
Absolute Point of Zero: Measurement of Gas Pressure with Temperature

Physics Laboratory 1

Visva Loganathan vloganathan@student.ethz.ch

Flurin Kuhn flkuhn@student.ethz.ch

Teaching Assistant

Dr. Zhao Xingyu xizhao@student.ethz.ch

Abstract We determined an estimate of the absolute zero temperature by measuring the gas pressure of a fixed volume at two reference temperatures (ice water and boiling water) and fitting the linear model $p = at + b$. The pressure sensor was calibrated against the barometric reference, yielding $C \approx 713.3 \text{ Pa/mV}$ and $p_0 \approx 7.934 \times 10^3 \text{ Pa}$. From the fit we obtained the intercept $t'_0 = -276.89^\circ\text{C}$, which deviates from the accepted value -273.15°C by 3.74°C ($\sim 1.37\%$). Using the calibrated thermometer, the liquid–nitrogen temperature was estimated as $t_{\text{LN}_2} \approx -186^\circ\text{C}$, about 10°C above the literature value. The main uncertainty stems from incomplete thermal equilibration, small parasitic volume and the two-point linear model. Overall, the method provides a reliable order-of-magnitude estimate; more temperature points and longer equilibration would further reduce the error.

ETH Zürich, November 7, 2025

Introduction

The absolute zero point The absolute zero is the lower limit of thermodynamic temperature. In the SI it is common practice to express a thermodynamic temperature T in terms of its difference from the reference temperature $T_0 = 273.15$ K (close to the ice point); this difference is the Celsius temperature [5, p. 133]. One degree Celsius therefore corresponds to $1/273.15$ of this interval.

For an ideal gas at fixed amount of substance n and fixed volume V , the pressure and temperature are related by [1]

$$pV = nRT,$$

so that, at constant n and V , the pressure is proportional to the absolute temperature: $p \propto T$. Extrapolating a linear $p(T)$ relation to $p = 0$ thus yields an estimate of the absolute zero [2]. In practice, the exact value cannot be reached experimentally, but it can be inferred by careful measurement and extrapolation.

Scope of this experiment. In this experiment we determine an estimate of the absolute zero by measuring the gas pressure of a fixed volume at two reference temperatures (ice water $\approx 0^\circ\text{C}$ and boiling water $\approx 100^\circ\text{C}$), calibrating the pressure sensor with a barometric reference, fitting a linear model $p = at + b$ (with t in $^\circ\text{C}$), and extrapolating the x -intercept $t_0 = -b/a$. From the measured nitrogen pressure we additionally estimate the temperature of liquid nitrogen.

Experiment

In this experiment a piezoresistive pressure sensor was used with a maximum signal error of 0.075 mV. The experimental setup can be seen in Fig.1.

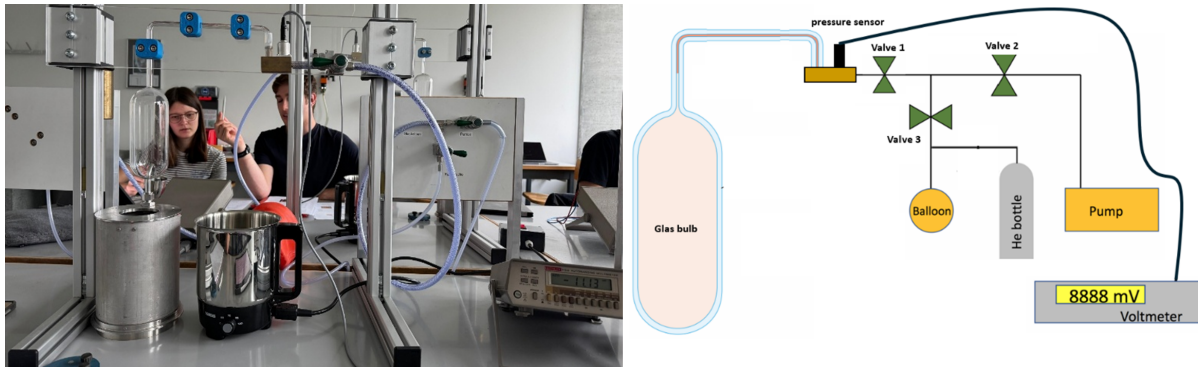


Figure 1: On the left a photograph and on the right a schematic of the experimental setup. [3]

Firstly, atmospheric ambient pressure p_L was determined, using a mercury barometer, as well as the table seen in Fig.2. Voltage U_L was measured by opening valve 1 and disconnecting the tube from the valve, exposing the piezoresistive pressure sensor to atmospheric pressure. The glass bulb was connected to the vacuum pump and evacuated, by connecting the tubes and opening valve 2, until the pressure reached 0.1 mbar after 10 minutes and the voltage U_t was measured. Then, valve 2 was closed to disconnect the pump from the bulb and valve 3 was opened to fill the bulb with helium. After three minutes, valve 3 was closed. The bulb was evacuated again for 10 minutes and filled with helium in the same way as in the previous step to remove residual air. The boiling point of water t_K was determined using atmospheric pressure p_L and the table in the laboratory, seen in Fig.3.

