B. Sc. III Physics
(Thermal Physics Lab)

1. To determine the Coefficient of Thermal Conductivity of Cu by Searle's Apparatus.
2. To determine the Coefficient of Thermal Conductivity of a bad conductor by Lee and Charlton's disc method.
3. To determine the Temperature Coefficient of Resistance by Platinum Resistance Thermometer (PRT).
4. To study the variation of Thermo-Emf of a Thermocouple with Difference of Temperature of its Two Junctions.
5. To calibrate a thermocouple to measure temperature in a specified Range using (1) Null Method, (2) Direct measurement using Op-Amp difference amplifier and to determine Neutral Temperature.
6. Coefficient of linear expansion using Gumber method.
7. Specific heat determination by calorimeter method.

References:

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2. A Text Book of Practical Physics, I.Prakash& Ramakrishna, 11th Ed., 2011, Kitab Mahal
3. Advanced level Physics Practicals, Michael Nelson and Jon M. Ogborn, 4th Edition, reprinted 1985, Heinemann Educational Publishers
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Experiment No. 1

PART II – HEAT

8

Thermal Conductivity

8.1 TRANSMISSION OF HEAT

Heat can be transferred from one point to another by three different ways viz., conduction, convection and radiation.

Conduction is the process in which heat is transmitted from one point to another by the lattice vibrations without the actual motion of the particles. This process is prominent in solids, where the particles are fixed at their positions.

Convection is the process in which heat is transmitted by the actual motion of the heated particles. It is prominent in the case of liquids and gases and plays an important role in climate changes and in the formation of land and sea breeze.

Radiation is the process in which heat is transferred from one place to another by the electromagnetic waves. This process does not require any intermediate medium. It is by this process that the heat of the sun reaches earth although there is no medium between the sun and earth apart from a thin layer of atmosphere.

8.2 COEFFICIENT OF THERMAL CONDUCTIVITY

Consider a cube of side x cm and area of each face A cm^2. The opposite faces of the cube are maintained at temperatures T_1 and T_2 where $T_2 > T_1$. Heat is conducted from higher to lower temperature. Quantity of heat Q conducted across the two opposite faces depends upon the following parameters.

$$Q \propto A$$

$$Q \propto T_2 - T_1$$

$$Q \propto \text{time } t$$

and
$$Q \propto \frac{1}{x}$$

$\therefore$
$$Q \propto \frac{A\,(T_2 - T_1)t}{x}$$

or
$$Q = \frac{K\,A\,(T_2 - T_1)t}{x} \tag{8.1}$$

Here K is a constant called the coefficient of thermal conductivity or simply thermal conductivity of the material of the cube.

If $A = 1\ \text{m}^2$, $(T_2 - T_1) = 1°\text{C}$, $t = 1$ sec and $x = 1\text{m}$

then $Q = K$.

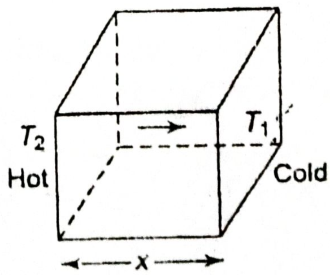


Fig. 8.1

Therefore, the ***co-efficient of thermal conductivity is defined as the amount of heat flowing in one second across the opposite faces of a cube of side 1m maintained at a difference of temperature of 1°C.***

The quantity $\frac{(T_2 - T_1)}{x}$ in Eqn. (8.1) represents the rate of fall of temperature across the two faces of the cube and is called ***temperature gradient*** and can be replaced by $\frac{dT}{dx}$ to include the cases where the rate of fall of temperature with distance is not uniform. As T decreases with increase in distance from the hotter end, the quantity dT/dx is negative. Therefore Eqn. (8.1) becomes

$$Q = -KA\frac{dT}{dx}t \tag{8.2}$$

The S.I. unit of thermal conductivity is *Joule per sec per metre per deg. kelvin* (J s^{-1} m^{-1} K^{-1}) or *Watt per metre per degree kelvin* (W m^{-1} K^{-1}). The C.G.S. unit is Cal s^{-1} cm^{-1} $°C^{-1}$.

