Instruction Sheet **382 00**

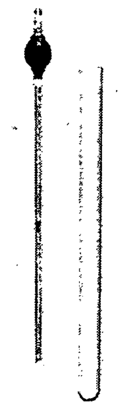

Fig. 1

Gas Thermometer

The gas thermometer is used to study the laws of ideal gases. Particularly, it allows an experimental introduction of the absolute temperature scale and determination of the absolute zero.

Literatur:
Physics Experiment Desciptions (599 922)
New Physics Leaflets for Colleges and Universities, Volume 2 (599 892)

1 Technical Data:

Gas thermometer:

Total length:	475 mm
Outer diameter of the capillary:	8 mm
Inner diameter of the capillary:	2.7 ± 0.2 mm
The variations in diameter along a capillary are generally smaller than 0.05 mm	
Outer diameter of hose nozzle:	8 mm

Test tube:

Length:	440 mm
Outer diameter:	30 mm

2 Description

The thermometer consists of a glass capillary open at one end in which a gas volume of variable size can be enclosed by means of a small mercury drop. The length of the enclosed gas volume can be read from a millimeter scale on the glass capillary.

A bulge at the upper open end of the thermometer contains silica gel to dry the air penetrating into the capillary. A gas-permeable sintered glass filter between bulge and capillary prevents the mercury from leaving the gas thermometer.

A second small bulge is provided directly before the filter to collect the mercury globules if the mercury drop should have ' due to vibration.

paratus comprises a large test tube, resistant to thermal shocks, which receives a heat bath whose temperature can be varied e. g. using a Bunsen burner.

3 Use

3.1 Collecting the mercury and adjusting a gas volume

Connect a gas syringe (100 ml gas syringe from set of 2 gas syringes with holder, 361 30, or gas syringe with three-way stopcock, 361 28) to the hose nozzle of the gas thermometer using PVC tubing. Now a full mercury drop can be brought into the small bulge below the sintered glass filter by creating a low pressure on the other side using the gas syringe. If the mercury drop has floured, collect the globules in the bulge by slightly tapping the capillary (gas thermometer in vertical position with the sealed end upward). A small mercury globule which might have remained at the sealed end of the gas thermometer will not affect the measurements.

Depending on the size of the desired gas volume to be adjusted anew (at ambient pressure), a corresponding low pressure must be produced by means of the gas syringe for which purpose the gas thermometer must be held again with its sealed end upward. Then bring the mercury drop to the capillary entrance before the bulge by slowly moving the sealed end downward. When now carefully relieving the gas syringe, the mercury drop in the capillary is displaced and finally comes to rest when the pressure in the capillary reaches ambient pressure. Repeat this procedure several times, if necessary.

It is advisable to use the mercury tray (309 63) during volume adjustment so that the mercury drop is collected if the glass should break.

3.2 Treatment of silica gel

Blue silica gel is capable of absorbing water and hence prevents humidity from penetrating into the capillary of the gas thermometer. Colourless silica gel is saturated with water and must either be replaced by fresh silica gel or be regenerated.

For regeneration, connect the gas thermometer with a vacuum pump with gas ballast device (e. g. gas ballast pump, Cat. No. 101 05 S) and heat the silica gel using a hot-air blower. The silica gel will have regained its deep blue colour after some hours.

4 Experiments on Gas Laws

4.1 Pneumatic spring

The gas volume enclosed in the gas thermometer by an easily displaced mercury seal may be considered as a pneumatic spring, similar in some way to a helical wire spring. If a force F acts on the mercury seal, it is displaced from its rest position (characterized by the length x_o or the volume $V_o = A_{cap} \cdot x_o$ respectively) by a magnitude Δx (see Fig. 2). The