Umwandlung der bei der Temperatur t (°C) abgelesenen Barometerstände b_t (mm Q.S.) auf die Bezugsstemperatur 0 (°C).
 Conversion of the barometer reading b_t (mm taken at the temperature t (°C)) for the reference temperature of 0 (°C).
 Récalculation des niveaux barométriques b_t (mm.) lus à la température t (°C) sur la température de référence 0 (°C).
 Conversión de las alturas barométricas b_t (mm. de mercurio), leídas con la temperatura t (°C), a la temperatura de referencia 0 (°C).

t	Niveau barométrique en mm. Q.S.												
	640	650	660	670	680	690	700	710	720	730	740	750	760
0	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.17	0.17
1	0.23	0.25	0.26	0.28	0.27	0.27	0.27	0.28	0.28	0.28	0.29	0.29	0.29
2	0.36	0.37	0.37	0.38	0.38	0.39	0.39	0.40	0.40	0.41	0.41	0.42	0.43
3	0.47	0.48	0.48	0.49	0.50	0.51	0.51	0.52	0.52	0.53	0.54	0.54	0.55
4	0.58	0.59	0.60	0.61	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69
5	0.69	0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.79	0.80	0.81
6	0.80	0.81	0.82	0.83	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91
7	0.91	0.92	0.94	0.95	0.96	0.96	0.98	0.99	1.01	1.02	1.03	1.04	1.05
8	1.01	1.03	1.05	1.06	1.08	1.10	1.11	1.13	1.14	1.16	1.18	1.19	1.21
9	1.13	1.14	1.16	1.18	1.20	1.21	1.23	1.25	1.27	1.28	1.30	1.32	1.34
10	1.24	1.25	1.27	1.29	1.31	1.33	1.35	1.37	1.39	1.41	1.43	1.45	1.47
11	1.34	1.35	1.38	1.41	1.43	1.45	1.47	1.49	1.51	1.53	1.55	1.58	1.60
12	1.46	1.48	1.50	1.52	1.54	1.57	1.59	1.61	1.64	1.66	1.68	1.70	1.73
13	1.56	1.59	1.61	1.64	1.66	1.69	1.71	1.73	1.76	1.78	1.81	1.83	1.86
14	1.67	1.70	1.73	1.75	1.78	1.80	1.83	1.86	1.89	1.91	1.95	1.98	1.99
15	1.78	1.81	1.84	1.87	1.89	1.92	1.95	1.98	2.01	2.03	2.06	2.09	2.13
16	1.89	1.92	1.95	1.98	2.01	2.04	2.07	2.10	2.13	2.16	2.19	2.22	2.25
17	2.00	2.03	2.06	2.10	2.13	2.16	2.19	2.23	2.26	2.29	2.31	2.35	2.38
18	2.11	2.14	2.18	2.21	2.24	2.28	2.31	2.34	2.37	2.41	2.44	2.47	2.51
19	2.22	2.25	2.29	2.32	2.36	2.39	2.43	2.46	2.50	2.53	2.57	2.60	2.64
20	2.33	2.37	2.40	2.44	2.48	2.51	2.55	2.58	2.62	2.66	2.70	2.73	2.77
21	2.44	2.48	2.52	2.55	2.59	2.63	2.67	2.71	2.75	2.78	2.83	2.86	2.90
22	2.55	2.59	2.63	2.67	2.71	2.75	2.79	2.83	2.87	2.91	2.95	2.99	3.03
23	2.66	2.70	2.74	2.78	2.82	2.87	2.91	2.95	2.99	3.03	3.07	3.11	3.15
24	2.77	2.81	2.85	2.90	2.94	2.98	3.03	3.07	3.11	3.15	3.20	3.24	3.29
25	2.88	2.92	2.97	3.01	3.06	3.10	3.15	3.19	3.24	3.28	3.33	3.37	3.42
26	2.99	3.03	3.08	3.13	3.17	3.23	3.27	3.31	3.36	3.41	3.45	3.50	3.55
27	3.10	3.14	3.19	3.24	3.29	3.34	3.39	3.43	3.48	3.53	3.58	3.63	3.68
28	3.21	3.26	3.31	3.36	3.41	3.46	3.51	3.56	3.61	3.66	3.71	3.76	3.81
29	3.31	3.37	3.42	3.47	3.52	3.57	3.63	3.68	3.73	3.78	3.83	3.88	3.94
30	3.42	3.48	3.53	3.58	3.64	3.69	3.74	3.80	3.85	3.91	3.96	4.01	4.07

Die in der Tabelle angegebenen Korrektionswerte k_t sind vom Barometerstand abzuziehen.
 The corrections k_t of this table should be deducted from the barometer reading.
 Les corrections k_t du tableau sont à déduire du niveau barométrique.
 Las correcciones k_t de la tabla hay que deducirlas de la altura barométrica.

Figure 2: Table to determine the corrected ambient pressure at given temperatures.