In analogy with electrical resistance, the reciprocal of thermal conductivity (1/K) is called ***thermal resistance.***

8.3 CLASSIFICATION OF MATERIALS ON THE BASIS OF THEIR THERMAL CONDUCTIVITY

Solids may be classified as good, medium and poor conductors of heat.

1. **Good conductors:** All metals come under the class of good conductors. The value of conductivity for metals is of the order of $10^{-2} - 10^{-1}$ Cal s^{-1} cm^{-1} $°C^{-1}$. For all metals the ratio of the thermal conductivity and electrical conductivity at a particular temperature is constant. This is known as *Wiedermann Franz Law.* All pure metals have a *negative temperature cofficient,* i.e., the value of the thermal conductivity for metals decreases with the rise of temperature. Alloys of metals on the other hand have a positive temperature coefficient of conductivity.
2. **Medium conductors:** The refractory material, bricks, various kinds of wood, chalk, saw dust etc., fall under this category. The value of the conductivity of these materials is of the order of $10^{-3} - 10^{-2}$ Cal s^{-1} cm^{-1} $°C^{-1}$.
3. **Poor conductors:** This category includes asbestos, wool, cork, ebonite, card-board etc. The value of K for these is of the order of 10^{-4} Cal s^{-1} cm^{-1} $°C^{-1}$. Such materials are used for heat insulation.

Experiment 8.1: To find the coefficient of thermal conductivity of a good conductor (copper) using Searle's conductivity apparatus.

Apparatus: Searle's apparatus, four thermometers, a beaker, steam boiler, heater, stop-watch.

Description of Apparatus

Figure 8.2 shows the Searle's apparatus. This apparatus is used for finding the coefficient of thermal conductivity of good conductors like copper, brass etc. The apparatus consists of a rod AB, the end A of which projects into a steam chamber S

while the other end B projects into another chamber W through which cold water circulates as indicated. The temperatures at entry and exit of water are given by thermometers T_3 and T_4 respectively. Two other thermometers T_1 and T_2 are placed a known distance apart in two holes drilled in the rod. To ensure good contact of the thermometre bulbs with the rod, a little mercury is placed in these holes. The whole rod is wrapped round with some non-conducting material like wool, felt, cork shaving etc.to insulate it from the surroundings.

