

**UNIVERSITY OF GAZIANTEP**  
**DEPARTMENT OF ENGINEERING PHYSICS**

**EP 143 HEAT LABORATORY HANDBOOK**

## EP 143 HEAT

### EXPERIMENT -1

#### THERMOCOUPLE

### 1. PURPOSE

To study the operation principles of thermocouples, obtain their calibration curves, and use them as a thermometer.

### 2. THEORY

When a pair of electrical conductors (metals) are joined together, a thermal emf is generated when the junctions are at different temperatures. This phenomenon is known as the Seebeck effect. Such a device is called a thermocouple. The resultant emf developed by the thermocouple is in the millivolt range when the temperature difference between the junctions is  $\sim 100$   $^{\circ}\text{C}$ . To determine the emf of a thermocouple as a function of the temperature, one junction is maintained at some constant reference temperature, such as ice-water mixture at a temperature of  $0$   $^{\circ}\text{C}$ . The thermal emf, which can be measured by a digital voltmeter as shown in Figure 1, is proportional to the temperature difference between the two junctions. To calibrate such thermocouple the temperature of the second junction can be varied using a constant temperature bath and the emf recorded as a function of the temperature difference between the two nodes. The output voltage,  $E$ , of a simple thermocouple circuit is usually written in the form,

$$E = AT + \frac{1}{2}BT^2 + \frac{1}{3}CT^3 \quad (1)$$

where  $T$  is the temperature in  $^{\circ}\text{C}$ , and  $E$  is based on a reference junction temperature of  $0$   $^{\circ}\text{C}$ . The constants  $A$ ,  $B$  and  $C$  are dependent on the thermocouple material. Providing a fixed reference temperature for the reference junction using an ice bath can make the use of a thermocouple cumbersome. Hence, commercially available thermocouples usually consist of two leads terminating in a single junction. The leads are connected to a thermocouple signal conditioning 'box' containing an electrical circuit which provides a reference voltage equal to

that produce by a reference junction placed at  $0^{\circ}\text{C}$ , a process called ‘ice point compensation’. These thermocouple signal conditioners or ‘power supplies’ usually display the temperature directly and or provide a voltage output that is proportional to the thermocouple temperature. A variety of thermocouples are available, suitable for different measuring applications (industrial, scientific, food temperature, medical research, etc.). They are usually selected based on the temperature range and sensitivity needed. Thermocouples with low sensitivities (B, R, and S types) have correspondingly lower resolutions. Other selection criteria include the inertness of the thermocouple material, and whether or not it is magnetic. Thermocouples are most suitable for measuring over a large temperature range, up to 1800 K. They are less suitable for applications where smaller temperature differences need to be measured with high accuracy, for example the range  $0\text{--}100^{\circ}\text{C}$  with  $0.1^{\circ}\text{C}$  accuracy.

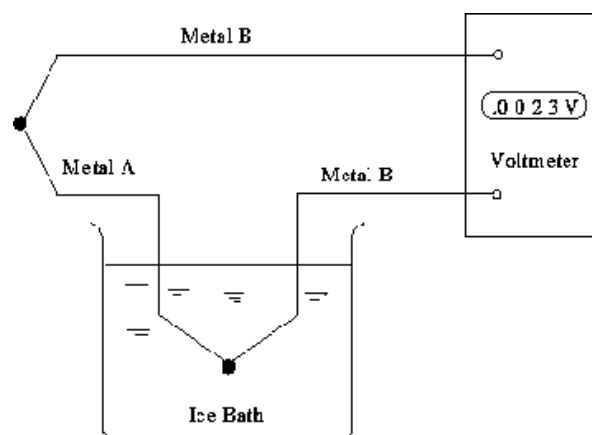


Figure 1 Measuring the EMF of a Thermocouple

### 3. EXPERIMENTAL PROCEDURE

3.1 ) Set up the experiment as shown in Fig. 1

3.2) One of the junctions of the thermocouple has been immersed into ice-water mixture at  $0^{\circ}\text{C}$  and the other one into the water in a container placed on a heater. Now read out the voltage appears between free ends the thermocouple.

3.3) Begin to heat the water in container to  $100^{\circ}\text{C}$  while recording the emf for every  $5^{\circ}\text{C}$  rise in temperature.

#### 4. CALCULATION

4.1) Plot a graph of temperature, T, versus thermo-electric emf  $\epsilon$ .

4.2) From the graph note the maximum emf  $\epsilon_{\max}$  and neutral temperature  $T_N$  at which this occurs.

4.3) Determine the slope of the graph at the origin which is equal to the constant A in below equation

$$E = AT + BT^2$$

4.4) Since  $\epsilon$  is maximum when neutral temperature ( $T_N$ ) is reached, substitute the values of A and  $T_N$  to find the value of constant B.

4.5) For  $T=200\text{ }^{\circ}\text{C}$  calculate  $\epsilon$  using equation  $E = AT + BT^2$  substituting the values of A and B found above. Find the % difference between this calculated and experimental value obtained from the graph.

#### 5. QUESTIONS

5.1) What does "Type K" mean?

5.2) Discuss the principles of operation of thermocouples and thermistors. Compare the advantages and drawbacks of using the two devices.

5.3) Plot the static calibration data for the thermocouple i.e. plot temperature vs. voltage. Does the voltage output confirm the expected trends? How and why?

5.4) What errors may be introduced by measuring temperature with a thermocouple?

You may wish to consider the heat transfer modes acting on the thermocouple.

5. What role does the reference junction play in thermocouple readings?

## EP 143 HEAT

### EXPERIMENT -2-a

#### DETERMINING THE SPECIFIC HEAT OF SOLIDS

##### 1. PURPOSE

The purpose of this experiment is to measure the specific heat capacity of unknown solid specimens which are considerably smaller than the specific heat capacity of water.

##### 2. THEORY

The specific heat is the amount of [heat](#) per unit mass required to raise the [temperature](#) by one degree Celsius. The relationship between heat and temperature change is usually expressed in the form shown in equation 1 where  $c$  is the specific heat. The relationship does not apply if a [phase change](#) is encountered, because the heat added or removed during a phase change does not change the temperature. The specific heat of water is  $1 \text{ calorie/gram } ^\circ\text{C} = 4.186 \text{ joule/gram } ^\circ\text{C}$  which is higher than any other common substance. As a result, water plays a very important role in temperature regulation. The specific heat per gram for water is much higher than that for a metal.

