

UNIVERSIDAD AUTÓNOMA DE CHIHUAHUA
FACULTAD DE INGENIERÍA

HEAT PRACTICES MANUAL

PHYSICS LABORATORY

LD DIDACTIC



HEAT

INDEX

2.1 THERMAL EXPANSION

P2.1.1.2 MEASUREMENT OF LONGITUDINAL EXPANSION

2.2 THERMAL ENERGY

P2.2.1.2 DETERMINATION OF THE THERMAL CONDUCTIVITY OF MATERIALS

P2.2.2.1 EFFICIENCY OF A SOLAR COLLECTOR: COMPARISON OF A THERMOSIFON CIRCULATION SYSTEM WITH A FORCED CIRCULATION SYSTEM

2.2.2.2. EFFICIENCY OF A SOLAR COLLECTOR II: OPTIMIZATION BY THERMAL INSULATION

2.3 HEAT AS A FORM OF ENERGY

P2.3.2.1 DETERMINATION OF SPECIFIC HEAT IN SOLIDS

P2.3.3.1 TRANSFORMATION OF MECHANICAL ELECTRICAL ENERGY INTO HEAT

P2.3.4.1 CONVERTING ELECTRICAL ENERGY INTO HEAT

2.4 TRANSITION PHASE

P2.4.1.1 DETERMINATION OF THE SPECIFIC HEAT OF VAPORIZATION OF WATER

P2.4.2.1 DETERMINATION OF THE SPECIFIC LATENT HEAT OF ICE

P2.4.3.1 OBSERVATION OF THE TRANSITION PHASE BETWEEN LIQUID AND GAS AT THE CRITICAL POINT

2.5 THEORY OF GASES

P2.5.2.1 VOLUME OF A GAS DEPENDENT ON PRESSURE AT CONSTANT TEMPERATURE AT CONSTANT PRESSURE

P2.5.2.2 VOLUME OF A GAS DEPENDENT ON TEMPERATURE AT CONSTANT PRESSURE

2.5.3.2 THE SPECIFIC THERMAL CAPACITY OF GASES

2.6 THERMODYNAMIC CYCLE

P3.6.4.1 DETERMINATION OF THE EFFICIENCY OF THE HOY AIR MOTOR AS A COOLER



PRACTICE 1

P2.1.1.2

MEASUREMENT OF LONGITUDINAL EXPANSION IN SOLIDS



HEATP2.1.1.2

Thermal expansion

Thermal expansion of solid bodies

THERMAL EXPANSION OF SOLID BODIES

Objects of the experiment

- Measuring the linear thermal expansion of a brass tube as a function of the overall length.
- Measuring the linear thermal expansion of glass, steel and brass tube and determining their linear expansion coefficient.

Principles

The length S of a solid body is linear dependent on its temperature ϑ :

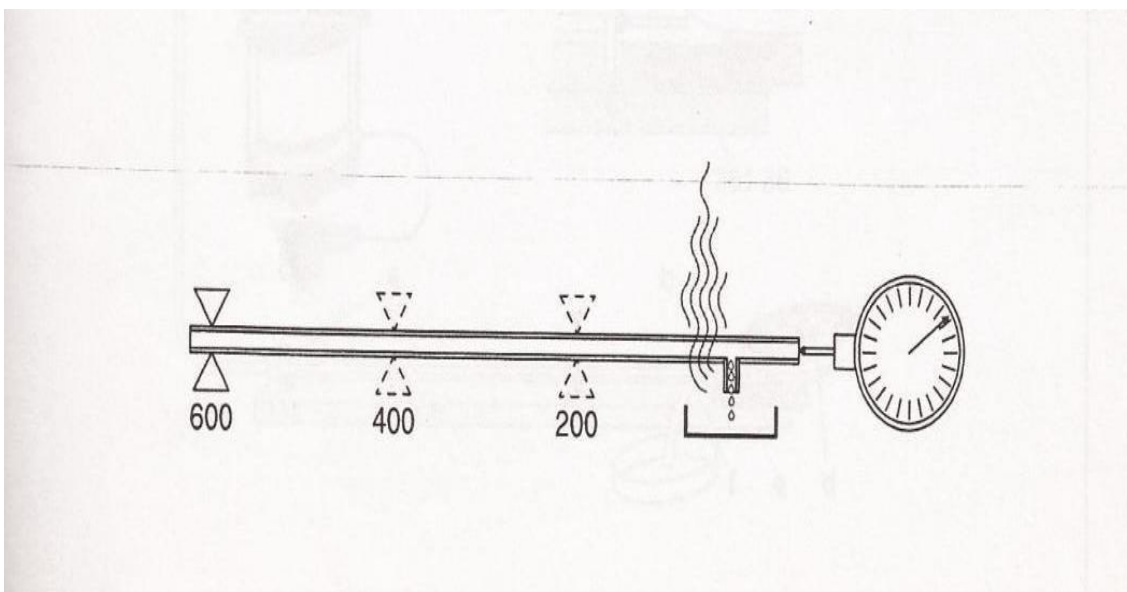
$$S = S_0 \cdot (1 + \alpha \cdot P)$$

S_0 : Length at 0°C , ϑ : Temperature in $^\circ\text{C}$

The linear expansion coefficient α is determined by the material of the solid body. For a given temperature difference between room temperature P_1 and the steam temperature P_2 , the change of length ΔS is closely proportional to the overall length S_1 at the room temperature. Specifically we can say:

$$\alpha = \frac{\Delta S}{S_1} \cdot \frac{1}{P_2 - P_1}$$

In this experiment, measures of thermal expansion are conducted on thin tubes through which steam is channelled. The effective length S_1 of each tube can be set as 200, 400 or 600 mm by mounting it in the correspondent manner. A dial gauge with 0.01 mm scale graduations is used to measure the length change.





Apparatus

1 Expansion apparatus	381 34
1 Holder for dial gauge	381 36
1 Dial gauge.....	361 15
1 Steam generator, 550W/230 V.	303 28
1 Silicone tubing, dia. 7x1.5 mm, 1m	667 194
1 Petri dish 150 x 25mm	667 185
1 Thermometer -10°C to -110°C	382 34

Setup

Setup the experiment as shown in fig. 1.

-Screw on the holder for dial gauge and clamp the dial gauge in place.

-Attach the fixed bearing of the expansion apparatus at the 600 mark and slide the open end of the brass tube into the fixed bearing.

-Slide the closed end of the brass tube into the guide fitting so that the hose nipple is pointing laterally downwards.

-Tighten the screw to fix the brass tube into the guide fitting in the fixed tube bearing (the screw must engage the ring groove of the tube).

-Insert the extension piece.

-Cut off a 20 cm length of silicone tubing, slide the section over the hose nipple and place the petri dish below this to catch the condensation.

-Use the long tubing section to connect the open end of the brass tube to the steam generator.

Note: Danger of scalding when the steam generator is used improperly.

Carrying out the experiment

-Determine the room temperature P_1 and write this down.

-Read off and write the zero position of the dial gauge.

-Fill the steam generator 2 cm of water, close the apparatus and plug it in.

-Read off and write down the maximum pointer deflection of the dial gauge.

-Allow the brass tube to cool down the temperature.

-Attach the fixed bearing of the expansion apparatus at the 400 mark and tighten the screw so that it engages the ring groove of the tube.

-Refill the steam generator with water, check the zero position of the dial gauge and repeat the measurement.

-Move the fixed bearing of the 200 mark and repeat the experiment.

-Replace the brass tube with a steel tube; attach the fixed bearing with the 600 mark and repeat the measurement.

-Conduct the same measurement on the glass tube.

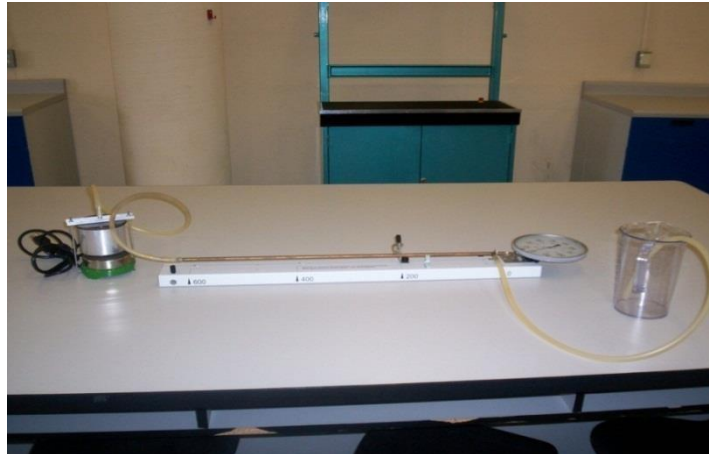


Fig.1: Experiment setup for measuring the linear thermal expansion with the expansion apparatus.

Measuring example

$$P_1 = 21$$

Table 1: Linear expansion ΔS between room temperature P_1 and steam temperature P_2 as a function of the effective length S_1 of the material.

Material	$\frac{S_1}{mm}$	$\frac{\Delta S}{mm}$
Brass	600	0.66
Brass	400	0.57
Brass	200	0.29
Glass	600	0.15
Steel	600	0.58

Evaluation and results

$$9_1 = 21$$

$$9_2 = 100$$

$$9_2 - 9_1 = 79$$

a) Linear expansion of brass tubes of different lengths

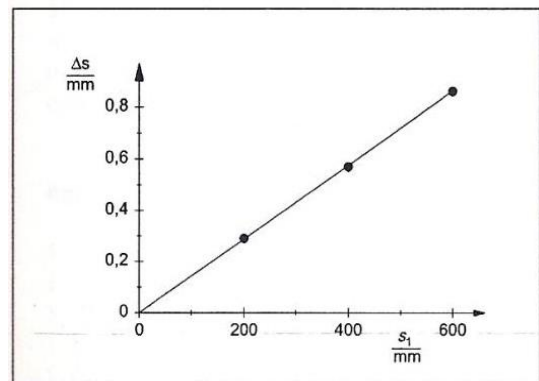


Fig.2 Thermal change in length ΔS of a brass tube as a function of the overall length S .

b) Linear expansion of tubes of different materials

The linear expansion coefficients are calculated from the measuring results from table 1 in accordance with α . Table 2 shows the results together with the literature values.

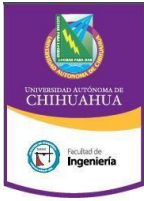


Table 2: Linear expansion coefficient α for different materials

		Measurement	Literature
Material	$\frac{S_1}{mm}$	$\frac{\alpha}{k^{-1}}$	$\frac{\alpha}{k^{-1}}$
Brass	600	$18.1 \cdot 10^{-6}$	$18 \cdot 10^{-6}$
Steel	600	$12.2 \cdot 10^{-6}$	$11 \cdot 10^{-6}$
Glass	600	$3.1 \cdot 10^{-6}$	$3 \cdot 10^{-6}$

PRACTICE 2

P2.1.2.2 DETERMINATION OF THE THERMAL CONDUCTIVITY OF MATERIALS



HEAT

P2.1.2.2

Thermal energy

Thermal conductivity by heat flow measuring plate

The thermal conductivity of different building materials is determined by a reference method on the principle heat flow measuring plate.

Theoretical introduction:

The quantity of heat ΔQ which flows through a sample of building material in the time Δt is proportional to the temperature difference $\Delta\theta$ between the front and rear sides of the plate, and is also proportional to the area A of the plate as well to the reciprocal value of the thickness d of the plate. The proportionality constant is called the thermal conductivity λ :

$$\Delta Q / \Delta t = \lambda * (A / d) * \Delta\theta \quad (1)$$

It is difficult to determine λ directly by measuring the thermal flow, the temperature difference $\Delta\theta$, and the geometrical dimensions of the plate. This is because, in contrast to the electrical current, there are no perfect insulators for heat currents, so that "heat leakages" prevent a simple determination of $\Delta\theta$. Therefore we are using in this experiment a reference method: The thermal conductivity λ_x for an unknown sample P_x is compared with the known value λ_0 of a reference sample P_0 . To do this, both plates are put on top of one other and the same amount of heat flows through both of them. The following equation applies:

$$\Delta Q / \Delta t = \lambda_0 * (A_0 / d_0) * \Delta\theta_0 = \lambda_x * (A_x / d_x) * \Delta\theta_x \quad (2)$$

If both samples are the same dimension with the same areas and thickness for each, it's following:

$$\lambda_x = \lambda_0 * (\Delta\theta_0 / \Delta\theta_x) \quad (3)$$

The heat flow can be calculated with the help (2), if λ_0 , A_0 , d_0 and $\Delta\theta_0$ are known. The reference sample is therefore designated the "heat flow measuring plate". In our experiment is consisting of polystyrene of the thermal conductivity $\lambda_0 = 0.16 \text{ W/(m * K)}$.

Apparatus

- 1 set of building material samples.....389 29
- 1 Heat measuring chamber 389 30
- 3 Temperature probes..... 666 193
- 1 Digital temperature control..... 666 189

1 Digital temperature meter, 4 inputs..	666 209
1 Low voltage set transformer	52 125
1 Ventilator.....	545 20
3 Connecting leads 1 m, black	500 444

Setting up:

The temperature sensors used in the experiment should be immersed into a common water bath. The temperature indications have to be compared first. If differences are stated, deviations from the average value should be noted in the measuring report. Later on the corresponding corrections can be made, so that the values of the significant temperature differences of the building material under test will be correct.

Detailed informations about the “sandwich” assembling of the two sample plates are given in the instruction sheet of the “set of building material samples”; also precise instructions about measuring temperature in the samples, about cooling the sample surfaces, and about casting of such samples in the casting mould.

