Versuch 41 Temperature measurement

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1 Introduction

The reason for this experiment is to measure the temperature with different methods. We are measuring between the boiling point of water and the boiling point of liquid nitrogen with a gas thermometer and a platinum resistance thermometer. Also, we measure with an infrared thermometer in the range of 0 degrees to 100 degrees. Then we measure the temperature distribution of a flame with a PtRh-thermocouple.
To define a temperature scale, we use two fix points. Our instruments all show the measurements in the celsius scale, which is defined by the melting point and the boiling point of water as fixpoints. Nevertheless, the only physically derivable scale is the Kelvin scale, starting at the abolute zero point with 0K and going up in the same stepsize as the Celcius scale.

1.1 Gas thermometer

A gasthermometer consists of a glass balloon filled with air which is connected to a pressure sensor that leads to a electric manometer with a tube. Derivable from the ideal gas equation,

$$pV = NkT \tag{1}$$

where p is the pressure, V ist the Volume, N is the number of particles, k represents the Boltzmann constant and T is the absolute temperature. The law of Amontons is the principle of the gasthermomter and is saying that while you keep V constant, T and p are proportional to each other. Therefore, by measuring the pressure you can calculate the temperature, assuming constant pressure in the glass baloon. Systemic errors can occur, for example that the gas inside the baloon can only be considered ideal to a certain limit.

1.2 The thermocouple

A thermocouple consists of two different metals which are connected at the top. Because of the Seebeck effect, a thermoelectric voltage U_{th} occurs depending on the temperature and the type of metal. Electrons flow from the metal with a lower work function to the metal with a higher work function.

$$U_{th} = K(T_1 - T_2) \tag{2}$$

Describes this thermoelectric voltage U_{th}, by multiplying K, a constant, depending on the two metals and the difference between the temperatures of the two metals T_1 and T_2. Unfortunately, these types of instruments can only measure temperature differences, so you still need to know T_1 or T_2 to compute the absolute temperature, for example the room temperature works for high temperatures a reference temperature. For exact measurements, you have to use two contact points in the thermocouple, to set an exact reference temperature.

1.3 The platinum resistance thermometer

This type of thermometer is based on the temperature dependent resistance of platinum. Platinum in particular has one of the most stable ratios between temperatur and resistance. If we know the relation between temperature and resistance, we can measure the resistance and get the temperature. For the Pt-100 Thermometer applies the following formula:

$$R(T) = R_0(1 + AT + BT^2) \tag{3}$$

with R(T) being the temperature-dependent resistance, A and B as platinum-dependent constants and $R_0 = 100\Omega$ Through simple formular reshaping, the reader can extract T(R) as the resistance-dependent temperature form formula (3). In the case, to measure the resistance R, a constant current I is applied and the voltage drop U across the PT resistor as measured, according to Ohms law:

$$R = \frac{U}{I} \tag{4}$$

To reduce the error because of heated wires, we use little currents. Furthermore, the wires have a resistance. That's why we use short wires for the two-circuit wire system. Another solution to the problem is the four-wire circuit, where systemic resistance errors are avoided.

1.4 The pyrometer

The intensity of thermal radiation, emitted by every body, only depends on the temperature of the body. The underlying theory defines an idealized black body that completely absorbs all the incident electromagnetic radiation and doesn't reflect. The intensity distribution of the emitted radiation is described by Planck's radiation law is:

$$M_\lambda(\lambda, T) dA d\lambda = \frac{2\pi hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{kT}} - 1} dAd \tag{5}$$

whereas M_λ is the radiant power which is radiated into the half space by the area element dA in the wavelength range λ to $\lambda + d\lambda$. The total power is computed through integration over A and all waverlengths:

$$P = \varepsilon(T)\sigma A T^4 \tag{6}$$

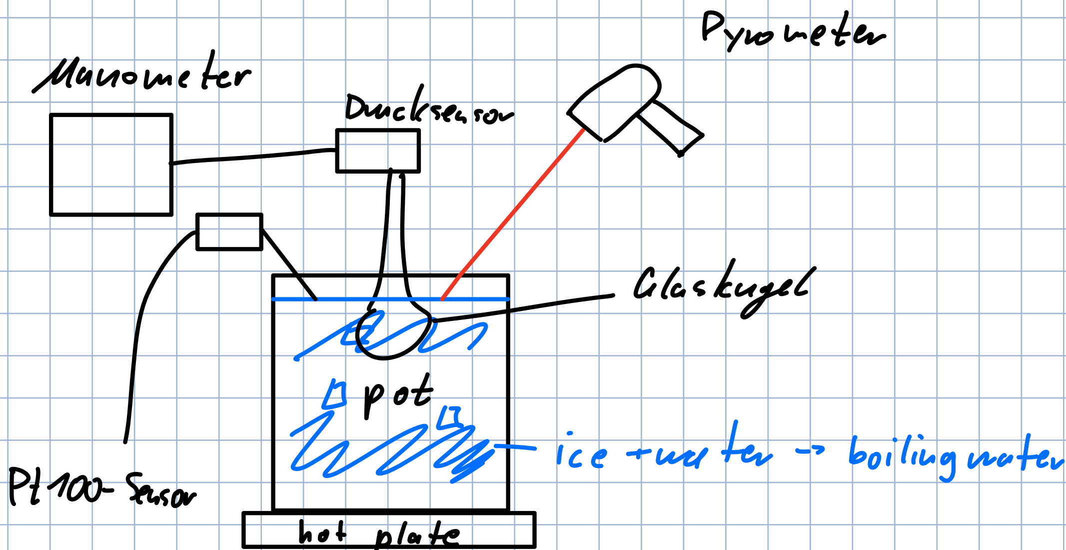
Therefore σ describes the Stefan-Boltzmann constant and T the absolute temperature. The factor ε reduces the emissivity for real bodies. So the radiated power is a function of temperature and area. Thermal imaging cameras also use this principle. For this experiment, pyrometers are used which integrate the radiation by a body in the range from $8\mu m$ to $14\mu m$.

2 Measurement setup list

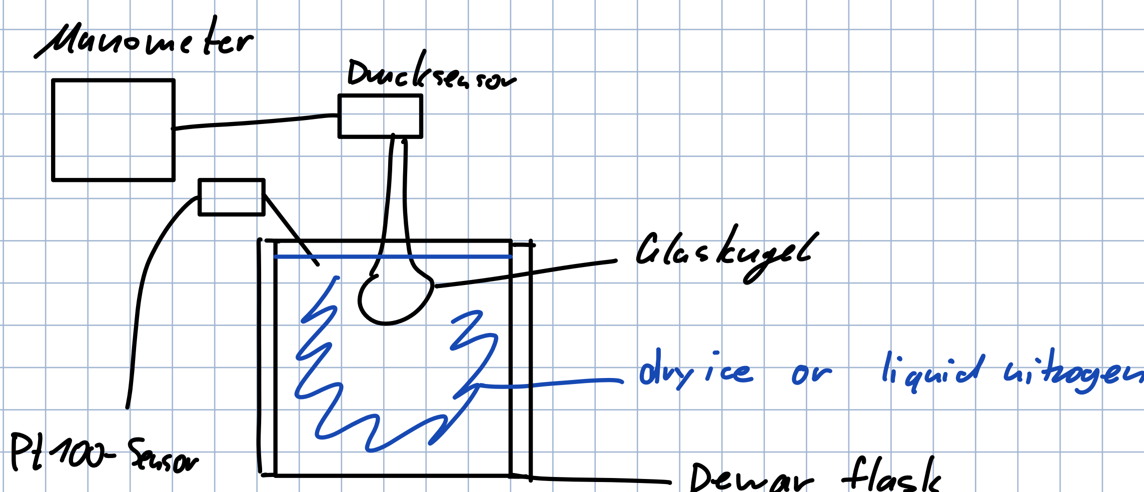
- Pyrometer
- Pt100 thermometer
- Constant current source 1mA
- Dewar flask
- Gas thermometer
- Temperature bath
- Thermocouple for high temperatures (type B, PtRH "EL18")
- Multimeter
- Butane gas bunsen burner
- Safety glasses and protective gloves