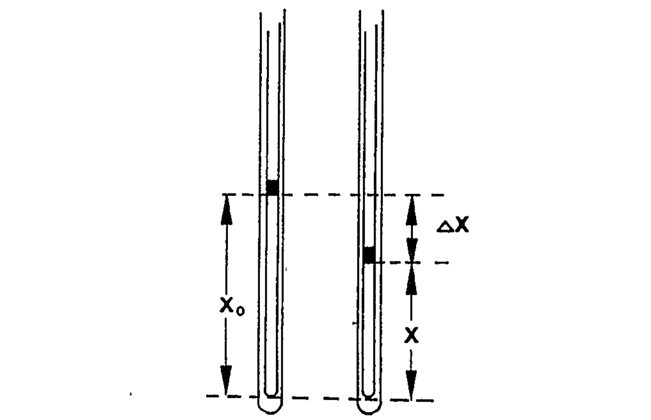

Fig. 2

forces to be exerted on the mercury seal can be produced in this experiment simply by exerting pressures. If in addition to the ambient (atmospheric) pressure p_{at} a pressure component Δp is prevailing above the mercury drop, the force $F = \Delta p \cdot A_{cap}$ is exerted on the seal. Then the seal is displaced until the pressure of the air volume below the seal (force of the pneumatic spring) exerts a counter-force of equal magnitude.

Question: Does Hooke's law apply to a pneumatic spring the same as to the helical spring?

Apparatus:	*Cat. No.*
1 Gas thermometer	382 00
1 Set of 2 gas syringe with holder	361 30
1 Stand base, 28 cm	301 01
1 Stand rod, 1 m	300 44
2 Leybold bosses	301 01
2 Universal clamps	301 72
1 Stand base, 20 cm	300 02
1 Stand rod, 47 cm	300 42
2 Sets of weights	315 31
or set of 10 weights	590 24
1 Three-way stopcock	665 255
1 Piece = 5 cm and 1 piece = 150 cm PVC tubing, 7 mm I. D.	from 667 191
For safe work with mercury we recommend in addition:	
1 Mercury tray	309 63
1 Mercury adsorbens	306 83

Set-up and performance of experiment:

a) At first, adjust the volume V_o in the gas thermometer (see 3.1). A suitable length x_o for adjustment lies at approx. two thirds of the total capillary length. After adjustment of the gas volume the gas thermometer should not be submitted to any vibration to prevent the mercury drop from flouring.

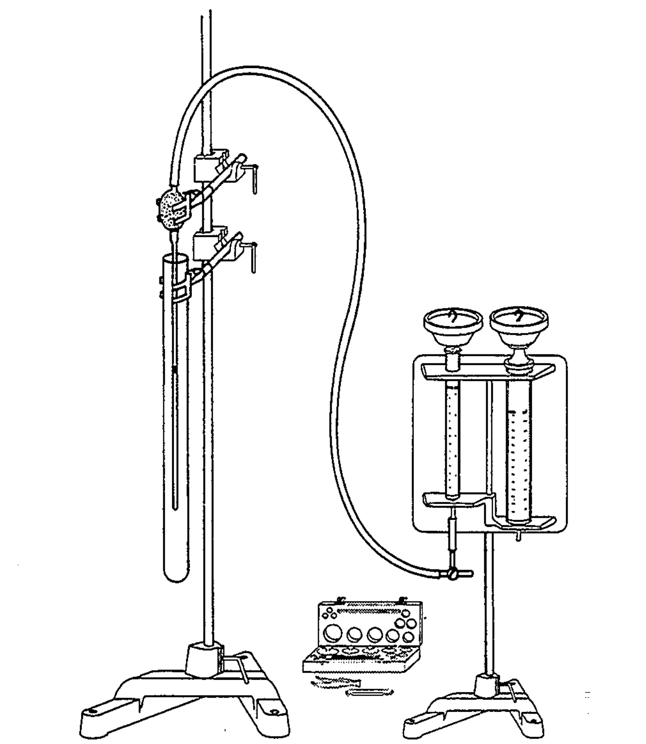

Fig. 3

b) Make experimental set-up according to Fig. 3: Prior to that thoroughly degrease the gas syringe. It would be preferable to use the 25 ml gas syringe from the set of 2 gas syringes with holder. In this experiment the large test tube is only used to collect mercury if a glass should break.

c) Before applying the weights, pull out the piston of the gas syringe as far as possible (for this purpose briefly connect the volume of the gas syringe with the ambient air via the three-way cock).

