Laboratory Manual

Course code: PHY 2104
Course title: Heat and Thermodynamics Practical

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List of Experiments:

1. To determine the specific heat of a liquid by the method of cooling.

2. To determine the thermal conductivity of a bad conductor by Lee and Charlton’s method.

3. To determine of Specific Heat of Solid with Radiation Correction.

4. To determine of coefficient of thermal conductivity of a metal using Searle’s apparatus.

5. To determine of Latent heat of fusion of ice with radiation correction.

6. To calibrate of a thermocouple and determination of unknown temperature.

7. To determine of the Ratio of the Specific Heats of a Gas by Clement and Desorme’s apparatus.

8. To determine the value of the mechanical equivalent of heat (J) by electrical method with radiation correction.

9. To determine of the value of J, the Mechanical equivalent of heat by Callendar and Barnes apparatus (with radiation correction)

10. To determine of temperature co-efficient of the resistance of the material of a wire.

Reference Books:

1. **Practical Physics,** Dr. Giasuddin Ahmed and Md. Shahabuddin
2. **Physics-I & II,** R. Resnick, D. Halliday

Experiment no 01: **Date:**

Name of the Experiment: Determination of the specific heat of a liquid by the method of cooling

Theory: Newton's law of cooling can be used to determine the specific heat of a liquid by observing the time taken by the liquid in cooling from one temperature to another.

Suppose a liquid of mass M_1 and specific heat S_1 is enclosed within a calorimeter of mass m and specific heat s. The thermal capacity of the system is (M_1S_1+ms). If the temperature of the liquid falls from θ_1 to θ_2 in timet_1, then the average rate of loss of heat is

$$(M_1S_1 + ms)\frac{(\theta_1 - \theta_2)}{t_1}$$

If now the first liquid be replaced by an equal volume of second liquid of known specific heat (say water) under similar conditions and if the time taken by the second liquid to cool through the same range of temperature fromθ_1 to θ_2 be t_2, then the average rate of loss of heat is

$$(M_2S_2 + ms)\frac{(\theta_1-\theta_2)}{t_2},$$

where M_2 and S_2 are the mass and specific heat of the second liquid, respectively.

Since the conditions are similar, these two rates are equal

$$(M_1S_1 + ms)\frac{(\theta_1 - \theta_2)}{t_1} = (M_2S_2 + ms)\frac{(\theta_1 - \theta_2)}{t_2}$$

or,

$$S_1 = \frac{M_2S_2t_1 + ms(t_1 - t_2)}{M_1t_2}$$

Apparatus: Double walled enclosure, Calorimeter, Thermometer, Heater, Stopwatch, etc.

Brief Procedure:

1. Clean and dry the calorimeter and measure the mass (m) of the calorimeter and stirrer using a balance.
2. Pour water up to two-third volume of the calorimeter. Measure the total mass (m'') of the calorimeter, water and stirrer. Calculate the mass (M_2) of water.
3. Put the calorimeter on the heater and hold the thermometer bulb in the middle of the water and raise the temperature around 62 ^{o}C. Keep the calorimeter into the double walled enclosure with the help of a tongs. Close the lid and fix the thermometer with holder so that its bulb is in the middle of the water.
4. Start the stopwatch when the temperature just falls to 60 °C. Note this temperature in the table. Go on recording the temperature of water up to 20-25 minutes at an interval of one minute. Gently stir the water during the whole process.
5. Pour out the water from the calorimeter and wipe it dry. Take experimental liquid in the calorimeter as the same volume of water. Repeat steps 2, 3 and 4 for liquid.
6. On a graph paper, plot curves (both for water and liquid) by taking temperature as ordinate and time as abscissa (see Graph 1). Calculate t_1 and t_2 from the graph.