Versuch 4.1 sketches

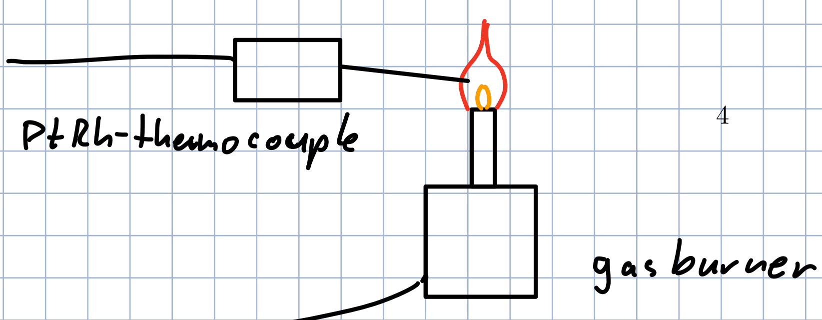
sketch 1: temperature measurement up to T = 100°C



sketch 2: temperature of dry ice and liquid nitrogen



sketch 3: Measurement of very high temperature flame of a gas burner



Messprotokoll Versuch 41 Temperaturmessung

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1. Calibration of Thermometers

At first, we have to calibrate the thermometers.
We measure the temperature with the Pt100-Thermeter of a wate-ice mixture. It consists half of ice, half of wate. we put de glasbaloon in the middle of the pot and mix it. At the same time we measure the voltage shown on the Pt100 and the temperature shown on the pyrometer.

To make the measurement of the fixpoint more accurate, we wait for the minimal voltage value and protocoll the voltage, the pressure of the gas and the pyrotemperature on the surface of the water. It will differ a bit from the true value, because the absorption of water isn't 1.

Table 1 - fixpoint measurement

	two-wire circuit	four-wire circuit
pyrotemperature in °C	$-1,5\,°C$	—
(Pt-100) minimal voltage in mV	101,7 mV	100,9 mV
pressure in mbar	916 mbar	

2.2 Temperature measurement up to T = 100°C

The following measurements with the Pt-100 are made with a four-wire circuit, because then there is a negligible error because of the wire resistence.

Now we heat the hot plate in steps of 10°C.
For each step, we stir up the water for 2 minutes and then measure again pressure, voltage and pyrotemperature.
To determine, when the particular steps of 10°C are reached, we use a rod thermometer.

table 2

temperature in °C	Pressure in mbar	voltage in V	pyrotemperature in °C
1	976	100,9	-1,5
11	959	105,9	12,6
20	994	108,8	20,4
30	1028	112,7	29,0
40	1062	116,6	39,1
50	1100	120,8	50,1
60	1137	125,1	59,3
70	1172	129,2	68,6
80	1205	133,0	78,2
90	1240	137,2	88,7
93	1242	138,8	91,6

errors: ± 0,25 % of meas. + 5 Digit Benning MM 7

mbar 1 mbar ± 1 Digit GDH 12 AN

error of the pyrometer: ~ ± 5 %
(for the first measurements it was much more stabel then for the last measurements)

The temperature scale depends on the measurement of the rod thermometer, so there is also an error in the steps of 10°C each.

Furthermore we have to use the diffrent instruments one at a time, while the heat plate still emits some heat and accounts for another error.

The scale of the rod thermometer exakt to a degree of 0,5°C.
So the error is approximately 0,5 °C.

2.3 Temperature of dry ice and liquid nitrogen at boiling point

After the glass balloon cooled down, we fill the Dewar flask with a ready-made dry ice and alcohol mixture.
After stiring we wait for a stabilized values and measure pressure and voltage. The pyrometer does not work for such low temperatures.
We repeat the measurement with liquid nitrogen.

table 3

	dry ice	liquid nitrogen
pressure in [Pa]	661	~~254~~ 253
voltage in [V]	68,3	20,8

After some time, the value stabelized a little bit lower.

roomtemperature : $(25,4 \pm 0,05)\,^\circ C$

3. Measurement of very high temperatures with the PtRh-termocouple

We measure five temperature distribution each for weak and strong air supply withe the PtRh thermocouple (Typ B, PtRh "EL 18")

table 4: weak air supply

Measurement count	voltage in mV	temperature in °C
1	0,6	350
2	1,2	490
3	1,8	600
4	2,4	690
5	1,1	470