BOILING POINT OF WATER
 (Degrees Fahrenheit)

Pressure	Points of saturation							Points of saturation						
	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in
760	100	3.94	100	3.94	100	3.94	100	3.94	100	3.94	100	3.94	100	3.94
750	99.7	3.93	99.7	3.93	99.7	3.93	99.7	3.93	99.7	3.93	99.7	3.93	99.7	3.93
740	99.4	3.92	99.4	3.92	99.4	3.92	99.4	3.92	99.4	3.92	99.4	3.92	99.4	3.92
730	99.1	3.91	99.1	3.91	99.1	3.91	99.1	3.91	99.1	3.91	99.1	3.91	99.1	3.91
720	98.8	3.90	98.8	3.90	98.8	3.90	98.8	3.90	98.8	3.90	98.8	3.90	98.8	3.90
710	98.5	3.89	98.5	3.89	98.5	3.89	98.5	3.89	98.5	3.89	98.5	3.89	98.5	3.89
700	98.2	3.88	98.2	3.88	98.2	3.88	98.2	3.88	98.2	3.88	98.2	3.88	98.2	3.88
690	97.9	3.87	97.9	3.87	97.9	3.87	97.9	3.87	97.9	3.87	97.9	3.87	97.9	3.87
680	97.6	3.86	97.6	3.86	97.6	3.86	97.6	3.86	97.6	3.86	97.6	3.86	97.6	3.86
670	97.3	3.85	97.3	3.85	97.3	3.85	97.3	3.85	97.3	3.85	97.3	3.85	97.3	3.85
660	97.0	3.84	97.0	3.84	97.0	3.84	97.0	3.84	97.0	3.84	97.0	3.84	97.0	3.84
650	96.7	3.83	96.7	3.83	96.7	3.83	96.7	3.83	96.7	3.83	96.7	3.83	96.7	3.83
640	96.4	3.82	96.4	3.82	96.4	3.82	96.4	3.82	96.4	3.82	96.4	3.82	96.4	3.82
630	96.1	3.81	96.1	3.81	96.1	3.81	96.1	3.81	96.1	3.81	96.1	3.81	96.1	3.81
620	95.8	3.80	95.8	3.80	95.8	3.80	95.8	3.80	95.8	3.80	95.8	3.80	95.8	3.80
610	95.5	3.79	95.5	3.79	95.5	3.79	95.5	3.79	95.5	3.79	95.5	3.79	95.5	3.79
600	95.2	3.78	95.2	3.78	95.2	3.78	95.2	3.78	95.2	3.78	95.2	3.78	95.2	3.78
590	94.9	3.77	94.9	3.77	94.9	3.77	94.9	3.77	94.9	3.77	94.9	3.77	94.9	3.77
580	94.6	3.76	94.6	3.76	94.6	3.76	94.6	3.76	94.6	3.76	94.6	3.76	94.6	3.76
570	94.3	3.75	94.3	3.75	94.3	3.75	94.3	3.75	94.3	3.75	94.3	3.75	94.3	3.75
560	94.0	3.74	94.0	3.74	94.0	3.74	94.0	3.74	94.0	3.74	94.0	3.74	94.0	3.74
550	93.7	3.73	93.7	3.73	93.7	3.73	93.7	3.73	93.7	3.73	93.7	3.73	93.7	3.73
540	93.4	3.72	93.4	3.72	93.4	3.72	93.4	3.72	93.4	3.72	93.4	3.72	93.4	3.72
530	93.1	3.71	93.1	3.71	93.1	3.71	93.1	3.71	93.1	3.71	93.1	3.71	93.1	3.71
520	92.8	3.70	92.8	3.70	92.8	3.70	92.8	3.70	92.8	3.70	92.8	3.70	92.8	3.70
510	92.5	3.69	92.5	3.69	92.5	3.69	92.5	3.69	92.5	3.69	92.5	3.69	92.5	3.69
500	92.2	3.68	92.2	3.68	92.2	3.68	92.2	3.68	92.2	3.68	92.2	3.68	92.2	3.68
490	91.9	3.67	91.9	3.67	91.9	3.67	91.9	3.67	91.9	3.67	91.9	3.67	91.9	3.67
480	91.6	3.66	91.6	3.66	91.6	3.66	91.6	3.66	91.6	3.66	91.6	3.66	91.6	3.66
470	91.3	3.65	91.3	3.65	91.3	3.65	91.3	3.65	91.3	3.65	91.3	3.65	91.3	3.65
460	91.0	3.64	91.0	3.64	91.0	3.64	91.0	3.64	91.0	3.64	91.0	3.64	91.0	3.64
450	90.7	3.63	90.7	3.63	90.7	3.63	90.7	3.63	90.7	3.63	90.7	3.63	90.7	3.63
440	90.4	3.62	90.4	3.62	90.4	3.62	90.4	3.62	90.4	3.62	90.4	3.62	90.4	3.62
430	90.1	3.61	90.1	3.61	90.1	3.61	90.1	3.61	90.1	3.61	90.1	3.61	90.1	3.61
420	89.8	3.60	89.8	3.60	89.8	3.60	89.8	3.60	89.8	3.60	89.8	3.60	89.8	3.60
410	89.5	3.59	89.5	3.59	89.5	3.59	89.5	3.59	89.5	3.59	89.5	3.59	89.5	3.59
400	89.2	3.58	89.2	3.58	89.2	3.58	89.2	3.58	89.2	3.58	89.2	3.58	89.2	3.58
390	88.9	3.57	88.9	3.57	88.9	3.57	88.9	3.57	88.9	3.57	88.9	3.57	88.9	3.57
380	88.6	3.56	88.6	3.56	88.6	3.56	88.6	3.56	88.6	3.56	88.6	3.56	88.6	3.56
370	88.3	3.55	88.3	3.55	88.3	3.55	88.3	3.55	88.3	3.55	88.3	3.55	88.3	3.55
360	88.0	3.54	88.0	3.54	88.0	3.54	88.0	3.54	88.0	3.54	88.0	3.54	88.0	3.54
350	87.7	3.53	87.7	3.53	87.7	3.53	87.7	3.53	87.7	3.53	87.7	3.53	87.7	3.53
340	87.4	3.52	87.4	3.52	87.4	3.52	87.4	3.52	87.4	3.52	87.4	3.52	87.4	3.52
330	87.1	3.51	87.1	3.51	87.1	3.51	87.1	3.51	87.1	3.51	87.1	3.51	87.1	3.51
320	86.8	3.50	86.8	3.50	86.8	3.50	86.8	3.50	86.8	3.50	86.8	3.50	86.8	3.50
310	86.5	3.49	86.5	3.49	86.5	3.49	86.5	3.49	86.5	3.49	86.5	3.49	86.5	3.49
300	86.2	3.48	86.2	3.48	86.2	3.48	86.2	3.48	86.2	3.48	86.2	3.48	86.2	3.48
290	85.9	3.47	85.9	3.47	85.9	3.47	85.9	3.47	85.9	3.47	85.9	3.47	85.9	3.47
280	85.6	3.46	85.6	3.46	85.6	3.46	85.6	3.46	85.6	3.46	85.6	3.46	85.6	3.46
270	85.3	3.45	85.3	3.45	85.3	3.45	85.3	3.45	85.3	3.45	85.3	3.45	85.3	3.45
260	85.0	3.44	85.0	3.44	8									