The heat quantity  $Q$  that is absorbed or evolved when a body is heated or cooled is proportional to the change of temperature and to the mass  $m$ :

$$\Delta Q = m.c.\Delta T \quad (1)$$

The factor of proportionality  $c$ , the specific heat capacity 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  $T_1$  and then poured into a quantity of water that has been weighed out and that has the temperature  $T_2$ . After the mixture has been carefully stirred, the pellets and the water reach the common temperature  $T_M$  through heat exchange.

The heat quantity evolved by the shot

$$\Delta Q_1 = c_1.m_1.(T_1 - T_M) \quad (2)$$

$m_1$ : mass of the shot

$c_1$ : specific heat capacity of the shot

is equal to the heat quantity absorbed by the water

$$\Delta Q_2 = c_2 \cdot m_2 \cdot (T_M - T_2) \quad (3)$$

$m_2$ : mass of the water

The specific heat capacity of water  $c_2$  is assumed to be known. The temperature  $T_1$  is equal to the temperature of steam. The unknown quantity  $c_1$  can therefore be calculated from the

measured quantities,  $T_2$ ,  $T_M$ ,  $m_1$  and  $m_2$ .

$$c_1 = c_2 \frac{m_2 \cdot (T_M - T_2)}{m_1 \cdot (T_1 - T_M)} \quad (4)$$

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

$$C_K = c_2 \cdot m_K \quad (5)$$

or the water equivalent  $m_K$  of the calorimeter vessel has to be taken into account. The absorbed heat quantity calculated in Eq. 3 is thus more precisely.

$$\Delta Q_2 = c_2 \cdot (m_2 + m_K) \cdot (T_M - T_2) \quad (6)$$

and Eq. 4 is extended to

$$c_1 = c_2 \frac{(m_2 + m_K) \cdot (T_M - T_2)}{m_1 \cdot (T_1 - T_M)} \quad (7)$$

$$Q = cm\Delta T$$

heat added
specific heat
mass
change in temperature

Material	Specific Heat	
	(cal/g °C)	(J/kg K)
Aluminum	0.215	900
Copper	0.092	385
Iron	0.107	448
Lead	0.031	130
Brass	0.092	385
Magnesium	0.245	1030
Zinc	0.093	390
Glass	0.27	746
Air	0.240	1006
Water	1.000	4190
Ice	0.500	2095

Table 1. Specific heat values of some materials

### 3. EXPERIMENTAL PROCEDURE

The experimental set up is illustrated in Fig.1.

3.1) Mount the heating apparatus in the stand material.

3.2) 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.

3.3) Attach silicone tubing to the bottom hose connection of the heating apparatus (steam outlet), and hang the other end seated at all connections.

3.4) Fill the sample chamber of the heating apparatus as completely as possible with lead shot, and seal it with the stopper.

3.5) Connect the steam generator to the mains, and heat the shot for about 20-25 minutes in the heating apparatus flowed through by steam.

In the meantime

3.6) Determine the mass of the empty Dewar vessel, and fill in about 180 gr of water.

3.7) Mount the cover for the Dewar vessel and insert the thermometer or the temperature sensor respectively.

3.8) Measure the temperature  $T_2$  of water.

3.9) Open the cover of the Dewar vessel and shift it aside; leave the mesh for samples of the cover in the Dewar vessel.

3.10) Drop the shots with the temperature of 100 °C into the mesh for samples, close the cover, and thoroughly mix the water with the shot.

3.11) Read the mixture temperature when the temperature of the water stops rising.

3.12) Determine the additional mass of  $m$  of the shot.

3.13) Repeat the experiment with copper and glass shot.



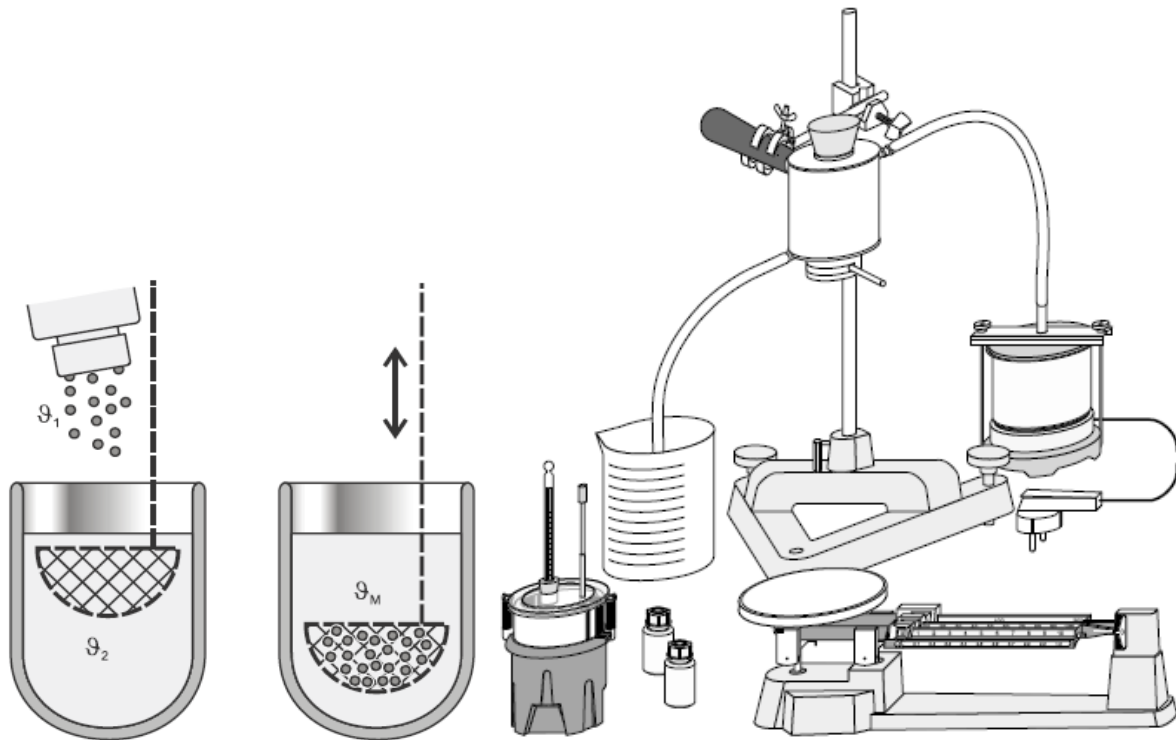


Fig. 1 Experimental setup for determining the specific heat of solids.

#### 4. CALCULATION

4.1) Calculate the specific heat of glass, copper and lead according to the experimental values, and compare with the literature, find the percentage difference. Comment on the calculations.