Place different weights, e. g. from the set of weights 315 31 successively on the weight plate of the 25 ml gas syringe and measure the corresponding excursions Δx from the length x_o of the pneumatic spring. Make sure that the weight plate is loaded as symmetrically as possible. If the load is very asymmetric, the piston might jam causing considerable measuring errors.

Evaluation of experiment:

When weights with the total mass G are placed on the plate of the 25 ml gas syringe, the following force is exerted on the mercury seal:

$$F = \frac{G}{A_{piston}} \cdot A_{cap}$$

where $A_{piston} = \frac{\pi}{4} \cdot d^2_{piston}$ cross-sectional area of the gas syringe

$A_{cap} = \frac{\pi}{4} \cdot d^2_{cap}$ cross-sectional area of the capillary

Make a diagram plotting the excursions Δx from rest position as a function of the force F (see Fig. 4).

Example of experiment:

$\frac{d_{cap}}{10^{-3}\,m}$	$\frac{A_{cap}}{10^{-6}\,m^2}$	$\frac{d_{piston}}{10^{-3}\,m}$	$\frac{A_{piston}}{10^{-4}\,m}$	$\frac{x_o}{10^{-3}\,m}$
2.7	5.7	15.5	1.9	277

Applied weight g	$\frac{\Delta x}{10^{-3}\,m}$	$\frac{F}{10^{-2}\,m}$
0	0	0
2x 50	12.5	2.94
2x100	24.5	5.89
3x100	35.5	8.83
2x200	45.0	11.77
(2x200)+(2x50)	55.0	14.72
(2x200)+(2x100)	62.5	17.66
(2x200)+(2x100)+(2x50)	70.0	20.60
(2x200)+(4x100)	78.0	23.54

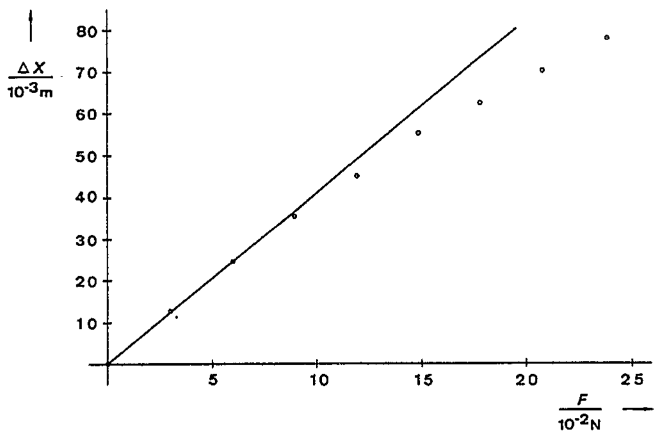

Fig. 4

Result:

With the pneumatic spring studied, Hooke's law applies to small excursions (up to 10 % of the total length) (see Fig. 4). For larger excursions, however, Hooke's law is not applicable to the pneumatic spring, which is entirely in correspondence with the helical spring where Hooke's law is also applicable to a limited range only.

4.2 Boyle's law (isothermal change of state)

The variable quantities gas pressure and gas volume of an enclosed amount of gas at constant temperature are not independent on each other. Within the volume of the gas thermometer enclosed by the mercury seal the pressure shall be changed over a larger range at constant temperature, every time determining the gas volume V.

Question: Does Boyle's law $p \cdot V = \text{const.}$ apply to isothermal changes of state?

To perform this experiment, the same equipment is required as for experiment 4.1.