The hose at position of the valve 1 was disconnected and the bulb was heated to the boiling point of water by submerging the bulb in the prepared kettle, seen in Fig.4. Furthermore, valve 1 was closed and the voltage U_K was measured. The bulb was submerged in a beaker and water, as well as ice, was added to cool the bulb to 0 °C, seen in Fig.5. As soon as the voltage was stable, the value U_E was recorded.

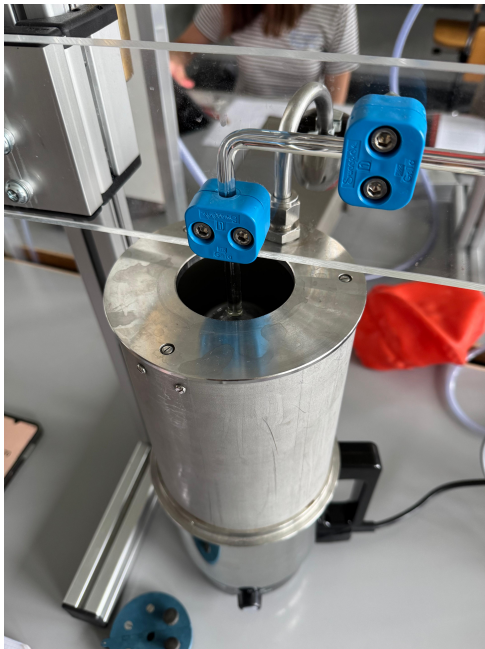


Figure 4: Experimental setup in kettle.

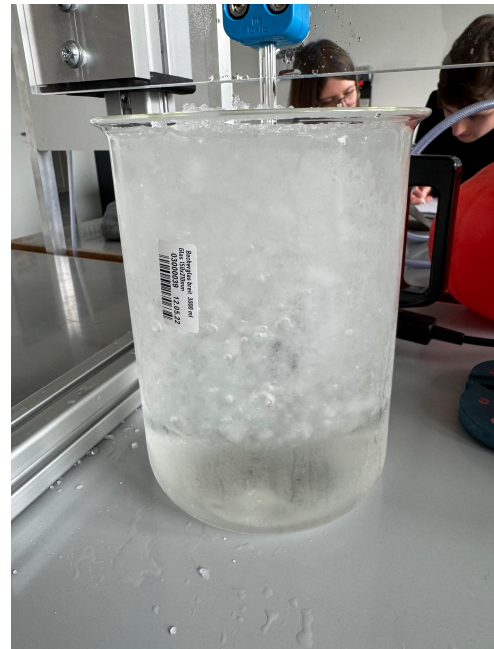


Figure 5: Experimental setup in ice water.

Moreover, the bulb was removed from the beaker, dried and submerged in liquid nitrogen to determine the voltage U_{LN_2} , seen in Fig.6.



Figure 6: Experimental setup in liquid nitrogen.

Results

The ambient pressure p_L was found to be 720 ± 1 mmHg which is equal to 96000 ± 133 Pa. This resulted in a corrected barometer reading p_L of 717 ± 1 mmHg, which is equal to 95600 ± 133 Pa. The air temperature t_L was determined to be 22.0 ± 1.0 °C and the voltage U_L was measured to be 122.9 ± 0.075 mV. The calibration points at low pressure were found to be $p_t = 0.10 \pm 0.10$ mbar, which is equal to 10.0 ± 10.0 Pa and $U_t = -11.11 \pm 0.075$ mV. The boiling point of water t_K was determined to be 98.5 °C and the voltage U_K at the boiling point was 122.5 ± 0.075 mV. The temperature of ice water t_E was determined to be 0.00 °C and the voltage U_E was 87.44 ± 0.075 mV. The voltage obtained by submerging the bulb in liquid nitrogen was found to be $U_{LN_2} = 20.97 \pm 0.075$ mV.