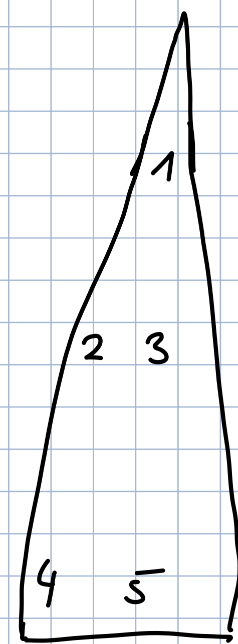
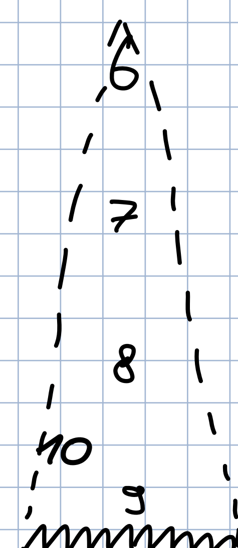


table 5: strong air supply

Measurement count	voltage in mV	temperature in °C
6	0,9	430
7	1,7	580
8	2,9	760
9	3,4	830
10	3,4	830



error: ± 0,1 mV

error Benning MM 7: ± 0,25 % of meas. + 5 Digi error convertion from mV to °C via table: ± 10 °C

Table 4 and 5 shows the measures of the PtRh-thermocouple, which means that the values are only differences to the room temperature.

So you have to add 25,1 °C to each value in table 4 and 5 to get the absolute Temperature in °C.

3.9.21 Tutor

Diagramm 1: pressure by gasthermometer as a function of temperature with calibration line through fixpoints

