

Experiment Number 7

Joule-Thomson effect

EP3290

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1 Aim

- a. Determination of the Joule-Thomson coefficient of CO_2 .
- b. Determination of the Joule-Thomson coefficient of N_2 .

2 Principle

A stream of gas is fed to a throttling point, where the gas(CO_2 or N_2) undergoes adiabatic expansion. The differences in temperature established between the two sides of the throttle point are measured at various pressures and the Joule-Thomson coefficients of the gases in question are calculated.

3 Equipment

- a. Joule-Thomson apparatus
- b. Temperature meter digital, 4-2
- c. Temperature probe, immers.type
- d. Rubber tubing, vacuum, i.d. 8 mm
- e. House clip f. 12-20 diameter tube
- f. Reducing valve for CO_2/He
- g. Reducing the valve f. nitrogen
- h. Wrench for steel cylinders

- i. Steel cylinder rack, mobile
- j. Steel cylinder, CO_2 , 10 L, full.
- k. Steel cylinder, N_2 , 10 L, full.

4 Procedure

The set-up of the experiment is as in Fig. 1.

If necessary, screw the reducing valves onto the steel cylinders and check the tightness of the main valves. Secure the steel cylinders in their location. Attach the vacuum between the reducing valve and the Joule-Thomson apparatus with hose tube clips.

On each side of the glass cylinder, introduce a temperature probe up to a few millimeters from the frit and attach with the union nut. Connect the temperature probe on the pressure side to inlet 1 and the temperature probe on the un-pressurized side to inlet 2 of the temperature measurement apparatus.

5 Important

The experimenting room and the experimental apparatus must be in a thermal equilibrium at the start of the measurement. The experimental apparatus should be kept out of direct sunlight and other sources of heating or cooling.

Set the temperature measurement apparatus at temperature difference measurement. Temperature meter should be switched on at least 30 min before performing the experiment to avoid thermal drift. Read operating instructions for further explanations of the temperature meter. Open the valves in the following order: steel cylinder valve, operating valve, reducing valve, so that an initial pressure of 100 kPa is established. Reduce the pressure to zero in stages, in each case reading off the temperature difference one minute after the particular pressure has been established. Perform the measurement for both gases, and determine the atmospheric pressure and ambient temperature.

6 Theory and evaluation

In real gases, the intrinsic energy U is composed of a thermo-kinetic content and a potential energy content: the potential of the intermolecular forces of attraction. This is negative and tends towards zero as the molecular distance increases. In real gases, the intrinsic energy is therefore a function of the volume, and:

$$\frac{\Delta U}{\Delta V} > 0$$

During adiabatic expansion $\Delta Q = 0$ during which also no external work is done, the overall intrinsic energy remains unchanged, with the result that the potential energy increases at the expense of the thermo-kinetic content and the gas cools.

At the throttle point, the effect named after Joule-Thomson is a quasi-stationary process.

A stationary pressure gradient $p_2 - p_1$ is established at the throttle point. If external heat losses and friction during the flow of the gas are excluded, then for the total energy H , which consists of the intrinsic energy U and displacement work pV :

$$H_1 = U_1 + p_1V_1 = U_2 + p_2V_2 = H_2$$

In this equation, p_1V_1 or p_2V_2 is the work performed by an imaginary piston during the flow of a small amount of gas by a change in position from position 1 to 2 or position 3 to 4 (see Figure 2). In real gases, the displacement work p_1V_1 does not equal the displacement work p_2V_2 ; in this case:

$$p_1V_1 < p_2V_2$$

This means that, from the molecular interaction potential, displacement work is permanently done and removed:

$$U_1 > U_2 \text{ or } T_1 > T_2$$

The Joule-Thomson effect is described quantitatively by the coefficients

$$\mu = \frac{T_1 - T_2}{p_1 - p_2}$$

For a change in the volume of a Van der Waals gas, the change in the intrinsic energy is

$$\Delta U = \frac{a}{V^2} \cdot \Delta V$$

and the Joule-Thomson coefficient is thus

$$\mu_{vdW} = \left(\frac{2a}{RT} - b \right) \cdot \frac{1}{c_p}$$

In this equation, c_p is the specific heat under constant pressure, and a and b are the Van der Waals coefficients.