Carrying out the experiment:

A gas syringe with attached weights connected to the gas thermometer enables a quantitative change of the gas pressure within the volume enclosed in the gas thermometer. Set-up and performance of the experiment are fully identical to those of experiment 4.1. The two experiments only differ in their evaluation.

Evaluation:

The total pressure p in the enclosed gas volume of the gas thermometer is composed of the atmospheric pressure p_{at} the weight pressure of the mercury seal p_{Hg}, the weight pressure p_{piston} of the syringe with empty weight plate and the weight pressure Δp caused by weights placed on the weight plate.

$$p = p_{at} + p_{Hg} + p_{piston} + \Delta p$$

When knowing the individual gravitational forces and cross-sectional areas, the weight pressures can easily be calculated:

$$p_{Hg} + \frac{G_{Hg}}{A_{cap}} \quad p_{piston} = \frac{G_{piston}}{A_{piston}} \quad \Delta p = \frac{G}{A_{piston}}$$

G is the total weight of the weight pieces placed on the weight plate. The gravitational force of the mercury seal can be calculated from the specific gravity γ of mercury and the volume V of the mercury seal.

The volume is calculated from $V = A_{cap} \cdot x$.

Plot the logarithm of the total pressure p as a function of the logarithm of volume V into a diagram; ($\lg p$ against $\lg V$, see Fig. 5). Determine the product $p \cdot V$ for different applied weights and enter the results into a table.

Example of experiment:

$\frac{d_{cap}}{10^{-3}\,m}$	$\frac{A_{cap}}{10^{-6}\,m^2}$	$\frac{d_{piston}}{10^{-3}\,m}$	$\frac{A_{piston}}{10^{-4}\,m^2}$	$\frac{x_o}{10^{-3}\,m}$
2.7	5.7	15.5	1.9	277

Density of mercury $\rho_{Hg} = 13.55 \times 10^3 \frac{kg}{m^3}$

Specific gravity of mercury $\gamma_{Hg} = \rho_{Hg} \cdot g = 1.329 \times 10^5 \frac{N}{m^3}$

Length of mercury seal $h = 10^{-2}$ m

$G_{piston} = 0.78$ N

$p_{at} = 101.3 \times 10^3 \frac{N}{m^2}$

$p_{Hg} = \frac{\gamma_{Hg} \cdot V_{Hg}}{A_{cap}} = \gamma_{Hg}\, h = 1.3 \times 10^3 \frac{N}{m^2}$

$p_{piston} = \frac{0.78\ N}{1.9 \times 10^{-4}\ m^2} = 4.1 \times 10^3 \frac{N}{m^2}$

Applied mass g	$\frac{x}{10^{-3}\,m}$	$\frac{V}{10^{-6}\,m^3}$	$\frac{\Delta p}{10^3\,\frac{N}{m^2}}$	$\frac{p}{10^3\,\frac{N}{m^2}}$	$\frac{p \cdot V}{10^{-3}\,Nm}$
0	277.0	1.58	0	106.7	168.6
2x 50	264.5	1.51	5.2	111.9	169.0
2x100	252.5	1.44	10.3	117.0	168.5
3x100	241.5	1.38	15.5	122.2	168.6
2x200	232.0	1.32	20.7	127.4	168.2
(2x200)+(2x50)	222.0	1.27	25.8	132.5	168.0
(2x200)+(2x100)	214.5	1.22	31.0	137.7	167.9
(2x200)+(2x100)+(2x50)	209.0	1.19	36.1	142.8	167.9
(2x200)+(4x100)	199.0	1.13	41.3	148.0	167.2