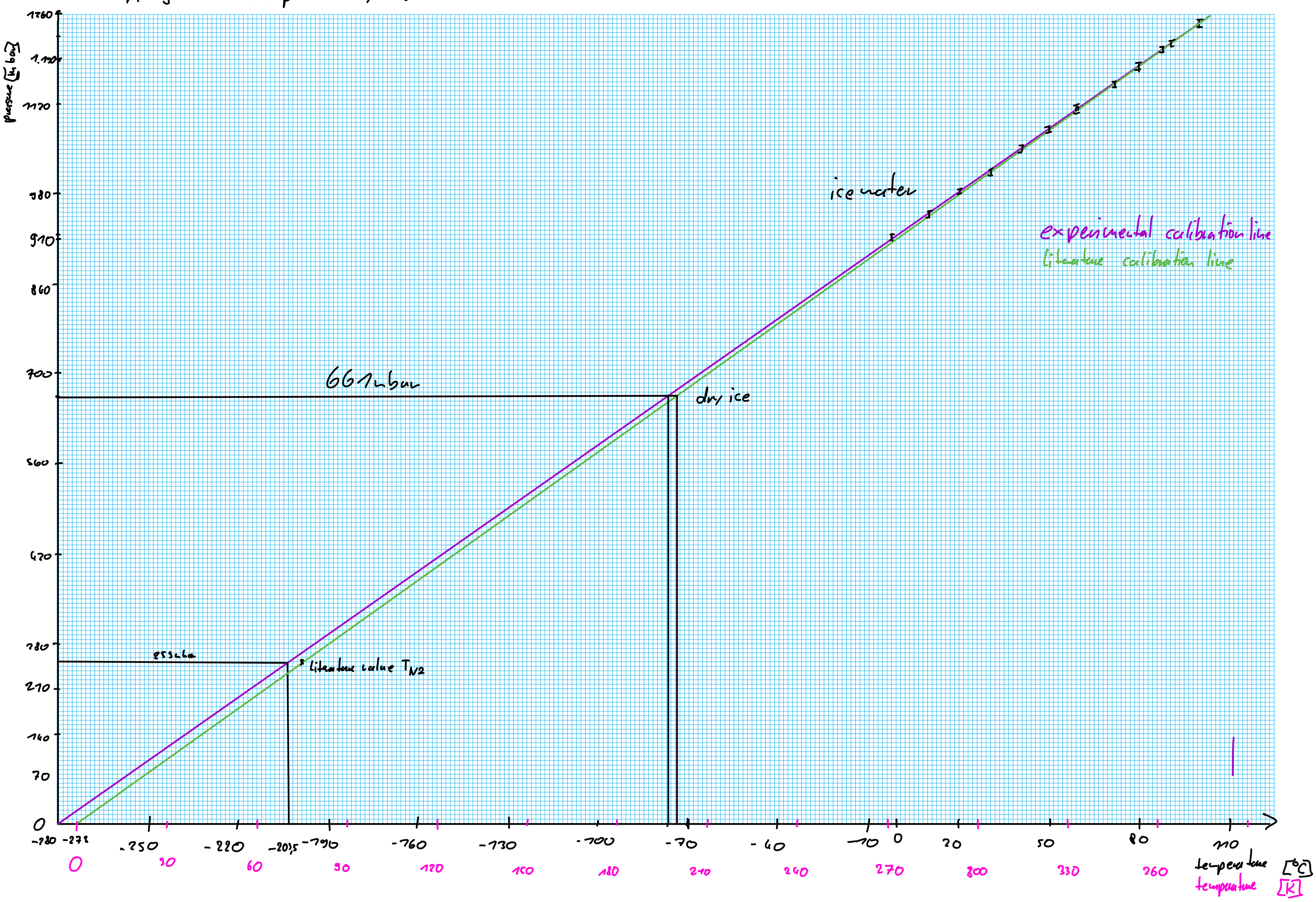


Diagramm 2 : resistance of Pt-100 against temperature