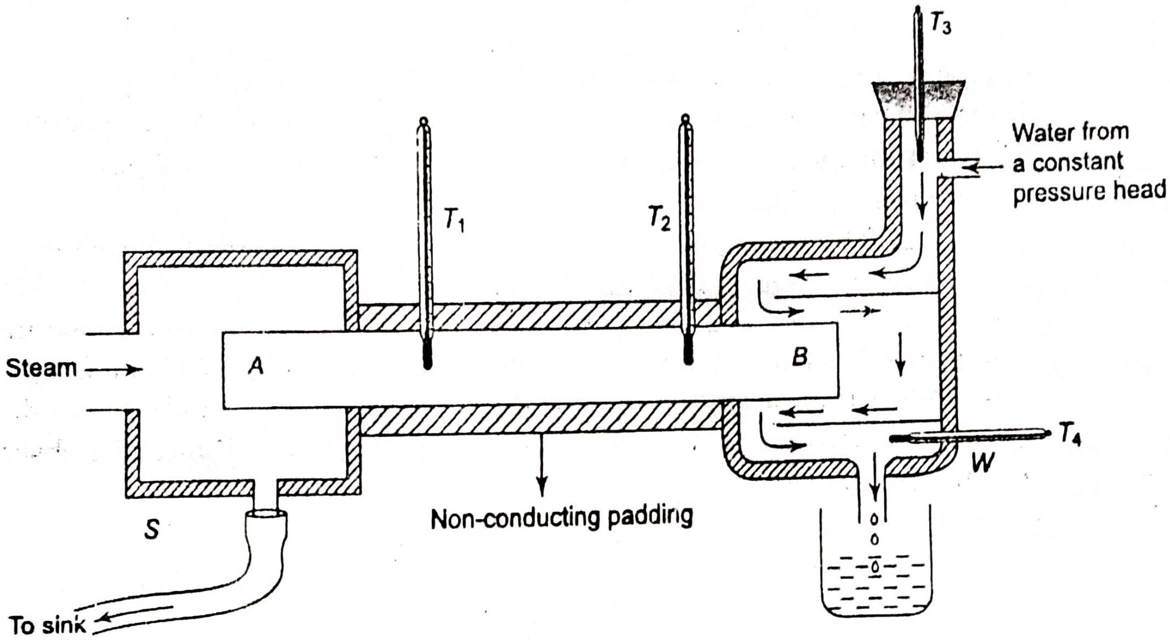


Fig. 8.2

Theory: When steam is passed through the steam chamber, the end A of the metal rod gets heated and heat is conducted from this hot end to the end B of the rod which is cold. The bar is thermally insulated so that there is no loss of heat by radiation or convection of air around it. When heat reaches the end B of the rod, some of it is taken away by the water flowing in chamber W around this end of the rod. The flow of water is regulated so that a steady state is reached after which the temperatures T_1, T_2, T_3 and T_4 are constant. After the steady state, any gain of heat by the rod from the steam is equal to the loss of heat by the rod to the water and the temperature of every part of the rod remains constant.

Let T_1 and T_2 be the temperatures at two points distance d apart inside the rod. If K is the coefficient of thermal conductivity, then the amount of heat Q passing through these points in one second is given by

$$Q = \frac{KA(T_1 - T_2)}{d} \quad (T_1 > T_2)$$

This heat is gained by water in one second which appears as increase in the temperature of water by $(T_4 - T_3)$. If m is the mass of water collected in t sec, this gain of heat by water in one second

$$= \frac{ms\,(T_4 - T_3)}{t}$$

where s is the specific heat capacity of water

$$\therefore \quad \frac{KA(T_1 - T_2)}{d} = \frac{ms\,(T_4 - T_3)}{t}$$

whence
$$K = \frac{ms\,(T_4 - T_3)\,d}{A(T_1 - T_2)\,t} \qquad (8.3)$$

Thus the co-efficient of thermal conducting K for the material of the rod can be determined.

Procedure

1. Insert the thermometers T_1 and T_2 into the holes in the rod.
2. Fill the steam generator S about half with water and start heating it.
3. Temperatures in T_1 and T_2 start rising. Start the flow of cold water through the water chamber W. Also insert two thermometers T_3 and T_4 into W as shown in Fig. (8.2).
4. Adjust the flow of water so that water comes out as a trickle through the exit. Temperature in T_4 also starts rising.
5. Wait till all the temperatures have become stationary. This shows that the steady state has been reached. Note the temperature of T_1, T_2, T_3 and T_4.
6. Now collect the water flowing out of W in 10 minutes in a clean and dry beaker and measure its volume with a graduated cylinder. Repeat the observation three times.
7. Change the rate of flow of water and get other sets of readings.
8. Measure the diameter of the rod AB with vernier callipers and also the distance d between the two thermometers T_1 and T_2.

Observations

Vernier constant = ... cm

Diameter of the rod = 1. ... cm

2. ... cm

Mean diameter = ... cm

radius r = ... cm.

Area of cross section A of the rod = πr^2

= ... cm^2

Distance between the thermometers T_1 and T_2, d = ... cm

Steady state temperatures, T_1 = ... °C

T_2 = ... °C.

density of water ρ = ... gm/c.c.

Sp. heat of water s = 1 Cal/g °C

S. No.	T_3 (°C)	T_4 (°C)	$T_4 - T_3$ (°C)	Volume of water collected V (c.c)	Mass of water collected $m = V\rho$ (g)	Time t (sec)	K
1							
2							
3							

Mean K =

Calculations

$$K = \frac{ms\,(T_4 - T_3)\times d}{A(T_1 - T_2)\times t}$$

Calculate K for each observation in the table

$$T_4 - T_3 = \ldots\ ^\circ\text{C}$$
$$T_1 - T_2 = \ldots\ ^\circ\text{C}$$
$$t = \ldots \text{ sec}$$

