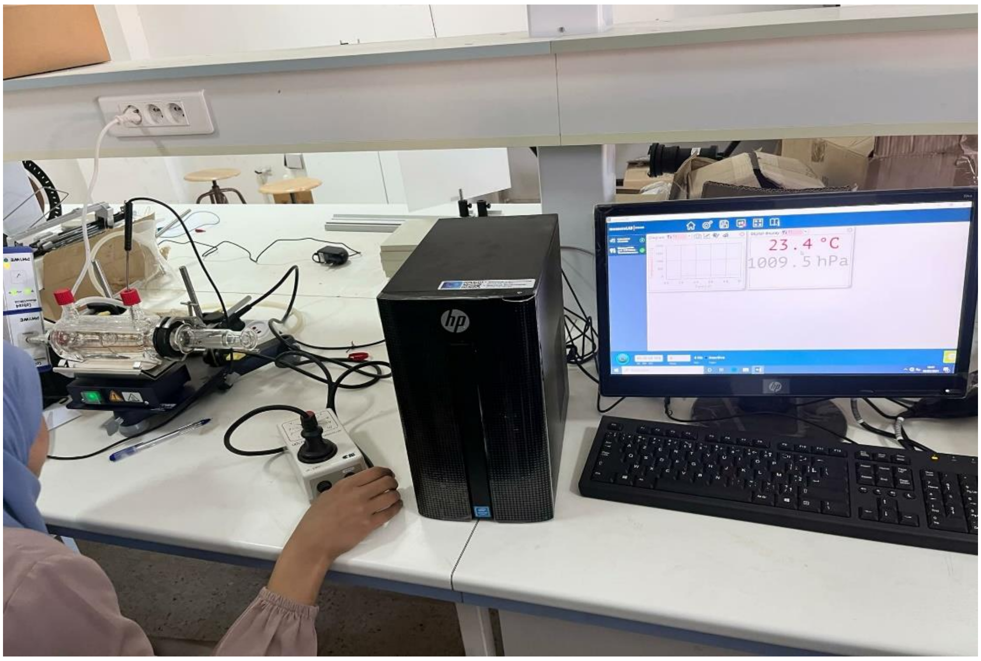
DEMOCRATIC AND POPULAR REPUBLIC OF Algeria
Ministry of Higher Education and Scientific Research
University of Relizane
Faculty of Sciences
Department of Physics

THERMODYNAMICS LAB



By: Dr. Fatma Zohra Fouddad

Destined for second-year LMD-SM students

Option: Materials physics

University year 2024/2025

General Introduction

Experimental physics plays a vital role in the education and training of science students. It not only complements theoretical learning but also enhances a deeper understanding of physical laws through observation, measurement, and analysis. Laboratory work provides an essential foundation for developing critical scientific skills such as hypothesis testing, data interpretation, error evaluation, and technical reporting.

This laboratory manual is designed for second-year undergraduate students in physics and focuses on three core areas of thermodynamics and material science: ***ideal gas behavior****,* ***thermal and electrical conductivity of metals****, and the* ***thermal expansion of solids****. Each chapter is carefully structured to include theoretical background, clear experimental procedures, data collection methods, and analytical guidance.*

By conducting these experiments, students will be able to apply theoretical concepts in real-life situations, Understand the relationships between physical quantities such as pressure, volume, temperature, heat, and length, develop laboratory techniques and follow safety protocols and analyze experimental data and draw meaningful conclusions.

Moreover, this manual encourages students to engage in ***active learning****, develop a scientific mindset, and appreciate the importance of precision and reproducibility in physical science. Whether the goal is to pursue academic research or practical engineering applications, the skills developed in this laboratory will be invaluable.*

In sum, this manual is more than a collection of experiments. it is a training ground for scientific inquiry and a bridge between theory and practice in the physical sciences.

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About the Document

This document is divided into three comprehensive chapters:

- Chapter I focuses on the Ideal Gas Laws, including Boyle–Mariotte's Law, Gay–Lussac's Law, and Amontons' Law. Each section combines historical context, theoretical definitions, and corresponding experimental setups to explore the relationships between pressure, volume, and temperature.
- Chapter II examines the Thermal and Electrical Conductivity of Metals, with particular attention to the methods used to evaluate heat transfer in metal rods. Students will learn how to calculate heat flow, analyze surrounding influences, and compare the thermal conductivities of different materials.
- Chapter III addresses the Linear Expansion of Solids, guiding students through experiments that measure how the length of a solid changes with temperature. The chapter provides step-by-step instructions, examples, and evaluation techniques.

Chapter I

Ideal Gaz Lows

This chapter is divided into four main sections. The first three sections are each dedicated to the study of one of the fundamental laws describing the behavior of gases: Boyle–Mariotte's law, Gay–Lussac's law, and Amontons' law. For each law, we present the theoretical background, the experimental procedure, and the objectives of the experiment. Finally, the fourth section concludes the chapter with a presentation of the theoretical analysis, followed by the evaluation, data, and results.

I.1. Introduction

The study of gases and their behavior under varying physical conditions is a foundational aspect of thermodynamics. The ideal gas law, expressed as PV= nRT, provides a macroscopic description of gas behavior, relating pressure ppp, volume V, temperature T, and the number of moles n through the universal gas constant R. Although idealized, this law effectively models the behavior of many real gases under moderate conditions.

This experiment aims to investigate the relationships among the state variables of a confined gas through the empirical validation of three classical gas laws: **Boyle–Mariotte's law** (pressure-volume relationship at constant temperature), **Gay–Lussac's law** (volume-temperature relationship at constant pressure), and **Amontons' law** (pressure-temperature relationship at constant volume). Each of these laws represents a specific case of the general ideal gas law in which one parameter is held constant.

Using the Cobra4 data acquisition system, gas behavior is monitored under controlled laboratory conditions. The objective is not only to verify the aforementioned laws experimentally but also to deduce key thermodynamic quantities, such as the universal gas constant and thermal coefficients, and to observe deviations that may arise due to non-ideal conditions.

I.2. Objective

To experimentally verify the gas laws: Boyle-Mariotte's law, Gay-Lussac's law, and Amontons' law using the Cobra4 system, and determine the universal gas constant and thermal coefficients.

I.3. Required Equipment

Us shown in Figure (I.1):

1. **Cobra4** Remote-Link and Sensor Unit Thermodynamics
2. Gas syringe with glass jacket
3. Power regulator
4. Thermocouple (T1)
5. Magnetic stirrer and bar
6. Silicone tubing

7. Water bath
8. Personal computer with USB interface and Cobra4 software

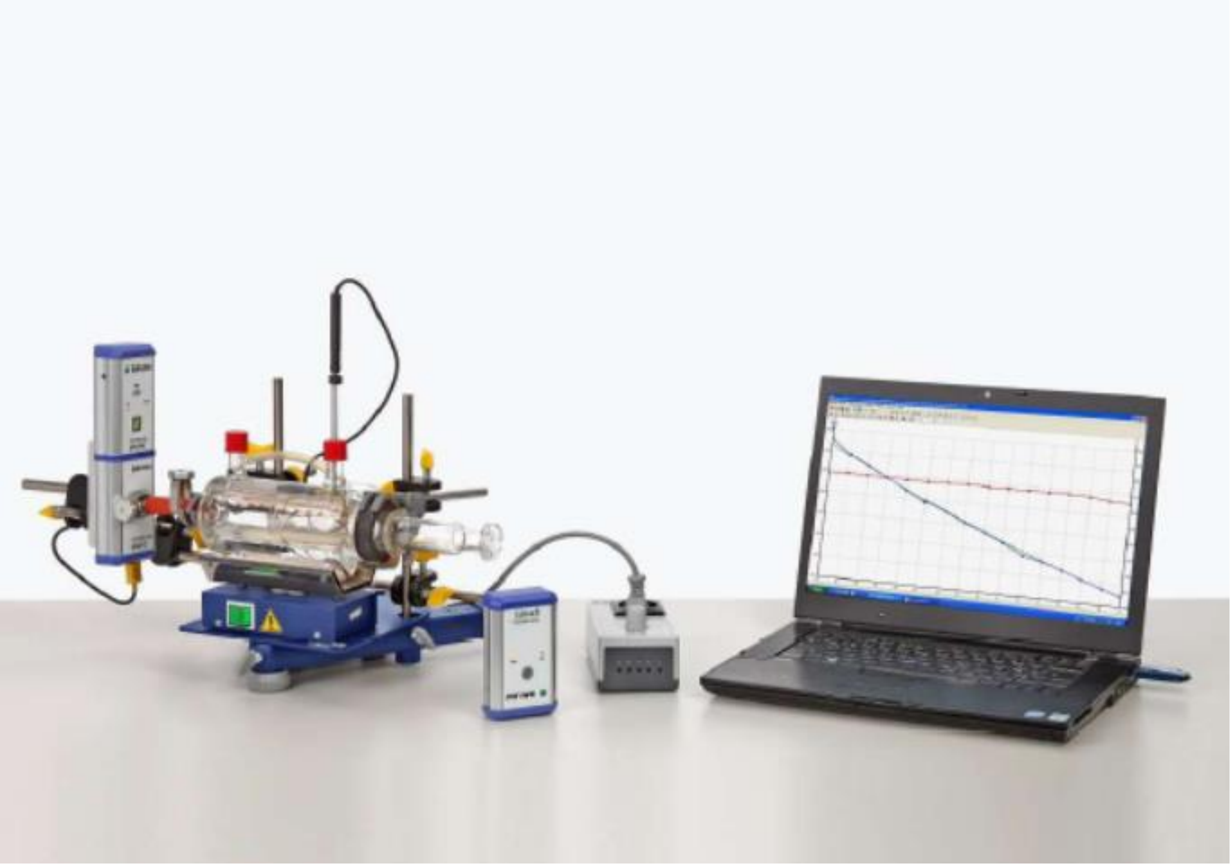


Fig. (I.1): Experimental set-up

I.4. Tasks

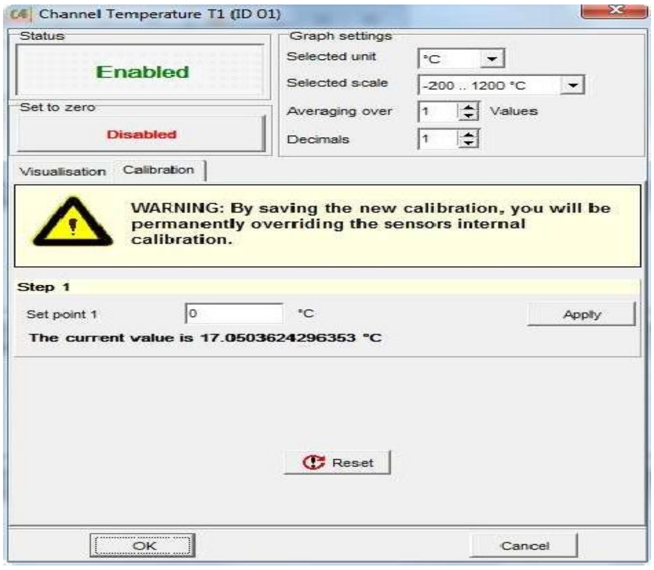
- ✓ Experimentally investigate the validity of the three gas laws for a constant amount of gas (air).
- ✓ Calculate the universal gas constant from the relationship obtained.
- ✓ Calculate the thermal coefficient of expansion from the results of measurements under isobaric conditions.
- ✓ Calculate the thermal coefficient of tension from the results of measurements under isochoric conditions.

I.5. Set-up

Set up the experiment as shown in Fig. (I.1).

1. Connect the Cobra4 Sensor Unit Thermodynamics with the Cobra4 Wireless-Link. Connect the thermocouple with the T1 socket of the Cobra4 Sensor Unit Thermodynamics.
2. Install the gas syringe in the glass jacket as described in the operating instructions supplied with the glass jacket.

