Exp. 19. Coefficient of thermal conductivity by Lee's disc method

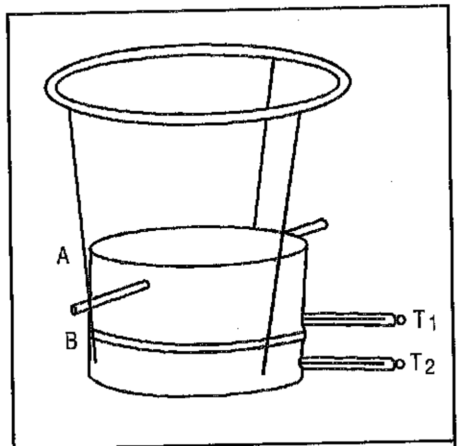


Fig. 19.1 (a)

Object

To determine the coefficient of thermal conductivity of card-board (bad conductor) by Lee's disc method.

Apparatus

Lee's disc apparatus, two sensitive thermometers, a piece of card-board, stop-watch, screw gauge and a vernier callipers.

Lee's disc apparatus [fig. 19.1(*a*)] consists of two metal discs A and B each of which is about 10 cm in diameter and 1.25 cm thick. The thin piece of card-board or glass as specimen in circular form having the same diameter as the discs, is placed between A and B. The thermometers T_1 and T_2 placed in drilled holes record the temperatures of A and B. The steam jacket S has the same diameter as A and B. The whole apparatus is suspended by three strings attached to hooks fixed in B.

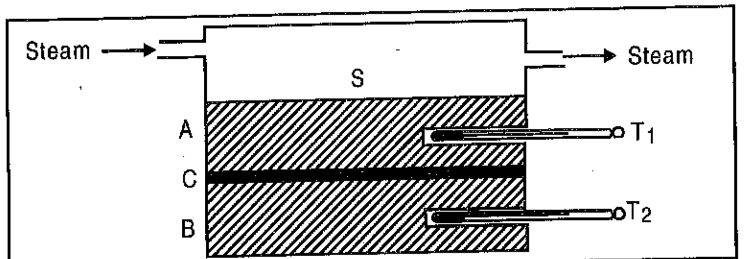


Fig. 19.1 (b)

Theory

As steam passes through A, heat is conducted through the specimen C and reaches B thereby warming it. After sometime, a steady state is reached when the rate of flow of heat through C = the rate of flow of heat from B by radiation and convection

i.e., $$K.A.\frac{\theta_1-\theta_2}{d} = M.s.\left(\frac{d\theta}{dt}\right) \quad \text{or,} \quad K = \frac{Msd}{A(\theta_1-\theta_2)}\left(\frac{d\theta}{dt}\right)$$

where

K = coefficient of thermal conductivity of card-board,

A = area of cross-section of specimen,

d = thickness of specimen,

θ_1, θ_2 = temperatures indicated by T_1 and T_2 in the steady state,

$\frac{d\theta}{dt}$ = rate of cooling of B at temperature θ_2,

M = mass of the disc B,

and s = specific heat of the material of B.

Procedure

(i) A piece of card-board is cut so that its diameter is same as that of disc A or B. The thickness is measured by a screw-gauge.

(ii) The disc is weighed and its diameter is determined by callipers. The specimen is then placed between the two discs as shown in the figure.

(iii) Steam chamber is placed over the disc A and steam as passed till the thermometers record constant readings for atleast five minutes. The thermometer readings θ_1 and θ_2 are noted.

(iv) The specimen (and A, if it is detachable from S) is removed and the steam chamber is placed above it. When the temperature of B rises by about 5°C above θ_2, the steam chamber is replaced by the specimen. The disc B is then allowed to cool under similar conditions as during the first part of the experiment. Temperatures are recorded at intervals of half-a-minute till the disc B has cooled to about 5°C below θ_2.

(v) A time-temperature graph is drawn with time as abscissa and θ as ordinate. From this, the slope $\frac{d\theta}{dt}$ of the tangent to the curve at temperature θ_2 is measured.