Fig. 1 Experimental set-up

Fig. 1 is showing a set-up with air cooling and with three temperature probes. A flat plate heater is used to ensure a homogenous heating-up procedure of the samples.

The first material sample P_x to be tested may be e.g. sandwich type (light-grey, fibrous). P_x is usually placed in the lower position, P_0 usually in the upper one.

Temperature measurements are provided for the following positions:

θ_1 At the lower face of P_x

θ_2 In between P_x and P_0

θ_3 At the upper face of P_0

Important note:

Make sure that the temperature probe of the lowest position (measuring θ_1) is connected to the temperature controller!

Carrying out the experiment:

Switch on the power supply of the plate heater (12V AC). Test the function of the temperature controller by variation of the preset temperature for θ_1 : The device should switch off the heating as soon as the actual temperature exceeding the preset value by more than 0.5K.

Adjust the preset value for θ_1 initially value to 60 . When the actually temperature θ_1 has reached the value, the preset value should reduce to 50 , and a time of 20 min. should be given to allow the system to reach its thermal equilibrium. As soon as the temperatures θ_2 and θ_3 remain constant (i.e. changes of less than 0.2K in 5 min.) θ_2 and θ_3 may be read off.

Repeat the measuring procedure with other material samples.

Results:

Tab. 1: Typical measuring examples

Material	$\frac{\theta_1}{\text{in}}$	$\frac{\theta_2}{\text{in}}$	$\frac{\theta_3}{\text{in}}$	$\frac{\lambda}{\text{in W/(m * K)}}$
Sándwich-type plaster	49.7	40.3	28.3	0.20
Insulating foam	50	30.3	25.4	0.04
Chip board	50.2	36.1	25.3	0.12
Gypsum	50.3	32.3	26.9	0.53

The temperature measuring values of tab.1 are already corrected with respect to differences in the indication at the different temperature probes. The temperature differences in equation (2) and (3) are given by: $\Delta Q_x = \theta_1 - \theta_2$ and $\Delta Q_0 = \theta_2 - \theta_3$.

With $\lambda_0 = 0.16 \text{ W/(m * K)}$ as thermal conductivity of polystyrene can be derived from equation (3) for materials with low heat conductivity (normal case):

$$\lambda_x = 0.16 * \Delta Q_x / \Delta Q_0$$

An exception is valid for the gypsum test plate:

$$\lambda_x = 0.16 * \Delta Q_0 / \Delta Q_x$$

From these equations will be obtained the thermal conductivity for each material by inserting θ_1, θ_2 and θ_3 as shown in the last column of Tab. 1

NOTE:

A technical heat flow measuring plate (P_0) for practical determination of the thermal conduction through a wall is realized as shown in Fig. 2. It is consisting of a rubber plate with a lot of embedded thermocouples, which are connected in series an array that all “hot junctions” are placed at one side (face) of the measuring plate and all “cold junctions” at the opposite side. The total voltage produced by all these thermocouples is therefore directly proportional to the temperature difference ΔQ_0 across the plate. From here and for other plate data as area, thickness, and thermal conductivity can be calculated $\Delta Q / \Delta t$.

PRACTICE 3

P2.2.2.1 EFFICIENCY OF A SOLAR COLLECTOR

HEAT P2.2.2.1

Thermal energy

Solar Energy

Efficiency of a solar collector: Comparison of a thermosiphon circulation system With a forced circulation system

By warming water in a collector, the water starts to circulate by itself, i.e. in a “thermosiphon circulation system” in the closed circuit system consisting of the solar collector and reservoir. It will be shown that the efficiency of the collector is considerably increased after circulation pump is put into use.

Solar cells are chiefly for the operation of electronic and even possibly electromechanical units independently of the main supply where electrical energy is needed only in small amounts otherwise difficult obtain.

Pairs of electron holes are generated in the pn-layer of silicone solar cell by incident light radiation. These pairs of electron holes are accelerated by electrical field existing in the pn-layer. Electrons are absorbed by n-type area, and the holes are absorbed by the p-type layer. A voltage U is built up between the connections of the solar cells. This voltage is approx. 0.55 V. If the solar cell is connected to a resistor R , a current flows. The voltage breaks down together with the electrical field, so that charges get separated in the pn-layer, which retain the current.

The direct conversion of radiation energy into electrical by solar cells is inefficient. The

amount converted into electrical energy is about 10%.

A solar collector absorbs radiation energy, and warms itself and the water flowing through it. When the collector is warmer than the environment, it gives off energy to the environment by radiation, convection and thermal conduction. The “efficiency” η , the ratio of the amount of the heat ΔQ given off to water to the absorbed radiation energy ΔE , is decreased by these losses.

$$\eta = \frac{\Delta Q}{\Delta E}$$

The losses are especially high in the thermosiphon circulation system because the collector gets very warm in places and then loses a lot of heat. The driving force for the water cycle occurs in this case because of the difference in density of the warm water in the collector and the cold water in the reservoir, i.e. warm water rises and is displaced by the cold water flowing from behind. To have the same circulation velocities as achieved through the circulation pump, it is necessary that the collector be strongly heated. In a thermosiphon pump, the collector can be kept

at almost the same temperature as the water in the reservoir

In our experiment, we are comparing the warming of water in the reservoir with the

forced circulation and with the thermosiphon, and then we analyse the measured temperature-time diagram.

Apparatus

1 Solar collector	389 50
1 Large stand base, V-shape	300 01
1 Stand rod, 75 cm	300 43
1 Leybold multiclamp	301 01
1 Stand rod, 25 cm	300 41
1 Photo flood lamp, 1000 W	450 70
1 Temperature probe	383 02
1 Digital temperature	
Measuring instrument	666 190
1 Transformer, extra-low voltage	591 09
1 STE-miniature pump	579 22
2 Connecting leads	501 20
Water	

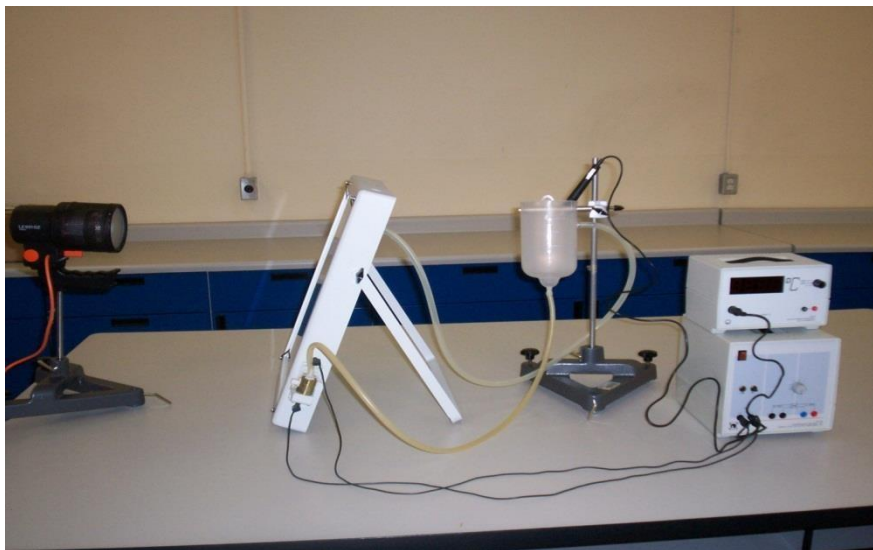


Fig.1: Experiment Setup for force circulation

Settin up and carrying out the experiment:

Note on a): Forced circulation

Set up the apparatus as shown in the fig.1 and connect them to each other. Hang the overflow basin as high as possible, but still in the shadow of the collector. Carry out the experiment without the Plexiglas covering. Close the opening for measuring temperature on the inflow and outflow chamber of the collector with rubber before filling the collector. Attach the outflow basin below the level of the edge of the table and fill it with water, and slowly lift it so the collector is filled from the bottom. Turn on the pump (20 V AC) and refill the outflow basin to the 1000 ml level. Wait few minutes for thermal equilibrium, and then set up the photo flood lamp at 50 cm distance for the collector and turn it on. Concentrate the light of the photo flood lamp on the middle of the collector. Set the lever of the photo flood lamp to the symbol CE. Measure the temperature in the outflow basin every 2 minutes. Stir the water well before each measurement. Terminate the experiment when $T = 50$.

To b) Thermospin circulation

Turn off the pump, replace the water in the outflow basin with cold tap water, turn the pump on and rinse through the collector with cold water for approx. 5 minutes. Alter that, empty the collector remove the pump and connect the outflow supports of the outflow chamber directly to the lower inflow chamber of the collector to produce a thermosiphon circulation system. (Fig. 2)

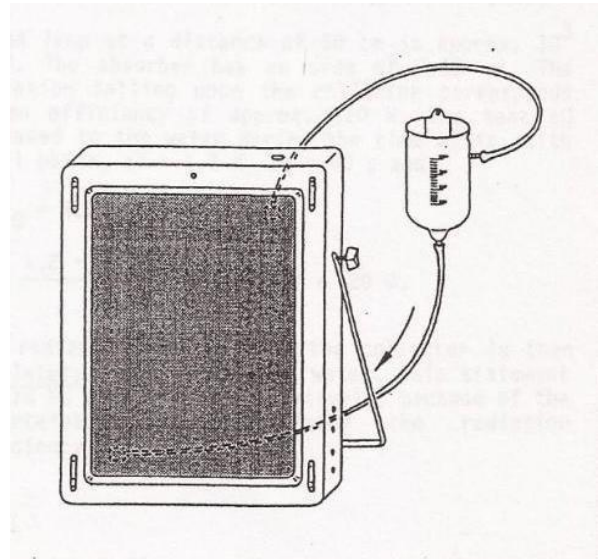


Fig. 2 Water circulation system during thermosiphon circulation

Lower the outflow basin to a level lower than the bottom edge of the collector and fill with water. Fill the hose system and collector from the bottom without forming bubbles by slowly raising the outflow basin. Connect the outflow basin to the stand material so that the water level is slightly above the upper edge of the collector.

For the time being, lay the collector on the table with the absorption surface facing down in order to remove air bubbles from the outflow chamber.

Important:

There must be closed water cycle without air bubbles and the water level in the outflow basin must be at the level of a 1000 ml level before beginning the experiment.

Turn on the photo flood lamp and measure the temperature in the outflow basin every two minutes. Always stir the water before measuring. Measure the temperature T_e of the inflowing water on occasion. To do this, hold the tip of the support for the outflow basin or carefully insert it a little. Terminate the experiment at $T = 30$ or $T_e = 50$ at the latest, because the temperature of the collector is then 60 . (See operating instructions for the allowed maximum temperature).

Measuring example:

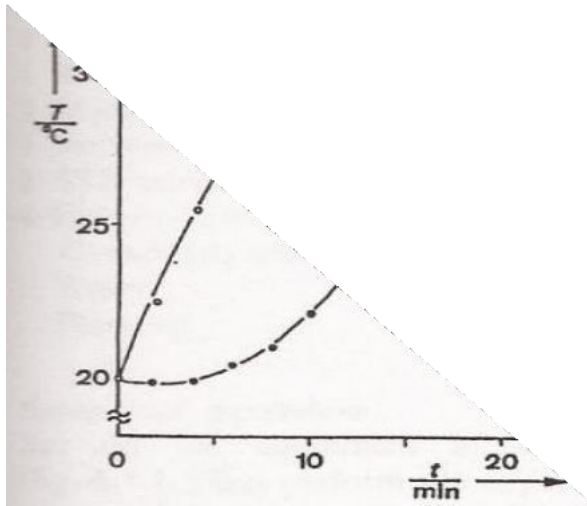


Fig. 3 Temperature T in the outflow basin during thermosiphon circulation (open circles) as a function of the time t .

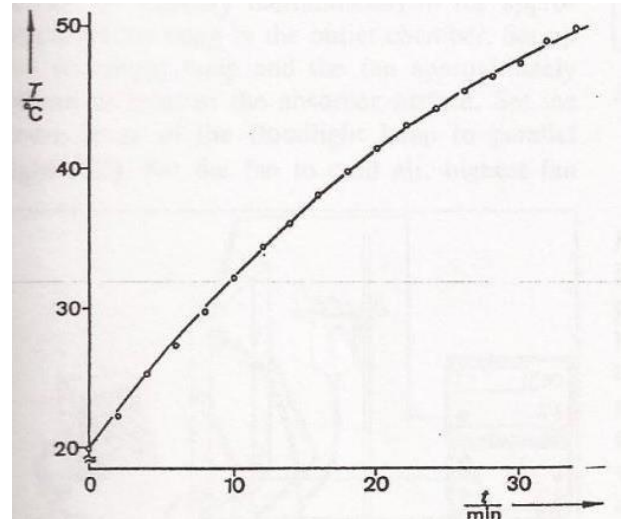


Fig. 4 Temperature T in the outflow basin during forced circulation; extended experiment duration as opposed to Fig. 3

Evaluation and results:

In Fig. 3 we can see that the water in the reservoir is heated only after some time has gone by (here approx. 6 min) during thermosiphon circulation. Afterwards the temperature difference of 5 to 10 K between the collector inflow and outflow temperature. This also corresponds approximately to the temperature difference $T_e - T$.

The temperature increase at the beginning of forced circulation is 1.4 K/min , and it is therefore twice as high as with thermosiphon circulation. This cannot be explained by the supply of energy from the circulation pump, which amounts to a maximum of 10 W , thus less than 10% of radiation efficiency. Fig. 4 shows that heatlosses of the heated absorption area are responsible for the carrying efficiency: the slope of the temperature curve and therefore the

efficiency (see below) decreases with increasing collector temperature. At 50 °C, the temperature increase has decreased to 0.5 K/min (about one third of the initial slope). The low efficiency during thermosiphon circulation can be attributed to the high collector temperature (a little higher than T_e).