3. Pay particular attention to the airtightness.
4. As an exception here, because no air is to be allowed to leak out even at higher pressures, lubricate the plunger with a few drops of multigrade motor oil, so that the glass plunger is covered with an un- interrupted clear film of oil throughout the entire experiment; but avoid excess oil.
5. Fill the glass jacket with water via the funnel and insert a magnetic stirrer bar.
6. Connect a silicone tube to the hose nipple of the jacket's upper tubular sleeve so that the bath fluid which expands on heating can flow through the tube into a beaker.
7. Insert the thermocouple and place it as close to the syringe as possible.
8. After adjusting the initial volume of the gas syringe to exactly 50 ml, connect the nozzle of the gas sy- ringe to Cobra4 Sensor-Unit Thermodynamics via a short piece of rubber tubing. Keep the tubing con- nections as short as possible.
9. Secure the tubing on both the gas syringe's nozzle and on the reducing adaptor with hose clips.
10. Start the PC and connect the Cobra4 Wireless Man- ager with a USB socket of the computer.
11. After the Cobra4 Wireless-Link has been switched on, the sensor is automatically recognized an ID number (01) is allocated to the sensor, which is indicated in the display of the Cobra4 Wireless-Link.



Status: Enabled

Set to zero: Disabled

Selected unit: °C

Selected scale: -200 .. 1200 °C

Averaging over: 1 Values

Decimals: 1

WARNING: By saving the new calibration, you will be permanently overriding the sensors internal calibration.

Step 1

Set point 1: 0 °C

The current value is 17.0503624296353 °C

Fig. (I.2): Settings for calibration.

I.6. For calibration

- After loading the settings of the experiment, you can calibrate your sensors as follows.
- In the Cobra4 Navigator under ‘Devices’ double- click the ‘Temperature T1’ symbol.
- Now you can change some measurement parameters.
- Under ‘Calibration’ enter a value for temperature measured with a thermometer and press ‘Apply’.
- Terminate the calibration with ‘OK’ (see Fig. (I.2).

I.7. Safety Precautions

Always wear protective gloves, goggles, and lab coat when handling heated water or pressurized gas systems.

Part A

Boyle-Mariotte's Law

A.1. History

The relationship between pressure and volume was first noted by Richard Towneley and Henry Power in the 17th century [5,6]. Robert Boyle confirmed their discovery through experiments and published the results [7]. According to Robert Gunther and other authorities, it was Boyle's assistant, Robert Hooke, who built the experimental apparatus. Boyle's law is based on experiments with air, which he considered to be a fluid of particles at rest in between small invisible springs. Boyle may have begun experimenting with gases due to an interest in air as an essential element of life [8]. For example, he published works on the growth of plants without air [9]. Boyle used a closed J-shaped tube and after pouring mercury from one side he forced the air on the other side to contract under the pressure of mercury. After repeating the experiment several times and using different amounts of mercury he found that under controlled conditions, the pressure of a gas is inversely proportional to the volume occupied by it [10].

The figure (I.1) shows Graph of Boyle's original data [4] showing the hyperbolic curve of the relationship between pressure (P) and volume (V) of the form $P = k/V$.

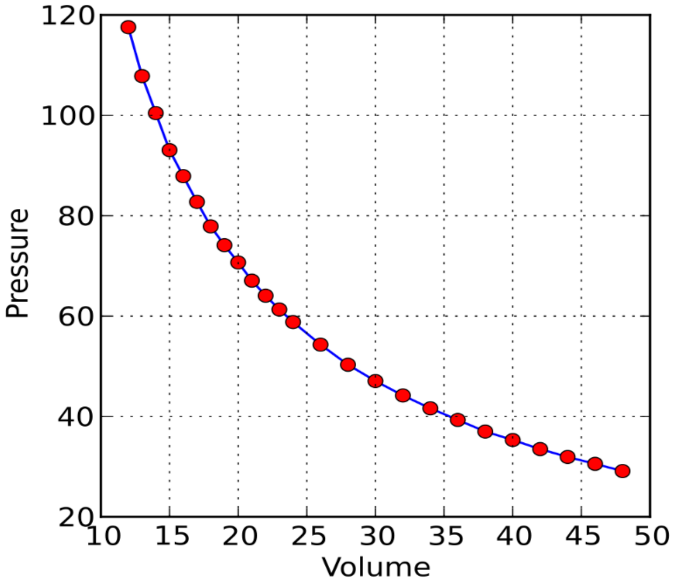


Fig. (I.3): Graph of Boyle's original data [4] showing the hyperbolic curve of the relationship between pressure (P) and volume (V) of the form $P = k/V$.

The French physicist Edme Mariotte (1620–1684) discovered the same law independently of Boyle in 1679 [11], after Boyle had published it in 1662 [10]. Mariotte did, however, discover that air volume changes with temperature [12]. Thus this law is sometimes referred to as Mariotte's law or the Boyle–Mariotte law. Later, in 1687 in the *Philosophiæ Naturalis Principia Mathematica*, Newton showed mathematically that in an elastic fluid consisting of particles at rest, between which are repulsive forces inversely proportional to their distance, the density would be directly proportional to the pressure [13], but this mathematical treatise does not involve any Mariott temperature dependance and is not the proper physical explanation for the observed relationship. Instead of a static theory, a kinetic theory is needed, which was developed over the next two centuries by Daniel Bernoulli (1738) and more fully by Rudolf Clausius (1857), Maxwell and Boltzmann.

A.2. Definition

Boyle's law, also referred to as the **Boyle–Mariotte law** or **Mariotte's law**, is an empirical gas law that describes the relationship between pressure and volume of a confined gas.

The figure (I.4) shows an animation showing the relationship between pressure and volume when mass and temperature are held constant.

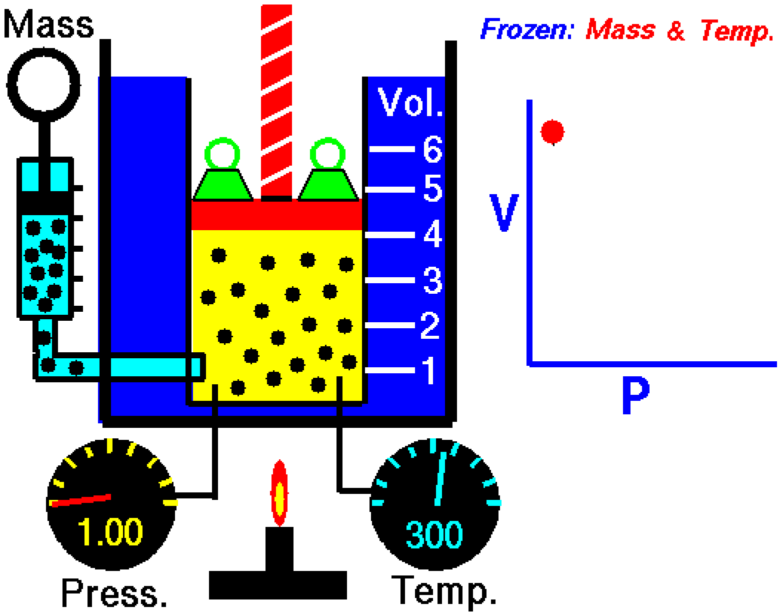


Fig. (I.4): Animation showing the relationship between pressure and volume when mass and temperature are held constant.

Boyle's law has been stated as the absolute pressure exerted by a given mass of an ideal gas is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged within a closed system **[1,2].**

Mathematically, Boyle's law can be stated as pressure is inversely proportional to the volume

$$P \propto \frac{1}{V} \tag{I.1}$$

Or:

$$PV = k \tag{I.2}$$

The product of pressure and volume is a constant number (here denoted as k)

Where *P* is the pressure of the gas, *V* is the volume of the gas, and *k* is a constant for a particular temperature and amount of gas.

Boyle's law states that when the temperature of a given mass of confined gas is constant, the product of its pressure and volume is also constant. When comparing the same substance under two different sets of conditions, the law can be expressed as:

$$P_1V_1 = P_2V_2 \tag{I.3}$$

Showing that as volume increases, the pressure of a gas decreases proportionally, and vice versa.

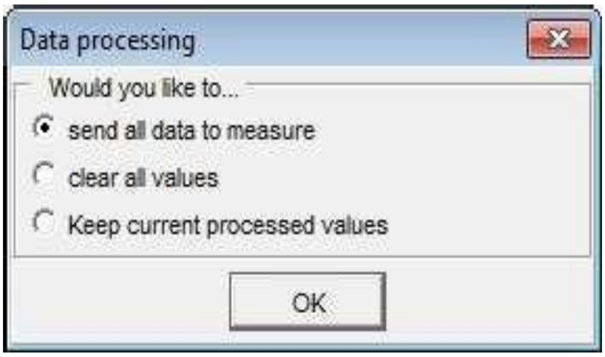
Boyle's law is named after Robert Boyle, who published the original law in 1662 **[3].** An equivalent law is

Mariotte's law, named after French physicist Edme Mariotte.

A.3. Lab I: Boyle–Mariotte's Law (Isothermal Process)

A.3.1. Procedure

1. Call up the 'Measure' programme and boot the experiment Boyle and Mariotte's law with Cobra4 (experiment > open experiment). The measurement parameters for this experiment are loaded now.
2. Switch on the Cobra4 Remote-Link.
3. Start the measurement with ●.
4. Subsequently expand the enclosed quantity of air in 1 ml steps to a volume of approximately 65 ml.



Data processing

Would you like to...

● send all data to measure

○ clear all values

○ Keep current processed values

Fig. (I.6): Window which appears after measurement

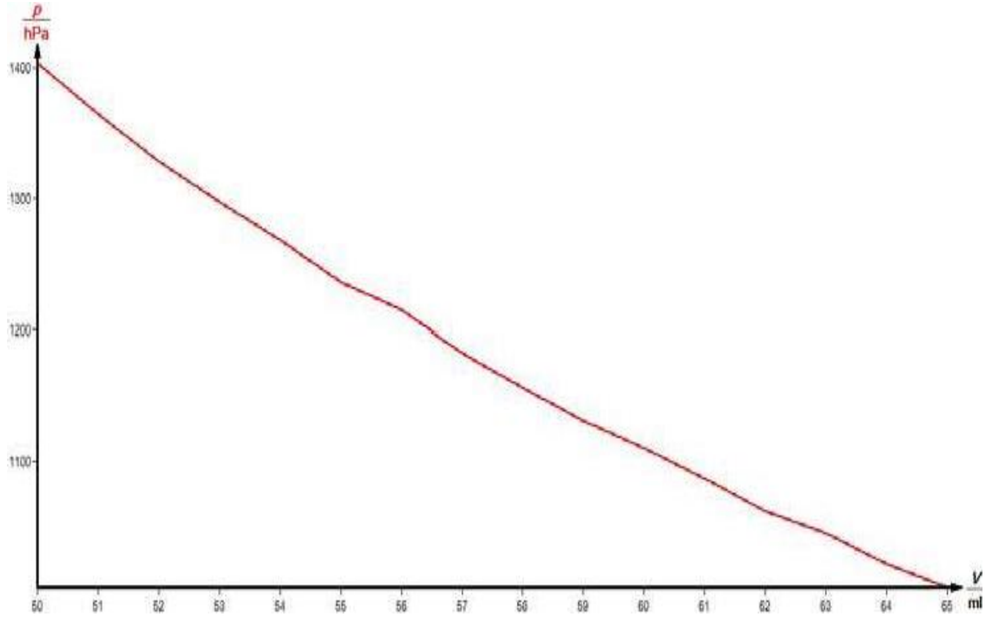
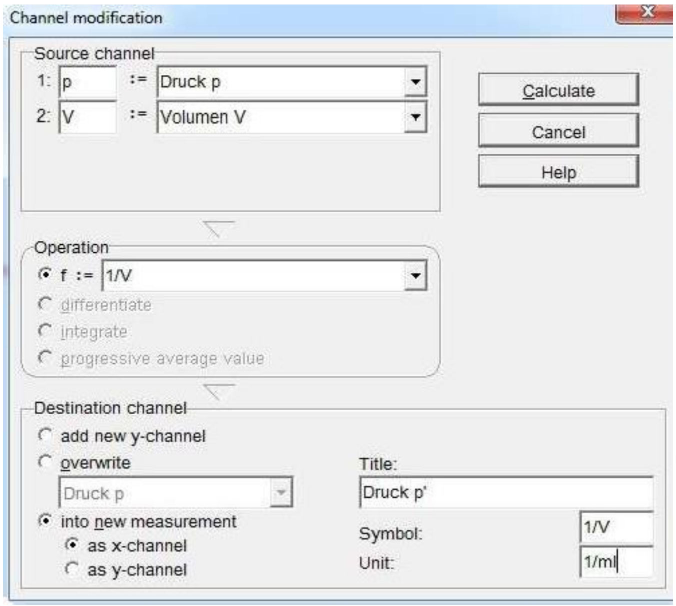


Fig. (I.7): Correlation between the volume *V* and the pressure p at constant temperatures ($T = 295.15$ K) and constant quantity of substance ($n = 2.086$ mmol).