Table 1: Overview of all measured results, rounded to their significant digits.

variable	value
p_L	95600 ± 133 Pa
t_L	22.0 ± 1.0 °C
U_L	122.9 ± 0.075 mV
p_t	10.0 ± 10.0 Pa
U_t	-11.11 ± 0.075 mV
t_K	98.5 °C
U_K	122.5 ± 0.075 mV
t_E	0.00 °C
U_E	122.5 ± 0.075 mV
U_{LN_2}	20.97 ± 0.075 mV

Data Analysis

Sensor calibration. From the two calibration points (ambient and low pressure) we use the linear sensor model

$$p = p_0 + CU \quad (U \text{ in mV, } p \text{ in Pa}).$$

With the *corrected* barometer reading for p_L we obtain

$$C \approx 713.3 \text{ Pa/mV}, \quad p_0 \approx 7.934 \times 10^3 \text{ Pa}.$$

Using the measured voltages at the reference temperatures then gives

$$p_K = p_0 + CU_K \approx 9.53 \times 10^4 \text{ Pa}, \quad p_E = p_0 + CU_E \approx 7.03 \times 10^4 \text{ Pa}.$$

Linear fit $p(t) = at + b$ **and x -intercept.** Fitting a straight line in the (t, p) -plane yields (values from our two points)

$$a \approx 2.539 \text{ mbar/}^\circ\text{C} \quad (253.9 \text{ Pa/}^\circ\text{C}), \quad b \approx 703.0 \text{ mbar} \quad (7.03 \times 10^4 \text{ Pa}).$$

The x -intercept (estimate of the absolute zero) is

$$t'_0 = -\frac{b}{a} \approx -276.89^\circ\text{C}.$$

Exact correction with ε and γ . Including the empty-space fraction $\varepsilon = 10^{-3}$ and the glass expansion $\gamma = 10^{-5} \text{ }^\circ\text{C}^{-1}$ leads to the quadratic form in t_0 :

$$\begin{aligned} a_q &= (1 + \varepsilon)p_E - (1 + \varepsilon + \gamma t_K)p_K, \\ b_q &= \varepsilon(p_K - p_E)t_K + (1 + \gamma t_K)p_K t_L - p_E(t_L + t_K), \\ c_q &= p_E t_L t_K, \\ t_0 &= \frac{-b_q \pm \sqrt{b_q^2 - 4a_q c_q}}{2a_q} \quad (\text{root near } -273.15^\circ\text{C}). \end{aligned}$$

With our numbers ($a_q = -251.28$, $b_q = -63\,697$, $c_q = 1\,523\,279$ in consistent units) we obtain

$$t_0 \approx -276^\circ\text{C}.$$

Liquid nitrogen. From the measured nitrogen pressure in the bulb we find

$$p_{\text{LN}_2} \approx 2.29 \times 10^4 \text{ Pa}.$$

Approximate estimate (linear model):

$$t'_{\text{LN}_2} \approx -186^\circ\text{C}.$$

Exact expression using

$$A = \frac{p_E}{t_E - t_0} + \varepsilon \frac{p_E - p_{\text{LN}_2}}{t_L - t_0}, \quad t_{\text{LN}_2} = \frac{A t_0 + p_{\text{LN}_2}}{A - \gamma p_{\text{LN}_2}}$$

gives $A \approx 2.55$ and

$$t_{\text{LN}_2} \approx -186^\circ\text{C}.$$

Our estimate ($\approx -186^\circ\text{C}$) differs from the literature boiling point of liquid nitrogen, -195.795°C at 1 atm, by about 10°C [4].

Comments on uncertainty and systematics. The fit is based on only two temperature points, so model uncertainty dominates. Further contributions are barometer correction at p_L , insufficient waiting time to reach thermal equilibrium, partial immersion

during the LN_2 measurement, and the corrections via ε and γ . Using the corrected p_L changes C , p_E , p_K slightly, while the intercept t_0 remains comparatively stable.