7. Using the given formula, determine the specific heat of the given liquid.

Experimental data:

Table: Time–temperature record for water and liquid

No. of obs.	Time (min)	Temperature of water (℃)	Temperature of liquid (℃)
1	00		
2	01		
3	02		
4	03		
5	04		
6	05		
7	06		
8	07		
9	08		
10	09		
11	10		
12	11		
13	12		
14	13		
15	14		
16	15		
17	16		
18	17		
19	18		
20	19		
21	20		
22	21		
23	22		
24	23		
25	24		
26	25		

Mass of the calorimeter + stirrer, m = g

Mass of the calorimeter + stirrer + liquid, m' = g

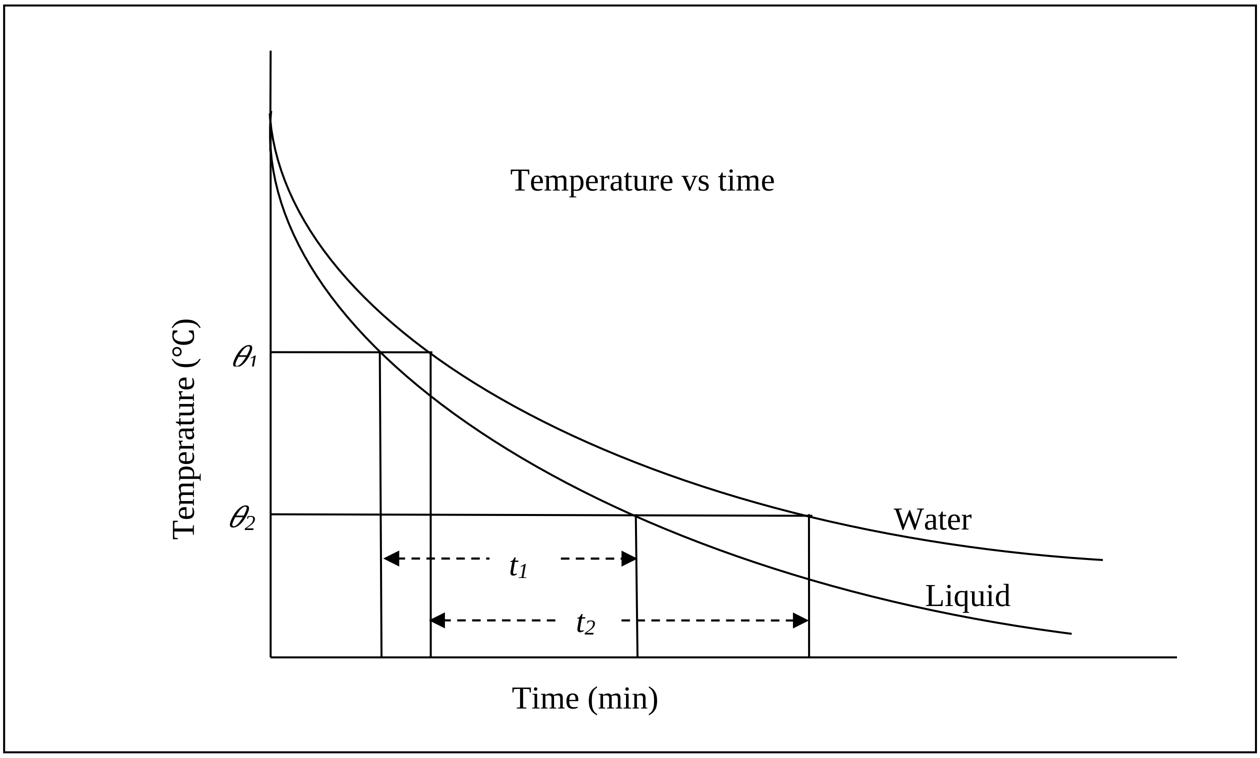
Mass of the liquid, $M_1 = m' - m$ = g

Mass of the calorimeter + stirrer + water, m'' = g

Mass of the water, $M_2 = m'' - m$ = g

Specific heat of the water, S_2 = 1.00 Cal g^{-1}°C^{-1}

Specific heat of the material of the calorimeter (Aluminum), s = 0.2096 Cal g^{-1}°C^{-1}
(Copper), s = 0.0909 Cal g^{-1}°C^{-1}



