Joule-Thomson effect

P2320600

Physics > Thermodynamics > Temperature & Heat

Difficulty level	Group size	Preparation time	Execution time
hard	-	10 minutes	30 minutes

This content can also be found online at:

http://localhost:1337/c/6475b4cadd89390002768e25

Informations

Introduction

Fig. 1: Experimental set-up (without PC)

A stream of gas is fed to a throttling point, where the gas (CO2 or N2) undergoes adiabatic expansion. the differences in temperature established between the two sides fo the throttle point are measured at various pressures and the Joule-Thomson coefficients of the gases in qestion are calculated. The principle of the Joule-Thomson effect is also applied, for example, in snow cannons for freezing water.

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Other information (1/2)

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Prior knowledge

The students must be familiar with units such as pressure, temperature, mass and volume and be able to perform calculations using them. They must also be familiar with general good laboratory practice and general laboratory safety regulations.

Principle

The Joule-Thomson effect has various applications, particularly in gas processing and cooling:

- Natural gas purification by condensin impurities after cooling; Cooling of natural gas directly at the extraction site; Production of highly pure gases such as oxygen and nitrogen through air seperation; Air cooling in air conditioners and refrigerators; Production of liquid nitrogen in cryogenics

The Joule-Thomson effect is most effictive in gases with high inversion temperatures, as the cool upon expansion at room temperature.

Other information (2/2)

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Learning Goal

In this experiment, students become familiar with the different behaviors of gases and deepen their knowledge of physical equations. By going through the different parts with the same volume of air while changing the external influences, they learn about the relationships between pressure, temperature and volume. It is a simple introduction to thermodynamics.

Tasks

The experiment aims to impart students with a deeper understanding of the thermodynamic principles and technical applications of the Joule-Thomson effect through practical experience and measurements.

Determination of the Joule-Thomson coefficient of CO2 and N2

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Robert-Bosch-Breite 10
37079 Göttingen

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Fax: 0551 604 - 107

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Safety instructions 1/2

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Fig. 2: safety instructions

Carbon dioxide

H280: Contains gas under pressure; may explode if heated.

P403: Store in a well ventilated place.

Nitrogen

H280: Contains gas under pressure; may explode if heated.

P403: Store in a well ventilated place.

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Setup and Procedure

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Robert-Bosch-Breite 10
37079 Göttingen

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Fax: 0551 604 - 107

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The set-up of the experiment is shown 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 PVC-tubing 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 millimetres 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 unpressurised side to inlet 2 of the temperature measurement apparatus.

Safety instructions 2/2

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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. The temperature meter should be switched on at least 30 min before performing the experiment to avoid thermal drift.

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Safety instructions 2/2

Important

Read the 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.

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Ausrüstung

Position	Material	Item No.	Quantity
1	Joule-Thomson apparatus	04361-00	1
2	Universal power supply, 600mA 3/4.5/5/6/7.5/9/12V, incl. 9 adaptors	11078-99	1
3	Reducing valve for CO2 / He	33481-00	1
4	Reducing valve f.nitrogen	33483-00	1
5	Wrench for steel cylinders	40322-00	1
6	Gas-cylinder Trolley for 2 Cyl.	41790-20	1
7	Steel cylinder,CO2, 10l, full	41761-00	1
8	Steel cylinder,nitrogen,10l, full	41763-00	1
9	Hose clip f.12-20 diameter tube	40995-00	2
10	PVC tubing webbed, inner dia. = 8 mm, l = 1 m	47528-01	2
11	Cobra SMARTsense High Precision Temperature - Sensor for measuring temperature, -50 ... +150 °C (Bluetooth + USB)	12950-00	1
12	measureLAB, multi-user license	14580-61	1

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Tel.: 0551 604 - 0
Fax: 0551 604 - 107
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Zusätzliche Ausrüstung

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Position	Material	Menge
1	PC with Windows XP® oder higher	1

Theory and evaluation

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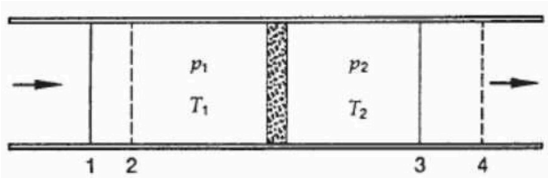

Fig. 2: Throttling and the Joule-Thomson effect

The staate for real gases is given by the van der Waals equation

$$\left(p + \frac{a}{V^2}\right) * (V - b) = RT$$

where p ist the pressure, V the molar volume and T the temperature of the gas.

R ist the universal gas constant, a und b are the

caracteristic Van der Waalas coefficients of the gas. The additional

pressure by intermolecular forces of attraction is described by a, b

represents the volume of molecules

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Theory and evaluation

In real gases the intrinsic energy U is composed of a thermocinetic and a potential component.