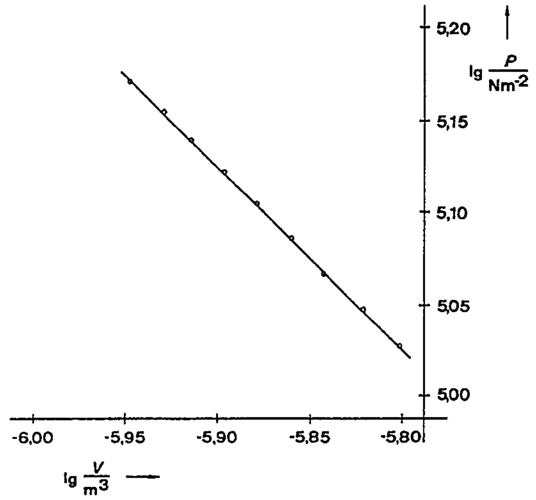

Fig. 5

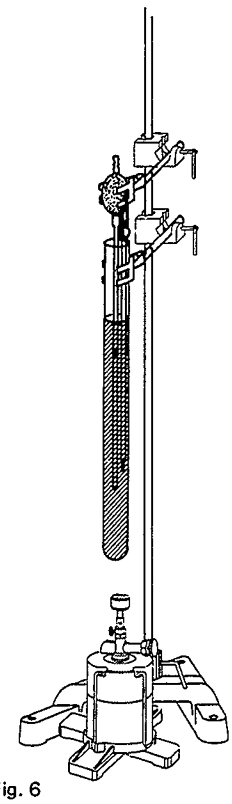

Fig. 6

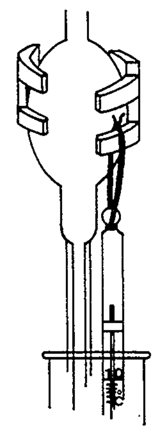

Fig. 7

Experimental result:

a) It can be seen by the diagram (Fig. 5) that lg p is proportional to lg V. The slope of the straight line connecting the test results is −1. From this it can be deduced that the pressure is inversely proportional to the volume and that the relation $p \cdot V$ = const. applies.

b) In all measurements made the product of pressure and volume is constant to approx. ±1 %.

4.3 Gay-Lussac's laws

The variable quantities volume and pressure of a given amount of gas are dependent upon the temperature. The dependency of pressure and volume upon the temperature shall be determined for the amount of gas enclosed in the gas thermometer by the mercury seal. The temperature range shall extend from 0 °C to approx. 100 °C.

Question: Is there a linear interrelationship between pressure and temperature or between volume and temperature respectively? Can an absolute temperature zero and hence an absolute temperature scale be defined by extrapolation toward low temperatures?

4.3.1 Dependence of the volume upon temperature at constant pressure (isobaric change of state)

Apparatus:		*Cat. No.*
1 Gas thermometer		382 00
1 Stand base, 28 cm		300 01
1 Stand rod, 1 m		300 44
2 Leybold bosses		301 01
2 Universal clamps		301 72
1 Thermometer, −10 °C to +110 °C		382 34
1 Length of fishing line	from	309 49
1 Bunsen burner	e. g.	303 11
with gas cartridge		303 12

Carrying out the experiment:

a) At first, enclose a freely selectable amount of air in the gas thermometer by means of a mercury seal (see 3.1). A suitable volume (at atmospheric pressure and room temperature) lies at approx. two thirds of the total volume of the capillary. After the gas volume is adjusted, the gas thermometer should not be exposed to any vibrations to prevent the mercury drop from flouring.

b) Make experimental set-up according to Fig. 6. Introduce the thermometer into the test tube in parallel to the gas thermometer and suspend it on a universal Bunsen clamp for gas thermometer using fishing line (loop of approx. 3 cm length) according to Fig. 7.

In this experiment the large test tube is used as container for the heat bath and to collect mercury if a glass breakage should occur.

c) Heat the water in the large test tube until it nearly boils, using a Bunsen burner. Boiling should be avoided as otherwise water may splash out at the top extinguishing the burner flame. To keep the temperature gradient between water and gas thermometer as small as possible, it is advisable to begin the measurements at high temperatures and then to let the water bath cool down slowly with the Bunsen burner switched off. Measure the enclosed volume in the gas thermometer after approx. every 10 °C (measurement of the length x). When room temperature is reached again, fill the test tube with a mixture of water and ice to adjust a temperature of 0 °C. Make sure that there is an interval of some minutes between filling in the ice water and reading the volume at 0 °C to avoid faulty measurements due to the temperature gradient.