4.2) Estimate how much energy is required to heat the air in your physics laboratory from a chilly  $10\text{ }^{\circ}\text{C}$  to a more comfortable  $20\text{ }^{\circ}\text{C}$ . Comment on the answer.

4.3) In a lab experiment, an  $80\text{ g}$  sample of water at  $20\text{ }^{\circ}\text{C}$  is mixed with  $80\text{ g}$  of aluminum at  $50\text{ }^{\circ}\text{C}$ . The specific heat of aluminum is  $0.20\text{ cal/g}^{\circ}\text{C}$ . In other words, it takes only  $0.2$  calories to raise the temperature of  $1\text{ g}$  of aluminum by  $1\text{ }^{\circ}\text{C}$ .

- a. What is the final temperature of the mixture?
- b. How many calories are required to change the temperature of 1 gram of aluminum by 5 °C?

## **5. QUESTIONS**

5.1) Find out which materials are used as coolants in nuclear reactors. What do these materials have in common?

5.2) Why is water commonly used in the cooling system of a motor car? Why is the system pressurised?

## EP 143 HEAT

### EXPERIMENT -2-b

#### DETERMINING THE SPECIFIC LATENT HEAT OF ICE

##### 1. PURPOSE

The purpose of this experiment is to measure the mixing temperature  $T_M$  of ice and water and to calculate the specific latent heat of ice.

##### 2. THEORY

When heat is transferred to a substance at constant pressure, the temperature of the substance in general increases. If, however, 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 melting of water to ice. The heat consumed per mass unit is called the specific latent heat  $L$ .

In the experiment, the specific latent heat  $L$  of ice is determined by means of a calorimeter filled with 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 temperature  $T_2$  and the mass  $m_2$  of the warm as well as the mass  $m_1$  of the ice are measured so that the latent heat can be calculated as follows:

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

$$\Delta Q_1 = c \cdot m_1 \cdot (T_M - 0 \text{ } ^\circ\text{C}) \quad (1)$$

$c$ : specific heat of water which the melted water absorbs in warming up from  $T_1 \approx 0 \text{ } ^\circ\text{C}$  to the temperature  $T_M$ , and the heat,

$$\Delta Q_2 = m_1 \cdot L_s \quad (2)$$

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

$$\Delta Q_3 = c \cdot m_2 \cdot (T_2 - T_M) \quad (3)$$

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:

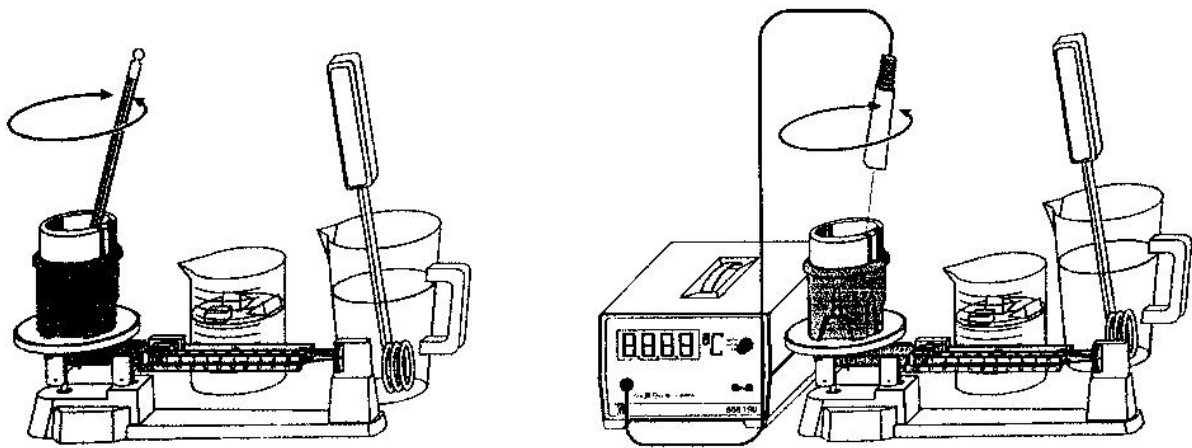
$$\Delta Q_4 = c \cdot m_k \cdot (T_2 - T_M) \text{ with } m_k = 20 \text{ g} \quad (4)$$

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

$$\frac{Ls}{c} = \frac{(m_2 + m_k)}{m_1} \cdot (T_2 - T_M) - (T_M - 0^\circ \text{C})$$

### 3. EXPERIMENTAL PROCEDURE

The experimental setup is illustrated in Fig 1.



- 1- Put the ice cubes into the beaker, which should be filled with cold water to a quarter so that the ice reaches a temperature of  $0^\circ \text{C}$  (check with the thermometer or the temperature sensor respectively).
- 2- Place the thermometer or the temperature sensor NiCr-Ni upright into the Dewar vessel.
- 3- Read the mass of the empty Dewar vessel.
- 4- Warm water up to a temperature between  $40^\circ \text{C}$  and  $50^\circ \text{C}$  in the plastic beaker.
- 5- Fill about 200 g of the warm water into the Dewar vessel and determine its mass  $m_2$  and temperature  $T_2$  (stir).
- 6- Put 50 g of "dry" ice cubes into the warm water.
- 7- Stir until the ice has completely melted and read the temperature  $T_M$ .

Table 1. Specific and latent heat values of some materials

Specific and Latent Heat Values				
Material	Specific Heat		Latent Heat of Fusion	
	(cal/g °C)	(J/kg K)	(cal/g)	(J/kg)
Aluminum	0.215	900	94.5	$3.96 \times 10^5$
Copper	0.092	385	49.0	$2.05 \times 10^5$
Iron	0.107	448	63.7	$2.67 \times 10^5$
Lead	0.031	130	5.5	$0.23 \times 10^5$
Brass	0.092	385	Unknown	Unknown
Magnesium	0.245	1030	88.0	$3.7 \times 10^5$
Zinc	0.093	390	27.0	$1.1 \times 10^5$
Styrofoam	0.27	1131	Unknown	Unknown
Air	0.240	1006	N/A	N/A
Water	1.000	4190	N/A	N/A
Ice	0.500	2095	79.7	$3.34 \times 10^5$

#### 4. CALCULATION

4.1) Calculate the specific vaporization heat of water and compare your result with the literature

#### 5. QUESTIONS

5.1) Compare the energy needed to raise the temperature of 1kg of water from 20°C to 100°C and the energy needed to boil 1 kg of water at 100°C.

5.2) A 5kg block of iron is heated to 800°C. It is placed in a tub containing 2 litre of water at 15°C. Assuming all the water is brought to the boil rapidly; calculate the mass of water which boils off.