For obtaining the result in C.G.S units

$$m = \ldots \text{ g}$$
$$s = 1 \text{ Cal/g}^\circ\text{C}$$
$$d = \ldots \text{ cm}$$
$$A = \ldots \text{ cm}^2$$

This gives $K = \ldots$ Cal s^{-1} cm^{-1} $^\circ C^{-1}$

For obtaining the result in S.I. units

$$m = \ldots \text{ kg}$$
$$s = 4185 \text{ J/kg.K}$$
$$d = \ldots\ m$$
$$A = \ldots\ m^2$$

This gives $K = \ldots$ Js^{-1} m^{-1} K^{-1}

Note: Remember that

$$1 \ cal\ s^{-1}\ cm^{-1}\ ^\circ C^{-1} = 418.5\ Js^{-1}\ m^{-1}\ K^{-1}$$

Result: The co-efficient of thermal conductivity of copper = … Cal s^{-1} cm^{-1} $^\circ C^{-1}$
= … Js^{-1} m^{-1} K^{-1}

Value from tables = …

% error =

Precautions and Sources of Error

1. Before passing steam, the initial readings of the thermometers should be noted and corrections should be made accordingly.
2. The temperatures in the thermometers should be recorded only after the steady state has been reached.
3. Any error due to the defects in thermometers can be removed by interchanging T_1 and T_2 and also T_3 and T_4 and taking the mean of the differences $(T_1 - T_2)$ and $(T_4 - T_3)$.
4. The rod should be thermally insulated so as to avoid loss of heat by radiation and air convection.
5. The rate of flow of water should be uniform and slow. This will ensure a reasonably large difference of temperature for the incoming and outflowing water.
6. See that there is no leakage of water at the corks through which the thermometers pass.

7. The radius of the rod occurs in the second power in the formula for K, hence the diameter should be measured very carefully at a number of places along the rod, and at each point it should be measured along two mutually perpendicular directions.

Weak Points

1. This method can only be used for measurement of the coefficient of thermal conductivity of good conductors of heat and is not suitable for the same purpose for bad conductors.
2. Since the calculations involve readings of four thermometers, these have to be very sensitive. The error due to the thermometers can be eliminated by interchanging the thermometers in each pair and repeating the reading. For more accurate results, the temperatures should be measured by platinum resistance thermometers or better still by thermocouples.
3. Any leakage in the water inlet or outlet may give serious error.
4. Heat loss by radiation cannot be entirely ruled out, as no perfect insulator of heat is known. Better results can be achieved if the rod is heated electrically.

8.4 THERMAL CONDUCTIVITY OF BAD CONDUCTORS

In measuring the conductivity of bad conductors such as wood, cork, rubber, glass, ebonite, asbestos etc, long bars or rods should not be used as in the case of metals, for it will be impossible to measure accurately the small rate of flow of heat even with a reasonably high temperature difference between the ends. Furthermore, since the rate of flow of heat by conduction Q is directly proportional to the cross-sectional area A and inversely proportional to the thickness d, it is advantageous to use the substance in the form of a thin disc of large area of cross section so that Q becomes measurable, inspite of K being small.

Experiment 8.2: To determine the coefficient of thermal conductivity of a bad conductor by Lee and Charlton's method.

Apparatus: Lee and Charlton's apparatus, circular disc (of the same diameter as the disc in apparatus) of a bad conductor, two thermometers, steam generator, stand and threads, a stop-watch, a screw gauge, vernier callipers, a balance.

Description of the Apparatus

The apparatus consists of a solid metal slab B of copper which is suspended horizontally by means of strings from a stand. There is a hollow cylindrical metal vessel A with inlet and outlet for steam.