Graph 1: Variation of temperature with time

Calculations:

Time taken by water to cool from θ_1 = °C to θ_2 = °C as obtained from the graph 1, t_2 = min

Time taken by the liquid to cool from θ_1 = °C to θ_2 = °C as obtained from the graph 1, t_1 = min

Discussions:

Specific heat of the liquid,

$$S_1 = \frac{M_2 S_2 t_1 + ms(t_1 - t_2)}{M_1 t_2}$$

Error Calculation:

Standard value of the specific heat of turpentine is 0.42 Cal $g^{-1}°C^{-1}$.

Percentage error = $\frac{Standard\ value \sim Experimental\ value}{Standard\ value} \times 100\ \%$

Result:

Discussions:

Experiment no 02: **Date:**

Name of the Experiment: Determination of the thermal conductivity of a bad conductor by Lee and Charlton's method.

Theory: Consider a thin layer of slab of a bad conductor, *S*(such as glass or ebonite).*A* and *B* are the thick discs of brass or copper, one on either side of *S*. *B* is a steam chamber from which heat passes to *S* and *A*(Fig. 8.1). When steam is passed through *B*, *A* is warmed up by the heat conducted through *S*. After some time, a steady state will be reached when the rate of flow of heat through *S* equals the heat lost from *A* by radiation and conduction.

If θ_1 and θ_2 be the temperatures of *B* and *A* in steady state, respectively, then the quantity of heat conducted per second through the slab *S* is

$$Q_1 = \frac{K\alpha(\theta_1 - \theta_2)}{d},$$

where *K* is the thermal conductivity of the slab *S* and α and *d* are the area of cross-section and thickness of *S*, respectively.

If $\frac{d\theta}{dt}$ be the rate of cooling of disc *A*, the heat lost (radiated) per second is

$$Q_2 = ms\frac{d\theta}{dt},$$

where *m* and *s* be the mass and specific heat of *A*.

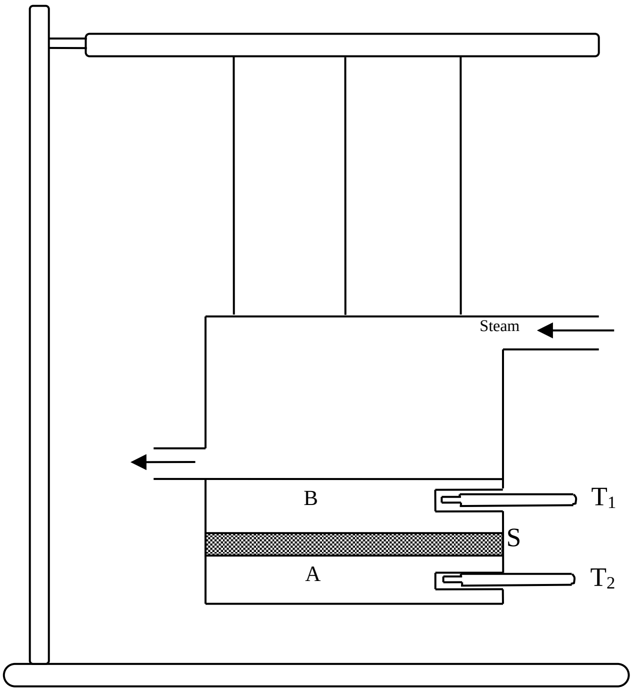


Fig. 2.1: Lee and Charlton's apparatus

In the steady state, $Q_1 = Q_2$.

$$\text{or,}\quad \frac{K\alpha(\theta_1 - \theta_2)}{d} = ms\frac{d\theta}{dt}$$

$$\text{or,}\quad K = \frac{ms\frac{d\theta}{dt}d}{\alpha(\theta_1 - \theta_2)}$$

Apparatus:

Lee and Charlton's apparatus, Slide callipers, Screw gauge, Thermometers, etc.