Observations

[A] Mass of lower disc B = ...gm

Specific heat of lower disc B = ...cal/gm/°C

Diameter of the specimen (= diameter of disc B) = ...cm

Steady temperature θ_1 = ...°C

Steady temperature θ_2 = ...°C

[B] *Measurement of the thickness of specimen*

See Observation table [C] in Expt. No. 6

[C] *Cooling of the lower disc*

Time in minutes	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	...
Temperature in °C	...	...	...	...	...	...

Calculations

$$A = \pi\ (\text{radius of card-board})^2 = \ldots\ \text{cm}^2$$

$$K = \frac{M.s.\frac{d\theta}{dt}.d}{A(\theta_1 - \theta_2)} = \ldots$$

% error :

Result

The value of the coefficient of thermal conductivity of card-board (correct to significant figures) = ...cal/sec/sq. cm/unit temp. gradient.

Precautions

(i) Temperatures θ_1 and θ_2 should be recorded when they remain steady for atleast 5 minutes.

(ii) The diameter of the specimen C should be made equal to that of the discs A and B

QUESTIONS

(i) See Q,. (i) to (vi) in Expt. No. 16.

(ii) What is the difference between this method and those described in Expt. Nos. 16, 17 and 18 ?

(iii) How can you apply this method in the case of liquids ?

Exp. 20. Determination of Radiation constant

Object

To determine the Stefan's radiation constant.

Apparatus

Stefan's radiation constant apparatus, silver-constantan thermocouple, a sensitive galvanometer and a weight box.

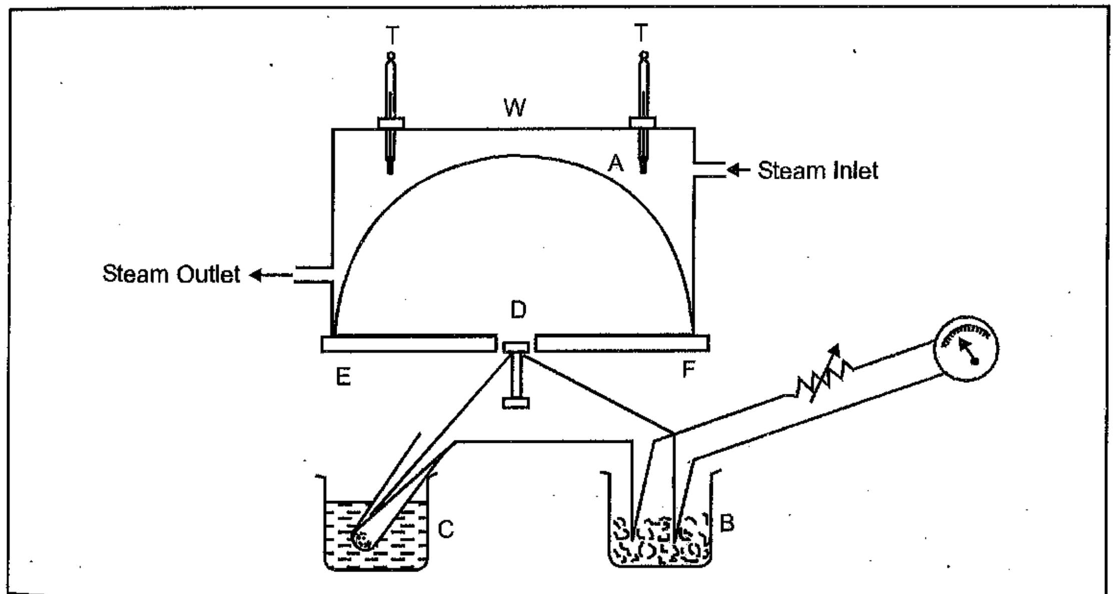


Fig 20.1

The apparatus (fig. 20.1) consists of a hollow metal hemisphere A blackened inside uniformly and fitted in a box W which serves as a steam chamber and whose mean temperature can be recorded by the two thermometers T T. The box W is fitted to a circular groove made on a table, of which the top EF is shown, with a small hole at its centre. The black surface of A acts as the black body radiator and the heat is received by a small silver disc D blackened on the upper surface so as to cover the central hole almost completely. The disc is arranged on the top of an ebonite rod so that with the help of a clamping device, it can be put or withdrawn at the centre of the hemisphere. From the lower surface of the disc are led away two wires. One of these is a constantan wire which goes to a sensitive galvanometer and the other is a silver wire going to the second junction placed in a test tube containing oil. The tube stands in a calorimeter C containing water. The junctions leading to the galvanometer are protected with cotton wool packed in a vessel B to avoid any disturbing effect due to the difference of temperature in the leads. A variable resistance, if necessary, is also included in the galvnometer circuit.