Collector efficiency η , i.e. the ratio of quantity of heat Q released to the absorbed radiation energy, can be estimated from the measured values, for example the forced circulation with a low collector temperature: the irradiation energy to the photo flood lamp at a distance of 50 cm is approx. 10^3 W/m^2 . The absorber has an area of 0.12 m^2 . The radiation falling upon the

collector corresponds to an efficiency of approx. 120 W. The heat ΔQ released to the water during the time Δt , with 1.2 lts of water, $\Delta T = 1.4 \text{ K}$, $\Delta t = 60 \text{ s}$ and

$$\frac{3}{2} \cdot 10^{-1} \cdot \rho \cdot c_p \cdot \Delta T = 4.2 \cdot 10^3 \text{ J/kg K}$$

$$\frac{\Delta Q}{\Delta t} = \frac{1 \cdot 4.2 \cdot 10^3 \cdot 1.4}{60} = 120 \text{ W}$$

The radiation falling onto the collector is then completely given off to the water. This statement should be only taken qualitatively, because of the uncertainty when determining the radiation efficiency ($\pm 30\%$).

PRACTICE 4

P 2.2.2.2 EFFICIENCY OF A SOLAR COLLECTOR II

HEAT

P2.2.2.2

Thermal energy

Efficiency of a solar collector II

A Plexiglas cover over the absorption surface reduces the convection losses of a solar collector and thus increases its energy yield.

Apparatus

1 Solar collector	389 50
1 Large stand base, V-shape	300 01
1 Stand rod, 75 cm	300 43
1 Leybold multiclamp	301 01
1 Stand rod, 25 cm	300 41
1 Photo flood lamp, 1000 W	450 70
1 Temperature sensor	666 193
1 Digital temperature Measuring instrument	666 190
1 Variable low voltage transformer S.....	52 135
1 STE-miniature pump	579 22
Connecting leads	501 20
Water	

Patience

Setup and procedure

Set up the equipment in accordance with Fig. 4.1. First perform the experiment without the Plexiglas cover. Before filling the circuit with water, close the temperature measurement opening on the inlet chamber of the collector with the rubber bung insert the temperature sensor (or mercury thermometer) in the appropriate rubber bung in the outlet chamber. Set up the footlight lamp and the fan approximately 50 cm in front of the absorber surface. Set the zoom lever of the foot light lamp to parallel light. Set the fan to cold air, highest fan setting. Lower the outlet vessel below the level of the bench surface and fill with 1 lt of water. The slowly rise it so the collector and the hose system is filled with water form below without bubbles. Switch on

EFFICIENCY OF A SOLAR COLLECTOR II: OPTIMISATION BYE THERMAL INSULATION

the circulation pump, the foot light lamp and the fan and read the temperature in the outlet chamber once a minute. After the maximum temperature (60) has been reached, rinse the collector with cold tap water (use the outlet vessel; never connect the collector directly to the water supply as this could destroy the collector).



Fig. 1 Experiment set up
Fasten the Plexiglas sheet in front of the absorber surface and repeat the experiment.

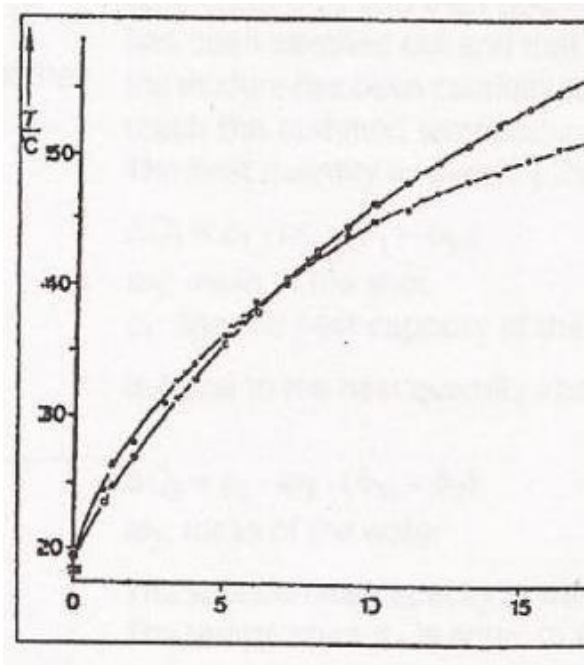


Fig.2 Water temperature T in the solar collector as function of the time t .

1. With Plexiglas cover
2. Without Plexiglas cover

Results

It can be seen in Fig. 2. That, although the Plexiglas absorbs radiation, the collector reaches higher temperatures with the Plexiglas cover than without it with the result that at the beginning of the experiment, the collector temperature increases more rapidly without the Plexiglas sheet. At collector temperatures of 40 and above, however, these radiation losses are more than compensated for by a reduction in convection, and the efficiency of the collector is increased.

PRACTICE 5

P 2.3.2.1 DETERMINATION OF SPECIFIC HEAT IN SOLIDS

HEAT

P2.3.2.1

Heat quantity

Heat capacities

DETERMINING THE SPECIFIC HEAT OF SOLIDS

Objects of the experiments

- Mixing cold water with heated cooper, led or glass shot and measuring the mixture temperature.
- Determining the specific heat f cooper, lead and glass

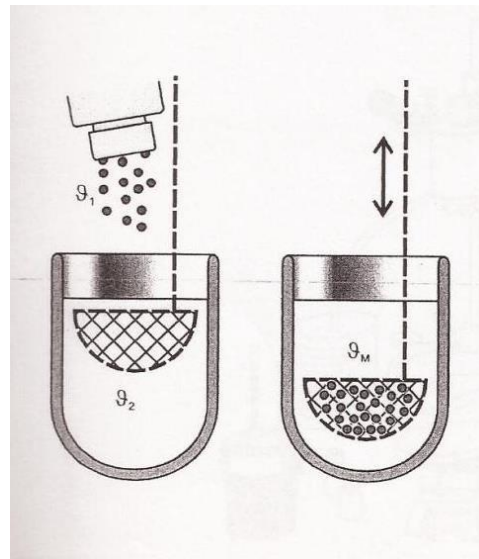
Principles

The heat quantity ΔQ that is absorbed or evolved when a body is heated or cooled is proportional to the change of temperatures ΔP and to the mass m :

$$\Delta Q = c \cdot m \cdot \Delta P$$

(I)

The factor of the proportionality c , the specific heat of the body, is a quantity that depends on the material.



in this experiment, the specific heat capacities of different substances, which are available as shot, are determined. In each case the shot is weighed, heated with steam to the temperature P_1 and then the poured into a quantity of water that has been weighed out and that has the temperature P_2 . After the mixture has been carefully stirred, the pellets and the water reach the common temperature P_m through heat exchange. The heat quantity evolved by the shot:

$$\Delta Q_1 = c_1 \cdot m_1 (P_1 - P_m)$$

m_1 : mass of the shot

c_1 : Specific heat capacity of the shot

Is equal to the heat capacity absorbed by the water:

$$\Delta Q_2 = c_2 \cdot m_2 (P_m - P_2)$$

m_2 : mass of the water

The specific heat capacity of water c_2 is assumed to be known. The temperature P_1 is equal to the temperature of the steam. The unknown quantity c_1 can therefore be calculated from the measured quantities P_2 , P_m , m_1 and m_2 .

$$c_1 = c_2 \cdot \frac{m_2 \cdot (P_m - P_2)}{m_1 \cdot (P_1 - P_m)} \quad (IV)$$

The calorimeter vessel too absorbs part of the heat evolved by the shot. Therefore, the heat capacity

$$c_k = c_2 \cdot m_k \quad (V)$$

Of the water equivalent of the calorimeter vessel has to be taken into account. The absorbed heat quantity calculated in equation (III) is thus more precisely:

$$\Delta Q_2 = c_2 \cdot (m_2 + m_k) \cdot (P_m - P_2) \quad (VI)$$

And equation (IV) is extended to:

$$c_1 = \frac{c_2 \cdot (m_2 + m_k) \cdot (P_m - P_2)}{m_1 \cdot (P_1 - P_m)} \quad (VII)$$

Apparatus

1 Dewar vessel	386 48
1 Cover of Dewar vessel	384 161
1 Copper shot, 200 gr	384 35
1 glass shot, 100 gr	348 36
1 Lead shot, 200 gr	315 76
1 School and lab balance 610 tare	
610 g	315 23
1 thermometer -10 to 110	382 34
Or	
1 temperature sensor NiCr-Ni	666 193
1 Digital thermometer	666 190
1 Steam generator, 550W/220V	303 281
1 heating apparatus ...	384 34
1 Beaker, 400ml	664 104
1 Stand base, V-shape, 20 cm	300 02
1 Stand rod, 47 cm	300 42
1 Leybold multiclamp	301 01
1 Universal clamp, 0... 80 mm dia ...	666 555
1 Silicone tubing int. dia. 7 x 1.5 mm,	
1 m	667 194
1 Pair of heat protective gloves	667 614

Setup and carrying out experiment

The experimental setup is illustrated in fig. 1.

-Mount the heating apparatus in the stand material.

-Fill water into the steam generator, close the device cautiously, and connect it to the top hose connection of the heating apparatus (Steam inlet) with silicone tubing.

Attach silicone tubing to the bottom hose connection of the heating apparatus (steam outlet), and hang the other end in the beaker. See to it that the silicone tubings are securely seated at all connections.

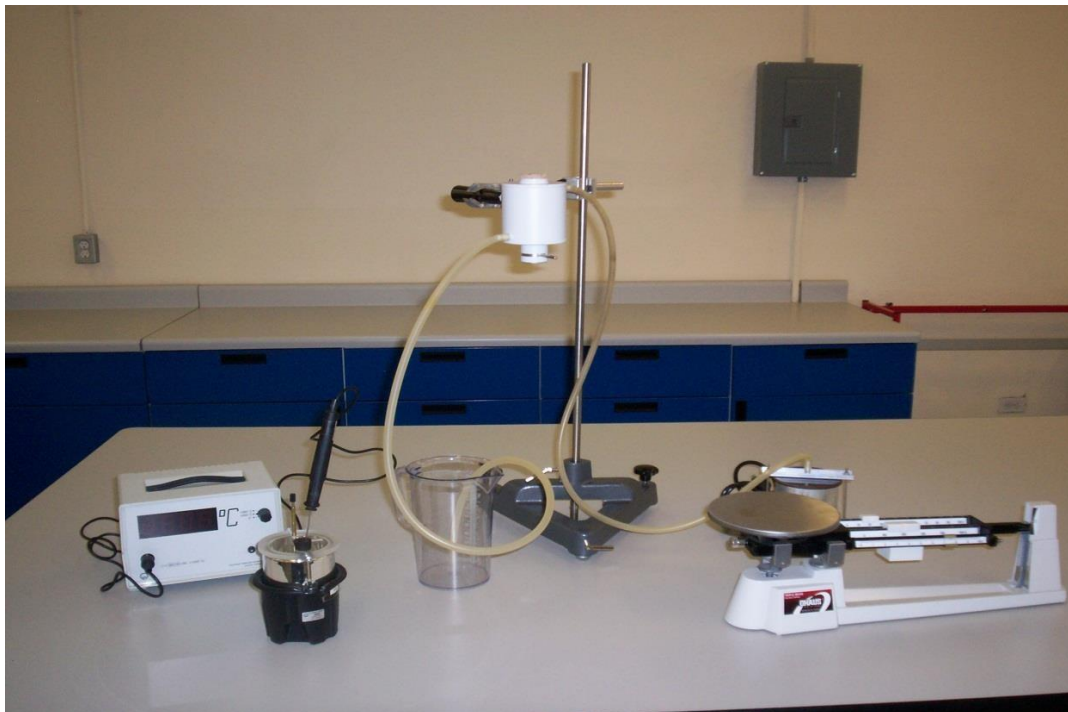
- Fill the sample chamber of the heating apparatus as completely as possible with lead shot, and seal it with the stopper.
- Connect the steam generator to the mains, and heat the shot about 20-25 minutes in the heating apparatus flowed through by steam.

In the meantime:

- Determine the mass of the empty Dewar Vessel, and fill in about 190 g of water.
- Mount the cover for Dewar vessel and insert the thermometer or the temperature sensor respectively

- Measure the temperature P_2 of the water
- Open the cover of the Dewar vessel and shift it aside; leave the mesh for samples of the cover in the Dewar vessel
- Drop the shot with the temperature of 100 into the mesh for samples, close the cover, and thoroughly mix the water stops rising
- Determine the additional mass m of the shot
- Repeat the experiment with copper and glass shot.

Fig. 1. Experimental setup for determinating the specific heat of solids



Measuring example

Mass of the water $m_1 = 180\text{ g}$

Temperature of the shot $P_2 = 100$

Table 1: measured values for determining the specific heat capacities.

Substance	$\frac{m_1}{kg}$	P_1	P_m
Lead	77	24.5	25.4
Copper	69	24	26.2
Glass	19	23.8	24.9

Evaluation

Water equivalent of the calorimeter: $m_k = 23\text{ g}$

Specific heat capacity of water: $c_2 = 4.19 \frac{kJ}{K \cdot kg}$

Table 2: Specific heat capacities determined experimentally and the corresponding values quoted in the literature.

Substance	$\frac{c}{\frac{kJ}{K \cdot kg}}$	$\frac{c}{\frac{kJ}{K \cdot kg}}$
	Experiment	Literature
Lead	0.133	0.1295
Copper	0.367	0.385
Glass	0.656	0.746

In table 2, the specific heat capacities according to equation (VII) are given. The agreement with the values quoted in the literature is satisfactory.