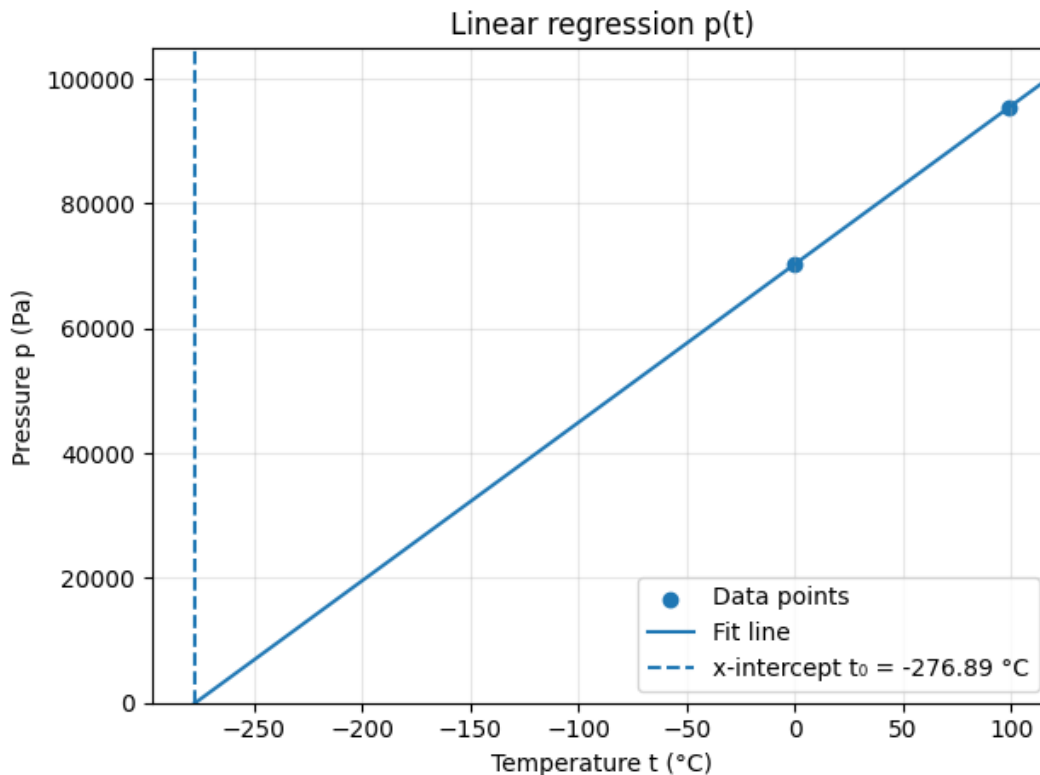


Figure 7: Linear regression $p(t)$ showing the x -intercept t_0 .

x-intercept and comparison to absolute zero. From our linear fit we obtain the x -intercept $t'_0 = -276.89^\circ\text{C}$. The accepted value of the absolute zero is -273.15°C . So the absolute deviation is:

$$\Delta t = |t'_0 - (-273.15^\circ\text{C})| = 3.74^\circ\text{C}.$$

Expressed as a relative (percent) deviation with respect to 273.15 K:

$$\delta = \frac{\Delta t}{273.15} \times 100\% \approx \frac{3.74}{273.15} \times 100\% \approx 1.37\%.$$

Thus, the simple linear extrapolation of $p(t)$ provides a reasonably accurate estimate of the absolute zero (only about 1.4% deviation). The remaining discrepancy can plausibly be explained by systematic effects such as insufficient cooling/thermal equilibration (we may have recorded the measurement slightly too early), as well as residual instrumental effects (barometer correction, sensor drift) that bias the intercept more than the slope.

Discussion

Accuracy of the x -intercept. Our linear fit gives $t'_0 = -276.89^\circ\text{C}$. Compared with -273.15°C this is $\Delta t = 3.74^\circ\text{C}$ or $\delta = 3.74/273.15 \approx 1.37\%$. This shows that a two-point linear extrapolation of $p(t)$ gives a reasonable estimate of the absolute zero. We attribute most of the $\sim 1.4\%$ deviation to incomplete cooling/thermal equilibration in the ice and LN_2 baths: the gas was likely slightly warmer at readout, raising p and shifting the intercept to more negative t .

Likely sources of discrepancy. (i) **Equilibration:** not fully at bath temperature \Rightarrow pressure offset. (ii) **Barometer reference:** corrected vs. uncorrected p_L alters C, p_0 (hence p_E, p_K) and slightly t_0 . (iii) **Parasitic volume / glass expansion** (ε, γ): imperfect values bias the exact t_0 . (iv) **Sensor behaviour:** nonlinearity/offset/resolution in U propagate via $p = p_0 + CU$ and affect b more than a . (v) **Geometry / immersion:** partial immersion or tiny leaks change the effective gas volume/temperature field.

Model limitations. With only $t_E \approx 0^\circ\text{C}$ and $t_K \approx 100^\circ\text{C}$ the fit is strictly linear; any curvature or temperature-dependent effects are absorbed into the intercept and dominate the model uncertainty.

Liquid nitrogen estimate. The approximate and exact LN_2 temperatures (from p_{LN_2} and A) are both $\sim -186^\circ\text{C}$, about 10°C above the literature value (-196°C), consistent with the effects noted above.

Improvements. (a) Add one–two intermediate temperature points; (b) ensure full equilibrium (longer wait, repeated readings); (c) document use of the corrected p_L ; (d) control immersion depth and minimise parasitic volume; (e) quantify instrument resolution to report an uncertainty on t_0 .

Conclusion

Using a piezoresistive sensor calibrated with the barometric reference, we obtained $C \approx 713.3 \text{ Pa/mV}$ and $p_0 \approx 7.93 \times 10^3 \text{ Pa}$; the corresponding pressures at the reference points are $p_E \approx 7.03 \times 10^4 \text{ Pa}$ and $p_K \approx 9.53 \times 10^4 \text{ Pa}$ [3]. A linear fit $p(t) = at + b$ to these points yields $a \approx 253.9 \text{ Pa/}^\circ\text{C}$ and $b \approx 7.03 \times 10^4 \text{ Pa}$, giving an intercept $t'_0 = -276.89 \text{ }^\circ\text{C}$. This differs from the accepted $-273.15 \text{ }^\circ\text{C}$ by $3.74 \text{ }^\circ\text{C}$ ($\sim 1.37\%$), showing that even a two-point extrapolation provides a reasonable estimate of the absolute zero. The exact correction that includes the parasitic volume and glass expansion ($\varepsilon = 10^{-3}$, $\gamma = 10^{-5} \text{ }^\circ\text{C}^{-1}$) leads to a consistent value ($t_0 \approx -276 \text{ }^\circ\text{C}$).