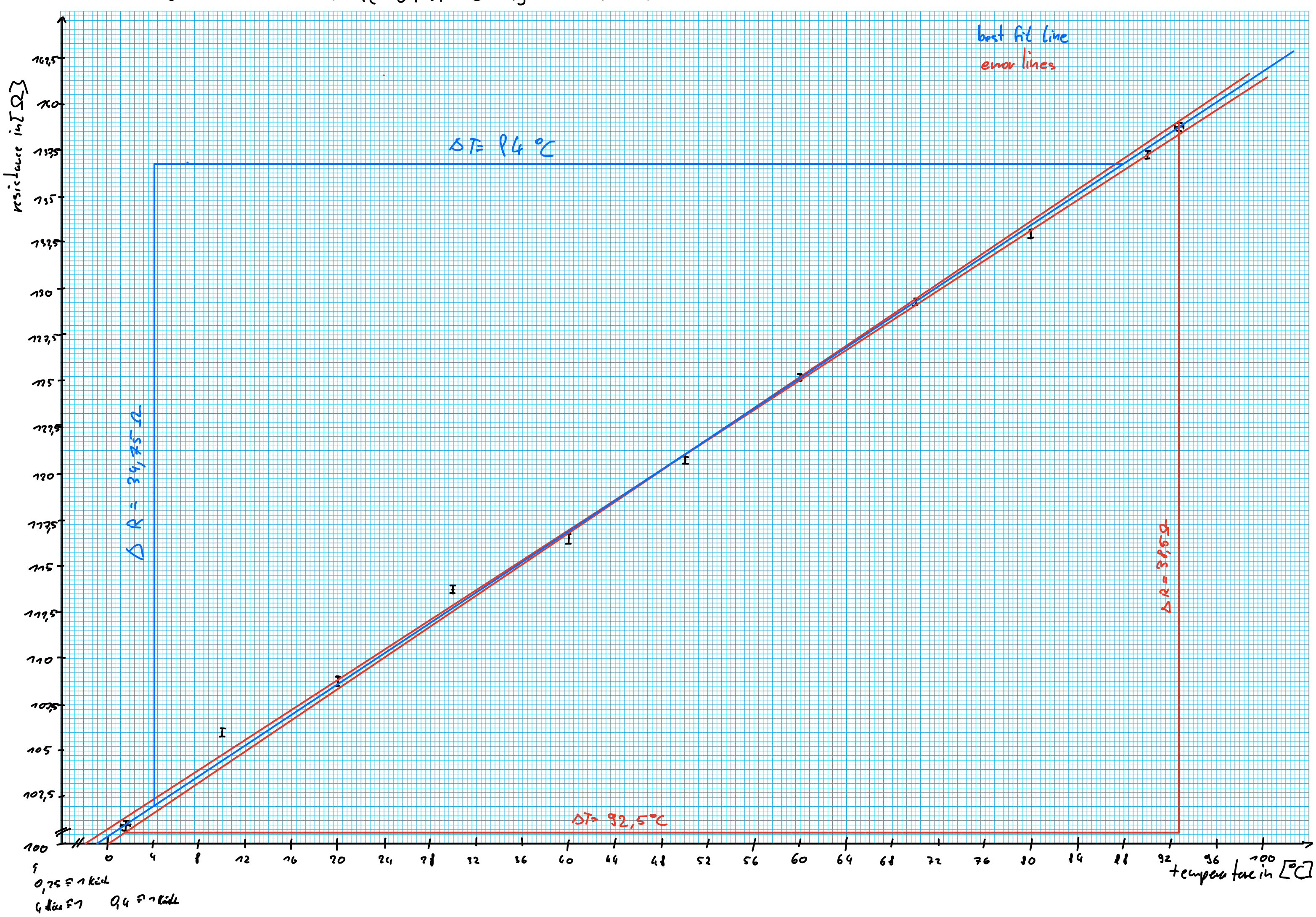
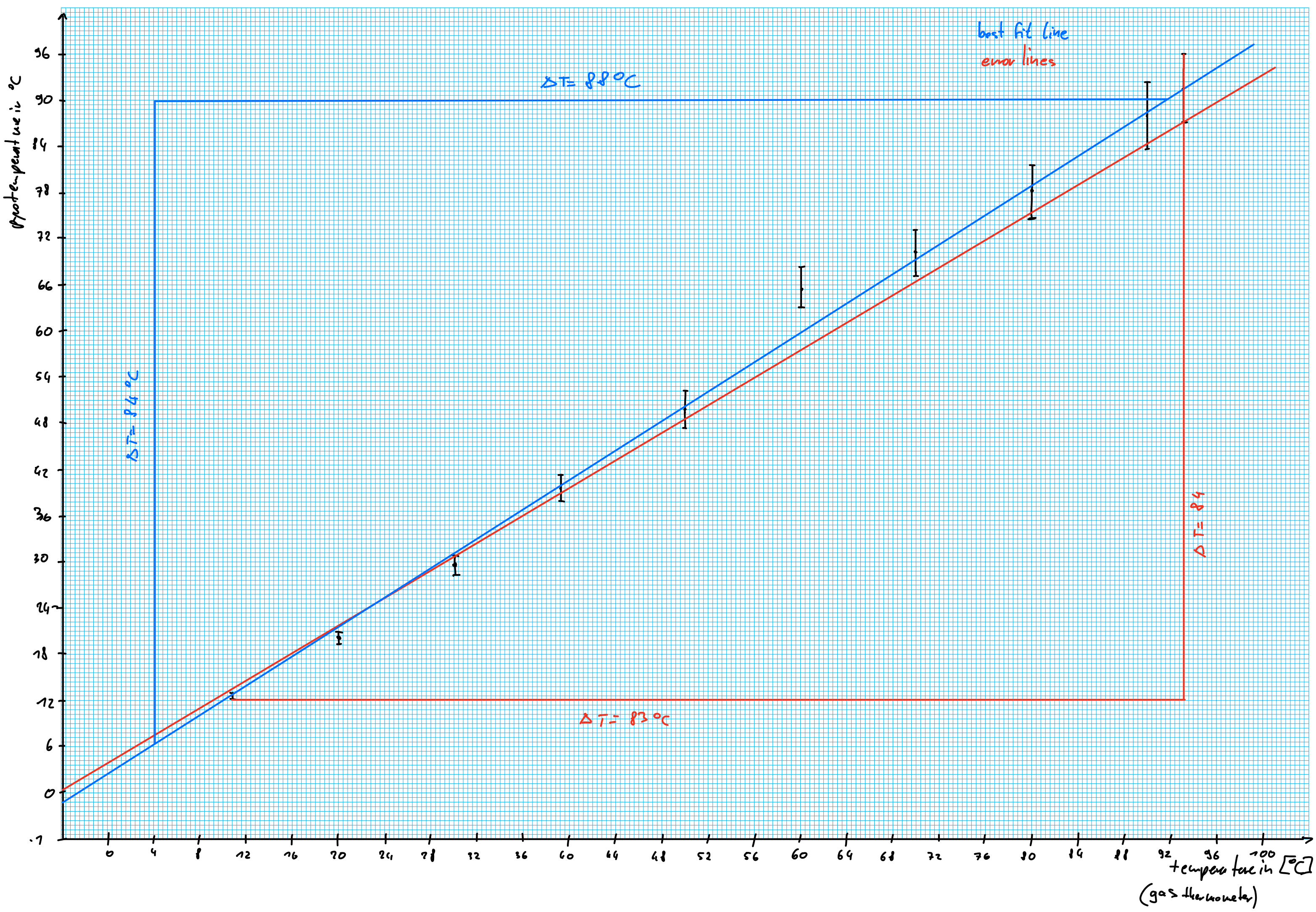