The total change of the intrinsic energy U of a real gas therefore depends not only on the temperature and the molar heat CV of a gas but also on the volume.The potential energy −a/V in the gas is given by the work against the intermolecular forces

$$U = C_v * T - \frac{a}{V}$$

Theory of evaluation

The total didfferential of the intrinsic energy is given by

$$\mathrm{d}U = \left(\frac{\partial U}{\partial T}\right)_V \cdot \mathrm{d}T + \left(\frac{\partial U}{\partial V}\right)_T \cdot \mathrm{d}V$$

with

$$\left(\frac{\partial U}{\partial T}\right) = C_V \ \text{for} \ \Delta V = 0$$

and

$$\left(\frac{\partial U}{\partial V}\right) = +\frac{a}{V^2} \ \text{for} \ \Delta T = 0 \,.$$

Robert-Bosch-Breite 10
37079 Göttingen

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Theory of evaluation

The expansion of the gas at the throttle-point is adiabatic (delta Q=0). If external heat losses and friction during the flow of the gas are excluded, the total energy H of the process is constant:

$$H = U + p \cdot V = U_1 + p_1 \cdot V_1 = U_2 + p_2 \cdot V_2$$

see Fig. 2

For further calculations, pressure p can be substituted by using van der Waals equation:

$$H = C_V \cdot T - \frac{a}{V} + \left(\frac{RT}{V-b} - \frac{a}{V^2} \right) \cdot V$$

Theory of evaluation

After calculating the differential of (1) and substituting the total differentials by finite differences again, one obtains a relation between ΔT and ΔV:

$$\Delta H = C_V \cdot \Delta T + \frac{2a}{V^2} \cdot \Delta V + \frac{RV}{V-B} \cdot \Delta T - \frac{RTV}{(V-b)^2} \Delta V + \frac{RT}{V-b} \cdot \Delta V$$

$$\Delta H = \left(C_V + \frac{RV}{V-b} \right) \cdot \Delta T + \left(\frac{2a}{V^2} - \frac{RTb}{(V-b)^2} \right) \cdot \Delta V$$

ΔH = 0 because H is constant.

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Theory of evaluation

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In the next step, b is considered to be small compared to V. The molar heat at constant volume CV can be replaced with the molar heat at constant pressure Cp via the ideal gas equation and under the assumption of even gas particle masses m:

$$C_{\mathrm{p,m}} = C_{\mathrm{V,m}} + R$$

Putting (3) into equation (2) results in

$$\frac{\Delta T}{\Delta V} = \frac{RTb-2a}{V^2 . C_{P,m}}$$

Theory of evaluation

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At the throttle point a pressure gradient p1−p2 and a temperature gradient T1−T2 are established. This effect is named the Joule-Thomson effect and is described by the coefficient

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

To derive a formula of this coefficient with Van der Waals forces involved, the difference ΔV in (4) has to be expressed in terms of Δp. This can be approximately done via the ideal gas equation again under the assumption of even gas particle masses m:

$$V = \frac{nRT}{p}$$

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Theory of evaluation

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After differentiating this equation to get an expression for dV, the total differentials are substituted by the finite differences, which results in the following:

$$\Delta V = \frac{RT}{p^2} \Delta p$$

Solving equation (4) for ΔT gives

$$\Delta T = \frac{\Delta V}{V^2 \cdot C_{p,m}} \cdot (RTb - 2a)$$

After replacing ΔV in (7) with the term in (6)

$$\Delta T = \frac{-RT\Delta p}{p^2} \cdot \frac{p^2}{R^2 \cdot T^2} \cdot \frac{RTb - 2a}{C_{p,m}}$$

Theory of evaluation

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Putting this into (4), the equation for the Joule-Thomson coefficient results in

$$\mu = \frac{\Delta T}{\Delta p} = \frac{1}{C_{p,m}} \cdot \left(\frac{2a}{RT} - b\right)$$

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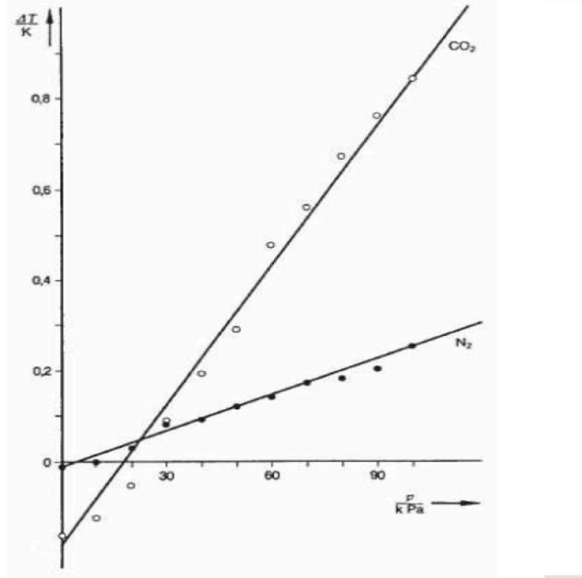