5. Record the volume for each step by pressing the switch on the Cobra4 Remote Link.
6. Mix the water in the glass jacket by moving the magnetic stirrer bar with the aid of a bar magnet and facilitate pressure equilibration in the gas syringe by turning the plunger.
7. Terminate the measurement by pressing ■.
8. Send all data to ‘measure’ (see Fig. (I.6)) and save the measurement (File > Save meausrement as…..).

Fig. (I.7) shows the graph as it is then pre- sented by the program.

To have the plot of pressure versus the reciprocal volume click $\sqrt{\alpha}$. Now you can perform some channel modifications (see Fig. (I.8)).



Source channel
1: p := Druck p
2: V := Volumen V

Operation
● f := 1/V
○ differentiate
○ integrate
○ progressive average value

Destination channel
○ add new y-channel
○ overwrite
Druck p
● into new measurement
● as x-channel
○ as y-channel

Title: Druck p'
Symbol: 1/V
Unit: 1/ml

Fig. (I.8): Settings for channel modification.

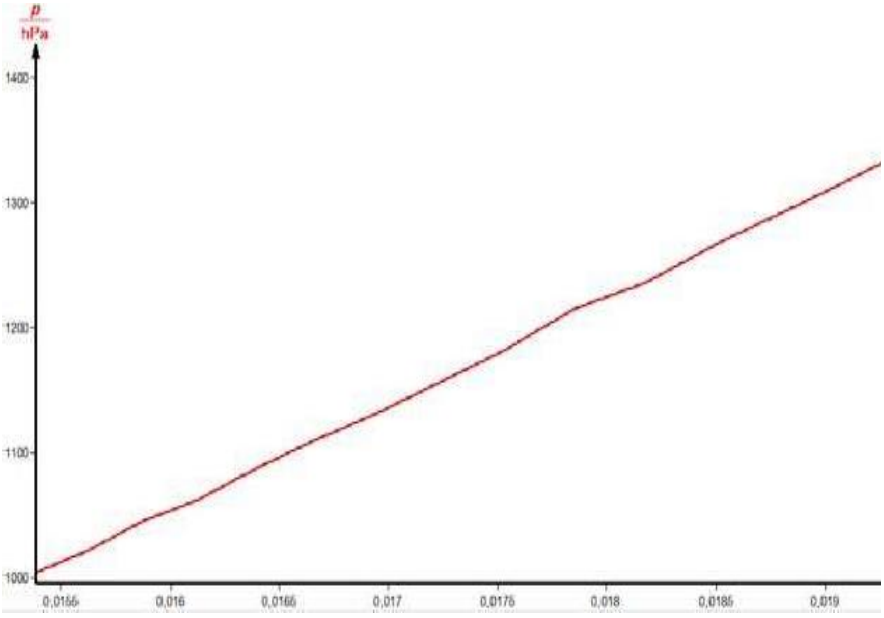


Fig. (I.9): Pressure p as a function of the reciprocal volume $1/V$ at constant temperature (T = 295.15 K) and constant quantity of substance (n = 2.086 mmol).

Fig. (I.9) shows the correlation between pressure p and the quantity $1/V$.

With 📈 you can let the program show the slope.

Part B

Gay–Lussac's Law

B.1. Introduction

Gay-Lussac's law usually refers to Joseph-Louis Gay-Lussac's law of combining volumes of gases, discovered in 1808 and published in 1809 **[14].** However, it sometimes refers to the proportionality of the volume of a gas to its absolute temperature at constant pressure. The latter law was published by Gay-Lussac in 1802 **[15]**, but in the article in which he described his work, he cited earlier unpublished work from the 1780s by Jacques Charles. Consequently, the volume-temperature proportionality is usually known as *Charles's law*.

B.2. Definition

Gay–Lussac's law states that the volume of a gas is directly proportional to its absolute temperature when the pressure and amount of gas are held constant. The law is written as:

$$V/T = \text{constant} \quad (p=\text{constant}) \qquad \text{(I.6)}$$

B.3. Experimental Approach

The gas syringe is connected to the Cobra4 system, and the pressure is kept constant. The temperature is gradually increased using a water bath with controlled heating. For each temperature increment, the volume of the gas is measured and recorded.

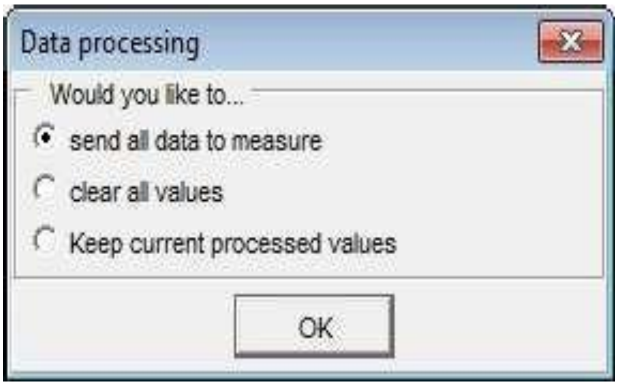
B.4.Objective:

This experiment aims to validate Gay–Lussac's law by plotting the volume as a function of temperature (V= f (T)), and to determine the coefficient of thermal expansion as well as estimate the universal gas constant R.

B.4. Lab2: Gay–Lussac’s Law (Isobaric Process)

B.4.1. Procedure

1. Call up the ‘Measure’ programme and boot the experiment Gay-Lussac’s law with Cobra4 (experiment > open experiment). The measurement parameters for this experiment are loaded now.
2. Switch on the Cobra4 Remote-Link.
3. Start the measurement with ●.
4. Record the first value for the initial temperature by pressing the switch of the Cobra4 Remote-Link.
5. Switch on the heating apparatus and adjust the power regulator so that the glass jacket is slowly heated.
6. Mix the water in the glass jacket by moving the magnetic stirrer bar with the aid of a bar magnet and facilitate pressure equilibration in the gas syringe by turning the plunger.
7. After each 1 ml increase in volume, take the next value.
8. After the gas volume has reached 60 ml, switch off the heating apparatus and terminate the measurement by pressing ■.
9. Send all data to ‘measure’ (see Fig. (I.8) and save the measurement (File > Save meausrement as…).



Data processing

Would you like to...

● send all data to measure

○ clear all values

○ Keep current processed values

Fig. (I.8): Window which appears after measurement

Fig. (I.9) shows the graph as it is then presented by the program.

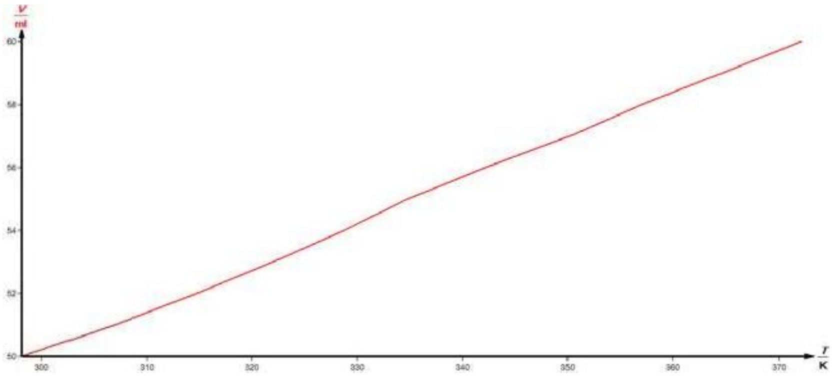
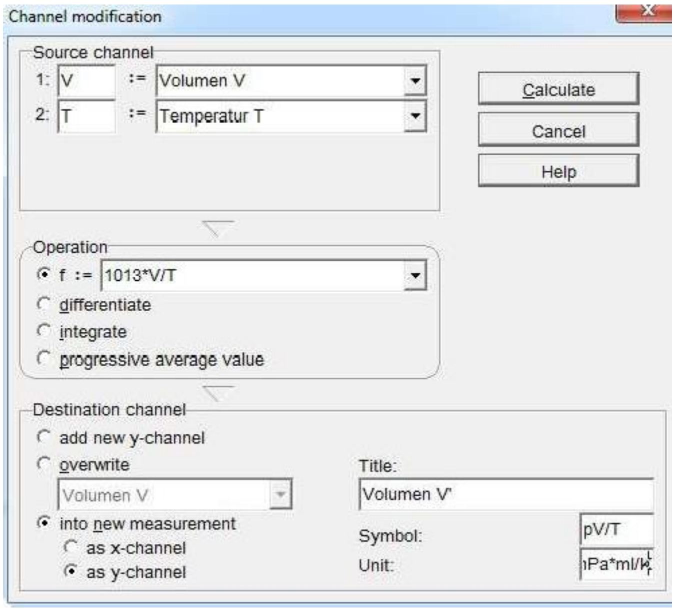


Fig. (I.9): Dependence of the volume *V* on the temperature *T* at constant pressure *p* = 1020 hPa and constant amount of substance (*n* = 2.23 mmol)

To have the plot of the quantity *pV*/*T* versus volume click √α. Now you can perform some channel modifications (see Fig. (I.10)).


Channel modification

Source channel
1: V := Volumen V
2: T := Temperatur T

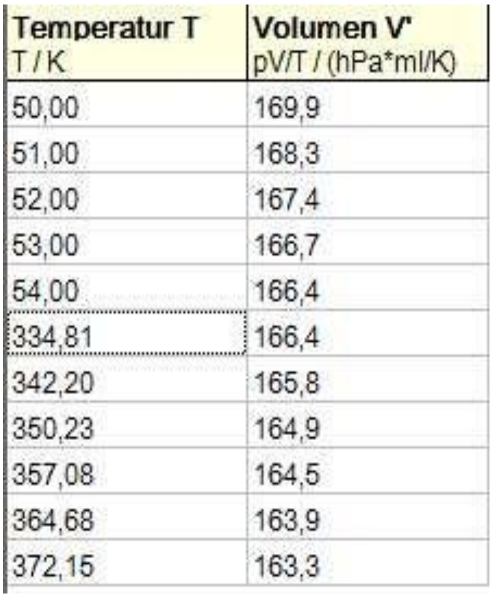
Operation
● f := 1013*V/T
○ differentiate
○ integrate
○ progressive average value

Destination channel
○ add new y-channel
○ overwrite Volumen V
● into new measurement
○ as x-channel
● as y-channel
Title: Volumen V'
Symbol: pV/T
Unit: hPa*ml/K

Fig. (I.10): Settings for channel modification.