A thin disc D of the material, whose coefficient of thermal conductivity is to be found, is placed between A and B. When

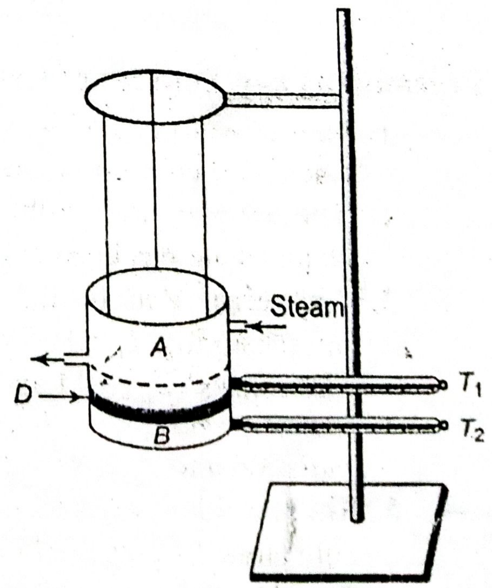


Fig. 8.3

Experiment No. 2

Description of Lee's apparatus:

The apparatus shown in Fig. 2 consists of two parts. The lower part C is circular metal disc. The experimental specimen G, usually rubber, glass or ebonite (here it is glass) is placed on it. The diameter of G is equal to that of C and thickness is uniform throughout. A steam chamber is placed on C. The lower part of the steam chamber, B is made of a thick metal plate of the same diameter as of C. The upper part is a hollow chamber in which two side tubes are provided for inflow and outflow of steam. Two thermometers T_1 and T_2 are inserted into two holes in C and B, respectively. There are three hooks attached to C. The complete setup is suspended from a clamp stand by attaching threads to these hooks.

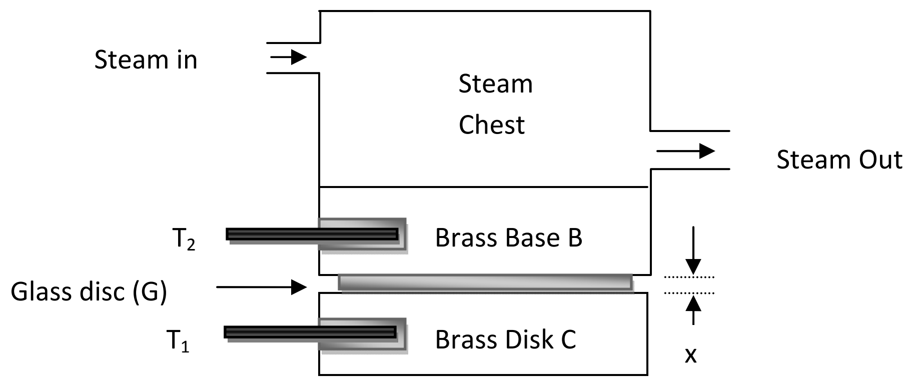
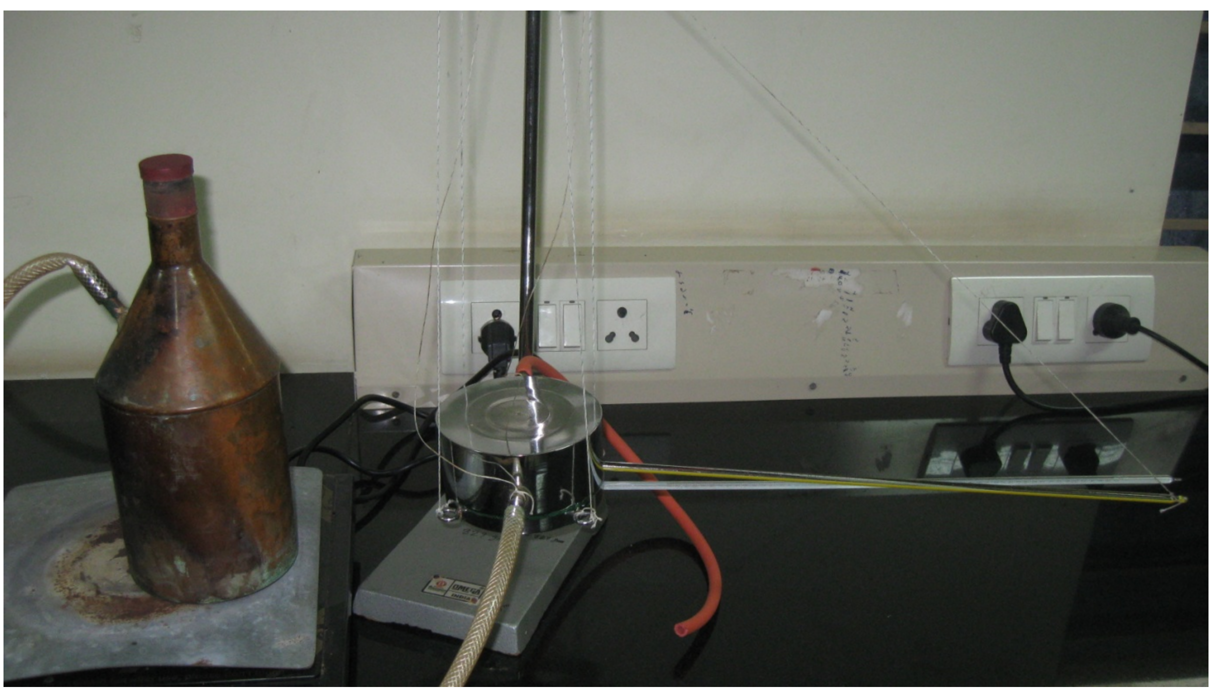