Brief Procedure:

1. Start heating the boiler apart from the bad conductor slab.
2. Measure the diameter of the bad conductor slab by using slide callipers.
3. Measure the thickness of the bad conductor slab by using screw gauge.
4. Put the slab between *A* and *B*.

5. When the steam starts to come from the outlet, start taking data from both the thermometers T_1 and T_2at an interval of every 5 minutes until they show steady readings (θ_1 and θ_2). Steady readings mean that they remain constant for at least 3 consecutive intervals, i. e. for 20 or 25 minutes.
6. After reaching the steady temperature θ_2 in thermometer T_2, stop the supply of steam and remove *B*. Place *A* with the slab still on the top of it on the heater and heat it till its temperature rises to (θ_2+10)°C.
7. Remove *A* with the slab still on top of it from the heater and allow it to cool. Note the temperature at an interval of every half minute until the temperature falls from (θ_2+10) to (θ_2-10) °C.
8. Plot a graph of temperature vs. time from cooling data. Draw a tangent at steady temperature (θ_2). Calculate the slope of the tangent.
9. Determine the thermal conductivity of the bad conductor using the given formula.

Experimental Data:

Vernier Constant (*V.C.*) of the slide callipers

$$V.\,C. = \frac{The\ value\ of\ one\ smallest\ division\ of\ the\ main\ scale}{Total\ number\ of\ divisions\ in\ the\ vernier\ scale}$$

Table-1: Table for the radius of the disc *S*

No. of obs.	Main scale reading, x (cm)	Vernier scale division, φ	Vernier constant, V_c (cm)	Vernier scale reading, $y = V_c \times \varphi$ (cm)	Diameter, $D = x + y$ (cm)	Mean diameter, D (cm)	Instru-mental error $\pm e$ (cm)	Corrected diameter, $D-(\pm e)$ (cm)	Radius, $r = D/2$ (cm)
1									
2									
3									
4									

Least Count ($L.C.$) of the Screw Gauge

$$L.C. = \frac{Pitch}{Total\ number\ of\ divisions\ in\ the\ circular\ scale}$$

Table-2: Table for the thickness of the disc S

No. of obs.	Linear scale reading, x (cm)	Circular scale division, β	Least count, L_c (cm)	Circular scale reading, $y = \beta \times L_c$ (cm)	Thickness, $d = x + y$ (cm)	Mean thickness, d (cm)	Instrumental error $\pm e$ (cm)	Corrected thickness, $d-(\pm e)$ (cm)
1								
2								
3								
4								

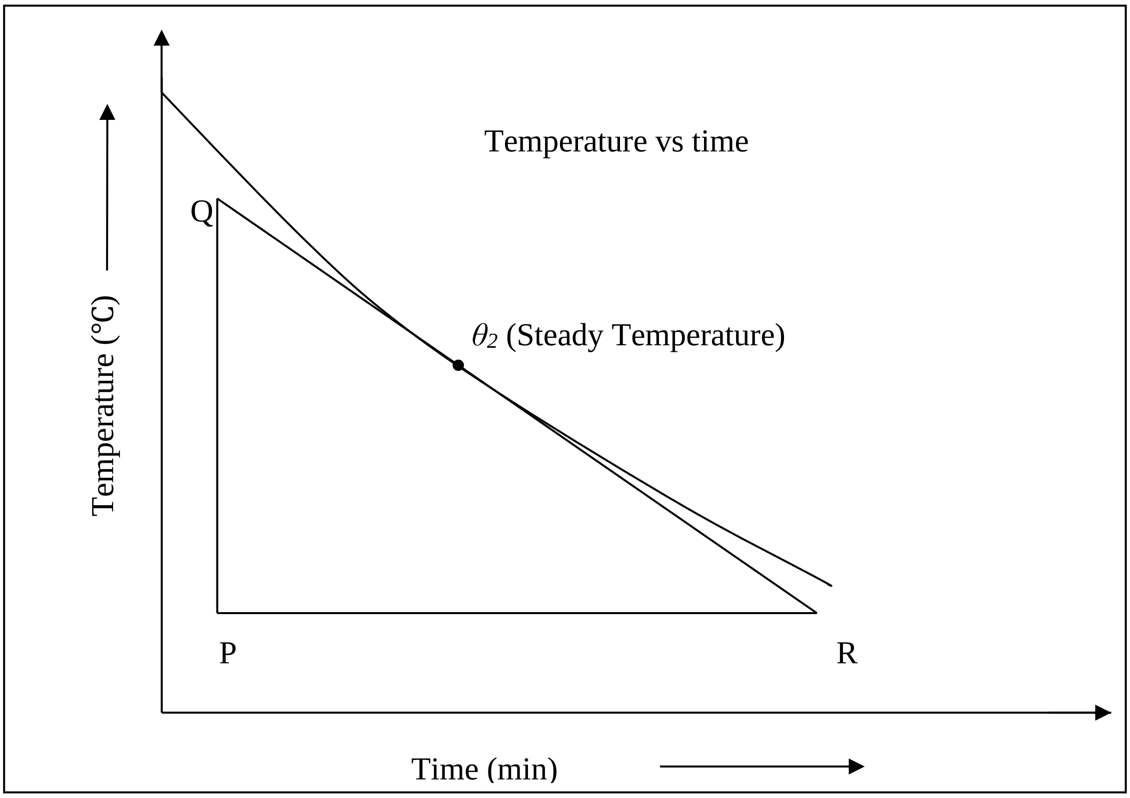
Table-3: Time- temperature records of B and A.