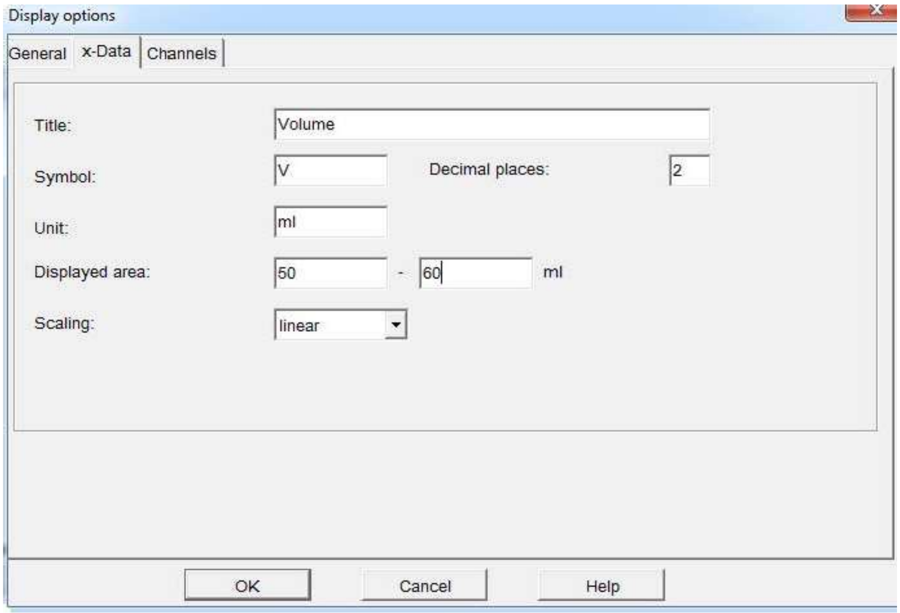
The settings are used by clicking 'Calculate'.
Click ▦ to get the data table.
Exchange the temperature values with volume values (50, 51, 52…60) (see Fig. (I.11)).

Click to change the settings for the display (see Figs. (I.12 and I.13)).



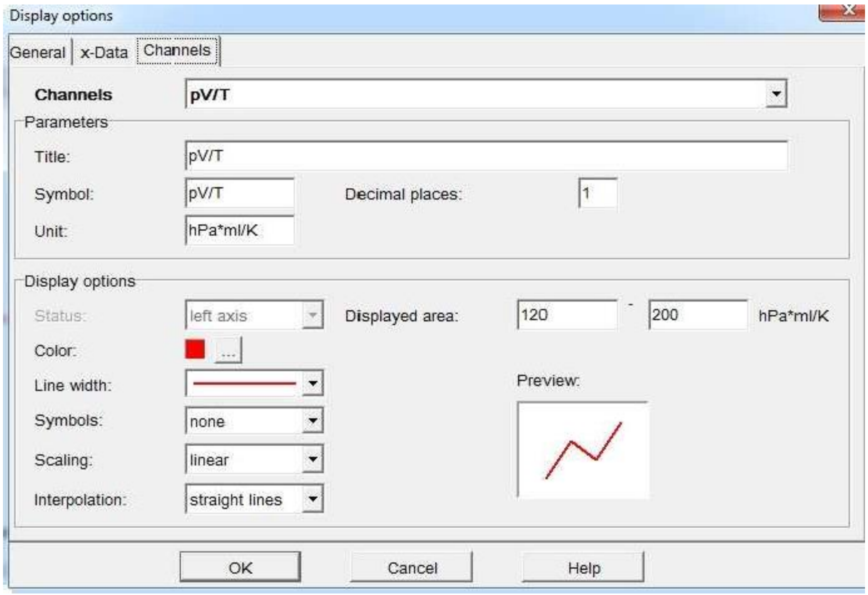
Temperatur T T / K	Volumen V' pV/T / (hPa*ml/K)
50,00	169,9
51,00	168,3
52,00	167,4
53,00	166,7
54,00	166,4
334,81	166,4
342,20	165,8
350,23	164,9
357,08	164,5
364,68	163,9
372,15	163,3

Fig. (I.11): Data table of the new graph.



Title: Volume
Symbol: V
Decimal places: 2
Unit: ml
Displayed area: 50 - 60 ml
Scaling: linear

Fig. (I.12): Settings for channels.



Channels pV/T

Parameters

Title: pV/T

Symbol: pV/T

Decimal places: 1

Unit: hPa*ml/K

Display options

Status: left axis

Displayed area: 120 - 200 hPa*ml/K

Color: 🟥

Line width:

Symbols: none

Scaling: linear

Interpolation: straight lines

Preview:

Fig. (I.13): Settings for x-data.

With ‘OK’ you get the new graph.

Fig. (I.14) shows the dependence of the quantity pV/T on the volume V.

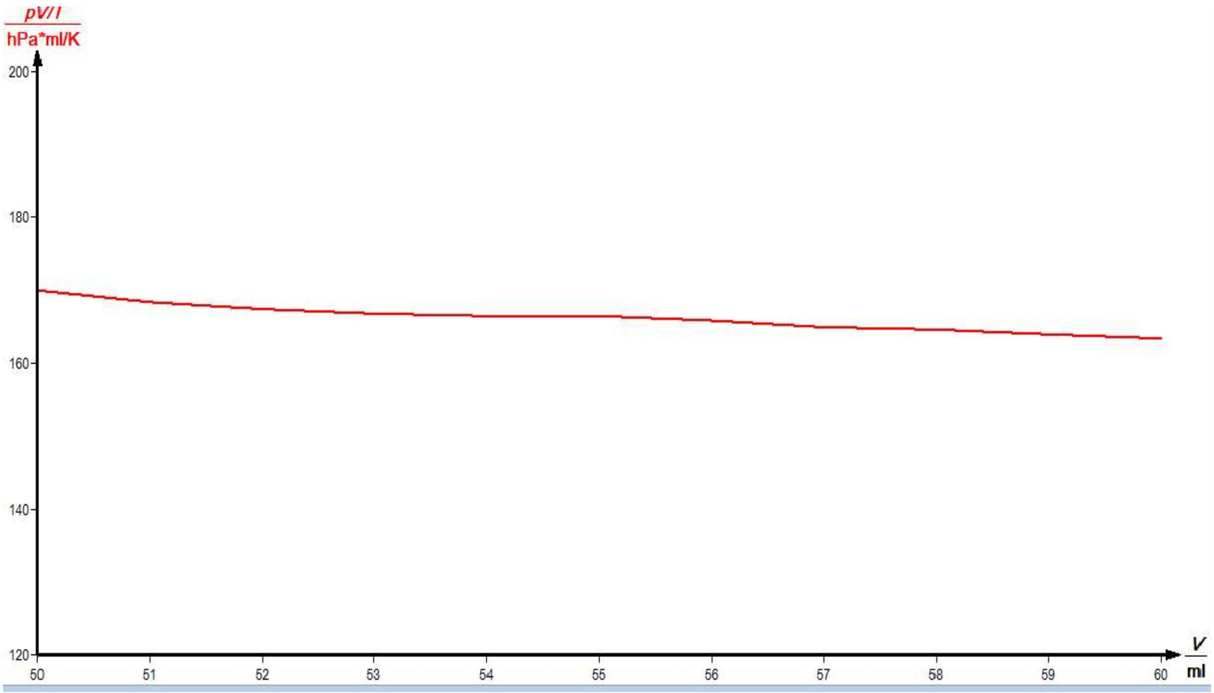


Fig. (I.14): The quantity pV/T depending on the volume V.

Part C

Amontons' Law

Amontons' Law

"For any gas at a constant volume, the pressure of the gas is directly proportional to its absolute temperature."

$$P_1 / T_1 = P_2 / T_2 = const$$

P and T are pressure and temperature.

Lab Objective

The goal is to confirm Amontons' law by plotting pressure versus temperature (p= f(T)) and to derive the coefficient of thermal tension and the value of R from the slope of the graph.

C.1. Amonton’s law

Toward the end of the 1600s, the French physicist Guillaume Amontons built a thermometer based on the fact that the pressure of a gas is directly proportional to its temperature. The relationship between the pressure and the temperature of a gas is therefore known as **Amontons' law**.

$$P \propto T$$

Amontons' law explains why car manufacturers recommend adjusting the pressure of your tires before you start on a trip. The flexing of the tire as you drive inevitably raises the temperature of the air in the tire. When this happens, the pressure of the gas inside the tires increases.

Amontons' law can be demonstrated with the apparatus shown in the figure below, which consists of a pressure gauge connected to a metal sphere of constant volume, which is immersed in solutions that have different temperatures.

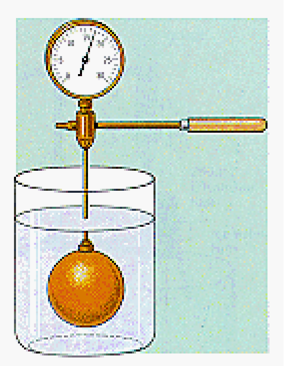
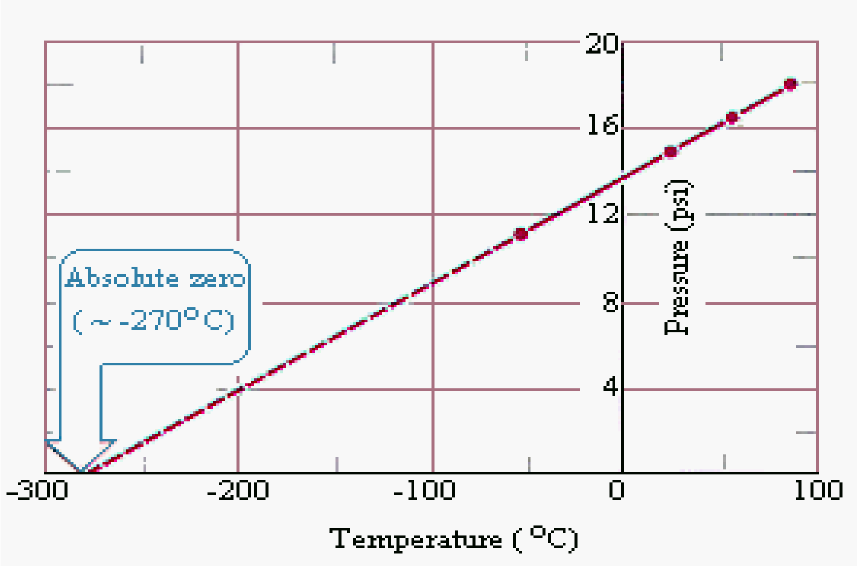


Fig. (I.15): The apparatus for demonstrating Amonton's law consists of

The following data were obtained with this apparatus.



C2. Amontons’ law Lab (Isochoric process)

C.2.1. Procedure

1. Call up the ‘Measure ‘programme and boot the experiment Amontons law option A with Cobra4 (experiment > open experiment). The measurement parameters for this experiment are loaded now.
2. Switch on the Cobra4 Remote-Link.
3. Start the measurement with ●.
4. Subsequently, adjust the heating apparatus to slow heating with the power regulator.
5. Mix the water in the glass jacket by moving the magnetic stirrer bar with the aid of a bar magnet and facilitate pressure equilibration in the gas syringe by turning the plunger.
6. Record the pressure corresponding to the initial temperature by pressing the switch of the Cobra4 Remote Link.
7. After each temperature increase of 5 K, push the plunger rapidly into the gas syringe until the gas volume is compressed to the initial volume of **V = 50 ml** and take the next value by pressing the switch of the Cobra4 Remote Link.
8. After the temperature has reached approximately 370 K or if there is an evident loss of air during compression, switch off the heating apparatus and terminate the measurement by pressing ■.
9. Send all data to ‘measure’ (see Fig. (I.8)) and save the measurement (File > Save measurement as…).

Fig. (I.16) shows the graph for the dependence of the pressure p on the temperature T at constant volume V as it is then presented by the program.