5.3) Sunlight of intensity  $0.6 \text{ kW m}^{-2}$  falls on a patch of ice. Assuming the ice absorbs 20% of the light; calculate what thickness of ice would melt in 1 minute. (Assume any water produced runs off).

5.4) Why would hydrogen make a better coolant than water? Why is water used much, much more often as a coolant?

5.5) Are you in thermal equilibrium with the room?

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## EP 143 HEAT

### EXPERIMENT -4

#### DETERMINING THE SPECIFIC VAPORIZATION HEAT OF WATER

##### 1. PURPOSE

In this experiment, you will calculate the heat of vaporization of water by boiling some water and using the steam that is produced to heat another sample of water. By measuring the increase in temperature of the second container of water, it will be possible to determine how much heat energy was possessed by the steam, from which the latent heat of vaporization can be calculated.

##### 2. THEORY

The heat of vaporization of water is the amount of heat absorbed as water undergoes the phase change from liquid to gas at its normal boiling point. More generally, when a substance boils, it absorbs an amount of heat ( $\Delta T$ ) that depends on the mass ( $m$ ) of the substance and its latent heat of vaporization ( $L_v$ ), according to the equation,

$$\Delta T = m \cdot L_v \quad (1)$$

So, in order to calculate the heat of vaporization of water, we need to know how much heat it takes in and its mass. The accepted value for the heat of vaporization of water is 2258 J/g. This means that to convert 1 kg of water at 100 °C to 1 g of steam at 100 °C, 2258 J of heat must be absorbed by the water. Conversely, when 1 g of steam at 100 °C condenses to give 1 g of water at 100 °C, 2258 J of heat will be released to the surroundings.

In this experiment, the specific vaporization heat  $L_v$  of water is determined by piping pure steam into a 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 as follows:

The heat emitted by the steam is the sum of the heat

$$\Delta Q_1 = c.m_1.(100^{\circ}\text{C} - T_M) \quad (2)$$

$c$ : specific heat of water.

which the condensed water emits cooling down from  $T_1 \approx 100^{\circ}\text{C}$  to the mixing temperature  $T_M$ , and the heat  $\Delta Q_2$ , which is emitted in the process of condensation from steam to water. The latter is the heat that has to be transferred to water at a temperature of  $T_1 \approx 100^{\circ}\text{C}$  in order that it vaporizes again;

$$\Delta Q_2 = m_1.L_v \quad (3)$$

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

$$\Delta Q_3 = c.m_2.(T_M - T_2) \quad (4)$$

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

$$\Delta Q_4 = c.m_K.(T_M - T_2) \text{ with } m_K = 20 \text{ g} \quad (5)$$

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

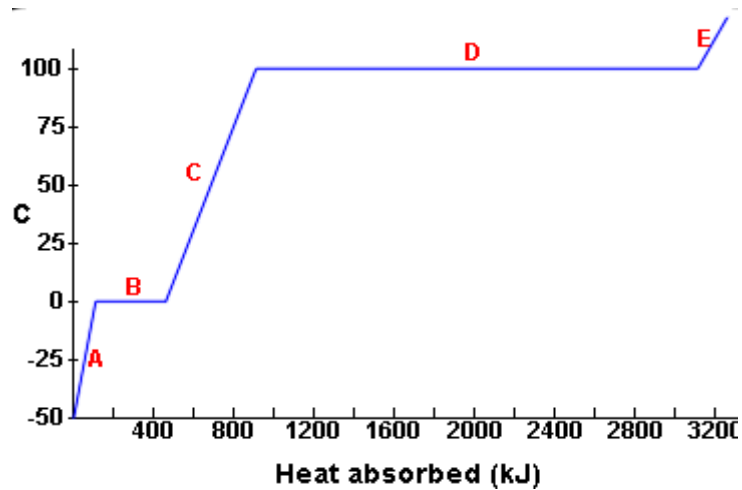
$$\frac{L_v}{c} = \frac{(m_2 + m_K)}{m_1} .(T_M - T_2) - (100^{\circ}\text{C} - T_M) \quad (6)$$

is found.

### Heating/cooling curves

The diagram shows the uptake of heat by 1 kg of water, as it passes from ice at  $-50^{\circ}\text{C}$  to steam at temperatures above  $100^{\circ}\text{C}$ , affects the temperature of the sample. One could reverse the process, and obtain a cooling curve. The flat portions of such curves indicate the phase changes.





- A: Rise in temperature as ice absorbs heat.
- B: Absorption of latent heat of fusion.
- C: Rise in temperature as liquid water absorbs heat.
- D: Water boils and absorbs latent heat of vaporization.
- E: Steam absorbs heat and thus increases its temperature.

### 3. EXPERIMENTAL PROCEDURE

The experimental set up is illustrated in Fig. 1. While the experiment is carried out, the Dewar vessel is placed on the school and lab. balance.

- 3.1) Clamp the thermometer or the temperature sensor NiCr-Ni.
- 3.2) Fill distilled water into the steam generator to a height of about 2 cm, put the lid on, and carefully close the gripping device.
- 3.3) 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 tube until it almost reaches the upper stopper.
- 3.4) Use the silicone tubing to connect the steam outlet tube of the steam generator to the steam inlet tube of the water separator. Do not clamp the water separator yet.