Evaluation of experiment:

Plot the volume values determined on the gas thermometer at different temperatures between 100 °C and 0 °C into a diagram (see Fig. 8). (Volume against temperature). Extrapolate the test plot line toward low temperatures.

Example of experiment:

$A_{cap} = 5.7 \times 10^{-6}\ m^2$

$\frac{\vartheta}{^oC}$	$\frac{x}{10^{-3}\ m}$	$\frac{V}{10^{-6}\ m^3}$
95	293	1.67
90	289	1.65
80	281	1.60
70	273	1.56
60	265	1.51
50	257	1.47
40	249	1.42
30	241	1.37
20	232	1.32
10	225	1.28
0	218	1.24

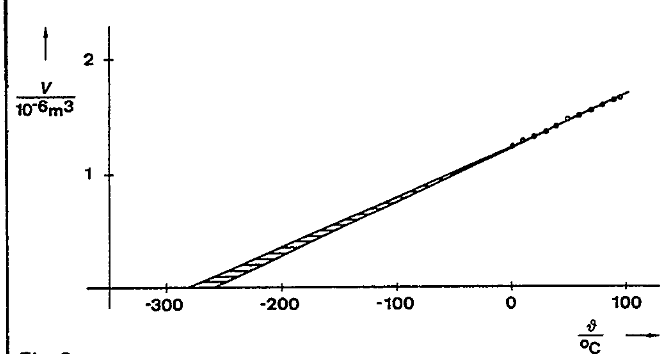

Fig. 8

Experimental result:

The test points (see Fig. 8) lie on a straight line and can be expressed by the equation

$$V = V_o\ (1 + a\ \vartheta).$$

V_o is the volume at 0 °C.

a amounts to

$(3.71 \pm 0.14) \cdot 10^{-3}\ {}^oC^{-1}$

taking into account the dispersion of measured results.

As absolute temperature zero "0.0 K" the intersecting point of the test plot line with the temperature axis (V= 0) can be defined: –270 °C ± 10 °C.

4.3.2 Dependence of the pressure upon the temperature at constant volume (isochoric change of state)

For this experiment the same equipment is required as for experiment 4.1.

Additionally required:		*Cat. No.*
1 Bunsen burner	e. g.	303 11
with cartridge		303 12
1 Thermometer, –10 °C to +110 °C		382 34
1 Length of fishing line	from	309 48

Carrying out the experiment:

a) Adjust volume and make experimental set-up as described in experiment 4.1. Set-up is according to Fig. 9. Prior to that degrease the gas syringe thoroughly.

It will be preferable to use the 25 ml gas syringe from the set of 2 gas syringes with holder (361 30).