Results

The specific heat capacities of the solids depend on the material and are considerable smaller than the specific heat capacity of water.

PRACTICE 6

P 2.3.3.1

TRANSFORMATION OF MECHANICAL ELECTRICAL ENERGY INTO HEAT

HEAT P2.3.3.1

Heat quantity

Heat as an energy form

TRANSFORMACIÓN DE ENERGÍA MECÁNICA EN ENERGÍA TÉRMICA

Instrucción de seguridad

Elegir el lugar para el experimentador del tal forma que no haya peligro de herirse si la pesa de 5 kg cae por algún motive imprevisto.

Descripción del ensayo

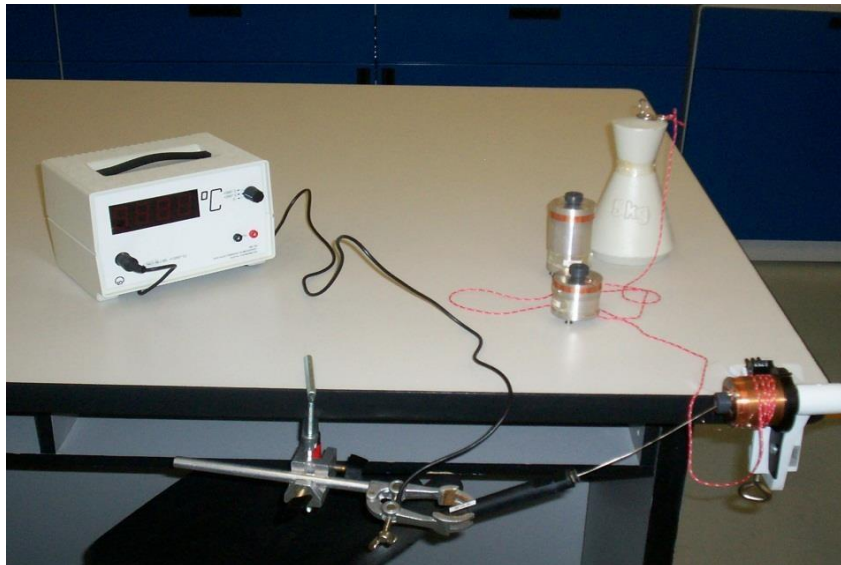
La energía es una de las magnitudes fundamentales de la física. La energía se presente en diferentes formas que pueden transformarse entre si. En un sistema cerrado la energía total se conserva durante los proceso de transformación.

En este ensayo se verifica experimentalmente la equivalencia entre energía mecánica E_m y energía térmica E_{th} . Para ello en el experimento se realiza un trabajo E_m mediante una manivela en contra de la fuerza de fricción. Esto conduce a un temperatura del calorímetro y con ello, un aumento de la energía térmica E_{th} . Mediante la medición de la temperatura T y el número de revoluciones se puede registrar cuantitativamente las 2 formas de energía con las unidades newton-metro (Nm) y Joule (J). De esta forma se verifica experimentalmente y en números la equivalencia: $E_m = E_{th}$.

Equipo requerido

1 Sensor-CASSY	524 010
1 CASSY Lab	524 200
1 Unidad timer o timer S	524 034 o 524 074
1 Unidad de temperatura.....	524 045
1 Sonda de temperatura NiCr-Ni.....	666 193
ó	
1 Adaptador de NiCr-Ni S.....	524 0673
1 Sonda de temperature NiCr-Ni	
tipo K.....	529 676
1 Barrera luminosa, infrarroja	666 193
1 Cable de conexión, 6 polos, 1.5m ...	501 16
1 Aparato básico del equivalente	

Mecánico del calor..... 388 00
 1 Calorímetro
 Por ej.
 1 Calorímetro de agua.....388 01
 O
 1 calorímetro de cobre con calefactor.388 02
 O
 1 Calorímetro de aluminio con
 Calefactor..... 388 03
 1 Pinza de mesa, simple..... 301 07
 1 Base de soporte, forma V..... 300 02
 1 Varilla de soporte, 10 cm..... 300 40
 1 Varilla de soporte, 25 cm.....300 41
 1 Mordaza, pinza cilíndrica.....301 11
 1 Pesa con gancho, 5 kg388 24
 1 PC desde Windows 95/98/NT



Montaje del ensayo (véase el esquema)

- Fije el aparato básico del equivalente mecánico del calor en una esquina de la mesa.
- Fije la pinza del apriete en el borde de la mesa a un distancia de unos 40 cm respecto al soporte de plástico del aparato básico. Sujete la mordaza con pinza cilíndrica a la varilla de soporte de 25 cm para utilizarla posteriormente con la sonda de temperatura tal como se muestra en el esquema.
- Coloque el calorímetro con el taladro hacia arriba y llénelo con agua por la abertura.
- Coloque la junta con el taladro y fíjela con la tapa atornillable.

- Coloque el cuerpo del calorímetro lleno en el aparato básico. Para ellos inserte la espiga del remacho del piso del calorímetro en la ranura del soporte de plástico y gírelo de tal forma que quede enclavado y el cuerpo del calorímetro quede fijo.
- Introduzca la sonda de temperatura lo más profundo posible en la abertura del calorímetro y apriete la tapa atornillable del calorímetro. Dije la sonda con el material de soporte ya listo tal como se muestra en el esquema.
- Coloque la pesa de 5 kg debajo del cuerpo del calorímetro.
- Enrolle la cinta de nylon unas 4 veces (máximo 6) alrededor del calorímetro y sujétela con la pesa que reposa en el suelo. La pesa debe colgar en el lado de la manivela hacia adelante.
- Accione la manivela y verifique si la pesa de 5 kg se eleva unos centímetros y que al continuar girando se mantiene a una altura determinada. En caso de que se eleve demasiado, reduzca el número de vueltas de la cinta de nylon; si no se eleva del suelo, entonces aumente el número de vueltas.
- Monte la barrera luminosa para medir las vueltas nE_{A1} (número de oscurecimientos) usando la base de soporte tal como se muestra en el esquema y conecte la unidad timer a la entrada A del sensor-CASSY.
- Conecte la sonda de temperatura para medir la temperatura P_1 a través de la unidad Temperatura (hembra T1) en la entrada B del sensor-CASSY.

Realización del ensayo

- Ajuste el oscurecimiento a cero, para accione el botón $\rightarrow 0 \rightarrow$ en ajustes nE_{A1} .
- Inicie la medición con **F9**.
- Gire la manivela y mida el aumento de temperatura en función de las vueltas realizadas.
- Detenga la medición con **F9** al alcanzar la temperatura final deseada P_1 .

Evaluación

Durante la medición se puede observar la gráfica de la temperatura P_1 en función de las vueltas. En el diagrama ya preparado **Evaluación** se grafica la energía térmica en función de la energía mecánica aplicada al girar la manivela en contra de la fricción. La energía mecánica E_m resulta del producto de la fricción F y la distancia s :

$$E_m = F \cdot s$$

$$\text{Con } F = m \cdot g$$

$$m = \text{masa de la pesa} = 5 \text{ kg}$$

$$g = \text{aceleración de la gravedad}$$

$$Y \ s = N \cdot d \cdot \pi$$

$$N = \text{número de vueltas}$$

$$d = \text{diámetro del calorímetro} = 0.047 \text{ m}$$

El aumento de la energía térmica como resultado del aumento de temperatura está dado por:

$$E_{th} = C \cdot (P_2 - P_1)$$

La capacidad calorífica C depende del calorímetro usado y deberá ser ingresada en Ajustes C según la siguiente tabla:

Calorímetro	Capacidad calorífica $C/(J/K)$
Agua (388 01)	$40 + m_{H2O} * 4.2$ (Masa del agua en gramos)
Cobre (388 02)	$264 + 4.2$ (para 1 g de relleno de agua en el agujero)
Aluminio (388 03)	$188 + 4.2$ (para 1 g de relleno de agua en el agujero)
Aluminio grande (388 04)	$384 + 4.2$ (para 1 g de relleno de agua en el agujero)

Mediante el ajuste de una recta que pasa por el origen se puede verificar la equivalencia entre energía mecánica y térmica. La pendiente de la recta es usualmente un poco menor a 1. Esto se debe a las pérdidas de calor no registradas, como por ejemplo, el contacto con la cuerda de nylon o con el soporte de plástico.

PRACTICE 7

P 2.3.4.1 CONVERTING ELECTRICAL ENERGY INTO HEAT

HEAT

Heat quantity

Conversion of electrical energy

P2.3.4.1

CONVERTING ELECTRICAL ENERGY INTO HEAT ENERGY – MEASURING WITH THE VOLTMETER AND AMPMETER

Objects of experiment

- The aim of the experiment is to establish the equivalence of electrical and heat energy

Theory:

Water will be heated up and from the temperature difference we will calculate the heat energy. The electrical energy will be measured with 2 millimeters and with the duration we can calculate the electrical energy.

We will use a Dewar vessel to minimize the losses of heat during the experiment. It must additionally be taken into account that the vessel itself possesses a certain heat capacity c_d (dependent on the liquid height). In order to determine c_d with water of a mass m_2 is poured into a calorimeter and the initial temperature v_2 is measured after heat compensation.

A quantity of water m_1 with a higher temperature v_1 is then added. The mixture temperature t_m is again obtained after heat compensation. The quantity of heat given off is described by:

$$\Delta Q_1 = c_1 m_1 (v_1 - v_m)$$

$$\Delta Q_2 = (c_d + c_2 m_2) (v_m - v_2)$$

Where $c_1 = c_2 = c_w$ (specific heat of water), we obtain the following

$$K = \frac{c_d}{c_w} = \frac{m_1(v_1 - v_m) - m_2(v_m - v_2)}{(v_m - v_2)}$$

The coefficient K can be seen as the mass of the water quantity which has the same heat capacity as the calorimeter.

The electrical energy can be calculated by:

$$E = UI \cdot \Delta t$$

With the voltage U and the current I and the time difference. If the temperature increases from v_1 to v_2 , we can set:

$$E = UI \cdot \Delta t = c_w (K + m_w) (v_2 - v_1)$$

Apparatus

1 Electric calorimeter attachment.....	384 20
1 Dewar vessel.....	384 48
1 thermometer –10 to 110	382 34
Or	
1 Digital thermometer.....	666 190
1 temperature sensor NiCr-Ni	666 193
Or	
1 Mobile CASSY.....	524 009
1 NiCr-Ni Adapter S.....	524 0673
1 NiCr-Ni temperature sensor 1.5 mm	529 676
1 Stop clock.....	313 07
1 Beaker, 250 ml squat.....	664 103
1 graduated cylinder, 250 ml.....	665 755
1 Multimeter LDanalog 20	531 120
1 Multimeter LDanalog 30	531 130
1 Variable extra low-voltage transformer.....	300 42
3Connecting lead 50 cm black.	501 28
1 Pair of cables 50 cm red/blue	501 45

Measuring example

In a mixing experiment we can measure the water equivalent of the calorimeter. We will get a value around 9.5 g. Please note that this value is a function of the filling of the calorimeter. Use always the same filling level or make a measurement as function of the level.

Mass of the water $m_w = 170 \text{ g}$
 Initial temperature $T_1 = 20.05$
 Final temperature $T_2 = 25.10$

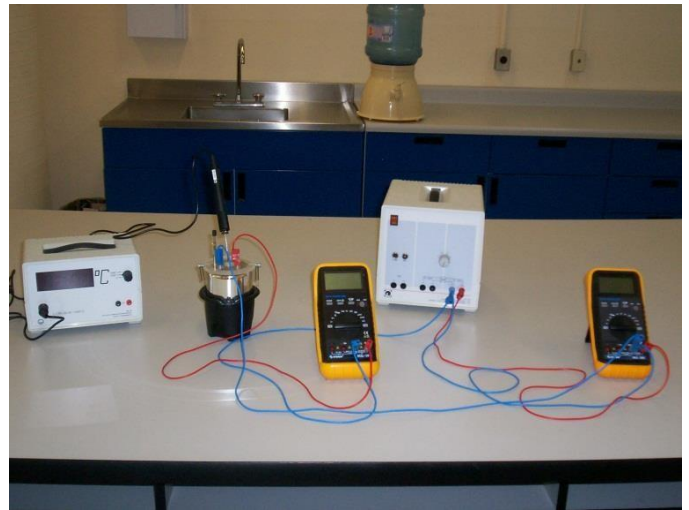


Fig. 1: Experimental setup for measuring with
 The digital thermometer 666 190

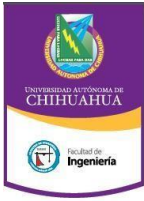
Time difference $t = 300 \text{ s}$

Current $I = 2.72 \text{ A}$

Voltage $U = 4.7 \text{ V}$

Evaluation and results

We can calculate the electrical energy
 $E_{elec} = U I t = 3835 \text{ Ws} = 3835 \text{ J}$. With a
 literature value of $c_w = 4.2 \text{ J/gK}$ for the
 specific heat of the water we get the heat
 energy $E_{heat} = 3807 \text{ J}$.



PRACTICE 8

P2.4.1.1 DETERMINATION OF THE SPECIFIC HEAT OF VAPORIZATION OF WATER

HEAT

P2.4.1.1

Phase transitions

Latent heat and vaporization heat

DETERMINING THE SPECIFIC VAPORIZATION HEAT OF WATER

Objects of the experiment

- Measuring the mixing Temperature T_m of the cold water and steam
- Calculating the specific vaporization heat of water

Principles

When heat is transformed to a substance at a constant pressure, the temperature of the substance generally increases. If a phase transition takes place, the temperature does not increase as the transferred heat is consumed in the phase transition. As soon as the phase transition is finished, the temperature increases again if the heat transfer is continued. A well-known example of a phase transition is given by the vaporization of water. The heat consumed per mass unit is called the specific vaporization heat Q_v .