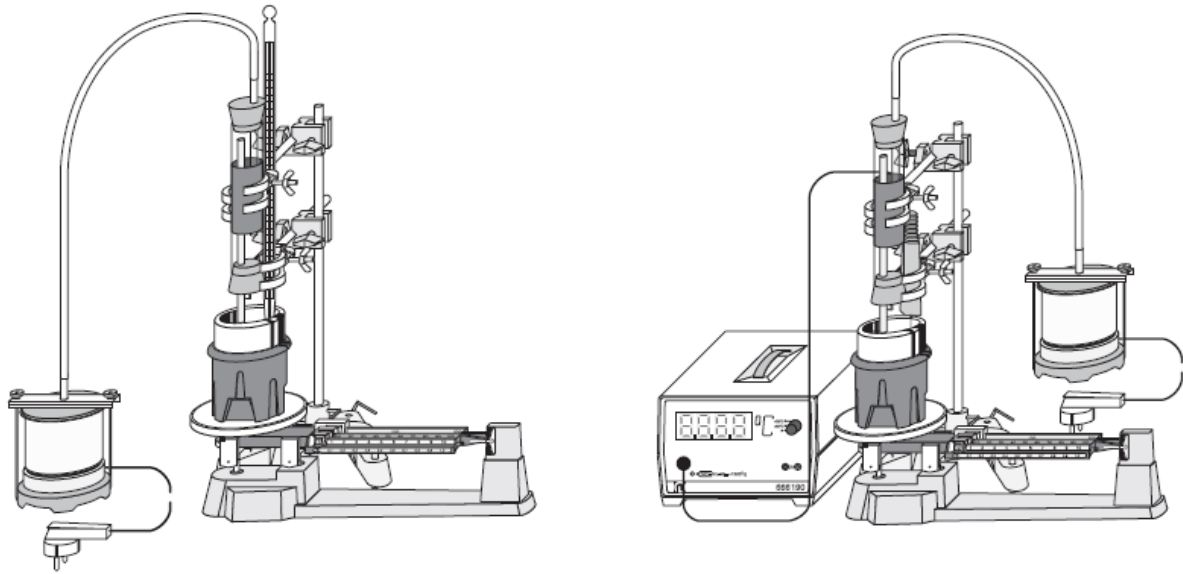


Figure 1. Experimental setup for the determination of the specific vaporization heat of water left: temperature measurement with a thermometer right: temperature measurement with a temperature sensor

**Filling cold water into the Dewar vessel:**

3.5) Read the mass of the empty Dewar vessel.

3.6) Fill about 150 g of distilled water into the vessel and determine its mass  $m_2$  and temperature  $T_2$ .

3.7) Clamp the water separator so that the steam outlet tube is by about 1 cm higher than the middle of the bottom of the Dewar vessel. If necessary, extend the tube with a short piece of silicone tubing.

3.8) Determine the total mass of the arrangement.

### **Piping steam into the vessel:**

3.9) Put the water separator into the beaker and make certain that the silicone tubings are well-fixed.

3.10) Connect the steam generator to the mains and wait for the steam to escape.

3.11) Clamp the water separator over the Dewar vessel once more and observe the increase of the total mass and the rise of the temperature.

3.12) After the total mass has increased by about 20 g, switch the steam generator off, and quickly determine the mixing temperature  $T_M$ .

### **4. CALCULATION**

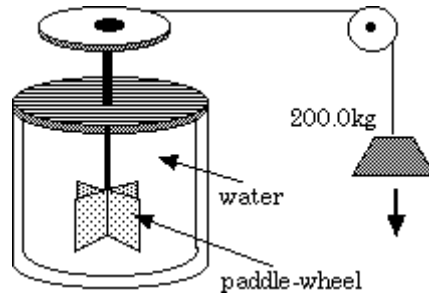
4.1) Calculate the specific vaporization heat of water and compare your result with the literature.

### **5. QUESTIONS**

5.1) It costs more to melt 5 kg of ice than vaporize 5 kg of liquid water? (Assume in each case that the temperature of the water remains constant during the phase change.) Explain.

5.2) How much heat (kJ) must be removed in order to change 2.71 moles of steam at  $112\text{ }^{\circ}\text{C}$  to water at  $30\text{ }^{\circ}\text{C}$ . Use a negative sign in your answer if heat is removed.

5.3) A 200.0 kg object is attached via an ideal pulley system to paddle wheels that are submerged in 0.480 kg of water at  $20.0\text{ }^{\circ}\text{C}$  in an insulated container as shown in the figure below. Then, the object falls through a distance of 5.00 m causing the paddle wheel to turn. Assuming that all of the mechanical energy lost by the falling object goes into the water, what is the final temperature of the water?



5.4) A perfectly insulated container contains 70 g of water at  $40^{\circ}\text{C}$ . A small heater is immersed in the water and is connected to a 12 V battery. An electric current of 13 A flows through the heating element. The specific heat of water  $4.2 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$  and the latent heat of vaporization is  $2.6 \times 10^6 \text{ J kg}^{-1}$ .

- (a) Calculate the power supplied by the heater?
- (c) Calculate the energy required for the water to reach boiling temperature  $100^{\circ}\text{C}$  ?
- (d) Calculate the time taken for the water to reach boiling temperature?
- (e) Calculate the energy required to vaporize all the water?
- (f) Calculate the time taken to vaporize all the water?

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## EP 143 HEAT

### EXPERIMENT -5

#### THERMAL EXPANSION OF SOLID BODIES

##### 1. PURPOSE

The purpose of this experiment is to measure the linear thermal expansion of glass, steel and brass tubes and to determine their linear expansion coefficients.

##### 2. THEORY

In [physics](#), thermal expansion is the tendency of matter to change in [volume](#) in response to a change in temperature. When a substance is heated, its constituent particles move around more vigorously and by doing so generally maintain a greater average separation. Materials that contract with an increase in temperature are very uncommon; this effect is limited in size, and only occurs within limited temperature ranges. The degree of expansion divided by the change in temperature is called the material's coefficient of thermal expansion and generally varies with temperature.

Most substances expand with increasing temperature and contract with decreasing temperature. This thermal expansion is usually quite small, but it can be an important effect. Suppose the length of a solid rod is  $L_0$  at some reference temperature  $T_0$ . If the temperature is changed by an amount  $\Delta T = T - T_0$ , then the length changes by an amount  $\Delta L = L - L_0$ . Experiments showed that under usual circumstances the change in length is proportional to the temperature change, in the length also depends on the material. The length  $L$  of a solid body is linearly dependent on its temperature  $T$ ;

$$L = L_0(1 + \alpha T) \quad (1)$$

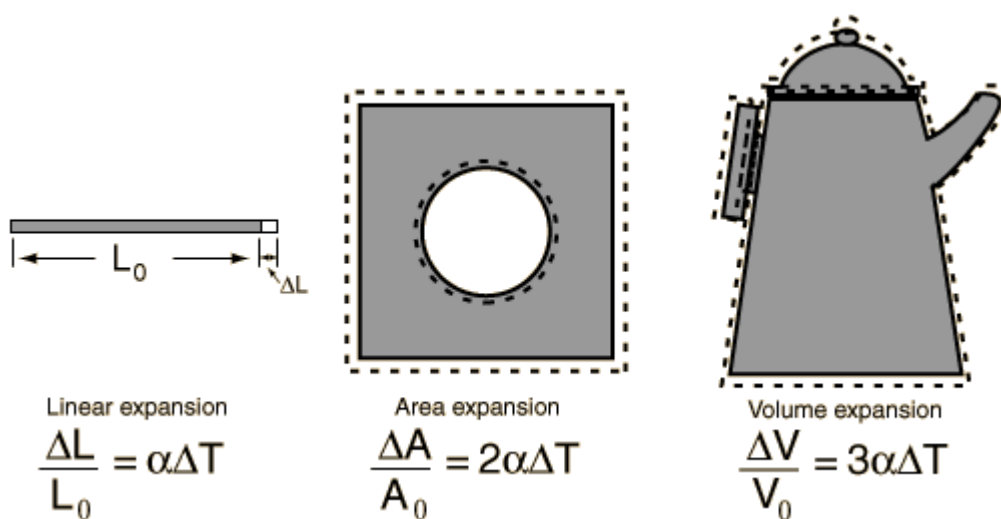
where  $L_0$  length at  $0^\circ C$  and  $T$  is temperature in  $^\circ C$ .