No. of observation	Time (minutes)	Temperature, θ_1 (°C)	Temperature, θ_2 (°C)
1	0		
2	5		
3	10		
4	15		

No. of observation	Time (minutes)	Temperature, θ_1 (°C)	Temperature, θ_2 (°C)
		θ_1 =	θ_2 =

Table-4: Time-temperature record of *A* during its cooling.

No. of obs.	Time, t (minutes)	Temperature, (°C)		No. of obs.	Time, t (minutes)	Temperature, (°C)
1	0	$\theta_2 + 10$		15	7.0	
2	0.5			16	7.5	
3	1.0			17	8.0	
4	1.5			18	8.5	
5	2.0					
6	2.5					
7	3.0					
8	3.5					
9	4.0					
10	4.5					
11	5.0					
12	5.5					
13	6.0					
14	6.5					$\theta_2 - 10$



Graph 1

Calculations:

Mass of the disc A, m = g

Specific heat of the material of A, s = 0.0909 Cal g^{-1}°C^{-1}

Radius of the specimen disc S, r = cm

Area of cross-section, $\alpha = \pi r^2$ =

= cm^2

From the graph 1, the slope of the tangent at θ_2 = ℃,

$$\frac{d\theta}{dt} = \frac{\mathrm{PQ}}{\mathrm{PR}}\ ℃\,\mathrm{min}^{-1} = \frac{\mathrm{PQ}}{\mathrm{PR}\times 60}\ ℃\ \mathrm{s}^{-1} =$$

Thermal conductivity,

$$K = \frac{ms\frac{d\theta}{dt}\ d}{\alpha(\theta_1 - \theta_2)}$$

Error Calculation:

The thermal conductivity of ebonite is 4.2×10^{-4} Cal cm^{-1} $s^{-1}°C^{-1}$.

Percentage error = $\frac{Standard\ value \sim Experimental\ value}{Standard\ value} \times 100\ \%$

<u>Result:</u>

<u>Discussions:</u>

Experiment no 03: **Date:**

Name of the Experiment: Determination of specific heat of solid with radiation correction.

Theory: Let a solid body of mass M of specific S be heated to a temperature T_2 ℃ and then dropped into water of mass W gm, contained in a calorimeter whose mass and specific heat are W_1 and S_1 respectively. The water and the calorimeter were both at the room temperature T_1 ℃ before the solid was dropped. But after the solid has been dropped, (the calorimeter and its contents gain heat while the solid loses heat and after a while mixture attains a final temperature, after radiation correction be T ℃.