In the experiment, the specific vaporization heat of the water is determined by piping pure steam into the calorimeter. The steam warms cold water up to a mixing temperature T_m and condenses to water, which is cooled down to the mixing temperature. The vaporization heat is transferred to the water. In addition to the mixing temperature, the initial temperature T_2 and the mass m_2 of the

cold water as well as the mass m_1 of the condensed water are measured so that the vaporization heat can be calculated follows:
The heat emitted by the steam is the sum of the heat

$$\Delta Q_1 = c \cdot m_1(100 - T_m)$$

C =specific heat of the water

Which the condensed water emits cooling down from $T_1 = 100$ to the mixing temperature T_m , and the heat ΔQ_2 , which is emitted in the process of condensation from steam to water. Latter is the heat that has to be transferred to water at a temperature of $T_1 = 100$ in order that it vaporizes again; therefore we have:

$$\Delta Q_2 = m_1 \cdot Q_v$$

Fig. 1: Experimental setup for determination of the specific vaporization heat of water.



Apparatus

1 Dewar vessel calorimeter with base384 48
1 School and lab balance 610 tare,	
610 g.....	315 23
1 thermometer –10 to 110	382 34
Or	
1 Digital thermometer.....	666 190
1 temperature sensor NiCr-Ni	666 193
1 Steam generator, 550W/230V.....	303 28
1 Water separator.....	529 676
1 Silicone tubing int Dia. 7x1.5mm, 1m..	667 194
1 Beaker, 400 ml, ss, hard glass.....	664 104
1 Stand base, V-shape, 20 cm.....	300 02
1 Stand rod, 47 cm	300 42
2 Leybold multiclamps.....	531 130
1 Universal clamps, 0, 80 mm dia	666 555
Additionally required:	
Distilled water	

The heat absorbed by the cold water in mixing with the steam is:

$$\Delta Q_3 = c \cdot m_2 \cdot (T_m - T_2)$$

At the same time, the calorimeter absorbs heat, which can be calculated since the water equivalent of the calorimeter is known:

$$\Delta Q_4 = c \cdot m_k \cdot (T_m - T_2) \text{ with } m_k = 20g$$

As the emitted heat $\Delta Q_1 + \Delta Q_2$ and the absorbed heat $\Delta Q_3 + \Delta Q_4$ are equal:

$$\frac{Q_v}{c} = \frac{(m_2 + m_k)}{m_1} \cdot (T_m - T_2) - (100 - T_m)$$

Is found.

Setup

Experimental setup is illustrated in fig. 1. While the experiment is carried out, the Dewar vessel is placed on the school and lab balance.

- Clamp a thermometer or the temperature sensor NiCr-Ni
- Fill the distilled water into the steam generator to high up about 2 cm, put a lead, and carefully close the gripping device.
- Shift the steam inlet tube of the water separator so that the distance to the lower stopper is larger than the distance to the upper stopper. Shift the steam outlet to until the almost reaches the upper stopper.
- Use the silicone tubing to connect the steam outlet to of the steam generator to the steam inlet tube of the water separator. Do not clamp the water separator yet.

Filling cold water into the Dewar vessel:

- Read the mass of the empty Dewar vessel.
- Fill about 150 g of distilled water into the vessel and determine its mass m_2 and temperature T_2 .
- Clamp the water separator so that the steam outlet is about 1 cm higher than the middle of the button of the Dewar vessel. If necessary, extend the tube with a sharp piece of silicone tubing.
- Determine the total mass of the arrangement.

Piping steam into the vessel:

- Put the water separator into the beaker and make certain that a silicone tubings are well fixed.
- Connect the steam generator to the mains and wait to the steam to escape.
- Clamp the water separator over the Dewar vessel once more and observe the increase of the total mass and the raise of the temperature.
- After the total mass has increased by about 20 g switch the steam generator of and quickly determine the mixing temperature.

Carrying out the experiment:

Measuring example:

Mass of the cold water $m_2 = 153.8\text{ g}$

Temperature of the cold water $T_2 = 28.1$

Apparent mass after immersion of the water: 154.3 g

Mass after the steam piped in: 174 g

Mixing temperture $T_m = 88.3$

Evaluation and results

$$m_1 = 19.7$$

$$m_2 = 153.8\text{ g}$$

$$m_k = 20\text{ g}$$

$$\text{Specific heat of the water } c = 4.19 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

$$\frac{Q_v}{c} = 520\text{K and } Q_v = 2.18 \cdot 10^3 \frac{\text{kJ}}{\text{kg}}$$

PRACTICE 9

P 2.4.1.2
DETERMINATION OF
THE SPECIFIC
LATENT HEAT OF
ICE

HEAT

P2.4.1.2

Phase Transitions

Latent heat and vaporization heat

DETERMINING THE SPECIFIC LATENT HEAT OF ICE

Objects of experiment

- Measuring the mixing Temperature T_m of ice and water
- Calculating the specific latent heat of ice

Principles

When heat is transferred to a substance at constant pressure the temperature of the substance in general increases. If, a phase transition takes place, the temperature does not increase as the the transferred heat is consumed in the phase transition. As soon as the phase transition is finished the temperature increases again if the heat transferred is continued. A well-known example of a phase transition is given by the melting of water tube ice. The heat consumed per mass unit is called the specific latent heat Q_s .

In the experiment, the specific latent heat of ice is determine by mains a calorimeter fill eith ice. The ice cools warm water to the mixing temperature T_m . In addition, it absorbs the latent heat. Besides the mixing temperature, the initial temeperature T_2 and the mass m_2 of the warm water as well of the mass m_1 of the ice are measured, so the latent heat can be calculated as follows:

The heat absorbed by the ice is the sum of the heat

$$\Delta Q_1 = c \cdot m_1(T_m - 0)$$

C: Specific heat of water

Which the melted water absorbs in warming up from $T_1 \approx 0$ to the temperature T_m and the heat.

$$\Delta Q_2 = m_1 \cdot Q_s$$

Which is absorbed in the process of melting from ice to water. The heat taken form the warm water when it is mixed with ice is

$$\Delta Q_3 = c \cdot m_2(T_2 - T_m)$$

At the same time heat is taken from the calorimeter. This heat can be calculated since the water equivalent m_k of the calorimeter is known:

$$\Delta Q_4 = c \cdot m_k (T_2 - T_m) \text{ with } m_k = 20 \text{ g}$$

As the emitted heat $\Delta Q_1 + \Delta Q_2$ and the emitted heat $\Delta Q_3 + \Delta Q_4$ are equal:

$$\frac{Q_s}{c} = \frac{(m_2 + m_k)}{m_1} \cdot (T_2 - T_m) - (T_m - T_0)$$

Fig. 1: Experimental set up for the determination for the specific latent heat of ice



Apparatus

1 Dewar vessel	384 48
1 School and lab balance 610 tare, 610 g	315 23
1 thermometer –10 to 110	382 34
Or	
1 Digital thermometer	666 190
1 temperature sensor NiCr-Ni	666 193
1 Immersion heater	303 25
1 Beaker, 400ml SS hard glass	664 104
1 Plastic beaker, 1000ml	590 06

Additionally required
100 g ice cubes

Setup

The experimental setup is illustrated in fig. 1. While the experiment is carried out the Dewar vessel is placed on the the school an lab balance.

- Put the ice cubes into the beaker, which should be filled with cold water to a quarter so the ice reaches a temperature of 0 (check with a thermometer or a temperature sensor)
- Place the thermometer or the temperature sensor right into the dewar vessel.

Carrying out the experiment

- Read the mass of the empty vessel.
- Warm water up to the a temperature between 40 to 50 in the plastic beaker.
- Fill about 200 g of the warm water into the dewar vessel and determine its mass m_2 and temperature T_2 (stir).
- Put 50 g of "dry" ice cubes into the warm water.
- Stir until the ice has completely melted and read the temperature T_m .

Measuring example:

Mass of the warm water $m_2 = 200 \text{ g}$

Temperature of the warm water $T_2 = 45.8$

Mass of water and ice = 251 g

Mixing temperature of the warm water $T_m = 23$

Evaluation and results:

$m_1 = 51 \text{ g}$

$m_2 = 200 \text{ g}$

Water equivalent of the Dewar vessel $m_k = 20 \text{ g}$

specific heat of water $c = 4.19 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$

$\frac{Q_s}{c} = 75.3 \text{ K}$ and $Q_s = 316 \frac{\text{kJ}}{\text{kg}}$

PRACTICE 10

P 2.4.3.1 OBSERVATION OF THE TRANSITION PHASE BETWEEN LIQUID AND GAS AT THE CRITICAL POINT

HEAT

Phase Transitions

Critical temperature

P2.4.3.1

OBSERVING THE PHASE TRANSITION BETWEEN THE LIQUID AND THE GAS PHASE AT THE CRITICAL POINT

Objects of experiment

- Observing the dissolution of the phase boundary between liquid and gas when heating above the critical temperature.
- Observing the formation of the phase boundary when cooling below the critical temperature.
- Observing the critical opalescence
-

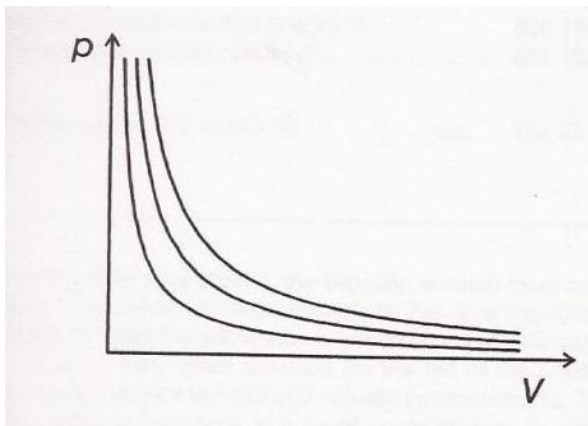


Fig. 1: pV diagram with the isotherms of an ideal gas

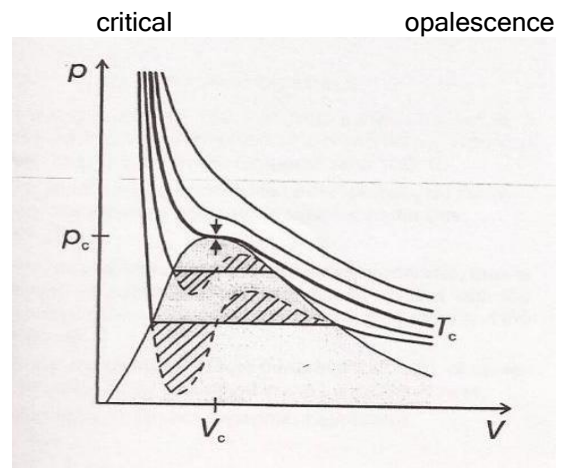


Fig. 2: pV diagram with the isotherms of a real substance. A liquid vapour mixture it sees in the shaded range. The arrows mark the critical point

Principles

One important characteristic of an ideal gas is that it does not condense, not even when the temperature approaches absolute zero. Such a gas does not exist in nature, as it would have to consist of particles, which are more in relation to their mean spacing even at low temperatures and except for elastic collisions do not interact with each other. When an ideal gas is compressed at a constant temperature the pressure increases inversely proportional to the volume. The relationship between the pressure p , the temperature T and the molar volume V of an ideal gas is described by the state equation for ideal gases $pV = RT$ ($R = 8.314 \frac{\text{J}}{\text{mol}\cdot\text{K}}$).

Most real gases approach the properties of an ideal gas when they are far enough away from their condensation or liquefaction point at room temperature and atmospheric pressure. As the gas approaches the condensation point at high pressure p or low temperature T its properties deviate significantly from those of an ideal gas. The density of the gas increases and the particles are on the average extremely close together. The behaviour of real gases is approximately by the Vander-Walls equation of state $(p + \frac{a}{V^2})(V - b) = RT$. In this equation the substance dependent Vander-Walls constant a , b , signify the mutual attraction of their effective volumes.

Fig.2 Shows the isotherms of a real gas in a pV diagram. The isotherm to which a horizontal tangent can be applied at the turning point is of particular importance. The turning point is referred to as the critical point; the quantities associated with this point are called critical Pressure p_c , critical molar volume V_c and the critical temperature T_c . Above the critical temperature the substance is gaseous at all pressures and the isotherms conform to the Vander-Walls equation which approaches the state of ideal gases here. The substance is termed a gas.

Below the critical temperature the situation is more complicated. If the volume is large

enough (in Fig. 2 to the right of the shaded range) the substance is gaseous and is referred to as a vapour. In very small volumes (to the left of shaded range) the substance is liquid and virtually incompressible. The shaded range corresponds to a liquid vapour mixture in which the vapour proportions form left to right. This is where the Vander-Walls Equation deviates from reality: At a constant temperature a change in the volume changes the vapour proportion on the mixture but not its pressure. The curve sections drawn with dashes which correspond to the Vander-Walls equation must be replaced by horizontal curve sections. This shows the vapour pressure at which the vapour and liquid are at equilibrium with respect to each other. As the liquid and the gas have different densities they are normally separated by gravity. The density of the vapour increases with the temperature while the liquid decreases. At the critical temperature these densities are identical. Liquid and vapour can no longer be distinguished: they are completely mixed.

As a mixture approaches the critical point, the light scattering within the pressure chamber reaches an extremely high level. This phenomenon is called the critical opalescence, and is caused by variations in density.