The linear expansion coefficient  $\alpha$  is determined by the material of the solid body. For a given temperature difference between room temperature  $T_1$  and steam temperature  $T_2$  the change in length  $\Delta L$  is closely proportional to the overall length  $L_0$  at room temperature. Specifically, we can say,

$$\alpha = \frac{\Delta L}{L_0 \Delta T} \quad (2)$$

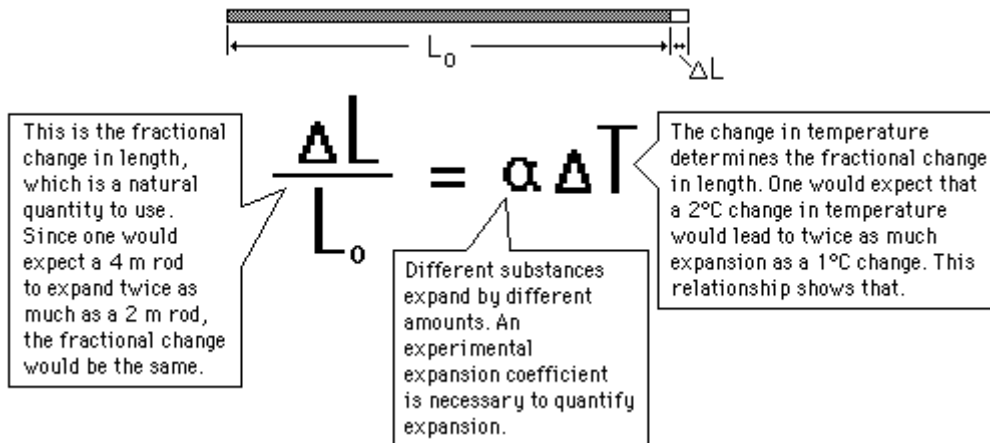
The coefficient of thermal expansion is used:

- in linear thermal expansion
- in area thermal expansion
- in volumetric thermal expansion



## Linear thermal expansion

The relationship governing the [linear expansion](#) of a long thin rod can be reasoned out as follows:



## Dial Gauge

Dial gauges and high definition display measuring devices, colloquially often also known as a dial gauge, are precision instruments. As with all mechanical devices, they are also subjected to wear and tear, aging, or are adversely affected by “accidents,” such as hard impacts. It is therefore necessary to test them for their measurement accuracy on regular intervals. This is also stipulated in various standards, as well as the required documentation for this. The principle of the dial gauge is based on a plug gauge, which is pushed into a housing against a spring force. This moves an indicator, displaying the measurement value on a scale, proportionally to the path via a gear. The display value may not exceed a certain error, compared with a norm, and must remain approximately equally low across the entire measurement range. Therefore, the clock is normally mounted in a temperate environment for testing purposes and mechanically/optically measured by hand. The tester then records the respective target and actual values, and issues a test badge. This procedure can now be drastically simplified thanks to modern electronics. After the test item has been inserted, the dial gage and high definition display testing device will assume all further work steps.

		Measurement	Literature
Material	$\frac{s_1}{\text{mm}}$	$\frac{\alpha}{\text{K}^{-1}}$	$\frac{\alpha}{\text{K}^{-1}}$
Brass	600	$18.1 \cdot 10^{-6}$	$18 \cdot 10^{-6}$
Steel	600	$12.2 \cdot 10^{-6}$	$11 \cdot 10^{-6}$
Glass	600	$3.1 \cdot 10^{-6}$	$3 \cdot 10^{-6}$

Table 1. Linear expansion coefficient  $\alpha$  for different materials.

### 3. EXPERIMENTAL PROCEDURE

In this experiment, measurements of thermal expansion are conducted on thin tubes through which steam is channeled. The effective length  $l_1$  of each tube can be set as 200, 400 or 600 mm by mounting it in a corresponding manner. A dial gauge with 0,01 mm scale graduations is used to measure the change in length.

The experimental set up as shown in figure 1.

- 3.1) Screw on the holder for dial gauge (e) and clamp the dial gauge in place
- 3.2) Attach the fixed bearing (a) of the expansion apparatus at the 600 mark and slide the open end of the brass tube into the fixed bearing
- 3.3) Slide the closed end of the brass tube into the guide fitting (b) so that the hose nipple (f) is pointing laterally downwards.
- 3.4) Tighten the screw to fix the brass tube in the fixed bearing
- 3.5) Determine the room temperature  $T_1$  and write this down
- 3.6) Read off and write down the zero position of the dial gauge



- 3.7) Fill the steam generator with about 2 cm of water, close the apparatus and plug it in.
- 3.8) Read off and write down the maximum pointer deflection of the dial gauge.
- 3.9) Allow the brass tube to cool down to room temperature.
- 3.10) 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
- 3.11) Refill the steam generator with water, check the zero position of the dial gauge and repeat the measurement
- 3.12) Move the fixed bearing to the 200 mark and repeat the experiment
- 3.13) Replace the brass tube with the steel tube; attach the fixed bearing at the 600 mark and repeat the measurement
- 3.14) Conduct the same measurement on the glass tube

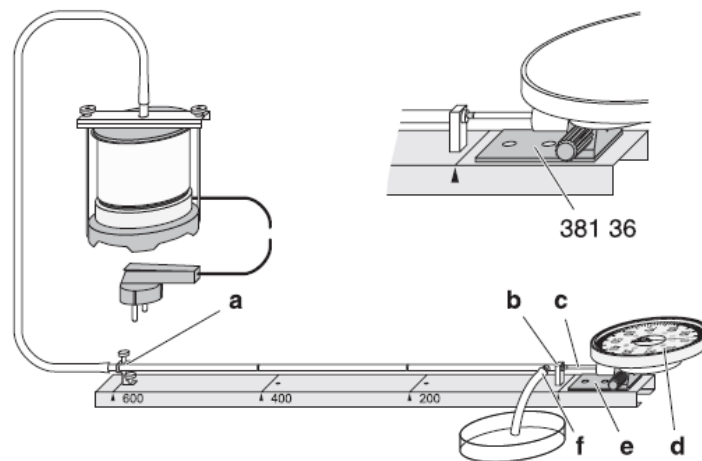


Figure1: Experiment set up measuring the linear thermal expansion apparatus

#### 4. CALCULATION

- 4.1) Calculate the thermal expansion coefficient for brass and steel, compare the experimental and theoretical values.