Theory

Let R_1 be the amount of radiation absorbed by the silver disc per unit area per sec. which will be equal to the amount of radiation emitted by the black body* at temperature T_1^oK.

Let R_2 be the amount of radiation emitted by the disc per unit area per sec. at temperature T_2^oK.

Now from Stefan's law

$$R_1 = \sigma T_1^4 \text{ and } R_2 = aT_2^4$$

(where σ is the Stefan's constant).

$$\therefore \quad R_1 - R_2 = \sigma(T_1^4 - T_2^4) \qquad ...(1)$$

Since the disc does not emit the full amount of heat it absorbs, the rate of radiation effectively gained by the disc D is $(R_1 - R_2)A$, where A is its area of cross-section.

Let m and s be the mass and specific heat of the disc D and let the rate of rise of temperature be $\frac{dT}{dt}$.

Then
$$ms\frac{dT}{dt} = \frac{(R_1 - R_2).A}{J}$$
$$= \frac{\sigma(T_1^4 - T_2^4)\,A}{J} \qquad \text{(from eqn. 1)}$$

Black body : A body which absorbs all the radiations incident on it of whatever wavelengths they may be but does not transmit or reflect any radiation, is known as a *perfectly black body.* A black body behaves as a perfect absorber as well as a perfect emitter, the emitted radiation at a given temperature being identical with absorbed radiation in all respects and thus the radiation inside a uniform temperature enclosure is called *full radiation.* The radiations of a perfectly black body within the constant temperature enclosure is *independent of the nature of the substance* and *is solely dependent on the equilibrium temperature of the enclosure and the surroundings.*

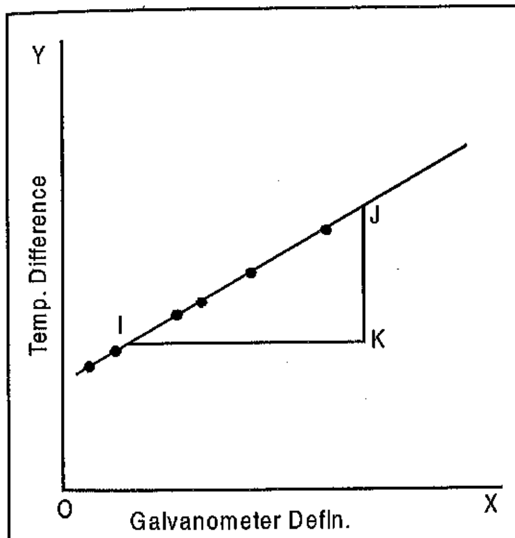
$$\sigma = \frac{Jms}{A(T_1^4 - T_2^4)}\frac{dT}{dt} \qquad ...(2)$$

Procedure

(*i*) *Standardisation of the thermocouple.*

First part of the experiment deals with the measurements of the temperature different between the junctions in terms of the deflection of the galvanometer. For this, the radiator A is kept at the room temperature and the silver disc is arranged in the central hole surrounded by cotton wool. The junction of the thermocouple in C is heated to a suitable temperature (say 60°C) and then allowed to cool. The galvanometer deflections are noted for every 2°C or 3°C fall in temperature. A graph (fig. 20.2) is drawn with the galvanometer deflection along X-axis and the temperature difference along y-axis. The slope of the straight line graph is then measured which is given by

$$\frac{JK}{IK} = \frac{dT}{ds}$$



Fg. 20.2

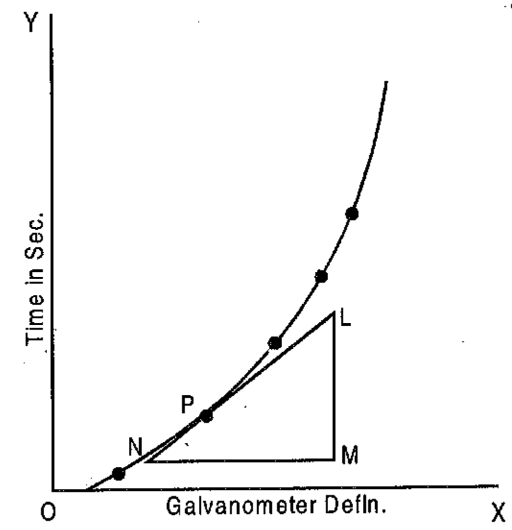


Fig 20.3

By measuring the temperature of the calorimeter C and knowing the galvanometer deflection, the temperature of the disc can be deduced from the graph.