The pressure chamber for observing the critical temperature allows us to demonstrate these phenomena. The cladding of the chamber is heated by a flow of hot water or steam. The two high-pressure resistant flat glass panes allow us to observe the behaviour of the filling inside the chamber when it exceeds the critical temperature due to heating, and again during cooling.

This pressure chamber contains a filling of sulfurhexafluoride SF_6 . At room temperature, its critical density—the inverse of the critical volume—is a close approximation of the average of the liquid and gas densities. At room temperature the pressure chamber is filled about half way with liquefied gas so that

the system passes through the critical point when heated.

SF_6 Have the following thermodynamic variables in the critical point:

Critical temperature = 318.7 K

Critical Pressure = 37.6 Bar

Critical molar volume = $200 \frac{cm^3}{mol}$

Safety notes

- The pressure chamber for demonstrating the critical temperature is on their higher pressure (minimum 20 Bar).
- Read and observe the safety notes contained in the instruction sheet
- Never unscrew the assembling screws

The gaskets used to seal the glass panes also act as a safety valve in the event of

Apparatus

1 Pressure chamber for

Demonstrating the critical temperature 371 401

1 Lamp, 6 V, 30 W 450 51

1 Lamp housing 450 60

1 Spherical condenser 460 20

1 Transformes, 6 V AC, 12 V AC, 30 VA ... 562 73

1 Small optical bench 460 43

1 Lence in holder $f=100mm$ 460 03

1 Right angled prism 461 11

4 Leybold multiclamp 301 01

1 Large stand base, V-shape 300 01

For heating

1 Circulation thermostat 30...100 666 768

2 Silicone tubing 7x1.5mm 1m 667 194

Or

1 Steam generator 550 W/230 V 303 28

1 Silicone tubing 7x1.5mm 1m 667 194

1 Beaker 400 ml 664 104

Temperature measurement

1 Digital thermometer 1 input 666 190

1 Temperature sensor NiCr-Ni 666 193

Or

1 1 thermometer -10 to 150 382 333

extreme overheating. They can be used at a maximum temperature of 100 .

- To ensure a long service life of the gaskets to don no allow the pressure chamber to become hotter than 90 .

Particularly when heating with steam generator there is a danger of bombs and scalding due to contact with the pressure chamber, the steam generator, the tubing and the receptacle.

- If you are using the steam generator observe the safety notes obtained in the instruction sheet.

- Do not touch the hot experiment apparatus.

Setup

Fig. 3 shows the experiment setup.

Note on using the steam generator:

Cut the silicone tubing into 2 sections of 0.5 m long to prevent the condensation in the tubing.

- Before connecting the silicone tubing, check the heating channel of the pressure chamber for obstructions by blowing through it.
- Before inserting the temperature sensor, add e.g. a little water in the corresponding hole for better heat transfer.
- Mount the aspherical condenser on the lamp housing.
- Set up the assembly as shown in fig. 3 so that the lamp, the glass panes of the pressure chamber, the lens and the right angled prism are all along one axis.
- Check the seating of the silicone tubing every time before putting the apparatus into operation, to ensure that no steam or hot water can escape in an uncontrolled manner and cause damage or injury.
- Connect the lamp to the transfer and project the contents of the pressure chamber on a light-coloured surface (e.g. a sheet of white paper tacked to the wall). Readjust the setup as necessary.
- Focus the image of the liquid meniscus by moving the lens to the small optical bench.



Fig. 3: The exact position of the individual components on the optical bench depends on the distance of projection surface and can be found most easily by moving the lens. Setup With steam generator for heating the pressure chamber.

Carrying out the experiment

Note on the steam generator:

When heating with steam the temperature in the pressure chamber for observing the critical temperature increases very quickly and is very difficult to control. The water in the reservoir must not boil so intensely that steam and water are both forced into heating channel together.

Do not fill the reservoir of the steam generator above 2 cm level.

Switch off the steam generator immediately when the water begins to boil

Make sure that the condensed water in the beaker cannot reach the level of the tubing, so the condensed water is not sucked back in when the system cools; this could cause damage to the pressure chamber due to thermal shock.

The following description is based on the use of circulation thermostat:

- Darken the room to observe the projected image.
- Switch the circulation thermostat and initially set it to a temperature of 40 °C.
- Starting from about 40 °C, increase the set temperature on the circulation thermostat slowly to ensure more even heating of the substance and enable clear observation of the disappearance of the phase boundary.
- After the system exceeds the critical temperature, set the circulation thermostat to a level below the critical temperature.

- To reduce the effects of troublesome temperature gradients over the volume of the chamber, it may be advisable after the system falls below the critical temperature to again slowly increase the temperature and repeat the experiment.

Measuring example and evaluation

The occurrence of the phenomena described in the following depends on the speed which the critical temperature is exceeded. The effects noted under "heating" occur when the circulation thermostat is used; When the steam generator is used, the reaction is more violent and over more quickly.

Heating:

Shortly after you start heating, characteristic streaking (sometimes called "schlieren") appears in the liquid phase. Next, the liquid begins to boil, and condensate drips from the top sections of the chamber walls. Finally, we can also see streaking in the gas phase, particularly at the boundary.

Shortly before the critical temperature is reached, the boiling is so violent that the liquid is inhomogeneous due to the gas bubbles, scatters the light diffusely. This makes the projected image of the liquid phase darker. The streaking becomes more intense, initially in the gas phase directly above the boundary, then in the entire gas and finally in the remaining liquid phase as well.

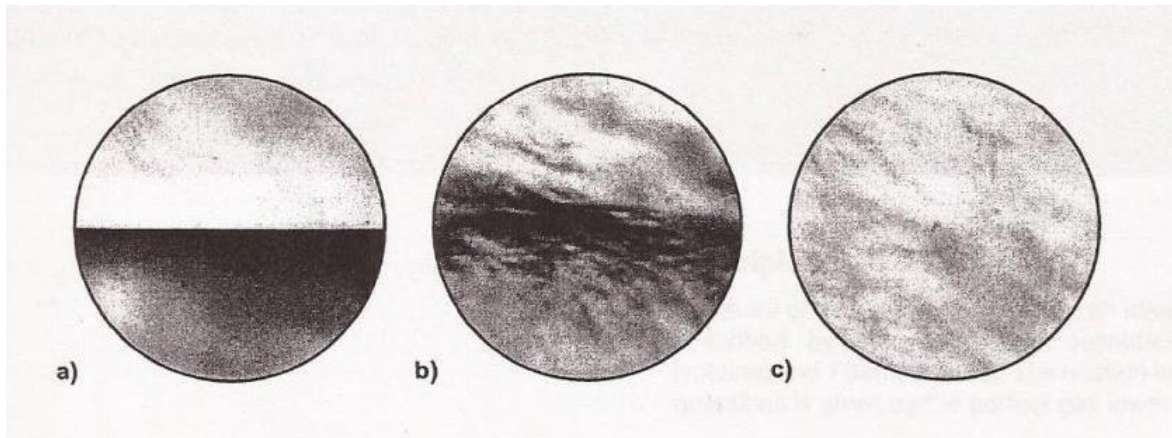


Fig. 4: The contents of the pressure chamber:

- a) Below the critical point
- b) At the critical point
- c) Above the critical point

Cooling:

When the heating is switched off, the streaking initially disappears almost completely, before stronger again as the critical temperature. At the bottom of the chamber, we can observe a slight darkening

caused by the formation of mist. The entire Chamber unit appears increasingly red-brown (critical opalescence) and the streaking increases further. Suddenly, the inside of the pressure chamber darkens, the gas condenses and a rise in the liquid level can be observed. The gas phase contains mist, which gradually condenses. Finally, the gas phase becomes clearer, while the liquid phase continues boiling.

Reheating:

The liquid Boils more intensely again, then the gas phase appears yellowish and the liquid phase is reddish-brown (critical opalescence). The phase boundary becomes broader, and then disappears completely. Finally, the temperature range in which critical opalescence occurs is exceeded and we can see only the turbulence related streaking in the chamber.

PRACTICE 11

**P 2.5.2.1 VOLUME OF A GAS
DEPENDENT ON PRESSURE
AT CONSTANT
TEMPERATURE AT
CONSTANT PRESSURE**

HEAT

Kinetic theory of gases

Gas laws

P2.5.2.1

PRESSURE-DEPENDENCY OF THE VOLUME OF A GAS AT CONSTANT TEMPERATURE (BOYLE-MARIOTTE'S LAW)

Objects of experiment

- Measuring the volume V of an air column as a function of the pressure p at a constant temperature T
- Confirm Boyle-Mariotte's law

Principles

The state of a quantity of n moles of an ideal gas is completely described by the measurable quantities p (pressure), V (volume) and T (temperature). The relation between these 3 quantities is given by the perfect gas laws:

$$p \cdot V = n \cdot R \cdot T \quad (I)$$

$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$: gas constant

If p , V or T remains constant, the other 2 quantities cannot be varied independently of each other. At a constant temperature, for example, Boyle-Mariotte's law states:

$$p \cdot V = \text{constant} \quad (II)$$

This law is confirmed in the experiment by

means of a gas thermometer. The gas thermometer consists of a gas capillary open at one end. A certain quantity of air is enclosed by means of a mercury seal. At an outside pressure p_0 , the enclosed volume is V_0 .

By pumping off air at room temperature with the hand pump, an under pressure Δp with respect to the outside pressure is generated

at the open end of the capillary so the pressure there is $p_0 + \Delta p$. The mercury seal itself exerts a pressure

$$p_{Hg} = \rho_{Hg} \cdot g \cdot h_{Hg} \quad (III)$$

$\rho_{Hg} = 13.6 \text{ g cm}^{-3}$: density of the mercury

g : acceleration of the free fall

h_{Hg} : height of the mercury seal

On the enclosed air so the pressure of the air is

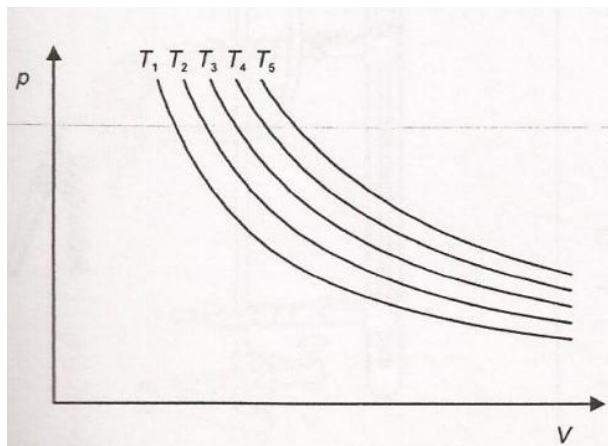
$$p = p_0 + p_{Hg} + \Delta p \quad (IV)$$

The volume of the enclosed air column is determined by the pressure p . V can be calculated from the height h of the air column and the cross-section of the capillary.

$$V = \pi \cdot \frac{d^2}{4} \cdot h \quad (V)$$

$d = 2.7 \text{ mm}$: inside diameter of the capillary

pV diagram of an ideal gas at a constant temperature T



Apparatus

1 Gas thermometer.....	382 00
1 Hand vacuum and pressure pump... 375 58	
1 Stand base, V shape, 20 cm.....	300 02
1 Stand rod, 47 cm.....	300 42
2 Clamps with jaw clamp.....	301 11

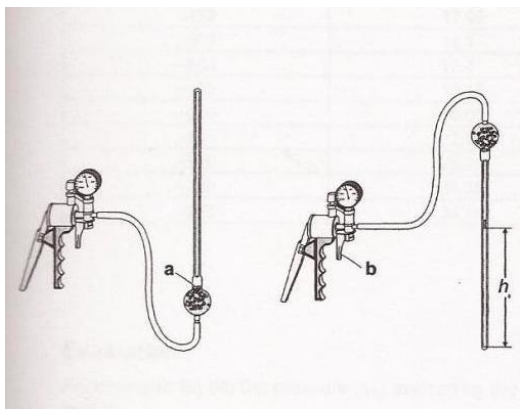
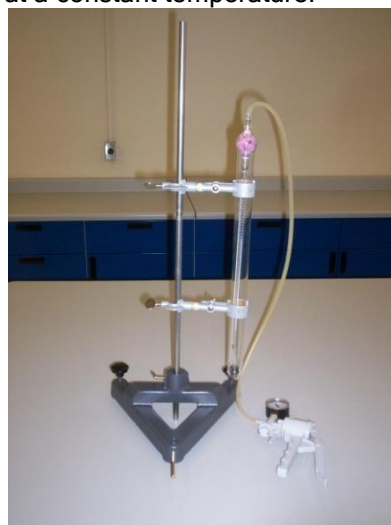


Fig 1: Collecting the mercury globules and adjusting the initial volume V_0 .

Fig. 2: Experimental setup for investigating the pressure-dependency of the gas volume at a constant temperature.



Setup:

Collecting the mercury globules:

- Connect the hand pump to the gas thermometer, and hold the thermometer so its opening is directed downward (see Fig. 1).

- Generate maximum underpressure that the hand pump, and collect the mercury in the bulge (a) so that it forms a drop.
The manometer of the pump displays the underpressure as a negative value.
- If there are mercury globules left, move them into the bulge (a) by slightly tapping the capillary.
A small mercury globule which might have remained at the sealed end of the capillary will not affect the experiment.

Adjusting the gas volume V_0 :

- Slowly turn on the gas thermometer into position for use (open end upward) so the mercury moves to the inlet of the capillary.
- Open the ventilation valve (b) of the hand pump carefully and slowly to reduce the under pressure to 0 so the mercury slides down slowly as one connected seal.