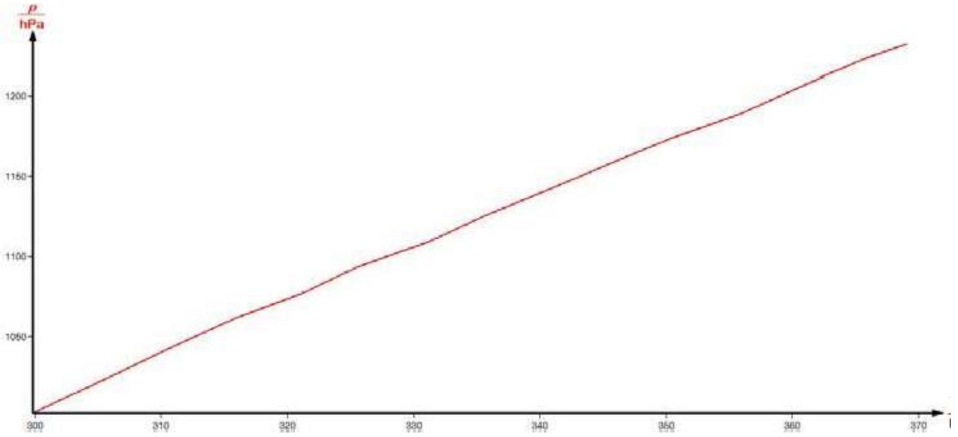
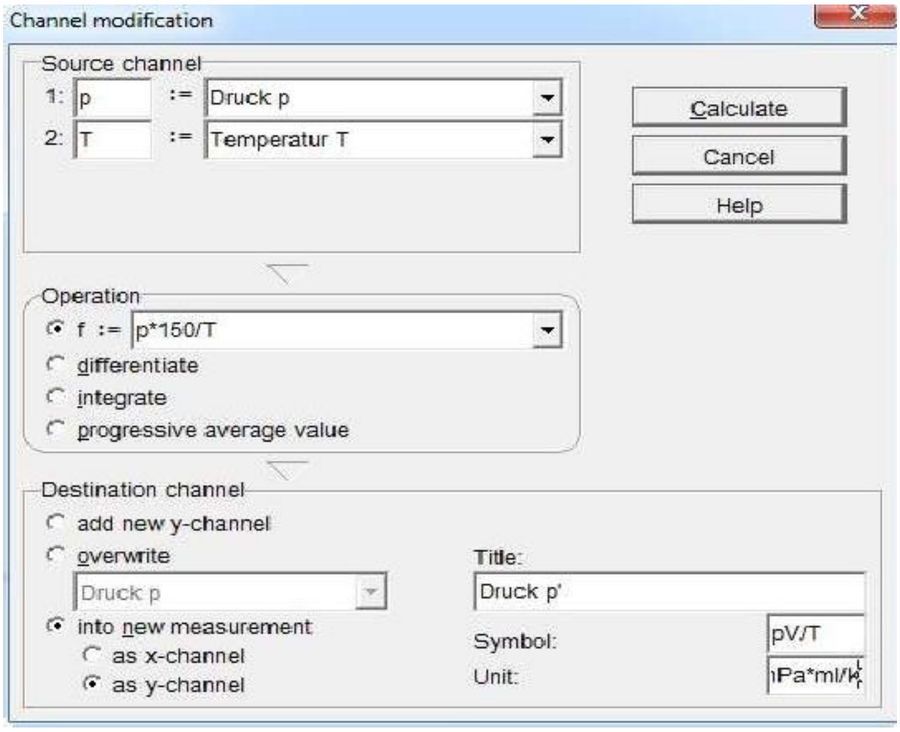


Fig. (I.16): Dependence of the pressure p on the temperature T at constant volume (V = 50 ml) and constant amount of substance (n = 2.23 mmol.

To have the plot of the quantity pV/T versus Temperature click √α. Now you can perform some channel modifications (see Fig. (I.17)).



Source channel
1: p := Druck p
2: T := Temperatur T

Operation
● f := p*150/T
○ differentiate
○ integrate
○ progressive average value

Destination channel
○ add new y-channel
○ overwrite
Druck p
● into new measurement
○ as x-channel
● as y-channel

Title: Druck p'
Symbol: pV/T
Unit: hPa*ml/K

Fig. (I.17): Settings for channel modification.

After pressing 'Calculate' you get the graph of the quantity pV/T versus the temperature T as it is shown in Fig. (I.18).

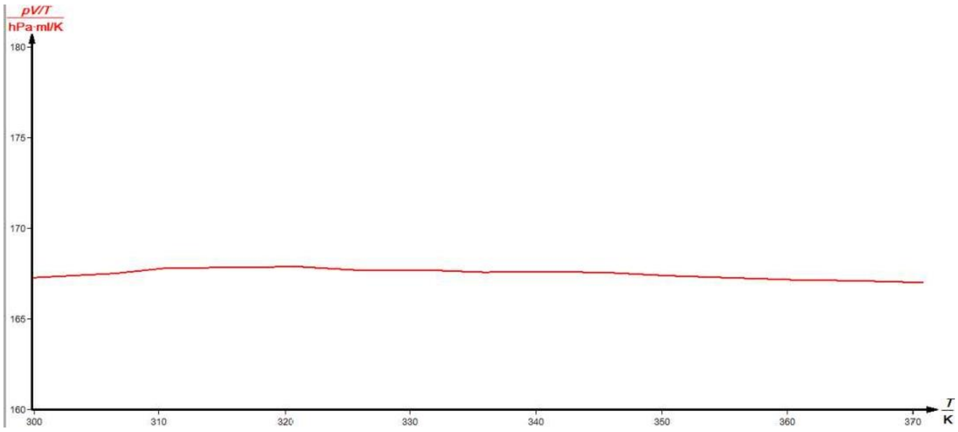


Fig. (I.18): The quantity pV/T depending on the temperature T.

Part D

Theory with Evaluation and Data with results

D.1. Theory and Evaluation

The state of a gas is a function of the state variables temperature T, pressure p and the amount of sub- stance n, which reciprocally determine one another. Thus, the dependence of pressure on the temperature, volume and amount of substance variables is described by the total differential

$$\mathrm{d}V = \left(\frac{\partial V}{\partial T}\right)_{p,n} \mathrm{d}T + \left(\frac{\partial V}{\partial p}\right)_{T,n} \mathrm{d}p + \left(\frac{\partial V}{\partial n}\right)_{T,V} \mathrm{d}n \qquad (1.6)$$

Analogously, the following is true for the change of pressure with T, V and n:

$$\mathrm{d}p = \left(\frac{\partial p}{\partial T}\right)_{V,n} \mathrm{d}T + \left(\frac{\partial p}{\partial V}\right)_{T,n} \mathrm{d}V + \left(\frac{\partial p}{\partial n}\right)_{T,V} \mathrm{d}n \qquad (1.7)$$

This relationship simplifies for a given amount of substance (n = const., dn = 0; enclosed quantity of gas in the gas syringe) and isothermal change of state (T = const., dT = 0) to:

$$\mathrm{d}V = \left(\frac{\partial V}{\partial T}\right)_{T,n} \mathrm{d}p \qquad (I.8)$$

and

$$\mathrm{d}p = \left(\frac{\partial p}{\partial T}\right)_{V,n} \mathrm{d}T \qquad (I.9)$$

The partial differential quotient $(\partial V/\partial p)T,n$ resp. $(\partial p/\partial V)T,n$ corresponds geometrically to the slope of a tangent to the function V = f(p) or p = f(V) and therefore characterizes the mutual dependence of pre sure and volume. The degree of this dependence is determined by the initial volume or the initial pressure. One thus defines the cubic compressibility coefficient X_0 by referring it to V or V_0 at T_0 = 273.15 K.

$$X_0 = \frac{1}{V_0}\left(\frac{\partial V}{\partial p}\right)_{T,n} \qquad \text{(I.10)}$$

The partial differential quotient $(\partial p/\partial T)V,n$ corresponds geometrically to the slope of a tangent to the function p = f(T) and thus characterises the dependence of the pressure on the temperature. The degree of this dependence is determined by the initial pressure. Therefore, one defines the thermal coefficient of tension β_0 as a measure of the temperature dependence by referring it to p or p_0 at T_0 = 273.15 K.

$$\beta_0 = \frac{1}{p_0}\left(\frac{\partial p}{\partial T}\right)_{V,n} \qquad \text{(I.11)}$$

The partial differential quotient $(\partial V/\partial T)p,n$ corresponds geometrically to the slope of a tangent to the function V = f(T) and thus characterises the mutual dependence of volume and temperature. The degree of this dependence is determined by the initial volume. The thermal coefficient of expansion γ_0 is there- fore defined as a measure of the temperature dependence of the volume by referring it to V or V_0 at T_0 = 273.15 K.

$$\gamma_0 = \frac{1}{V_0}\left(\frac{\partial V}{\partial T}\right)_{p,n} \qquad \text{(I.12)}$$

For the limiting case of an ideal gas (sufficiently low pressures, sufficiently high temperatures), the correspondence between the state variables p, V, T and n is described by the ideal gas law:

$$pV = n\mathrm{R}T \qquad \text{(I.13)}$$

R: Universal gas constant

For cases of constant quantity of substances and isothermal process control this equation changes into the following equations:

$$pV = const \tag{I.14}$$

And

$$p = \text{const.} \cdot \frac{1}{V} \tag{I.15}$$

According to this correlation, which was discovered by Charles and Amontons, the graphic presentation of the pressure as a function of the temperature results in an ascending straight line (Fig. (I.16)) where $p = 0$ at $T = 0$.

From (I.11) and the ideal gas law (I.13) the following is true for the slope of these linear relationships

$$\left(\frac{\partial p}{\partial T}\right)_{V,n} = p_0\beta_0 = \frac{n\mathrm{R}}{V} \tag{I.16}$$

From this, the thermal coefficient of tension β_0 and the universal gas constant R can be determined for a known initial pressure p_0 and a known quantity of substance n. The enclosed constant amount of sub- stance n is equal to the quotient of the volume V and the molar volume V_m.

For the limiting case of an ideal gas (sufficiently low pressure, sufficiently high temperature), the integration of a differential equation resulting from (1.7) and (I.12), where γ_0 = constant, yields

$$\frac{V_0}{T_0} = \frac{V}{T} \tag{I.17}$$

and

$$V = const. \cdot T \tag{I.18}$$

According to this correlation, which was discovered by Gay- Lussac, the graphic presentation of the volume as a function of the temperature provides a sending straight line (Fig. (I.9)) where

$V = 0$ for $T = 0$.

From (I.18) and the ideal gas law (I.13) the following is true for the slope of these linear relationships:

$$\left(\frac{\partial V}{\partial T}\right) = V_0\gamma_0 = \frac{n\mathrm{R}}{p} \tag{I.19}$$

From this, the thermal coefficient of expansion γ_0 and the universal gas constant R are experimentally accessible for a known initial volume V_0 and a known amount of substance n. Fig. (I.11) and (I.14) show the quantity pV/T appearing to be nearly constant.

According to this correlation, which was determined empirically by Boyle and Mariotte, a pressure in- crease is accompanied by a volume decrease and vice versa. The graphic representation of the functions $V = \mathrm{f}(p)$ or $p = \mathrm{f}(V)$ results in hyperbolas (Fig. (I.8)). In contrast, plotting the pressure p against the re- ciprocal volume $1/V$ results in straight lines where $p = 0$ at $1/V = 0$ (Fig. (I09)). From the slope of these linear relationships,

$$\left(\frac{\partial p}{\partial V^{-1}}\right)_{T,n} = n\mathrm{R}T \tag{I.20}$$

it is possible to determine the gas constant R experimentally when the enclosed constant quantity of air n is known. This is equal to the quotient of the volume V and the molar volume V_m,

$$n = \frac{V}{V_m} \tag{I.21}$$

which is $V_0 = 22.414\ \mathrm{l} \cdot \mathrm{mol}^{-1}$ at $T_0 = 273.15$ K and $p_0 = 1013.25$ hPa at standard conditions. A volume measured at p and T is therefore first reduced to these conditions using the relationship obtained from (I.13):

$$\frac{p_0V_0}{T_0} = \frac{p_1V_1}{T_1} = \frac{pV}{T} \tag{I.22}$$

For the limiting case of an ideal gas (sufficiently low pressure, sufficiently high temperature), the integra- tion of a differential equation resulting from (1.2) and (I.11), where β_0 = const., yields

$$\frac{p_0}{T_0} = \frac{p}{T} \tag{I.23}$$

and

$$p = \text{const.} \cdot T \tag{I.24}$$

D.2. Data and results

The theoretical values for an ideal gas are:

R (lit.) = 8.31441 Nm · K^{-1} · mol^{-1} = J · K^{-1} · mol^{-1} $_0$ (lit.) = 3.661 · 10^{-3} K^{-1}

β_0 (lit.) = 3.661 · 10-3 K^{-1}

D.2.1. Boyle and Mariotte's law

Figs. (I.8) and (I.9) confirm the validity of Boyle and Mariotte's law. From the slope obtained for n = 2.086 mmol and T = 295.15 K, $(\partial p/\partial V^{-1})T,n$ = 4.6464 kPa/m^{-3} = 4.6464 Nm of the linearized correlation between p and $1/V$ (Fig. 6), the universal gas constant can be calculated to be R = 7.547 Nm · K^{-1} · mol^{-1}.