Fig. 3 shows the temperature differences measured at various pressures. The measurement values in Fig. 3 give the straight line gradients.

$$\mu_{CO_2} = (1.084 \pm 0.050) \cdot 10^{-5} \frac{K}{Pa}$$

and

$$\mu_{N_2} = (0.253 \pm 0.030) \cdot 10^{-5} \frac{K}{Pa}$$

where N2 is an approximation for air.

Theory of evaluation

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The two temperature probes may give different absolute values for the same temperature. But this is no problem, as only the temperature difference is important for the determination of the Joule-Thomson coefficients.

The literature values are

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

at 20 °C and 10^−5 Pa, and

$$\mu_{air} = 0.23 \cdot 10^{-5} \frac{K}{Pa}$$

at 20 °C and 10^−5 Pa.

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Robert-Bosch-Breite 10
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Theory of evaluation

For CO_2, with

a= 3.60 Pa m^6 /mol^2

b= 42.7 cm^3/mol

cp= 366.1 J/mol K

equation (8) gives the coefficient

$$\mu_{CO_2} = 0.795 \cdot 10^{-5} \ \frac{\mathrm{K}}{\mathrm{Pa}}$$

Theory of evaluation

For air, with

a= 40 Pa m^6 /mol^2

b= 39,1 cm^3/mol

cp= 9 J/mol K

equation (8) gives the coefficient

$$\mu_{\mathrm{air}} = 0.387 \cdot 10^{-5} \ \frac{\mathrm{K}}{\mathrm{Pa}}$$

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Robert-Bosch-Breite 10
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info@phywe.de
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Theory of evaluation

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Remarks

The formula for the Joule-Thomson coefficient indicates the condition for a cooling process

$$T_i = \frac{2a}{R \cdot b}$$

where Ti is the inversion temperature. If Δp < 0 the temperature T has to be lower then Ti to cool the gas with the process:

Δp < 0 and T < Ti then ΔT < 0.

For air (N2) or CO 2 cooling is observed at room temperature. H2 or He have a positive coefficient at room temperature, for H2 this can be hazardous because self ignition is possible.

Measurement 1/2

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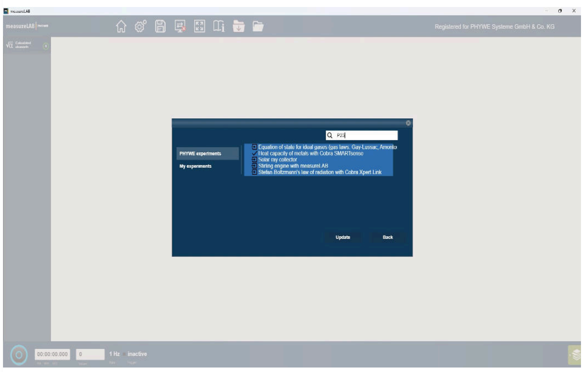

Fig.3: measureLAB software interface

- start measureLAB Software .
- load experiment P2320600.

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Robert-Bosch-Breite 10
37079 Göttingen

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Measurement 2/2

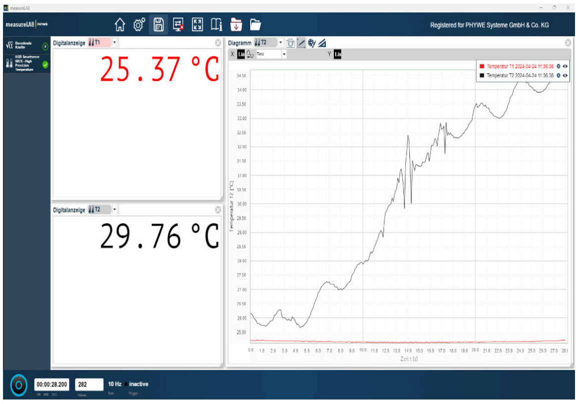

Fig.4: measureLAB software interface with the high precision sensor and the two temperature sensors

- start the sensor and press it for at least 3 seconds.
- the sensor will be displayed on the left side of the measureLAB control panel. Please checkmark it.
- start the measurement using this button 
- end the measurement using this button. 

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37079 Göttingen

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Fax: 0551 604 - 107

info@phywe.de
www.phywe.de