Carrying out the experiment:

- Determine the outside pressure p_0
- Read the height of the mercury seal from the scale of the gas thermometer.
- Generate an under pressure with the hand pump and increase it step by step.
- Each time read the height h of the air column, and record it with Δp .

Measuring example:

Outside pressure: $p_0 = 1011 \text{ hPa}$

height of the mercury seal: $h_{Hg} = 11 \text{ mm}$

Table 1: The height of the enclosed quantity or air as a function of the under pressure.

$\frac{\Delta p}{\text{hPa}}$	$\frac{h}{\text{cm}}$
0	7
-60	7.7
-100	8
-150	8.45
-200	8.9
-250	9.5
-300	10.5
-340	10.95
-410	12.1
-450	12.95
-500	14.1
-550	15.4
-600	17.15
-650	20.05
-690	22.5
-740	26.75
-780	31.35
-800	34.75

Evaluation

According to the equation (III) the pressure p_{Hg} exerted by the mercury seal is:

$$p_{Hg} = 13.6 \frac{\text{g}}{\text{cm}^3} \cdot 9.81 \frac{\text{m}}{\text{s}^2} \cdot 11 \text{ mm} = 15 \text{ hPa}$$

Table 2: The pressure p (calculated from the values of table 1) of the enclosed quantity of air as a function of the volume V (calculated from the values in table 1).

$\frac{V}{\text{mm}^3}$	$\frac{p}{\text{hPa}}$
401.1	1026
441.1	966
458.4	926
484.2	876
510	826
544.4	776
601.7	726
627.4	686
693.3	616
742	576
807.9	526
882.4	476
982.7	426
1148.9	376
1289.3	336
1532.8	286
1796.4	246
1991.2	226

Fig. 3: The pressure p of the enclosed air column as a function of the volume V at the constant temperature T

Fig. 3 shows a plot of the measuring values of table 2. The smooth curve drawn is the hyperbola

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

With $C = 424000 \text{ hPa mm}^3$

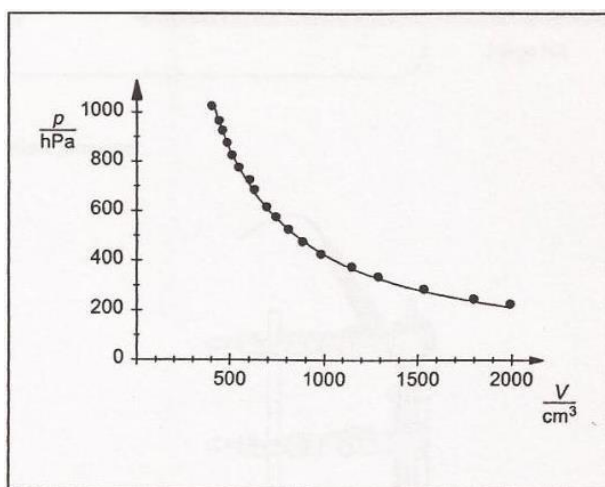
Within the accuracy of measurement, the curve agrees with the measuring values.

Results:

At constant temperature, the pressure and the volume of an ideal gas are inversely proportional to each other.

Or:

The product of the pressure and the volume of an ideal gas is constant if the temperature is constant (Boyle-Mariotte's law).



PRACTICE 12

P 2.5.2.2 VOLUME OF A GAS
DEPENDENT ON
TEMPERATURE AT CONSTANT
PRESSURE

Heat

Kinetic theory of gases

Gas laws

P2.5.2.2

TEMPERATURE DEPENDENCY OF THE VOLUME OF A GAS AT A CONSTANT PRESSURE

Objects of experiment

- Determination of the temperature dependency of the volume of a gas at constant pressure.

Principles

The state of a quantity of n moles of an ideal gas is completely described by the measurable quantities p (pressure), V (volume) and T (temperature). The relation between these 3 quantities is given by the perfect gas laws:

$$p \cdot V = n \cdot R \cdot T \quad (I)$$

$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$: gas constant

If p , V or T remains constant, the other 2 quantities cannot be varied independently of each other. At a constant temperature, for example, Gay-Lussac's law relationship states:

$$V \propto T \quad (II)$$

This relationship is confirmed in the experiment by means of a gas thermometer. The gas thermometer consists of a gas capillary open at one end. A certain quantity of air is enclosed by means of mercury seal. At an outside pressure p_0 , the enclosed volume is V_0 . The gas thermometer is placed in a water bath of $P \approx 90$ which is allowed gradually to cool. The open end of a gas thermometer is subject to the ambient air pressure. Thus the pressure of the enclosed air column remains constant during the experiment. Its volume is given by:

$$V = \pi \cdot \frac{d^2}{4} \cdot h \quad (III)$$

d

= 2.7 mm: inside diameter of the capillary

h : height of the gas volume

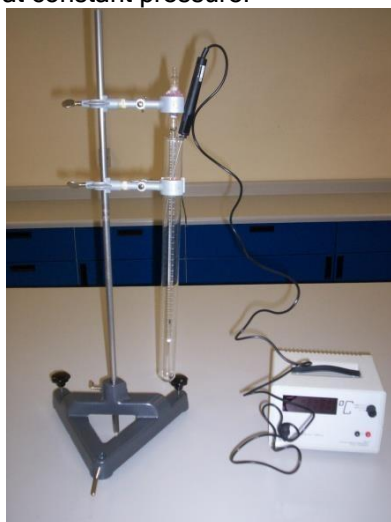
Apparatus

1 Gas thermometer.....	382 00
1 Digital thermometer.....	666 190
1 Temperature sensor NiCr-Ni.....	666 193
1 Stand base, V shape, 20 cm.....	300 02
1 Stand rod, 47 cm	300 42
2 Clamps with jaw clamp.....	301 11
1 Hot plate.....	666 767
1 Beaker, 400 ml, Hard glass	664 103

Setup

- Make the experimental setup of the large test tube and the gas thermometer as in fig. 1
- Introduce the temperature sensor NiCr-Ni into the large test tube parallel to the gas thermometer and connect it to the digital thermometer.

Fig.1: Experimental setup for measuring the temperature dependency of the volume of a gas at constant pressure.



Carrying out the experiment

- Heat about 400 ml of water in the beaker to about 90 by means of hot plate and fill in the large test tube.
- Measure the temperature P and the height h of the enclosed gas volume of the gas thermometer while the heat bath is gradually cooling down.

Measuring example

Table 1. The height h of the enclosed quantity of air as a function of the temperature P .

P —	$\frac{h}{mm}$
87.2	49.5
80.8	48.5
75.5	47.5
67.7	46.5
58.7	45.5
51.4	44.5
42.3	43.5
35.7	42.5
30.2	41.5
25	40.5

Evaluation

Table 2. The volume V as function of the temperature (Calculated with equation (III) with values in table 1)

P —	$\frac{V}{mm^3}$
87.2	283.4
80.8	277.7
75.5	272
67.7	266.5
58.7	260.5
51.4	254.8
42.3	249.1
35.7	243.3
30.2	237.6
25	231.9

Fig. 2 shows a plot of the measuring values of table 2. The straight line shown in fig. 2 is calculated by linear regression:

$$V = 213.8 \text{ mm}^3 + 0.79 \text{ mm}^3 / \text{P} \cdot T$$

From the extrapolation of the linear regression results the absolute temperature zero can be defined by the intersection point of the regression line with temperature axis ($V=0$)

$$P = -270 \pm 7$$

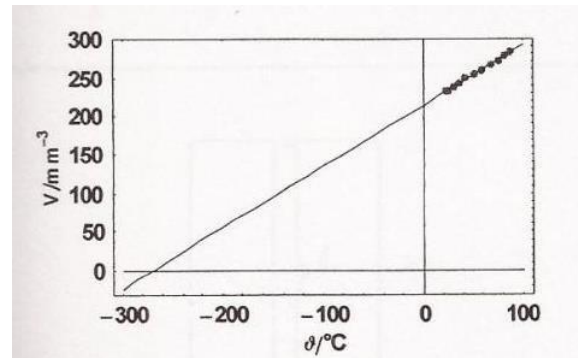


Fig. 2: The volume V of the enclosed air column as function of the temperature P

Results

At a constant pressure p , the volume V and the temperature T of an ideal gas are proportional to each other (Gay-Lussac's law).

PRACTICE 13

P 2.5.3.2 THE SPECIFIC THERMAL CAPACITY OF GASES

Kinetic theory of gases
Gas laws

The ratio of the specific heats $k = \frac{c_p}{c_v}$ is to be determined for air, neon and carbon monoxide with the help of the gas elastic resonance apparatus.

In a precision graph tube with scales for measuring volume, a gas column with the cross-section A , whose volume V and pressure p can be varied, is brought to sympathetic vibration. To do this a magnetic piston connecting to a glass column is moved through an electromagnetic alternating current field as a suspended mass m . This periodically compresses and expands the gas (adiabatic constitutional change).

If the frequency of the alternating current field is equal to the driving frequency f_0 of the system, then it oscillates with the maximum amplitude (the minimum off-resonance due to friction can be neglected). The time of vibration T of the glass tube closed on both sides and the piston in the middle is:

$$T = \frac{2\pi}{A} \cdot \sqrt{\frac{m \cdot V}{2pk}} \quad (1)$$

With $V = 1 \cdot A$ and $r = 2\pi \cdot f$ is following that k :

$$k = \frac{2\pi^2 \cdot l \cdot m}{A} \cdot \frac{f_0^2}{p} \quad (2)$$

**DETERMINING THE
RATIOS OF THE SPECIFIC
HEATS OF AIR, NEON AND
CARBON MONOXIDE**

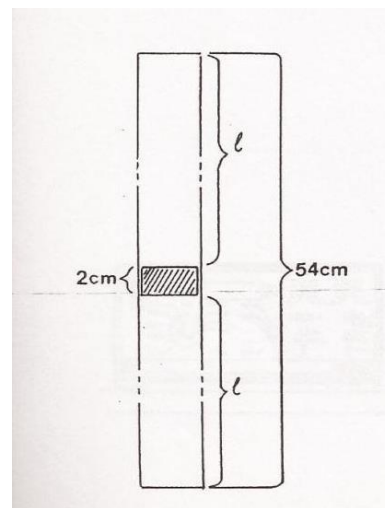


Fig.1 :Glass flask of the gas elastic resonance apparatus.

l = Length of the gas column (0.28m)

A
= Cross - section of the gas column ($1.52 \cdot 10^{-4} \text{m}^2$)

m = Mass of the piston ($8.8 \cdot 10^{-3} \text{kg}$)

p = Gas pressure

f_0 = Resonance frequency

If the inherent values due to the apparatus design are used, we obtain:

$$k \approx 297.1 \cdot \text{s}^2 \cdot \text{Pa} \cdot \frac{f_0^2}{p} \quad (3)$$

(Pa=pressure, s=seconds)

Derivation from (2):

The force equation applies to the tube opened on one side:

$$m\ddot{x} = -dp \cdot A \quad (4)$$

Because the vibration is and adiabatic process, the equation $p \cdot V^k$ (Poisson's law) applies.

That follows that:

$$\frac{dp}{dV} = -p \cdot \frac{k}{V}$$

$$m\ddot{x} = -p \cdot \frac{k}{V} \cdot dp \cdot A$$

With $dV = A \cdot x$ and $\frac{V}{A} = l$ and the linear force $F = -D \cdot x$ we obtain that:

$$m\ddot{x} = -\frac{p \cdot k \cdot A}{l} \cdot x = -D \cdot x \quad (5)$$

For the glass tube enclosed on both sides and the piston in the middle, the direction force D is twice as large:

$$m\ddot{x} = -\frac{2p \cdot k \cdot A}{l} \cdot x = -D^* \cdot x \quad (6)$$

From the relation for the time of vibration of a harmonic oscillator:

$$T = 2\pi \cdot \sqrt{\frac{m}{D^*}}$$

And the relationship (6) for the direction force we obtain the frequency:

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{2p \cdot k \cdot A}{1 \cdot m}} \quad (7)$$

(2) Follows from this.

Apparatus

1 Gas elastic resonance apparatus.....	371 07
1 Alternating current power supply (approx. 1A), adjustable frequency (Approx. 10 Hz to 20 Hz) and frequency measuring device, e.g.	
1 RC oscillator D (with digital display Of frequency)	522 57
Or	
1 Function generator S12	522 62
1 Power supply, 12 V ~	562 73
1 Counter p	575 45
1 Measuring instrument 3E	531 57
1 Battery.....	685 45
1 Clamp for bench tops.....	301 06
1 Pressure minican of carbon monoxide	660999
1 Pressure minican of neon.....	660 985
1 Valve for fine adjustment.....	660 981

Setting up

Before inserting the apparatus into the experiment arrangement, turn the tube with opened valve by 180° in the opposite side direction of the operating position, so that the piston can slide to the upper end of the tube; close the valve immediately and set up the experiment as in fig. 2. Let the piston slide in the position needed for the experiment by briefly opening the valve.

Attach the coil so that the upper edge is at the same level as the lower edge of the piston (see fig. 2).

Important:

The inside of the glass tubing must definitely be free from any type of dirt, so the piston can move freely. It can be cleaned with a bottle cleaner moistened with alcohol.

Note:

If the glass tubing is very clean, then it can also be used in a horizontal arrangement. This has the advantage that the piston remains in one position and does not sink slowly to the bottom.