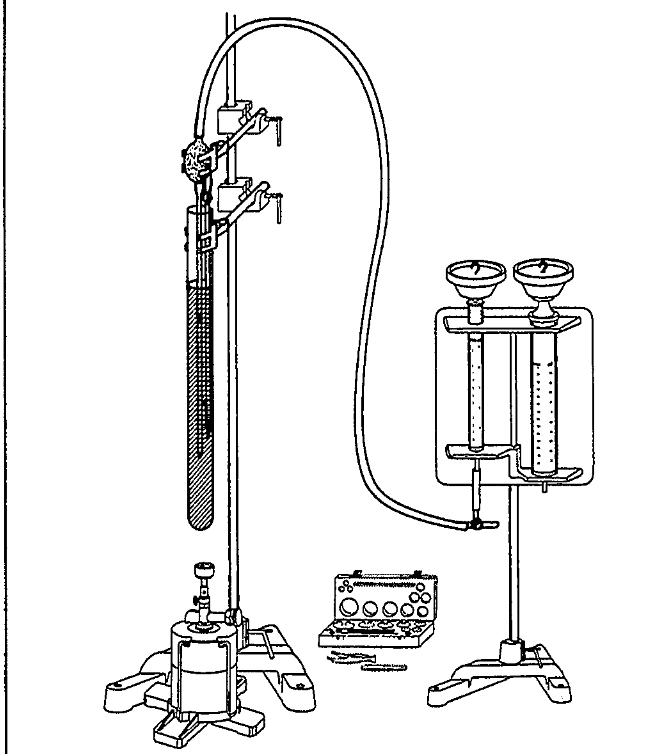

Fig. 9

The large test tube is now used not only to collect mercury in case of glass breakage but also to receive the heat bath. Fill approx. 75 % of the large test tube with a mixture of water and ice. Introduce the thermometer into the test tube in parallel to the gas thermometer and suspend it on a universal Bunsen clamp for gas thermometer using fishing line (loop of approx. 3 cm length) according to Fig. 7.

b) Note down the lower mark of the mercury seal at the adjusted temperature of 0 °C. Then heat the water in the large test tube until it nearly boils. Boiling should be avoided as otherwise water will spill out on top extinguishing the flame of the Bunsen burner. At approx. 95 °C water temperature, place weights on the weight plate of the 25 ml gas syringe until the original gas thermometer volume at 0 °C is reached again. Before applying the weights, pull out the thoroughly degreased piston of the gas syringe as far as possible (for that purpose briefly connect the gas syringe volume with the ambient air via the three-way cock). Now let the water bath cool down slowly with the Bunsen burner switched off. After cool-down by steps of 10 °C, measured with the thermometer, remove so many weights from the gas syringe until the original volume at 0 °C has established again. Note down the mass of the weights as a function of the temperature of the heat bath.

Evaluation of experiment:

The pressure in the gas thermometer volume can be determined from the atmospheric pressure and the individual weight pressures as described in the evaluation for experiment 4.2. Plot the pressures as a function of the temperature in a diagram (see Fig. 10). Extrapolate the test plot line toward smaller temperatures.

Example of experiment:

p_{at} 10^3 Nm^{-2}	p_{piston} 10^3 Nm^{-2}	p_{Hg} 10^3 Nm^{-2}	x_o 10^{-3} m	A_{piston} 10^{-4} m
101.6	4.1	1.3	257	1.9

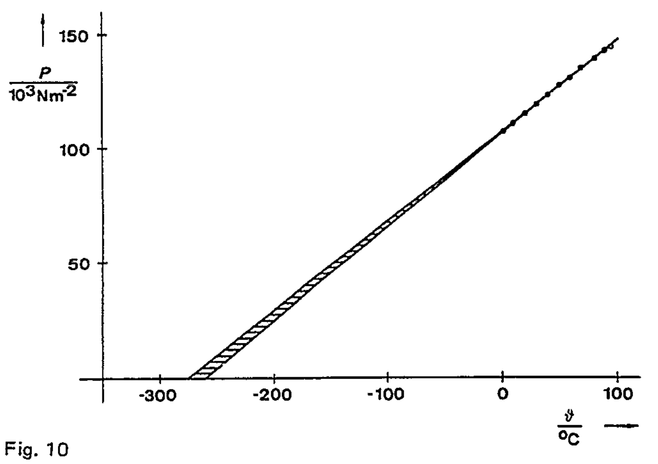

Fig. 10

ϑ °C	Applied mass g	Δp 10^3 Nm^{-2}	p 10^3 Nm^{-2}
95	(2x200)+(3x100)+20	37.2	144.2
90	(2x200)+(2x100)+50+20	34.6	141.6
80	(2x200)+(2x100)+(2x20)	33.0	140.0
70	(2x200)+100+50	28.4	135.4
60	(2x200)+(2x20)+(3x10)	24.3	131.3
50	(3x100)+50+(2x20)	20.1	127.1
40	(3x100)+10	16.0	123.0
30	(2x100)+20+10	11.9	118.9
20	(2x50)+(2x20)+10+5	8.0	115.0
10	(2x20)+(3x10)+5	3.9	110.9
0	0	0	107.0

Experimental result:

The test points (see Fig. 10) lie on a straight line and can be expressed by the equation

$$p = p_o\,(1 + \alpha\vartheta)$$

p_o is the pressure at 0 °C.