7 Observations

7.1 ΔT vs ΔP for CO_2

S.No	ΔP	ΔT
1	0	-0.12
2	0.05	-0.06
3	0.1	-0.02
4	0.15	0.03
5	0.2	0.09
6	0.25	0.14
7	0.3	0.2
8	0.35	0.23
9	0.4	0.31
10	0.45	0.36
11	0.5	0.4
12	0.55	0.46
13	0.6	0.52
14	0.65	0.56
15	0.7	0.6
16	0.75	0.65
17	0.8	0.71
18	0.85	0.75

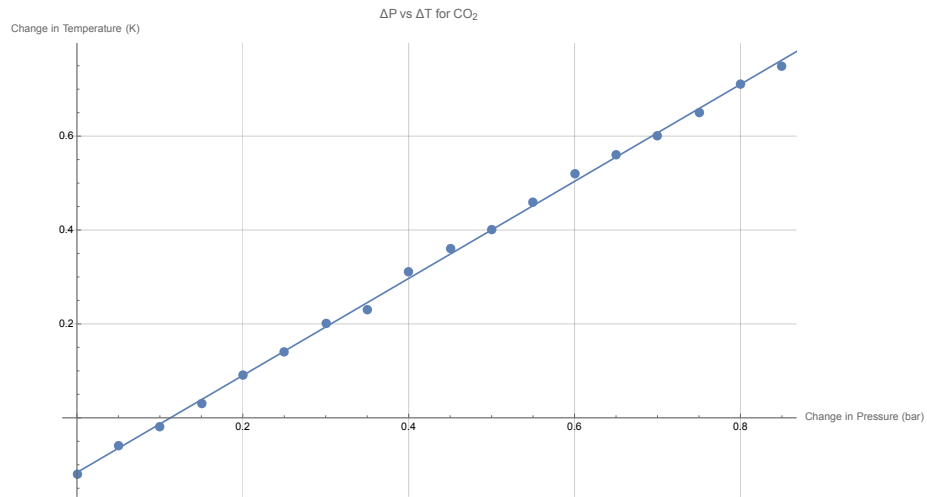


Figure 1:

$$\mu_{CO_2} = (1.03344 \pm 0.00868246) \times 10^{-5} \frac{K}{Pa}$$

7.2 ΔT vs ΔP for N_2

S.No	ΔP	ΔT
1	0	-0.08
2	0.05	-0.06
3	0.1	-0.05
4	0.15	-0.04
5	0.2	-0.03
6	0.25	-0.01
7	0.3	-0.01
8	0.35	0
9	0.4	0.01
10	0.45	0.01
11	0.5	0.02
12	0.55	0.03
13	0.6	0.04
14	0.65	0.06
15	0.7	0.07
16	0.75	0.08
17	0.8	0.1
18	0.85	0.11
19	0.9	0.11
20	0.95	0.12
21	1	0.12