(*ii*) *Measurement of* $\frac{dT}{dt}$: The disc D is removed and separated from cotton wool and steam is passed in W for a long time so that the radiator A attains a steady temperature as indicated by the two thermometers. The calorimeter C is filled with water at room temperature. Now the disc D is again introduced in the central hole and simultaneously from the instant, the deflections of the galvanometer are recorded at regular short intervals (say, 10 sec). A second graph (fig. 20.3) is drawn between the galvanometer deflections along X-axis and time along Y-axis. At a suitable point P on the graph (preferably the curved portion), a tangent is drawn as shown in the figure and the gradient of this tangent line is given by

$$\frac{LM}{MN} = \frac{dt}{ds}$$

Hence the rate of rise of temperature of the disc when the radiator is put on is given by

$$\frac{dT}{dt} = \frac{dT}{ds} \times \frac{ds}{dt} = \frac{JK}{IK} \times \frac{NM}{ML}$$

Thus, $\frac{dT}{dt}$ is determined.

(*iii*) The temperature of the disc at P is obtained by knowing the galvanometer deflection at this point (chosen for drawing the tangent) and then the difference in temperature between the junctions is determined from the first graph. The knowledge of the excess temperature at P over the initial temperature of the disc gives the temperature of the disc at P which is then converted to the absolute scale.

(*iv*) Other convenient points (say, Q and R) are also taken for drawing tangents and the average value of $\frac{dT}{dt} \times \frac{1}{T_1^4 - T_2^4}$ is obtained.

(*v*) The mass of the disc is determined by weighing. Thus, knowing all the quantities, Stefan's constant σ can be determined.

Observations

[A] Mass of the disc = ... gm

Specific heat of the disc (given) = ... cal/gm/°C

Diameter of the disc = ... cm

[B] *Standardisation of the thermocouple* $\left(\text{Measurement of } \frac{dT}{ds}\right)$

Room temperature = ... °C

Zero-error of the galvanometer = ...

Temp. difference between D and C	...	...	...	...	...	...	...	...	...	...	...	...	etc.
Corresponding gal. deflection	...	...	...	...	...	...	...	...	...	...	...	...	

[C] *Measurement of* $\frac{ds}{dt}$

Zero-error of the galvanometer

Time in sec	...	...	...	...	...	...	...	...	...	etc.
Corresponding gal. deflection	...	...	...	...	...	...	...	...	...	

[D] *Determination of* $\frac{dT}{dt} \times \frac{1}{T_1^4 - T_1^4}$

Temperature of the steam chamber (T_1) = ...°K

For tangent point	$\frac{dT}{dt} = \frac{JK}{IK} \times \frac{NM}{ML}$	Temp. of the disc. (T_2) in °K	$\frac{dT}{dt} \times \frac{1}{T_1^4 - T_2^4}$
P	...	...	...
Q	...	...	...
R	...	...	...
		Mean	

Calculations

$$\sigma = \frac{Jms}{A} \cdot \frac{1}{(T_1^4 - T_2^4)} \cdot \frac{dT}{dt}$$

= ... ... erg per sq. cm per sec.

% *error* :

Result

The Stefan's radiation constant (correct to significant figures)

= ... erg per sq. cm per sec.

Precautions

(*i*) The junctions to the galvanometer are put in a vessel B packed with cotton wool to prevent any electrical effect due to the temperature difference at these junctions.

(*ii*) For measuring $\frac{ds}{dt}$, sufficient time should be allowed so that the temperature of the radiator A may become steady.

(*iii*) Tangent points should be chosen in the curved portion of the graph since in the linear portion errors arise by conduction from the silver disc.