α amounts to

$$(3.74 \pm 0.11) \times 10^{-3}\ ^{o}C^{-1}$$

taking into account the dispersion of measured results.

As absolute temperature zero "0.0 K" the intersecting point of the test plot line with the temperature axis (p =0) can be defined: −267 °C ± 8 °C.

Note:

Measurement of the gas pressure as a function of temperature, the volume remaining constant, can also be made using a U-tube manometer as shown in Fig. 11. The gas syringe with three-way cock (361 28) is used to keep the volume in the gas thermometer constant. The pressure can directly be read from the manometer. For the sake of accuracy it is recommended to fix a mm-scale between the U-tube and its support. For safety reasons (spilling of mercury in case of breakage), however, the set of two gas syringes (361 30) should be used for this experiment.

Notes:

1. The five-digit numbers quoted in brackets refer to the catalogue numbers of the respective apparatus.
2. The specifications and illustrations are not binding in every detail for the design of the apparatus. It is our policy always to keep our manufacturing programme right up to date so that it makes full allowance for the developments acquired in all scientific and technical fields.

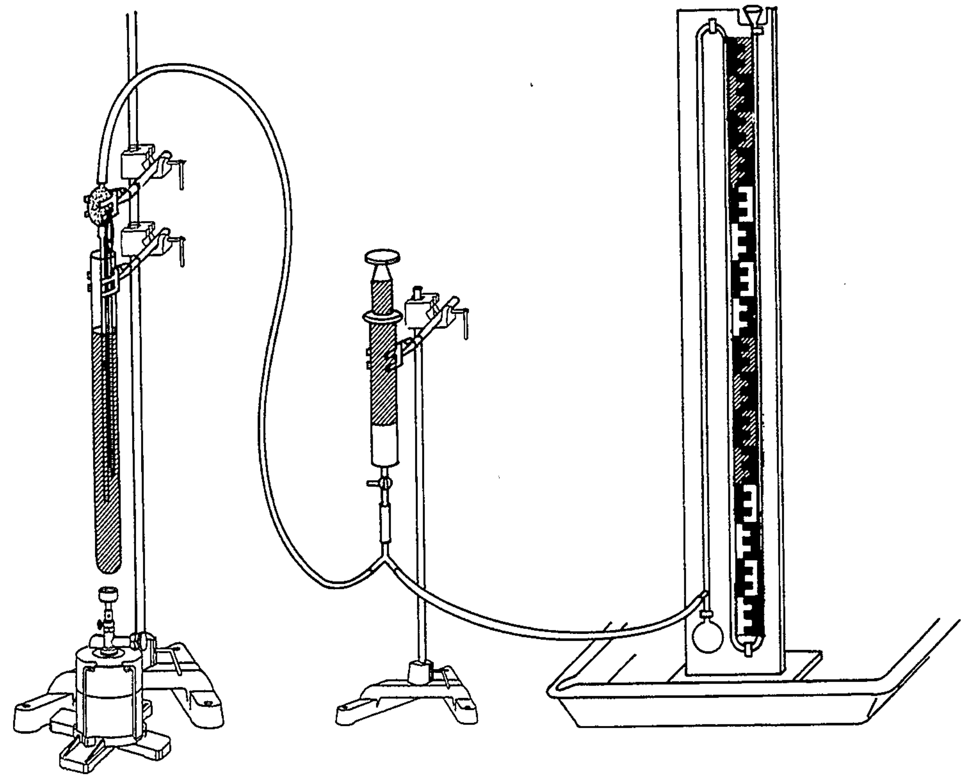
Fig. 11