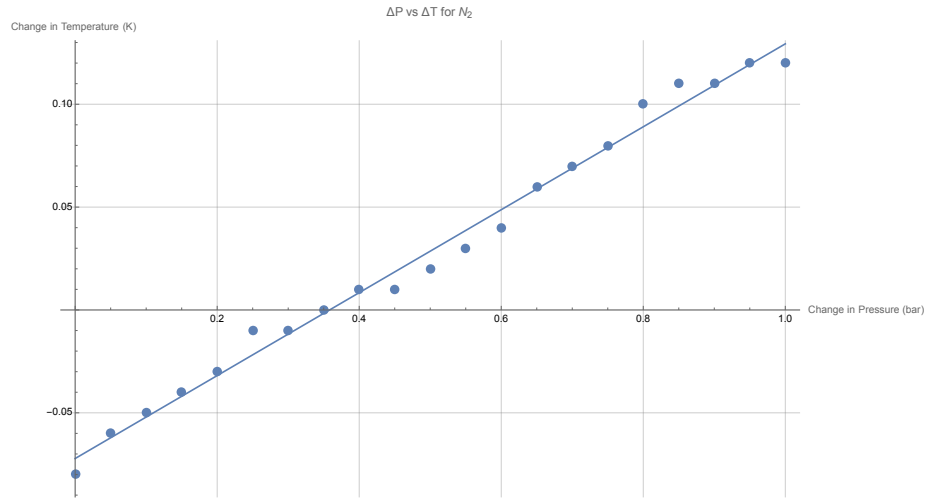


Figure 2:

$$\mu_{N_2} = (0.0201588 \pm 0.00637132) \times 10^{-5} \frac{K}{Pa}$$

8 Calculations

8.1 Theoretical value of Joule-Thomson coefficient of CO_2

$$a = 3.60 Pa \frac{m^6}{mol^2}$$

$$b = 42.7 \frac{cm^3}{mol}$$

$$c_p = 366.1 \frac{J}{molK}$$

$$T = 304K (\text{At the time of Experiment})$$

$$\mu_{CO_2} = \left(\frac{2a}{RT} - b \right) \cdot \frac{1}{c_p}$$

$$\mu_{CO_2} = 0.766 \times 10^{-5} \frac{K}{pa}$$

8.2 Experimental value of Joule-Thomson coefficient of CO_2

$$\mu_{CO_2} = (1.03344 \pm 0.00868246) \times 10^{-5} \frac{K}{pa}$$

8.3 Theoretical value of Joule-Thomson coefficient of N_2

$$a = 1.41 Pa \frac{m^6}{mol^2}$$

$$b = 39.1 \frac{cm^3}{mol}$$

$$c_p = 288.9 \frac{J}{molK}$$

$$T = 304K (\text{At the time of Experiment})$$

$$\mu_{N_2} = \left(\frac{2a}{RT} - b \right) \cdot \frac{1}{c_p}$$

$$\mu_{N_2} = 0.3699 \times 10^{-5} \frac{K}{pa}$$

8.4 Experimental value of Joule-Thomson coefficient of N_2

$$\mu_{N_2} = (0.0201588 \pm 0.00637132) \times 10^{-5} \frac{K}{pa}$$

9 Conclusion

The literature values are

$$\mu_{CO_2} = 1.16 \times 10^{-5} \frac{K}{Pa}$$

at 20°C and 10⁵ pa

$$\mu_{N_2} = 0.23 \times 10^{-5} \frac{K}{Pa}$$

at 20°C and 10⁵ pa.

The experimental values are

$$\mu_{CO_2} = (1.03344 \pm 0.00868246) \times 10^{-5} \frac{K}{pa}$$

at 31°C and 10⁵ pa.