The deviation from the literature value is due to the unavoidable lack of gas-tightness with increasing de- viation from atmospheric pressure through compression or expansion, whereby the condition dn = 0 is violated and the observed slope $(\partial p/\partial V^{-1})T$ is diminished in comparison with the value measurable with a constant quantity of substance.

D.2.2. Gay-Lussac's law

The investigation of the correlation between volume and temperature with a constant quantity of gas of n = 2.23 mmol, calculated according to the relations (I.21) and (I.22), confirms the validity of the Gay-Lussac's first law, with the linear relationship demonstrated in Fig. (I.14). From the corresponding slope $(\partial V/\partial T)p,n$ = 0.18 ml/K and for the initial volume V_0 = 50 ml, the following values are obtained for the universal gas constant R and the coefficient of thermal expansion γ_0.

R (exp.) = 8.07174 Nm · K^{-1} · mol^{-1} $_0$ (exp.) = 3.04 · 10^{-3} K^{-1}

D.2.3. Amontons' law

The investigation of the correlation between pressure and temperature with a constant quantity of gas of n = 2.23 mmol, calculated according to the relations (I.21) and (I.22), confirms the validity of the Charles' (Amontons') law with the linear relationship demonstrated in Fig.

(I.16). From the corresponding slope $(\partial p/\partial T)V,n = 3.72$ hPa/K and for the initial pressure p_0 = 1002.2 hPa, the following values are obtained for the universal gas constant R and the coefficient of thermal tension β_0.

R (exp.) = 8.34 Nm · K^{-1} · mol^{-1} β_0 (exp.) = 3.71 · 10-3 K^{-1}

Chapter II

THERMAL CONDUCTIVITY OF METALS

Objectives

- understand the thermal conductivity of metals.
- measure the coefficient of thermal conductivity of a metal (Cu or Al).

II.1. Introduction

Thermal conductivity of materials can't be measured directly unlike electrical conductivity. There are two different types of techniques for measurement of thermal conductivity, namely steady- state techniques and transient techniques. In general, steady-state techniques perform a measurement when the temperature of the materials measured does not change with time. This makes signal analysis simple. The transient techniques perform a measurement during the process of heating up and it is not simple. The advantage is that measurements can be made quickly.

In metals, thermal conductivity approximately tracks electrical conductivity according to Wiedmann-Franz law, as freely moving electrons transfer not only electric current but also heat energy. However, the general correlation between electrical and thermal conductivity does not hold for other materials, due to the increased importance of phonon carriers for heat in nonmetals.

II.2. Objectives

- Determine the heat capacity of the calorimeter in a mixture experiment as a preliminary test. Measure the calefaction of water at a temperature of 0°C in a calorimeter due to the action of the ambient temperature as a function of time for copper and aluminum.
- To begin with, establish a constant temperature gradient in a metal rod with the use of two heat reservoirs (boiling water and ice water).
- After removing the pieces of ice, measure the calefaction of the cold water as a function of time and determine the thermal conductivity of the metal rod (Copper/Aluminium).

II.3. Theory and Evaluation

If a temperature difference exists between different locations of a body, heat conduction occurs. In this experiment there is a one-dimensional temperature gradient along a rod. The quantity of heat ***dQ*** transported with time dt is a function of the cross-sectional area A and the temperature gradient **ΔT/Δx** perpendicular to the surface.

$$\frac{dQ}{dt} = -\lambda A.\frac{\delta T}{\delta x} \qquad \text{-------------1}$$

is the heat conductivity of the substance.

The temperature distribution in a body is generally a function of location and time and is in accordance with the Boltzmann transport equation

$$\frac{\Delta Q}{\Delta t} = \frac{\lambda}{\rho . c} . \frac{\delta^2 T}{\delta x^2} \text{----------------2}$$

Where ρ is the density and 'c' is the specific heat capacity of the substance.

After a time, a steady state $\frac{\delta T}{\delta x} = 0$ --------------3

is achieved if the two ends of the metal rod having a length l are maintained at constant temperatures T_1 and T_2, respectively, by two heat reservoirs.

On reaching constant temperature gradient (steady state), equation 3 can be considered as

having been satisfied by the metal rod. In order to calculate the heat energy transported by the metal rod according to Equation 1, the ambient heat fraction must be subtracted.

That is

$$\frac{dQ_{rod}}{dt} = \frac{dQ_{total}}{dt} - \frac{dQ_{surrounding}}{dt} \qquad \text{--------------4}$$

At room temperature the conduction electrons in metal have a much greater mean free path than the phonons. For this reason, heat conduction in metal is primarily due to the electrons.

The correlation between the thermal conductivity λ and the electrical conductivity σ is established by the Wiedemann-Franz law:

$$\frac{\lambda}{\sigma} = LT \qquad \text{-----------------5}$$

The Lorenz number L, which can be experimentally determined using Equation (5), is established by the theory of electron vapour (for temperatures above the Debye temperature) to be:

$$L = \frac{\pi^2}{3} . \frac{k^2}{e^2} = 2.4x10^{-8} \frac{W\Omega}{2} \quad \text{-------------------6}$$

Where k = Universal gas constant =1.38x10^{-23} J/K, e = Elementary unit charge = 1.602x10^{-19}

II.4. Procedure for thermal conductivity estimation

II.4.1. Heat capacity

It is the amount of heat required to change its temperature by **1°: Q = Cdt**

Where: **Q** = heat supplied (J) and **C** = heat capacity (Jk^{-1}).

II.4.1.1 Measurement of heat capacity of lower calorimeter

The heat capacity of the calorimeter is obtained from results of the mixing experiment

$$c = c_w . m_w . \frac{T_w - T_m}{T_m - T_R} \quad \text{------------7}$$

and the following formula:

c_W= Specific heat capacity of water, m_W = Mass of the water, T_W = Temperature of the hot water, T_m = Mixing temperature and T_R = Room temperature.

1) Method :

1. Weigh the calorimeter at room temperature.
2. Measure the room temperature and temperature of preheated water provided.
3. Fill the calorimeter with hot water, determine the mixing temperature of water.
4. Reweigh the calorimeter to determine the mass of the water.
5. Calculate the heat capacity of the calorimeter using eq(7).

II.4.2. Determination of the influence of the surroundings

The addition of heat from the surroundings is calculated from the temperature increase (Temperature (T) rise of the cold water in the calorimeter)

$$Q = (c_w . m_w + c) . (T - T_0) \quad \text{----------------8}$$

$$dQ = (c\ m\ + c)\ dT/\ dt$$

Where T_0 = Temperature at time **t = 0 sec**.

By plotting a graph between heat energy supplied versus time, heat energy supplied by surroundings with time **(dQ_{surr}/dt)** can be estimated.

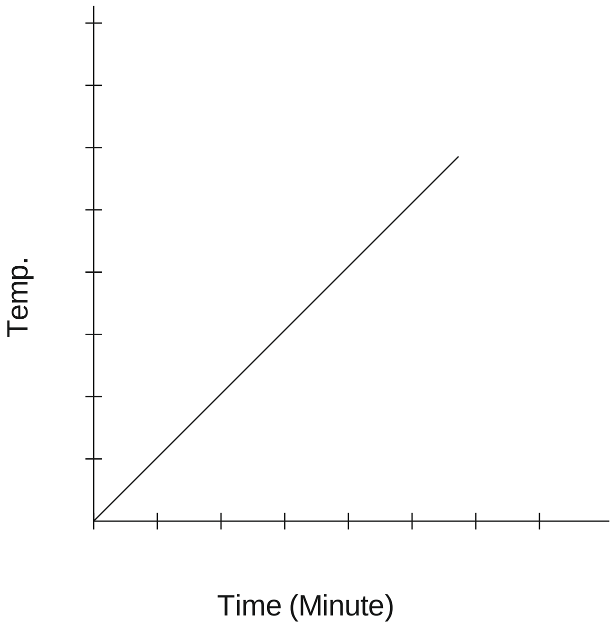
1) *Method :*

1. Weigh the empty lower calorimeter.
2. Add ice to the lower calorimeter till the temperature reaches to 0°C.
3. Then remove the ice and take the temperature readings in 1 min interval till the temperature rises to 12°C.
4. Reweigh the calorimeter to determine the mass of the water that it contains.

Table for calefaction of cold water using eq8)

Time (m)	Temp. °C

Slope of the graph give us: $\frac{dQ_{surr}}{dt}$



II.4.3. Determination of the heat flow through metal rod thermal conductivity

Equation for the measurement of the thermal conductivity of Aluminium/copper rod is given by:

$$\frac{dQ_{rod}}{dt} = -KA.\frac{\Delta T}{\Delta x}$$

II.4.3.1. Method :

1. Perform the experimental set-up according to Fig. 1.
2. Weigh the empty, lower calorimeter.
3. Insert the insulated end of the metal rod into the upper calorimeter vessel. To improve the heat transfer, cover the end of the metal rod with heat-conduction paste.

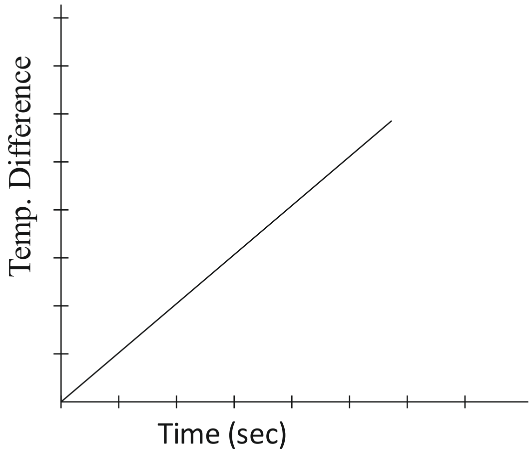
4. Attach the metal rod to the support stand in such a manner that the lower calorimeter can be withdrawn from beneath it.
5. The height of the lower calorimeter can be changed with laboratory jack. When doing so, care must be taken to ensure that the non-insulated end of the rod remains completely immersed in the cold water during the experiment.
6. The temperature probe must be positioned as close to the rod as possible.
7. The outermost indentations on the rod are used to measure the temperature difference in the rod. To improve the heat transfer between the rod and the temperature probe, use heat conduction paste.
8. Using an immersion heater, bring the water in the upper calorimeter to a boil, and keep it at this temperature.
9. Ensure that the upper calorimeter is well filled to avoid a drop in temperature due to contingent refilling with water.
10. Keep the water in the lower calorimeter at 0°C with the help of ice.
11. The measurement can be begun when a constant temperature gradient has been established between the upper and lower surface probes.
12. At the onset of measurement, remove the ice from the lower calorimeter.
13. Measure and record the change in the differential temperature and the temperature of the water in the lower calorimeter for a period of 5 minutes.
14. Weigh the water-filled calorimeter and determine the mass of the water.
15. Sample Calculations.