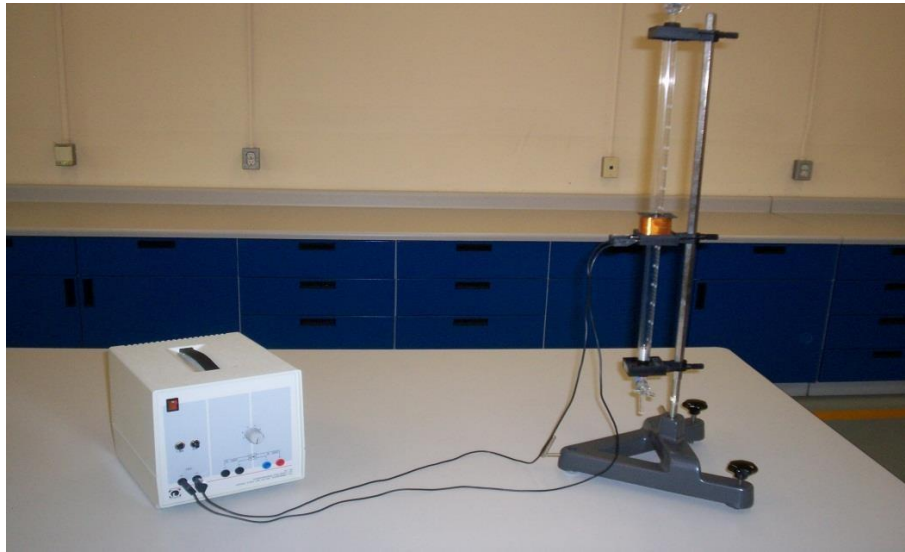


Fig. 2: Arrangement to set and measure the resonance frequency.

The resonance tube is filled with the other gases as shown in fig. 3.
To do this, bring the piston all the way to the top. The glass tube is first opened and is then closed after filling the gas.

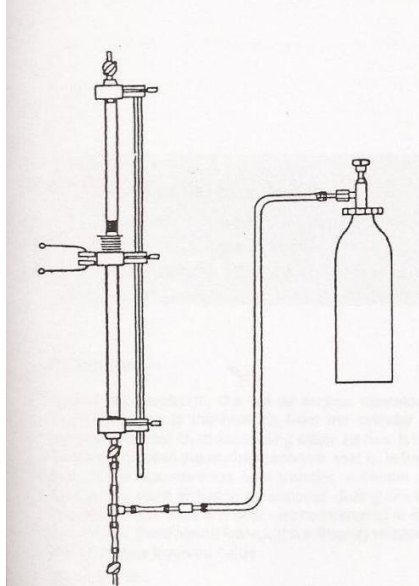


Fig. 3: Filling with gas

Carrying out the experiment:

First choose a frequency of approx. 40 Hz to 50 Hz and set the current to 1 A. To find the resonance frequency, slowly increase the generator frequency for 20 Hz onwards, until the maximum amplitude is just passed; then the lower frequency until the maximum amplitude as seen before is achieved again.

Measuring example:

$$k = 297.1 \cdot \frac{f_0^2}{p} = \frac{297.1 \cdot \text{Pa} \cdot \text{s}^2}{1027 \cdot 10^5 \text{Pa}} \cdot f_0^2$$

$$k = 2893 \cdot 10^{-3} \text{s}^2 \cdot f_0^2$$

- a) Resonance of the air: $f_0 = 21.9 \text{ Hz}$
- b) Resonance of the CO_2 : $f_0 = 21 \text{ Hz}$
- c) Resonance of the Ne: $f_0 = 23 \text{ Hz}$

Evaluation and results:

From the measuring examples, it follows that:

$$k_{air} = 1.39$$

$$k_{CO_2} = 1.27$$

$$k_{Ne} = 1.53$$

Theoretical values:

$$k_{air} = 1.40$$

$$k_{CO_2} = 1.29$$

$$k_{Ne} = 1.64$$

PRACTICE 14

P 2.6.2.3
DETERMINATION OF THE
EFFICIENCY OF THE HOY
AIR MOTOR AS A COOLER

Heat

Thermodynamic cycle

Hot-air engine: quantitative experiment

P2.5.2.2

TEMPERATURE DEPENDENCY OF THE VOLUME OF A GAS AT A CONSTANT PRESSURE

Objects of experiment

- Measuring the heat Q_2 extracted from the cylinder head during one revolution.
- Measuring the heat Q_1 transferred to the cooling water during one revolution.
- Determining the efficiency η of the refrigerator.

Principles

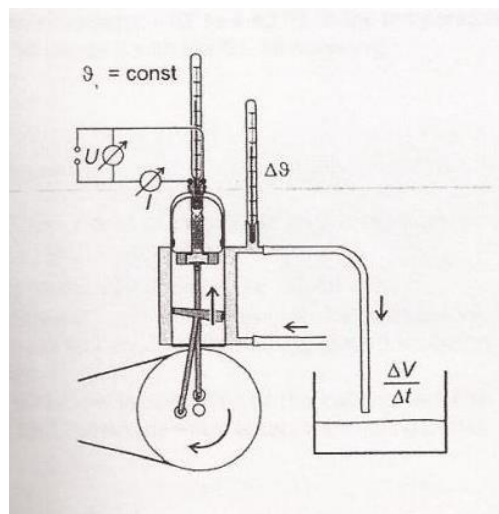
During one revolution, the hot-air engine, operated as refrigerator, extracts heat Q_2 from the cylinder head and transfer the heat Q_1 to the cooling water. As heat is transferred from the colder to the hotter reservoir, that is, in the opposite direction of a spontaneous heat transfer, a certain amount of mechanical work W has to be supplied during one revolution. The refrigerator thus is a heat engine operated in reverse direction. If there are no losses, the following relation between quantities involved holds:

$$Q_1 = Q_2 + W \quad (I)$$

The efficiency of a refrigerator is defined as the ratio:

$$\eta = \frac{Q_2}{W} \quad (II)$$

Determining the efficiency of the refrigerator



The efficiency is determined experimentally by driving the flywheel of the engine with an electric motor at an angular velocity f and determining the electric calorific power that permanently keeps the cylinder head at room temperature in a compression measurement. The electric work supplied per revolution is equal to Q_2 and extracted from the cylinder head, that is:

$$Q_2 = \frac{U \cdot i}{f} \quad (III)$$

U : heating voltage; i : heating current

In addition, the increase in temperature ΔP of the cooling water is measured and the power transferred to the cooling water.

$$P = C \cdot \rho \cdot \frac{\Delta V}{\Delta t} \cdot \Delta P \quad (IV)$$

C

$= 4.185 \text{ Jg}^{-1}\text{K}^{-1}$: specific heat of the water

$\rho = 1 \text{ g cm}^{-3}$: density of water

$\frac{\Delta V}{\Delta t}$: volume flow rate of the cooling water

Is determined. From this we obtain the heat transfer to the cooling water during one revolution:

$$Q_2 = \frac{P}{f} \quad (V)$$

Apparatus

1 Hot-air engine	388 182
1 Accessories for hot-air engine.....	388 221
1 experiment motor	347 35
1 Control unit for experiment motor....	347 36
1 Variable extra-low-voltage	
Transformer S.....	521 35
1 Multimeter METRAmax 2	531 100
1 Multimeter METRAmax 3	531 712
1 Counter P	575 45
1 Slot sensor, Infra-red.....	337 46
1 Transformer, 6~, 12~/30VA.....	562 73
1 Adapter cable, 4 pole, 1.5m long ...	501 18
1 Thermometer, -10°C to +40°C	382 36
1 Plastic beaker, 1000 ml	590 06
1 Stop-clock ii, 60s/30min	313 17
1 Stand base, V shape, 20 cm	300 022
2 Stand rods, 25 cm	300 41
Connection leads (partly with 2.5 mm ² cross	
Section)	
Additionally required:	
Open water vessel (At least 10)	
1 Submersible pump 12V	388 181
1 Low voltage power supply.....	522 16
2 Silicone tunings, int. Dia. 7x1.5 mm,	
1m.....	667 194

The difference $W = Q_1 - Q_2$ of the quantities determined in the above-mentioned way is the mechanical work to be supplied during one revolution. It is also contain the mechanical work W_R which is required to overcome the friction of the piston and causes additional warming of the cooling water. The mechanical work to be supplied for the thermodynamic cycle, which is for the transfer of heat from the colder to the warmer reservoir, therefore is:

$$W = Q_1 - Q_2 - W_R \quad (IV)$$

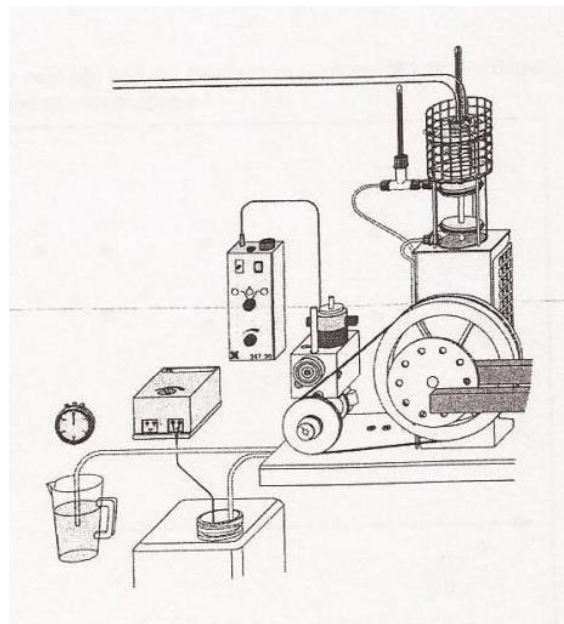


Fig. 1: Determining the volume throughput ΔV

Setup:

The experimental setup is illustrated in fig. 2

Temperature measurement in the cooling water:

- Remove the GL14 screwing form the cooling water outlet of the cylinder head, and mount the temperature adapter from the accessories for the hot-air engine.
- Insert the thermometer (382 36) in the temperature adapter, and clamp it with the GL 18 screwing.

Safety notes

The glass components of the hot-air engine must not be exposed to excess thermal load.

- Mind the instruction sheet of the hot-air engine.
- Do not operate the hot-air engine without cooling water, and check whether the cooling water circulation is flawless,
- Do not allow the temperature of the cooling water to exceed 30°C when the water enters the cooling circuit.

Cooling water supply:

- Fill at least 10 lts. Of water into the open water vessel, and hang the submersible pump in.
- Connect the output of the pump to the cooling water inflow of the engine, and guide the cooling water drain into the water vessel.
- Connect the pump to the low-voltage supply.

Or

- Connect the cooling water inflow of the engine to the tap, and guide the drain to the runoff.

Mounting the “thermometer with heater”:

- Remove the filament of the “thermometer with heater” (form the accessories of the engine), from the contact pins.
- Unscrew the screw gasket form the “cylinder head cap with screw gasket”

and screw the “thermometer with heater” on the cylinder head cap.

- Put the filament back on the contact pins, and see to it that filament does not touch the thermometer glass.
- Cautiously mount the cylinder head cap on the cylinder of the engine.
- Turn the flywheel of the engine, and make sure that the filament does not touch the displacement piston in any position of the piston.
- While turning the flywheel check the packing of the engine: if necessary, close the hose nozzle for the pressure sensor with a stopper.
- Connect the variable extra-low-voltage transformer S to the thermometer with heater with a voltmeter and an ammeter (measuring range 10A).

Next:

- Stop the clockwise motion of the motor and continue observing the temperature of the cooling water.
- Determine the change of the temperature ΔP of the cooling water and take it down.

Remark:

If the volume of the available cooling water is too small, the temperature of the vessel will also rise, the measured temperature change has then to be corrected correspondingly.

- Vary the rotational speed of the motor and repeat the measurement.

Measuring example

Volume throughput of the cooling water: 780 cm^3 in 5 minutes

Temperature P_1 in the cylinder head: 20

Table 1: Heating voltage U , heating current I and temperature increase ΔP of the cooling water as function of the rotational speed f .

$\frac{f}{s^{-1}}$	$\frac{U}{V}$	$\frac{I}{A}$	$\frac{\Delta P}{\text{---}}$
2.7	7.5	1.7	2.4
2.9	7.6	1.8	2.5
3.2	8	1.9	2.7
3.4	8.2	2	2.9
3.7	8.6	2.1	3.2
4	9	2.2	3.5

Evaluation and results

Table 2: Heat Q_1 transferred to the cooling water, frictional work of the piston W_R , heat Q_2 extracted from the cylinder head and mechanical work W Supplied form the thermodynamic cycle as functions of the rotational speed f .

$\frac{f}{s^{-1}}$	$\frac{Q_1}{J}$	$\frac{W_R}{J}$	$\frac{Q_2}{J}$	$\frac{W}{J}$
2.7	9.7	1.1	4.7	3.9
2.9	9.4	1.1	4.7	3.6
3.2	9.2	1	4.8	3.4
3.4	9.3	1	4.8	3.5
3.7	9.4	1	1.9	3.5
4	9.5	1	5	3.5

Table 3: The efficiency η of the refrigerator as function of the rotational speed f .

$\frac{f}{s^{-1}}$	η
2.7	1.2
2.9	1.3
3.2	1.4
3.4	1.4
3.7	1.4
4	1.4

In table 2 the heat supplied to the cooling water, the frictional work of the piston, the heat extracted from the cylinder head and the mechanical work supplied by the thermodynamic cycle, all during one revolution, are listed. Fig. 3 is a plot of Q_2 and W as function of the speed f . The efficiency η is calculated from Q_2 and W according to (II) and Q_2 . Within the accuracy of measurement, it is constant for the rotational speeds $f = 3 s^{-1}$ (see table 3), but it is far below the values achieved by refrigerator used in practice.

Fig. 3 The heat (●) and the mechanical work W (■) as functions of the rotational speed f .