From the measured nitrogen pressure we obtained $t_{\text{LN}_2} \approx -186 \text{ }^\circ\text{C}$, about $10 \text{ }^\circ\text{C}$ above the literature value, plausibly explained by incomplete thermal equilibration and geometry/immersion effects observed during the LN_2 step. Overall, the method and calibration are sound; adding one or two intermediate temperatures and enforcing longer equilibration would further tighten the uncertainty on t_0 and t_{LN_2} .

Appendix

AI Usage Declaration

This report was prepared with assistance from ChatGPT (OpenAI) for language polishing, formatting suggestions, and for helping to develop, debug, and correct the syntax of the Python code. The AI was not used to generate raw data, to select results, or to determine the final conclusions. All scientific content (methods, calculations, results, and interpretation) was critically reviewed and validated by the authors. The authors take full responsibility for the accuracy of the analysis and for any remaining errors. No confidential or personal data were provided to the AI system during the preparation of this report.

References

- [1] Peter Atkins, Julio de Paula, and James Keeler. *Atkins' Physical Chemistry*. 11th ed. Oxford: Oxford University Press, 2018.
- [2] David Halliday, Robert Resnick, and Jearl Walker. *Fundamentals of Physics*. 10th ed. Hoboken, NJ: John Wiley & Sons, 2014.
- [3] *Physikpraktikum für 3. Semester — Experiment 09: Absoluter Nullpunkt*. Lab manual. Restricted access (ETH login required). ETH Zürich, Departement Physik, Oct. 10, 2025. URL: https://ap.phys.ethz.ch/Anleitungen/Bilingual/09_Manual.pdf.
- [4] Royal Society of Chemistry. *Nitrogen — Element 7*. 2025. URL: <https://periodic-table.rsc.org/element/7/nitrogen>.
- [5] *SI Brochure: The International System of Units (SI). 9th edition, version 3.02*. Brochure. Version 3.02. Bureau International des Poids et Mesures (BIPM), Aug. 2025. URL: <https://www.bipm.org/documents/20126/41483022/SI-Brochure-9-EN.pdf>.

Python Code

```
1 import numpy as np
2 import matplotlib.pyplot as plt
3 from pathlib import Path
4
5 # ===== SETTINGS (EDIT THESE) =====
6
7 # Use corrected barometer reading for calibration?
8 USE_CORRECTED_pL = True # True = use corrected pL; False = use uncorrected pL
9
10 # --- Sensor readings (from your sheet) ---
11 UL_mV = 122.92 # U at ambient pressure (mV)
12 Ut_mV = -11.11 # U at low pressure (mV)
13 pt_Pa = 10.0 # low pressure in Pa (e.g. 0.1 mbar 10 Pa)
14
15 # Barometer readings (Pa)
16 pL_uncorr_Pa = 95991.84 # uncorrected barometer reading
17 pL_corr_Pa = 95609.21 # corrected barometer reading
18
19 # Measurements at reference temperatures (mV)
20 UE_mV = 87.44 # U at ice water (~0C)
21 UK_mV = 122.50 # U at boiling water (t_K)
22
23 # Reference temperatures (C)
24 t_E = 0.0
25 t_K = 98.493
26
27 # Output folder for figures
28 OUTDIR = Path("output")
29
30 # ===== CALIBRATION: p = p0 + C * U =====
31
32 pL_Pa = pL_corr_Pa if USE_CORRECTED_pL else pL_uncorr_Pa
33 C_Pa_per_mV = (pL_Pa - pt_Pa) / (UL_mV - Ut_mV)
34 p0_Pa = pL_Pa - C_Pa_per_mV * UL_mV
35
36 # Compute pressures at the two temperature points (convert to mbar for display)
37 pE_Pa = p0_Pa + C_Pa_per_mV * UE_mV
38 pK_Pa = p0_Pa + C_Pa_per_mV * UK_mV
39 pE_mbar = pE_Pa / 100.0
40 pK_mbar = pK_Pa / 100.0
```

```

41
42 # ===== DATA FOR REGRESSION =====
43
44 t_C    = np.array([t_E, t_K], dtype=float)      # temperatures in C
45 p_mbar = np.array([pE_mbar, pK_mbar], dtype=float) # pressures in mbar
46
47 # ===== LINEAR REGRESSION p = a*t + b (in Pa) =====
48
49 MBAR_TO_PA = 100.0
50 t = t_C
51 p = p_mbar * MBAR_TO_PA
52
53 # Fit: returns slope a (Pa/C), intercept b (Pa)
54 a, b = np.polyfit(t, p, deg=1)
55
56 # x-intercept where p=0
57 t0 = -b / a
58
59 # Convert to mbar-units for human-readable line
60 a_mbar = a / MBAR_TO_PA
61 b_mbar = b / MBAR_TO_PA
62
63 # ===== CONSOLE OUTPUT =====
64
65 print("=== Calibration (using {} pL) ===".format("corrected" if
        USE_CORRECTED_pL else "uncorrected"))
66 print(f"C = {C_Pa_per_mV:.3f} Pa/mV,    p0 = {p0_Pa:.2f} Pa")
67 print(f"pE = {pE_mbar:.2f} mbar at t_E = {t_E:.3f} C")
68 print(f"pK = {pK_mbar:.2f} mbar at t_K = {t_K:.3f} C\n")
69
70 print("=== Linear regression p = a*t + b ===")
71 print(f"a (Pa/C)    = {a:.6g}")
72 print(f"a (mbar/C) = {a_mbar:.6g}")
73 print(f"b (Pa)      = {b:.6g}")
74 print(f"x-intercept t0 (C) = {t0:.3f}")
75 print(f"Line in mbar: p(t) = {a_mbar:.5f} * t + {b_mbar:.2f}\n")
76
77 # ===== PLOTS =====
78
79 OUTDIR.mkdir(exist_ok=True)
80