Time	**Temp. of lower calorimeter °C**	**dT °C**

Where : $dQ = (c_W\, m_W + c)\,(T-T_0)$ *

Slope of graph give $\frac{dQ}{dt}$ total:

$$\frac{dQ}{dt} = (c_w m_w + c)\frac{dT}{dt}$$



So:

$$\left(\frac{dQ}{dt}\right)_{rod} = \left(\frac{dQ}{dt}\right)_{total} - \left(\frac{dQ}{dt}\right)_{surr}$$

and calculate λ using eq (6).

Test Report of Thermal Conductivity of Copper

THERMAL CONDUCTIVITY OF COPPER

HEAT CAPACITY OF LOWER CALORIMETER

Formula Used

$$C=C_w M_w \frac{T_w - T_m}{T_m - T_r}$$

Specific Heat of Water (C_w) in Joule Kg^{-1} K^{-1}	Mass of Water (M_w) in Kg	Temperature of Water (T_w) in Centigrade	Mixing Temperature (T_m) in Centigarde	Room Temperature (T_r) in Centigrade	Heat Capacity (C) in Joule / Kelvin
4200	0.89	46.2	44.3	32.6	608

DETERMINATION OF CALCIFICATION

Formula Used

$$\frac{dQ_{surroundings}}{dt}=(C+C_w M_w)\frac{dT}{dt}$$

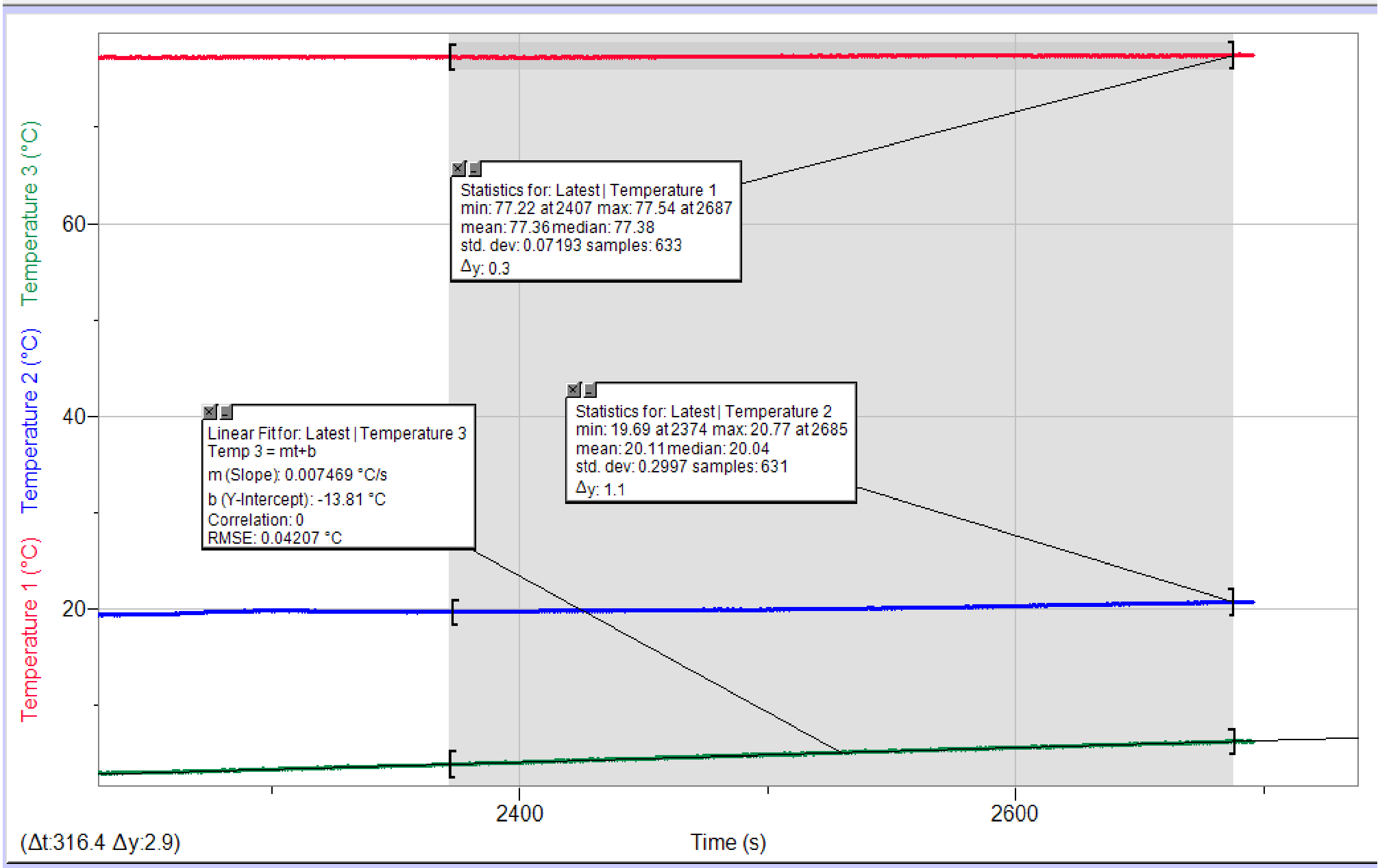
Heat Capacity (C) in Joule / Kelvin	Mass of Water (M_w) in Kg	Specific Heat of Water (C_w) in Joule Kg^{-1} K^{-1}	dT/dt from graph in Kelvin / second	$dQ_{surroundings}/dt$ in Joule/second
608	0.76	4200	107×10^{-5}	4.06

DETERMINATION OF dQ_{total}/dt

Formula Used

$$\frac{dQ_{total}}{dt} = (C + C_w M_w)\frac{dT}{dt}$$

Heat Capacity (C) in Joule / Kelvin	Mass of Water (M_w) in Kg	Specific Heat of Water (C_w) in Joule Kg^{-1} K^{-1}	dT/dt from graph in Kelvin / second	dQ_{total} /dt in Joule/second
608	0.8	4200	748.6×10^{-5}	32.06



Statistics for: Latest | Temperature 1
min: 77.22 at 2407 max: 77.54 at 2687
mean: 77.36 median: 77.38
std. dev: 0.07193 samples: 633
Δy: 0.3

Statistics for: Latest | Temperature 2
min: 19.69 at 2374 max: 20.77 at 2685
mean: 20.11 median: 20.04
std. dev: 0.2997 samples: 631
Δy: 1.1

Linear Fit for: Latest | Temperature 3
Temp 3 = mt+b
m (Slope): 0.007469 °C/s
b (Y-Intercept): -13.81 °C
Correlation: 0
RMSE: 0.04207 °C

Temperature 1 showing the temperature of the upper end of the rod.
Temperature 2 showing the temperature of the lower end of the rod.
Temperature 3 showing the temperature of the lower calorimeter.

DETERMINATION OF dQ_{rod} /dt

Formula Used

$$\frac{dQ_{rod}}{dt} = \frac{dQ_{total}}{dt} - \frac{dQ_{surroundings}}{dt}$$

= (*32.06 – 4.06*) Joule/second

= *28* Joule / second

DETERMINATION OF DIFFERENCE IN TEMPERATURE OF UPPER AND LOWER END OF THE ROD

Formula Used

$$\Delta\theta = \theta_1 - \theta_2$$

= (*77.36 – 20.11*) Kelvin

= *57.25* Kelvin

where, θ_1 = Mean Temperature of the Upper end of the rod; and
θ_2 = Mean Temperature of the Lower end of the rod.

That temperature gradient was obtained at a **distance, Δx = 0.315 meter**.

DETERMINATION OF THERMAL CONDUCTIVITY OF COPPER ROD

Formula Used

$$\frac{dQ_{rod}}{dt} = -KA\frac{\Delta\theta}{\Delta x}$$

Radius of the Rod, R in m	Area of cross – section, A = πR^2 *in m* ^{2}	$\Delta\theta$ in Kelvin	Δx in m	**dQ_{rod} /dt** in Joule / Kelvin	K in Watt meter $^{-1}$ Kelvin $^{-1}$
1.275×10^{-2}	510.446×10^{-6}	57.25	0.32	28	301.8

Chapter III

Measuring the linear expansion of solids as a function of temperature

Objects of the experiment

- Measuring the linear thermal expansion of brass, steel and glass tubes as a function of temperature.
- Determining the linear expansion coefficients of brass, steel and glass.

Chapter III: Measuring the linear expansion of solids as a function of temperature

III.1 Principles

The length s of a solid body is linearly dependent on its temperature T :

$$S = S_0\ (1+ \alpha\, \vartheta)\ \ \text{(I)}$$

S_0: length at room temperature, ϑ: temperature in °C

The linear expansion coefficient □ is determined by the mate- rial of the solid body.

In this experiment a circulation thermostat is used to heat the water which flows through the various tube samples. A dial gauge with 0.01 mm scale graduations is used to measure the change of length $\Delta s = s - s_0$ as a function of temperature T.

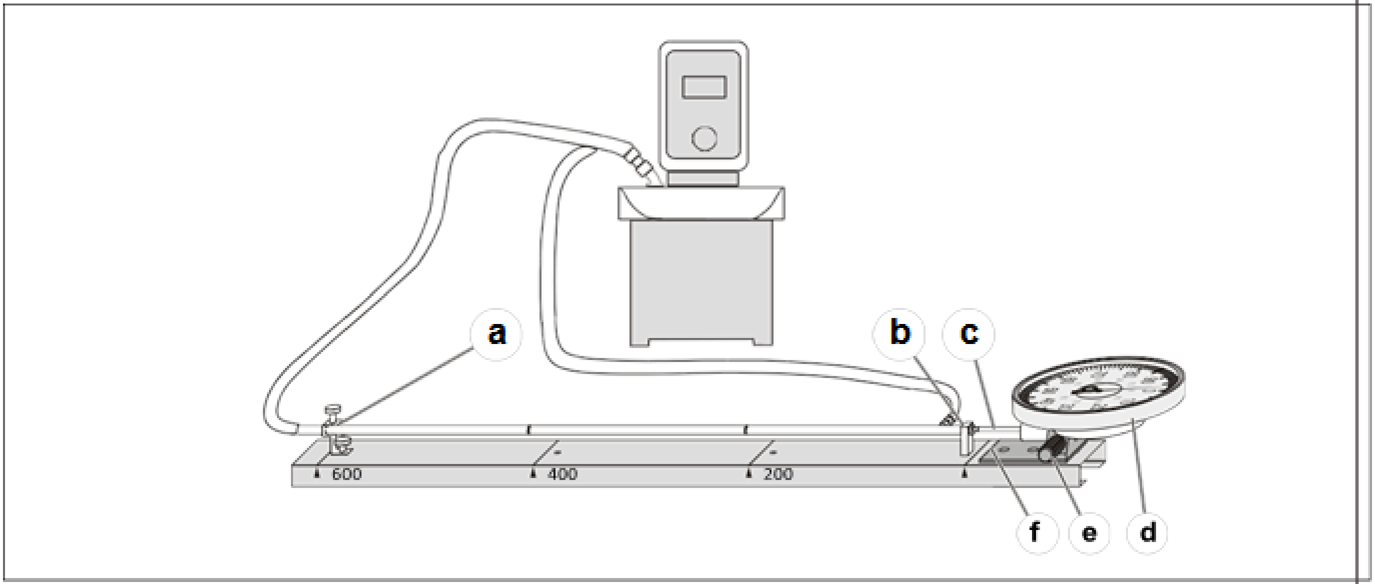


Fig. 1: Schematic representation of the experimental setup to meas- ure the linear thermal expansion of tubes with the expansion apparatus as a function of temperature.

Apparatus

1 Longitudinal expansion apparatus D	381 341
1 Dial gauge, 10 mm	361 15
1 Holder for dial gauge	381 36
1 Thermometer -10 ... +110°C	382 34
1 Circulation thermostat +25 ... +100 °C	666 768
1 Pump set	666 7703
2 Silicone tubing, 7 mm Ø	667 194
2 Water, pure, 5 l	675 3410

III.2. Setup

The setup of the experiment is shown in Fig. 1 schematically.