4.2) Draw the graph of the change in length  $\Delta l$  as a function of effective length  $l_1$  for brass and steel. Compare these two graphs.

## 5. QUESTIONS

5.1) Explain what is meant by the linear coefficient of expansivity? How may it be determined in the case of a solid?

5.2) What do you understand by the statement that the coefficient of linear expansivity of steel is  $1.1 \times 10^{-5} \text{ K}^{-1}$ ?

5.3) Explain how linear expansion of metal rods can be used as thermometer. What would be the problems with this method?

5.4) Explain the working principle of Dial Gauge.

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## EP 143 HEAT

### EXPERIMENT -6

#### DETERMINING THE VOLUMETRIC EXPANSION COEFFICIENT OF LIQUIDS

##### 1. PURPOSE

The purpose of this experiment is to measure the volume expansion of water and ethanol as a function of temperature and determining the volumetric expansion coefficient  $\gamma$ .

##### 2. THEORY

If the temperature  $T$  of a liquid of volume  $V_0$  is changed by  $\Delta T$ , then the volume will, as in the case of a solid, change by

$$\Delta V_0 = \gamma \cdot V_0 \cdot \Delta T \quad (1)$$

The volumetric expansion coefficient  $\gamma$  is practically independent of the temperature  $T$ , but it does depend on the material. In general, liquids expand more than solids. The volumetric expansion coefficient can be determined by means of a dilatometer. A dilatometer consists of a glass flask with a capillary of known radius  $r$  at the opening as a riser tube. The level  $h$  of the liquid in the riser tube is read from a mm-scale. It increases when the glass flask is uniformly warmed in a water bath and the volume of the liquid expands.

The change in the liquid level  $\Delta h$  corresponds to a change in volume

$$\Delta V = \pi \cdot r^2 \cdot \Delta h \quad (2)$$

with  $r = (1.5 \pm 0.08)$  mm.

However it has to be taken into account that the dilatometer itself also expands because of the warming. This expansion counteracts the change in the liquid level. The change in volume of the liquid thus is

$$\Delta V_0 = \Delta V + \Delta V_D \quad (3)$$

where the volume change  $\Delta V_D$  of the dilatometer is

$$\Delta V_D = \gamma_D \cdot V_0 \cdot \Delta T \quad (4)$$

with  $\gamma_D = 0.84 \cdot 10^{-4} \text{ K}^{-1}$ .

From (1), (3), and (4) the volumetric expansion coefficient of the liquid is found to be

$$\gamma = \frac{1}{V_0} \cdot \frac{\Delta V}{\Delta T} + \gamma_D \quad (5)$$

So there is still the volume  $V_0$  of the dilatometer to be determined. This is done by determining the masses  $m_1$  of the empty, dry dilatometer and  $m_2$  of the dilatometer filled with

pure water up to the lower end of the riser tube. Since the density  $\rho$  of water at a known temperature  $T$  is known to a high accuracy (see table 1), the volume is obtained from

$$V_0 = \frac{m_2 - m_1}{\rho} \quad (6)$$

### 3. EXPERIMENTAL PROCEDURE

#### Calibration of the dilatometer:

- 3.1 ) Determine the mass  $m_1$  of the empty dilatometer.
- 3.2) Fill the flask with pure water up to the bottom third of ground opening.
- 3.3) To eliminate air bubbles, heat the dilatometer in the water bath almost to boiling without the riser tube attached.
- 3.4) Allow the water bath to cool off to room temperature; top off the liquid level as necessary. Take down the temperature  $T$ .
- 3.5) Attach the riser tube, press your finger on the opening, then remove the riser tube and allow it to drain.
- 3.6) Replace the riser tube on the flask, dry the dilatometer and measure the mass  $m_2$  of the

water-filled dilatometer.

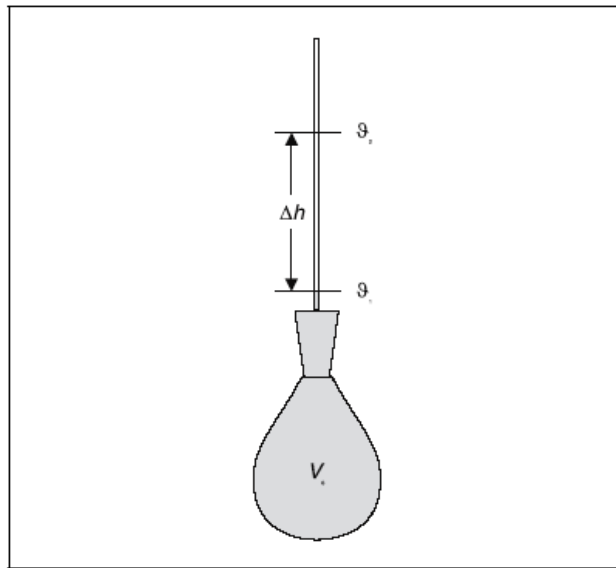


Figure 1. Calibration of the dilatometer.

### Measuring the volume expansion of water and ethanol:

The experimental setup is illustrated in Fig. 2.

*Note: After the hot plate has been switched off, the heating of the liquid continues for some time so that the dilatometer may run over.*

3.7) Dip the dilatometer into the heating bath so that the riser tube sticks out.

3.8) Switch the hot plate on at the lowest step, and switch it off when the liquid level in the dilatometer is just below the highest mark of the scale.

3.9) Wait until the liquid level has reached its maximum, then allow the water bath to cool down by about 1-2 °C.

3.10) Let the water bath continue cooling down, and determine the level  $h$  of the water in the riser tube as a function of the temperature.

3.11) Then fill in ethanol into the thoroughly dried dilatometer, warm it up in the water bath, and repeat the measurement of the liquid level  $h$  as a function of the temperature.