Fig.2



Photograph of thermal conductivity measurement setup

When steam flows for some time, the temperatures recorded (T_1 and T_2) gradually remain steady. This is the steady state.

Let at the steady state, temperature of C = T_1.

Temperature of B = T_2.

Surface area of G = A

Conductivity of G = k

Thickness of G = x

Hence amount of heat flowing through G per second, H is given by Eq. (1). When the apparatus is in steady state (temperatures T_1 and T_2 constant), the rate of heat conduction into the brass disc C is equal to the rate of heat loss from the bottom of it. The rate of heat loss can be determined by measuring how fast the disc C cools at the previous (steady state) temperature T_1 (with the top of the brass disk covered with insulation). If the mass and specific heat of the lower disc are m and s, respectively and the rate of cooling at T_1 is dT/dt then the amount of heat radiated per second is,

$$H = ms\frac{dT}{dt} \quad \text{.........(2)}$$

Equating (1) and (2) and simplifying, k can be determined as,

$$k = \frac{ms\left({}^{dT}\!/_{dt}\right)x}{A\,(T_2 - T_1)} \quad \text{.........(3)}$$

Procedure:

1. Fill the boiler with water to nearly half and heat it to produce steam.
2. In the mean time, take weight of C by a weighing balance. Note its specific heat from a constant table. Measure the diameter of the specimen by a scale or slide calipers, if possible. Calculate the surface area, $A = \pi r^2$.
3. Measure the thickness of the specimen by screw gauge. Take observations at 5 spots and take the mean value.
4. Put the specimen, steam chamber etc. in position and suspend it from the clamp stand. Insert the thermometer. Check if both of them are displaying readings at room temperature. If not, note the difference θ, is to be added to ($T_2 - T_1$) later.
5. Now stem is ready. Connect the boiler outlet with the inlet of the steam chamber by a rubber tube.
6. Temperatures recorded in the thermometers will show a rise and finally will be steady at T_1 and T_2.
7. Wait for 10 minutes and note the steady temperature. Stop the inflow of steam.
8. Remove the steam chamber and the specimen G. C is still suspended. Heat C directly by the steam chamber till its temperature is about $T_1 + 7°$.

9. Remove the steam chamber and wait for 2 – 3 minutes so that heat is uniformly distributed over the disc C.
10. Place the insulating material on C. Start recording the temperature at ½ minute intervals. Continue till the temperature falls by 10^0 from T_1.

Observations:

(I) Details of the sample G

(a) Diameter: (using scale/slide calipers)

Table-1:

Sl No.	Diameter (cm)	Mean Diameter (cm)
1		
2		
3		

Surface area of G = A = ………………………………

Thickness: (using screw gauge)

Table – 2:

Pitch = …………… **Least count=…………………………**

Sl No.	Initial Reading I (cm)	Final Reading F (cm)	Difference (I ~ F) in cm	Mean (cm)
1				
. . .				
5				

(II) Details of the lower disc C

Mass of the disc, m = ……..