$$\mu_{N_2} = (0.0201588 \pm 0.00637132) \times 10^{-5} \frac{K}{pa}$$

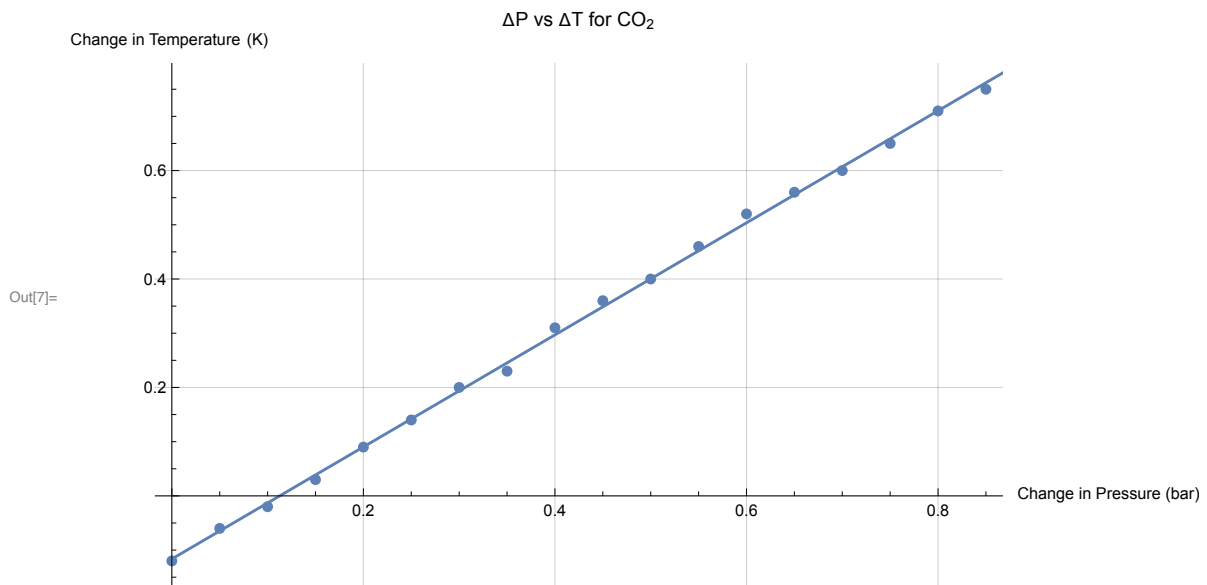
at 31°C and 10⁵ pa. The literature values and experimental values are in the limit of error.

Experiment-7 Joule-Thomson effect

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Joule Thomson Coefficient of CO₂

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In[1]:= p1 = Range[0, 0.85, 0.05];  
t1 = {-0.12, -0.06, -0.02, 0.03, 0.09, 0.14, 0.2,  
      0.23, 0.31, 0.36, 0.4, 0.46, 0.52, 0.56, 0.6, 0.65, 0.71, 0.75};  
  
In[3]:= data1 = Transpose[{p1, t1}];  
lm1 = LinearModelFit[data1, x, x]  
  
Out[4]= FittedModel[ $-0.116433 + 1.03344 x$ ]  
  
In[5]:= Normal[lm1]  
Out[5]=  $-0.116433 + 1.03344 x$   
  
In[6]:= RootMeanSquare[data1[[All, 2]] - # /> data1[[All, 1]] & /> {lm1}]  
Out[6]= {0.00868246}  
  
In[7]:= Show[ListPlot[data1,  
  AxesLabel -> {"Change in Pressure (bar)", "Change in Temperature (K) "},  
  Plot[lm1[x], {x, 0, 1}], PlotLabel -> "ΔP vs ΔT for CO2", GridLines -> Automatic]
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$$\mu_{\text{CO}_2} = (1.03344 \pm 0.00868246) \times 10^{-5} \frac{\text{K}}{\text{pa}}$$

Joule Thomson Coefficient of N_2

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In[8]:= p2 = Range[0, 1, 0.05];
t2 = {-0.08, -0.06, -0.05, -0.04, -0.03, -0.01, -0.01, 0.0, 0.01,
      0.01, 0.02, 0.03, 0.04, 0.06, 0.07, 0.08, 0.1, 0.11, 0.11, 0.12, 0.12};

In[10]:= data2 = Transpose[{p2, t2}];
lm2 = LinearModelFit[data2, x, x]

Out[11]= FittedModel[ $-0.0722078 + 0.201558 x$ ]

In[12]:= Normal[lm2]
Out[12]=  $-0.0722078 + 0.201558 x$ 

In[13]:= RootMeanSquare[data2[[All, 2]] - # /@ data2[[All, 1]] & /@ {lm2}]
Out[13]= {0.00637132}

In[14]:= Show[ListPlot[data2,
  AxesLabel → {"Change in Pressure (bar)", "Change in Temperature (K)"}],
  Plot[lm2[x], {x, 0, 1}], PlotLabel → "ΔP vs ΔT for  $N_2$ ", GridLines → Automatic]

```

ΔP vs ΔT for N_2

Out[14]=

$$\mu_{N_2} = (0.0201588 \pm 0.00637132) \times 10^{-5} \frac{K}{pa}$$