Diagramm 3 : pyrometer measurement



3 Evaluation

3.1 Calibration of thermometers at 0°C

We measure the temperature of the ice-water mixture with the Pt-100 thermometer with a two-wire circuit and a four-wire circuit. The voltage with four-wire circuit is as expected about 0,8mV lower then the measurement with the two-wire circuit, because of the missing wire resistance. To enter the pressure p_{NB} in diagramm 1, we compute:

$$p_{NB} = p_{gem} \frac{1013,25hPa}{p_{LD}} = (1242 \pm 1)mbar \cdot \frac{1013,25hPa}{(1007,6 \pm 0,1)hPa} = 1249,0 \pm 1,0mbar \tag{7}$$

where $p_{LD} = 1007,6 \pm 0,1hPa$ describes the air pressure
and $p_{gem} = (1242 \pm 1)$mbar is the temperature measured at the boiling point. The relative error following the gausian error propagation is:

$$\frac{\Delta p_{NB}}{p_{NB}} = \sqrt{(\frac{\Delta p_{gem}}{p_{gem}})^2 + (\frac{\Delta p_{LD}}{p_{LD}})^2} = 8,112 \cdot 10^{-4} \tag{8}$$

So the absolute error is (see error of end result in formula 7):

$$\Delta p_{NB} = 1,03 \tag{9}$$

The calibration line through the two fixpoints of water intersects with the x-Axis at approximately -280°C. Entering the measured pressure value for liquid nitrogen gives a temperature of about 203,5°C. Compared with the literature value $T_{N2} = 77K = -195.8°C$, it differs about 7,7°C. To better determine the absolute zero-point, we use this value to draw our literature calibration line (compare Diagramm 1) and get (273± 1,5) °C for the absolute zero-point. This is an absolute deviation of 7°C, the relative deviation is 3 percent. The calibration line derived from the literature value of liquid nitrogen almost reproduces the absulute zero-point of -273,15°C (compare wikipedia, "absolute zero") with only a difference of 0,05 percent. For the pressure measured for dry ice we get a temperature of -77,5°C, using the experimentally elaborated calibration line and -73,5°C, using the literature calibration line. The entered measurements of the gas thermometer in the range from 0°C to 100°C (see Diagramm 1) fit the calibration line pretty well. The error of the pressuresensor (Modell: GDH 12 AN) was difficult to draw because of the low resultion of the graph paper.
To compare the different measurement methods we plot the resistance of the Pt100 against the temperature (see diagramm 2). The relative error of the Voltmeter $(0,25\% \pm 5Digit)$ converts to an absolute error in the range of 0,25V to 0,35V. Accounting for the error of the rod thermometer on the x-Axis (approximately 0,5°C) would lead to the same slope of the error line a_F, so it is neglected in diagramm 2:

$$a_F = \frac{38,5\Omega}{92,5°C} = 0,4162\frac{\Omega}{°C} \tag{10}$$

the best fit line a_A follows as:

$$a_A = \frac{34,75\Omega}{84°C} = 0,4137\frac{\Omega}{°C} \tag{11}$$

what results in the following slope:

$$a = 0,4137\frac{\Omega}{°C} \pm 0,0025\frac{\Omega}{°C} \tag{12}$$

It is obvious that there is a linear relationship between the temperature and the voltage measured. If we compare this to the linear part of the polynomial in equation (3), with the slope :

$$a_* = RA = 100\Omega \cdot 3,9083 \cdot 10^-3\frac{1}{°C} = 0,39083\frac{\Omega}{°C} \tag{13}$$