Specific heat of the material, s = 380 J/kg. °C

(III) Correction of Thermometers

Room temperature recorded T_2 = …………………

Room temperature recorded T_1 = …………………

So correction of thermometers $\theta = T_2 - T_1$

(IV) Steady Temperature

Temperature of C = …………………………………..

Temperature of B = ……………………………………

Taking thermometer error in to account, the difference = $(T_2 - T_1 + \theta)$

(V) **Table-3:** Time – Temperature record during cooling

Time (minute)	0	½	1	….	…..	…..	…..	……	…….
Temperature °C									

Graph:

Using the data from Table – 3, plot the cooling curve (time versus temperature) and determine the slope $dT/dt = \Delta T/\Delta t$ at the steady temperature T_1 (Fig. 3).

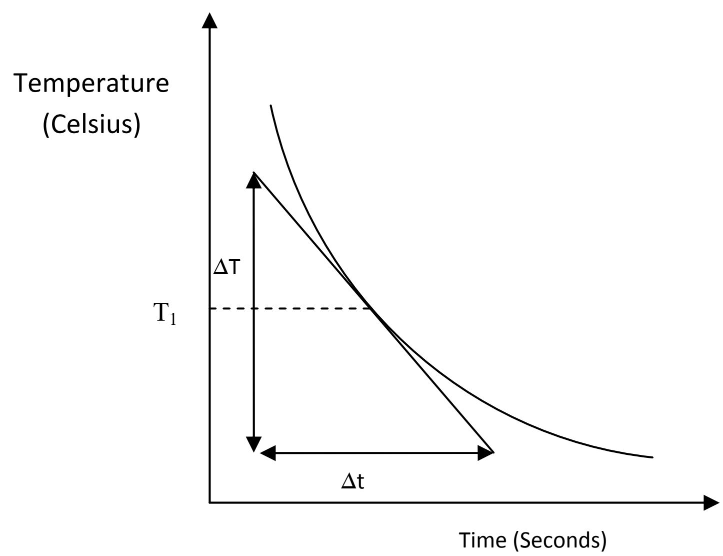


Fig. 3

Calculation: k = …………….

Discussion and conclusion:

Probable errors and precautions:

1. Don't record T_1 and T_2 unless they have remained steady for at least 10 minutes.
2. The tangent to the cooling curve should be done very carefully. An error in dT/dt will result in a wrong result for k.

3. The radiation loss only due to the surface of G in contact with C is taken into account here while there is some loss at the edges. Therefore, the diameter of the specimen disc S should be sufficiently large than its thickness.
4. Since room temperature might change during the course of the experiment, it is advised to complete the experiment quickly.

Error analysis: $\frac{\Delta k}{k} = \sqrt{\left(\frac{\Delta\left(\frac{dT}{dt}\right)}{\frac{dT}{dt}}\right)^2 + \left(2\frac{\Delta d}{d}\right)^2 + \left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta T_2 + \Delta T_1}{T_2 - T_1}\right)^2}$

Experiment No. 3

Physics 213 Laboratory   Coefficient of Linear Expansion

Purpose: To measure the coefficients of expansion of several metals.

Equipment: Linear-expansion apparatus, steam generator, breaker, 100^{o} C thermometer, rubber tubing, metal rods of aluminum, iron, copper, brass, and steel.

Theory: The change in length per unit length per degree rise in temperature is called the *coefficient of linear expansion*. It is defined by

$$\alpha = \frac{1}{L_0}\frac{dL}{dT} \qquad (1)$$

where a is the coefficient of linear expansion, L_0 is the initial length and dL/dT is the rate of change in length with temperature T. Logically the initial temperature should be a fixed standard, such as 0^{o} C; however, because the value of a is very small for solids, the error introduced by using any other initial temperature is not large.

