entire thermodynamic process, including the filling of the cylinder at $t =$ s. We note here that due to compression of the gas the temperature increases. Given the educational context, this is a surplus for students to see.

FIG. 1. placeholder for device

At $t =$ s the valve is opened and the pressure drops in s from $p_1 =$ hPa to $p_2 =$ hPa. The expected temperature decrease is observed as well ($\Delta T =$ C). Once the valve is closed again, we see the pressure in the vessel increases quickly to a maximum of $p_3 =$ hPa.

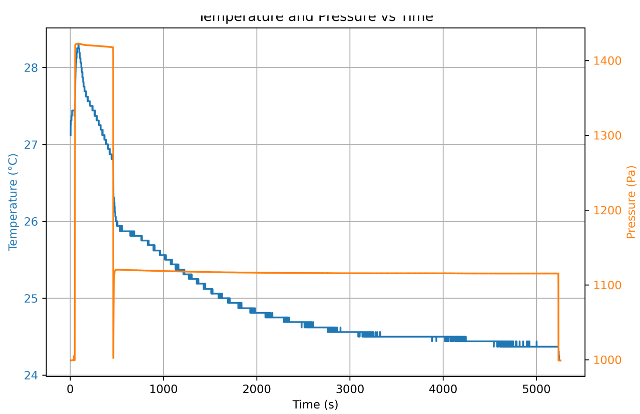


FIG. 2. pressure and temperature as function of time

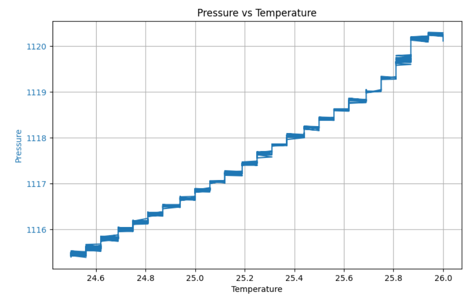
Using equation (3) we find a value for the specific heat ratio of $1.45 \pm X$ where the literature value is known to be ... .

```
# Naar eindtemperatuur
low_t = 600
high_t = 4000

fig, ax1 = plt.subplots(figsize=(8, 5))

color_temp = 'tab:blue'
ax1.set_xlabel('Temperature')
ax1.set_ylabel('Pressure', color=color_temp)
ax1.plot(temp[low_t:high_t], pressure[low_t:high_t], colo
ax1.tick_params(axis='y', labelcolor=color_temp)
ax1.grid()


fig.tight_layout()
plt.title(' Pressure vs Temperature ')
plt.show()
```



5. *Discussion & Conclusion*

Our aim was to devise a cheap (scalable) but accurate experiment in the topic of thermodynamics. Determining the specific heat ratio using the valve of a fire entinguisher and an arduino as logger ... more process than expected (filling)

6. *Appendix*

a. *Setup and assumptions*

- Ideal gas in a rigid vessel of volume V.
- State (1): initial equilibrium at (P_1, T_{atm}).
- Rapid vent to atmosphere (no heat exchange during the short release) to State (2): pressure equals barometric pressure $P_b \equiv P_{atm}$, temperature drops to T_2.
- Valve is then closed; gas reheats **at constant volume** (no work) back to T_{atm}, reaching State (3): pressure P_2.
- The quick release (1)→(2) is adiabatic; the recovery (2)→(3) is isochoric.

b. Step 1 — Adiabatic release (1)→(2) For a reversible adiabatic process of an ideal gas,

$$T^{\gamma} P^{1-\gamma} = \text{const.} \tag{4}$$

Thus,

$$T_1^{\gamma} P_1^{1-\gamma} = T_2^{\gamma} P_b^{1-\gamma}, \qquad (T_1 = T_{atm}). \tag{A1}$$

c. Step 2 — Isochoric reheat (2)→(3) At constant V, $P/T = \text{const}$. Hence,

$$\frac{P_b}{T_2} = \frac{P_2}{T_{atm}} \;\Rightarrow\; T_2 = T_{atm}\,\frac{P_b}{P_2} = T_1\,\frac{P_b}{P_2}. \tag{A2}$$

d. Step 3 — Eliminate T_2 and solve for γ Insert (A2) into (A1) and cancel T_1^{γ}:

$$P_1^{1-\gamma} = \left(\frac{P_b}{P_2}\right)^{\gamma} P_b^{1-\gamma} = P_b\,P_2^{-\gamma}. \tag{5}$$

Take natural logs and rearrange:

$$(1-\gamma)\ln P_1 = \ln P_b - \gamma \ln P_2 \tag{6}$$

$$\Rightarrow \quad \gamma(\ln P_1 - \ln P_2) = \ln P_1 - \ln P_b \tag{7}$$

$$\Rightarrow \quad \boxed{\gamma = \frac{\ln P_1 - \ln P_b}{\ln P_1 - \ln P_2}}. \tag{8}$$

This matches the expression quoted in the main text, with $P_b = P_{atm}$.