the quadratic term was negligible, because the constant B is very small. Diagramm 3 shows the temperature measurement with the pyrometer against the temperature measurement with the gas thermometer converted with the calibrating line in diagramm 1. The expectation is a line through the origin with the slope one, if both instruments would measure the temperature exactly the same way. The relative error of the pyrometer is ±5%. so the errorbars get bigger, the higher the temperature gets. The error line and best fit line follow as:

$$a_F = \frac{84°C}{83°} = 1,012 \tag{14}$$

$$a_A = \frac{84°C}{88°} = 1,0476 \tag{15}$$

so the slope is:

$$a = 1,05 \pm 0,04 = 1,05 \pm 4\% \tag{16}$$

The tabels 4 and 5 show the temperature for different locations in a flame, measured with the PtRh thermocouple. Because it can only measure temperature differences, here are the absolute temperatures of the flame:

table 6: weak air supply absolute temperature

Measurement count	temperature in °C
1	375,1
2	515,1
3	625,1
4	715,1
5	995,1

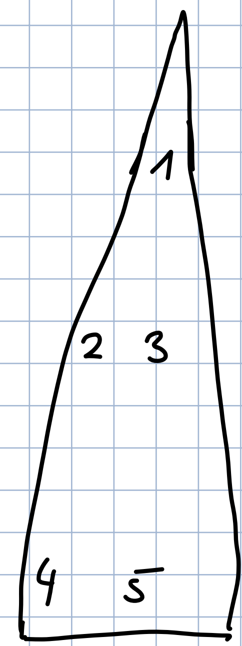
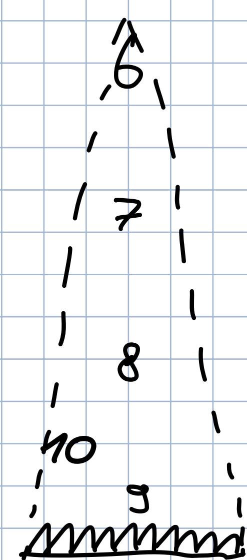


table 7: strong air supply absolute temperature

Measurement count	temperature in °C
6	455,1
7	605,1
8	785,1
9	855,1
10	855,1



error convertion from mV to °C via table: ± 10 °C

4 Discussion

In this experiment we compared different thermometers for different temperatures. First, we calibrated a gas thermometer and determined the absolute zero-point. Our result (273± 1,5) °C is astonishingly close to the literature value of 273,15 °C. This is equivalent to a deviation of $0,1\sigma$. The experimental calibration line differs though (compare diagram 1). This might be due to the temperature fluctuation especially for the ice-water mixture, because it is not possible to get a homogeneous mixture, where the temperature is equally distributed.
The volume of the glass baloon isn't exactly constant, it expands a tiny bit when the baloon is heat up. The neck of the glassbaloon also represents an additional volume to account for, regarding this effect. Furthermore it was not possible to get the water up to 100°C, so we had to use interpolation methods to determine the fixpoint for boiling water (formula 7). This might lead to a bigger error for the slope of the calibration line.
For the Pt100-thermometer we investigated the relationship between temperature and resistance and conducted a linear ratio. Our value for the slope $a = 0,4137\frac{\Omega}{°C} \pm 0,0025\frac{\Omega}{°C}$ is close to the value given in the script $a_* = 0,39083\frac{\Omega}{°C}$, but we propably unterestimated the error of the slope because the deviation is greater then our error range. In diagramm 3 the expected slope of one is almost met $a = 1,05 \pm 0,04 = 1,05 \pm 4\%$ with a deviation of just 0,05 (respectively 5%). One can suspect, that the pyrometer is a little less accurate then the gas thermometer, because we neglect the effects of reflection, absorbtion and transmission regarding the water.
The measurements of the flame show that a flame is hotter with strong air supply then with weak air supply. Respectively the hottest temperatures reached for the different air supplies have a difference of 140°C, with the strong air supply accounting for the hotter flame.
The error of the PtRH-thermocouple of about 0,1 mV is completey outweight by the huge convertion erros with the table. That makes it hard to make use of the high accuracy of the thermocouple. The voltmeter, adapted to the thermocouple can also measure temperature, so it would have been easier to just switch the device to temperature measurement.