The change in length and the total length are always expressed in the same units; the value of the coefficient is therefore independent of the length unit used but depends on the temperature unit. The value of the coefficient of expansion should be specified as "per degree centigrade" or "per degree Fahrenheit." If ΔL represents a small finite change in length of a metal bar for a finite change in temperature , then the value of a may be found from

$$\alpha = \frac{1}{L_0}\frac{\Delta L}{\Delta T} \qquad (2)$$

Overview:: A rod of a common metal is encased in a metal jacket. Its length is measured at room temperature. The change in length is measured when the temperature is raised from room temperature to the temperature of steam. From these observations the coefficient of linear expansion will be computed for several metals, and compared with accepted values. In this experiment, be sure to measure and record the room temperature length of each metal rod **before** heating any of the metal rods.

CAUTION: Steam can cause severe burns. Handle all hot apparatus with care!

Micrometer-screw Linear Expansion Apparatus. The apparatus shown in Figure 1 is designed for measurement of the increase in length of the rod by means of a micrometer screw (detail shown in Figure 2). See next page.

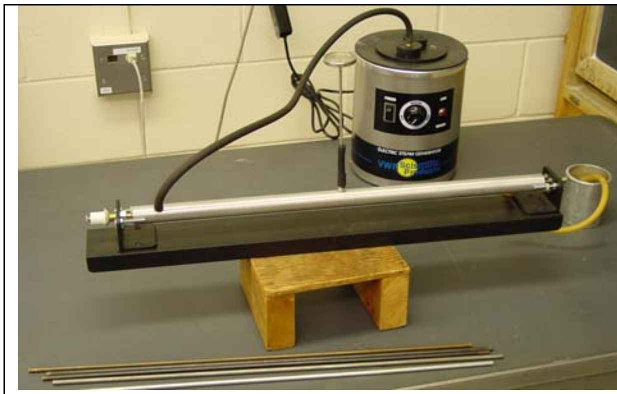


Figure 1 The linear expansion apparatus. The rods are placed inside the silver jacket and the whole assembly is placed o the black base.

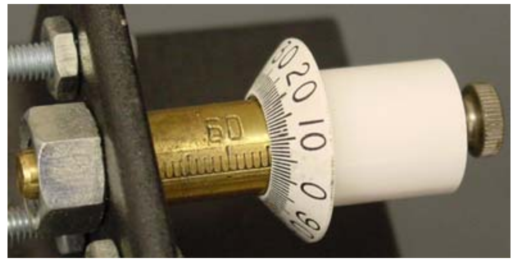


Figure 2 Close-up of the micrometer screw at one end of the apparatus. The brass barrel is marked in cm (stamped numbers) with tick marks every mm. the dial allows measurement of 0.01 mm with index being the horizontal line marked on the brass barrel.

Procedure:

1). Fill the steam generator two-thirds full of water and turn it on.

2). Insert a rod into the jacket, place it on the base and adjust the micrometer screw until it touches the rod (and the other end of the rod touches the fixed screw). Read the length of the rod using the micrometer scale. Record the length of the rod, the material the rod is composed of, and the room temperature. **Repeat this procedure for each rod before heating up any of the rods**.

3). Insert a rod in the jacket and place the jacket in the base. Connect the tubing from the steam generator to the expansion apparatus. Lead the tubing from expansion apparatus into a beaker well below the level of the apparatus.

4). Place the thermometer in the opening provided in the expansion apparatus. Allow steam to flow through the jacket until a steady temperature is reached.

5). Turn the micrometer screw until it is snug. Record the readings of the micrometer screw and the thermometer. Turn off the water and drain the jacket. Turn back the micrometer screw at least two full turns.

6). Replace the rod with one made from a different metal by using the new rod to push the old rod out of the jacket. Repeat steps 3 through 5.

7) Repeat steps 3 through 6 for all rest of the rods.

8). Disconnect the apparatus, empty the steam generator and beaker, mop up the water, and leave everything in neat shape.

Calculations:

1). From the difference in micrometer-screw readings, or the difference in scale readings, determine the change in length of each rod.

2). From the initial and final temperatures, record the temperature difference.

3). Calculate the coefficient of linear expansion by the use of Eq. (3).

4) Compare this value with a standard value, taken over about the same temperature range. Compute the percent difference between the two, and discuss errors and sources of errors.