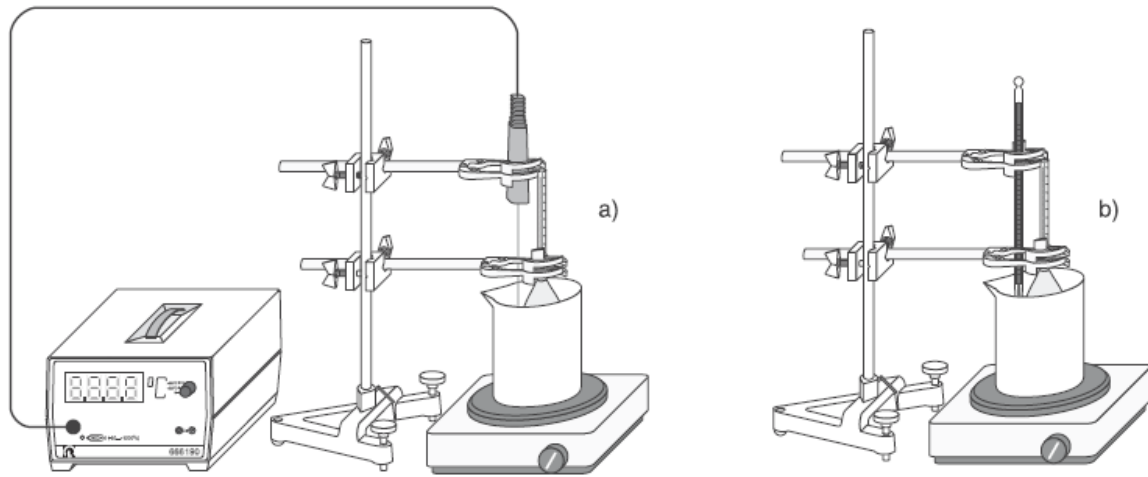


Figure 2. Experimental set up for the determination of the volumetric expansion coefficient of liquids.

$\vartheta$	$\frac{\rho}{\text{g} \cdot \text{cm}^{-3}}$	$\vartheta$	$\frac{\rho}{\text{g} \cdot \text{cm}^{-3}}$
15 °C	0.999099	23 °C	0.997540
16 °C	0.998943	24 °C	0.997299
17 °C	0.998775	25 °C	0.997047
18 °C	0.998596	26 °C	0.996785
19 °C	0.998406	27 °C	0.996515
20 °C	0.998205	28 °C	0.996235
21 °C	0.997994	29 °C	0.995946
22 °C	0.997772	30 °C	0.995649

Table 1. Values quoted in the literature for the density  $\rho$  of pure water as a function of the temperature T.

$\vartheta$	$\frac{h}{\text{cm}}$	$\vartheta$	$\frac{h}{\text{cm}}$
38 °C	9.9	32 °C	4.6
37 °C	9.1	31 °C	3.7
36 °C	8.25	30 °C	2.7
35 °C	7.4	29 °C	1.8
34 °C	6.5	28 °C	0.9
33 °C	5.55		

Table 2. The level  $h$  of ethanol as a function of the temperature  $T$ .

$\vartheta$	$\frac{h}{\text{cm}}$	$\vartheta$	$\frac{h}{\text{cm}}$
60 °C	9.5	45 °C	4.25
59 °C	9.3	44 °C	3.9
58 °C	8.9	43 °C	3.55
57 °C	8.6	42 °C	3.2
56 °C	8.2	41 °C	2.9
55 °C	7.85	40 °C	2.6
54 °C	7.5	39 °C	2.3
53 °C	7.1	38 °C	2.0
52 °C	6.75	37 °C	1.7
51 °C	6.4	36 °C	1.4
50 °C	6.0	35 °C	1.1
49 °C	5.7	34 °C	0.8
48 °C	5.3	33 °C	0.55
47 °C	4.95	32 °C	0.3
46 °C	4.6		

Table 3. The level  $h$  of pure water as a function of the temperature  $T$

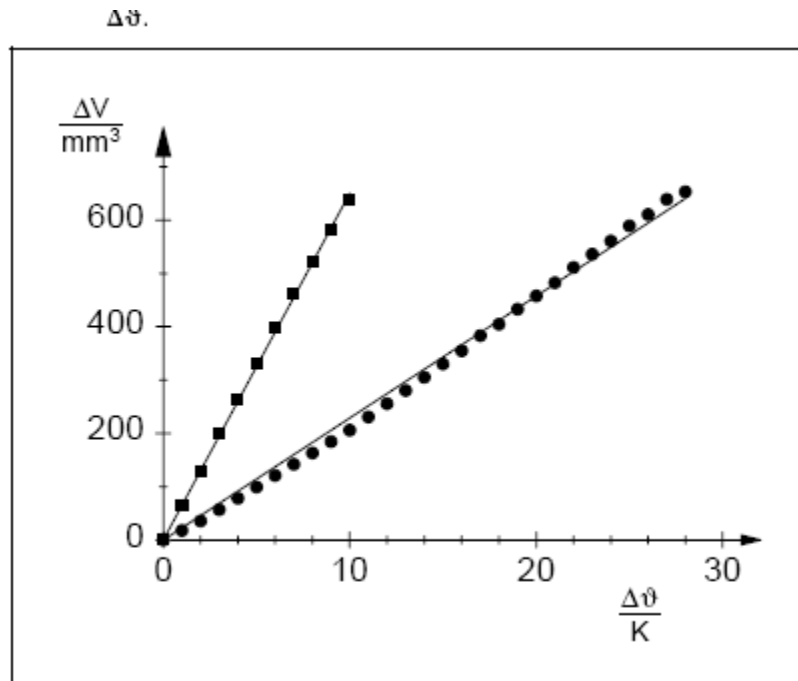


Figure 3. Thermal volume expansion  $\Delta V$  of water (circles) and ethanol (boxes) as functions of the temperature difference  $\Delta T$ .

#### 4. CALCULATION

4.1) Calculate the thermal expansion coefficients for water and ethanol and compare your result with the literature, than find the percentage difference.

4.2) Draw the thermal volume expansion  $\Delta V$  of water and ethanol as functions of the temperature difference  $\Delta T$ .



## 5. QUESTIONS

5.1) The coefficient of volume expansion for gasoline is  $10.8 \times 10^{-4}/^{\circ}\text{C}$ . At a gas station the gasoline is held in underground storage tanks where the ground temperature is  $13^{\circ}\text{C}$ . If you add exactly 12.0 liters of gasoline to your car's gas tank during the summer when the temperature is  $35^{\circ}\text{C}$ , what volume will this gasoline occupy when it warms to this ambient temperature?

5.2) What are the liquids used in the thermometers and are they all of the same accuracy?

5.3) Why are liquids, but not solids or gases, utilized in hydraulic systems such as automobile brakes?

5.4) Many scientists believe that earth's inner core is solid while its outer core is liquid. State conditions that might make this possible even though the inner core is thought to be at a higher temperature than the outer core?

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