1. Screw on the holder for dial gauge 381 36 **(e)** (for details refer to instruction sheet 381 341 of expansion apparatus) and clamp the dial gauge in place 361 15 **(d)**.
2. Attach the fixed bearing **(a)** of the expansion apparatus at the 600 mark and slide the open end of the brass tube into the fixed bearing.
3. Slide the closed end of the brass tube into the guide fitting **(b)** so that the hose nipple **(f)** is pointing laterally down- wards.
4. Tighten the screw to fix the brass tube in the fixed bearing (the screw must engage the ring groove of the tube).
5. Insert the extension piece **(c)** (see instruction sheet for dial gauge 361 15).
6. Prepare the circulation thermostat and the pump set. For a detailed description refer to instruction sheet 666 768.
7. Fill the water bath of the circulation thermostat with dis- tilled water.
8. Connect the expansion apparatus to the circulation ther- mostat using the silicone tubing, i.e. connect the open end of the brass tube and the hose nipple **(f)** to the hose nip- ples of the pump set of circulation thermostat.
9. Use the thermometer 382 34 to measure the temperature J of the water bath.

Note: Be sure to read the instruction sheet of the circulation thermostat 666 768 before using this device.

Safety notes

- ✓ Check the seating of the silicone tubing every time be- fore putting the apparatus into operation, to ensure that no hot water can escape in an uncontrolled manner and cause damage or injury.
- ✓ Follow the safety hints of the circulation thermostat.
- ✓ When using the glass tube follow the instructions printed on the thermal expansion apparatus.

III.3. Carrying out the experiment

1. Turn the housing of the dial gauge to set the zero position.

2. Measure the initial temperature, i.e. room temperature J_0.

3. Switch on the circulation thermostat and set the tempera- ture about 5 °C above J_0.
4. Wait until a thermal equilibrium has been established.
5. Measure the temperature J.
6. Read off and write down the pointer deflection of the dial gauge.
7. Increase the temperature J in steps of approx. 5° C until approx. 100° C.
8. Allow the brass tube to cool down to room temperature.
9. Replace the brass tube with the steel tube, i.e. attach the fixed bearing **(a)** of the expansion apparatus at the 600 mark and slide the open end of the steel tube into the fixed bearing.
10. Conduct such a measurement on the glass tube. For this measurement increase the temperature J in steps of approx. 10° C.

III.4. Measuring example

Table 1: Measured change of length Ds as a function of the temperature ϑ

Brass		**steel**		**glass**	
ϑ °C	Δs mm	ϑ °C	Δs mm	ϑ °C	Δs mm
20.0	0.03	24.1	0.07	30.4	0.02
25.0	0.09	26.0	0.09	39.9	0.04
30.0	0.13	30.5	0.12	49.9	0.05
35.0	0.18	34.1	0.15	60.3	0.08
40.0	0.24	40.7	0.20	70.3	0.09
45.0	0.30	44.3	0.22	79.9	0.11
50.0	0.35	49.7	0.26	90.5	0.12
57.0	0.41	52.7	0.28	98.9	0.15
59.8	0.46	62.8	0.35	–	–
64.0	0.50	66.8	0.38	–	–
70.0	0.55	69.1	0.39	–	–
75.0	0.60	72.9	0.42	–	–
80.0	0.67	76.8	0.45	–	–
85.0	0.71	80.1	0.47	–	–
90.0	0.77	84.9	0.51	–	–
95.0	0.82	89.6	0.55	–	–
99.8	0.86	92.8	0.56	–	–
–	–	98.6	0.60	–	–

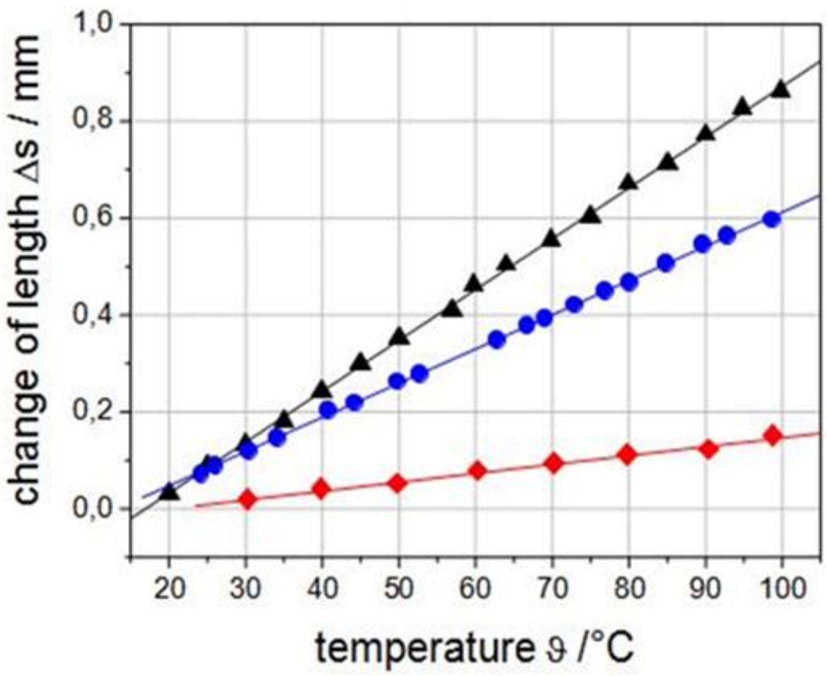


Fig. 2: Change of length Ds as a function of temperature J : brass (▲), steel (●), glass (□). The solid lines correspond to a fit according equation (II).

III.5. Evaluation and results

The various measurements are summarized in Table 1. To determine the linear expansion coefficient a the change of length Ds is plotted as a function of temperature J (Fig. 2).

Subtracting the initial length s_0 at room temperature at both sides of equation (I) gives the change of length Ds:

$$S - S_0 = S_0 . \propto . \vartheta$$

$$\Delta S = k . \vartheta \quad \text{(II)}$$

With $k = S_0 . \propto$

The linear fit of equation (II) to the measured data gives the linear expansion coefficients a (Fig. 2). The results are sum- marized in Table 2.

Table 2: Linear expansion coefficients a determined from Fig. 2 according equation (III.4).

Material	$\frac{\Delta s}{\text{mm}}$	Measurement $\frac{\alpha}{K^{-1}}$	Literature $\frac{\alpha}{K^{-1}}$
brass	600	$17.8 \cdot 10^{-6}$	$18 \cdot 10^{-6}$
steel	600	$11.7 \cdot 10^{-6}$	$11 \cdot 10^{-6}$
glass	600	$3.1 \cdot 10^{-6}$	$3 \cdot 10^{-6}$

III.6. Supplementary information

Additionally, the linear thermal expansion can be measured as function of the overall tube length s_0. The experimental procedure to determine the linear thermal expansion from a temperature difference $DJ = J_1 - J_0$ is described in the leaflet P2.1.1.2.

instead of using the steam generator of P2.1.1.2 the circulation thermostat can be used to determine the change in length Ds. Thus, the linear expansion coefficient e.g., of brass tubes of different lengths (200 mm, 400 mm, 600 mm) can be determined as shown in Fig. 2 in leaflet P2.1.1.2 by measuring the initial temperature J_0 and the final temperature J_1 by setting the temperature with the circulation thermostat (see also instruction sheet 381 341 of expansion apparatus).

Conclusion

The experiments presented in this laboratory manual form an essential part of the learning process in thermodynamics and material physics. By engaging in hands-on activities, students move beyond passive learning and are encouraged to observe, question, and understand physical laws through direct experimentation. The combination of theoretical study and practical application provides a deeper and more comprehensive grasp of the subject matter.

In Chapter I, students explore the fundamental behavior of gases under varying conditions of pressure, volume, and temperature. The laws of Boyle–Mariotte, Gay–Lussac, and Amontons are not merely abstract formulas, but real, measurable relationships that describe how ideal gases respond to environmental changes. Through carefully designed experiments, students witness firsthand the validity of these gas laws and gain insight into the assumptions and limitations behind the concept of an ideal gas.

Chapter II shifts the focus toward the thermal and electrical properties of metals. Thermal conductivity, an essential property in many industrial and technological applications, is investigated using calorimetric methods. These experiments not only allow students to understand how heat is transferred through different materials but also highlight the importance of precision and environmental factors in experimental science. The inclusion of heat capacity measurements and thermal loss evaluations provides a holistic approach to studying conductive processes in solid materials.

Chapter III is dedicated to the linear expansion of solids, a phenomenon that plays a crucial role in engineering, construction, and materials science. By measuring how a solid change in length with temperature, students explore the microscopic interpretation of thermal expansion, which relates to the vibrational motion of atoms. This chapter reinforces the idea that even seemingly minor physical changes can have significant practical consequences, especially when materials are subjected to varying thermal conditions.

Throughout all three chapters, this manual emphasizes critical thinking, scientific rigor, and methodological accuracy. Students are encouraged not only to follow procedures but also to understand the reasoning behind each step, interpret the results critically, and relate them to real-world applications. Furthermore, attention to safety, calibration, and error analysis cultivates a responsible and professional approach to experimental work.

In conclusion, the Thermodynamics Laboratory experience provides students with the tools and mindset required for scientific investigation. It nurtures curiosity, analytical thinking, and a respect for the precision that underpins all scientific discovery. Whether pursuing careers in research, engineering, education, or applied sciences, students will find that the skills and knowledge gained from these experiments will serve as a strong foundation for their future endeavors.

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family name:

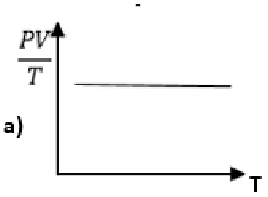
First name:

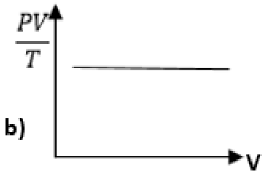
Thermodynamic Lab Exam

1. How to calculate the number of moles in the expression: $P = f\left(\frac{1}{V}\right)$:

   a) $\frac{m}{V}$ **b)** $\frac{V_0}{V_M}$ **c)** $\frac{PV}{RT}$

2. The shape of the curve is:





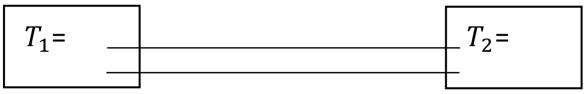
3. In the expression for the thermal conductivity of the metal, why are both calorimeters open?

   a) To ensure thermal conduction of the metal
   b) To ensure contact between the two calorimeters

4. $\Delta Q = (mC + C_{cal})\Delta t$ Equation defining the amount of heat:

   a) Q_{Tot} (Total) **b)** Q_{Surr} (Environment) **c)** Q_{Rob} (Rod)

5. In the expression, what is the value T_1 and T_2



$T_1 > T_2$

6. In the following expression, complete with the appropriate signs $(-, +, =)$:

$$\frac{dQ_{rod}}{dt} \qquad \frac{dQ_{Tot}}{dt} \qquad \frac{dQ_{surr}}{dt}$$

7. The change in the rod's length as a function of temperature is::

   a) Linear direction b) Inversely linear

8. We have the relation $\Delta\ell = f(\Delta\theta)$, give the unit of the slope.
9. Why is a gas called "ideal"? Because the molecular interactions are :

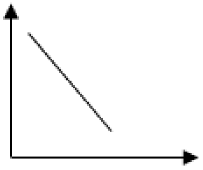
   a) Weak b) Strong

10. The ideal gas law is given by:

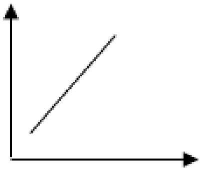
    a) $PV = nRT$ **b)** $PT = nRV$ **c)** $TV = nRP$

11. La courbe $P = f\left(\frac{1}{V}\right)$ est de la forme :

a)



b)



c)