```

```
81 # --- Wide view in Pascals (y-axis in Pa) ---
82 left = min(t0 - 20, float(np.min(t_C)) - 20)
83 right = max(t0 + 20, float(np.max(t_C)) + 20)
84 t_wide = np.linspace(left, right, 500)
85
86 # Regression line in Pa
87 p_wide_Pa = a * t_wide + b # a,b are in Pa/C and Pa
88
89 plt.figure()
90 plt.scatter(t_C, p, label="Data points") # p is in Pa
91 plt.plot(t_wide, p_wide_Pa, label="Fit line")
92 plt.axvline(t0, linestyle="--", label=f"x-intercept t0 = {t0:.2f} C")
93
94 # y-borders in Pa
95 ymin = min(0, float(np.min(p)) * 0.9)
96 ymax = max(float(np.max(p)) * 1.1, 1000.0)
97
98 plt.xlim(left, right)
99 plt.ylim(ymin, ymax)
100 plt.xlabel("Temperature t (C)")
101 plt.ylabel("Pressure p (Pa)")
102 plt.title("Linear regression p(t)")
103 plt.legend()
104 plt.grid(True, alpha=0.3)
105 plt.tight_layout()
106 plt.savefig(OUTDIR / "regression_en_wide_Pa.png", dpi=160, bbox_inches="tight")
107
108 plt.show()
```

Name 1 Visva Loganathan

Datum: 03.10.2025

Name 2 Flurin Kuhn

Platz-Nr:

09 - absolute Zero

Calibration of the pressure sensor

barometer ± 0.1 bar

Calibration point at ambient pressure

-2.87

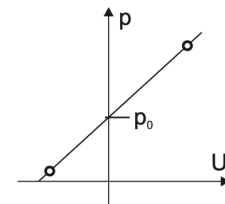
(uncorrected barometer reading)	(temperature at barometer)	(corrected barometer reading)
$p_L = 720 \pm 1$ mm Hg (t_L)	air temp $t_L = 22 \pm 1$ °C	$p_L = 717.13$ Torr
$p_L = 95'991.84$ Pa	$U_L = 122.92 \pm 0.075$ mV	$= 95'609.21$ Pa

Calibration point at low pressure

$p_t = 0.1 \pm 0.1$ mbar	$p_t = 10 \pm 10$ Pa	$U_t = -11.1$ mV
--------------------------	----------------------	------------------

Sensor characteristics: $p = p_0 + CU$:

$p_0 = 7934$ Pa	$C = 713.3$ Pa/mV
-----------------	-------------------



Determination of the absolute zero

At the temperature of boiling water

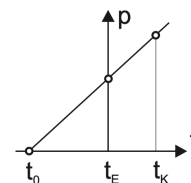
$t_K = 98.493$ °C	$U_K = 122.50$ mV	$p_K = 953.13$ mbar
-------------------	-------------------	---------------------

At the temperature of ice water

$t_E = 0$ °C	$U_E = 87.44$ mV	$p_E = 703.04$ mbar
--------------	------------------	---------------------

Approximation for the temperature of the absolute zero:

$t'_0 = -276.88$ $t_0 \approx t'_0 = -\frac{p_E}{p_K - p_E} t_K$



Volume of the empty space / volume of the glass bulb: $V_s/V = \epsilon = 1 \cdot 10^{-3}$

Cubic expansion coefficient of glass: $\gamma = 1.0 \cdot 10^{-5} \text{ } ^\circ\text{C}^{-1}$

$a = -251.28$	$b = -63'697.25$	$c = 1'523'379.41$
---------------	------------------	--------------------

Absolute zero of temperature:

+) -275.50 °C

→ Messungenauigkeiten: Zu wenig lange gewartet

→ Nur 2 Messpunkte

$t_0 = -$

→ 228.91 mBar

Determination of the temperature of liquid nitrogen

$U_{LN2} = 20.97$ mV	$p_{LN2} = 22'891.901$ Pa	$t'_{LN2} = -185.80$ °C
corr. coeff A = 2.55	$t_{LN2} = -186.02$ °C	

→ Messungenauigkeiten allgemein und t_0

→ Behälter nicht vollständig N_2 eingetaucht