Then the heat lost by the solid $=MS(T_2 - T)$ and the heat and the heat gained by the calorimeter and its contents

$$=W(T - T_1) + W_1S_1((T - T_1) = (W + W_1S_1)(T - T_1)$$

Since, heat lost= heat gained

$$MS(T_2 - T) = (W + W_1S_1)(T - T1)$$

$$\text{or, } S = \frac{(W+W_1S_1)(T-T1)}{M(T_2-T)}$$

Apparatus: Regnault’s apparatus, Balance, two thermometers, steam boiler, pieces of solid, stopwatch.

Experimental data:

Mass of the solid, M = gm

Wight of the calorimeter + stirrer, W_1 = gm

Wight of the calorimeter + stirrer + water, W_2 = gm

Wight of water, $W = W_2 - W_1$ = gm

Specific heat of the material of the calorimeter + stirrer, S_1 =

Temperature of the hot solid, T_2 = ℃

Initial temperature of water + calorimeter, T_1 = ℃

Final temperature of the mixture after applying radiation correction, T = ℃

Calculations:

Specific heat of the material of the given solid is

$$S = \frac{(W + W_1 S_1)(T - T1)}{M(T_2 - T)}$$

Error Calculation:

Percentage error = $\frac{Standard\ value \sim Experimental\ value}{Standard\ value} \times 100\ \%$

Result:

Discussions:

Experiment no 04: **Date:**

Name of the Experiment: Determination of coefficient of thermal conductivity of a metal using Searle's apparatus.

Theory: If two points of a material of length d and area of cross section A are maintained at temperatures θ_1 and θ_2 where θ_1 is greater than θ_2, then the amount of heat flowing from the hotter to the colder point in t sec is given by

$$Q = KA\frac{(\theta_1 - \theta_2)t}{d}$$

Where K is the thermal conductivity of the material.

To measure Q, cold water is made to circulate round the colder ends through a coil of tube in contact with this end so that the quantity of heat Q raises the temperature from θ_3 to θ_4 of m gm of water flowing in sec, then

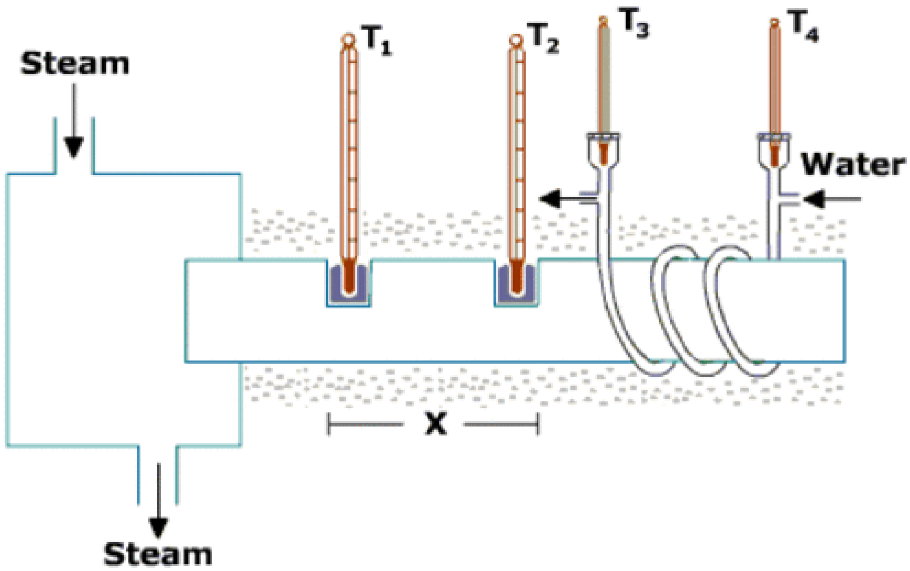
$$Q = m \times 1(\theta_4 - \theta_3) = m(\theta_4 - \theta_3)$$

with the specific heat of water be unity. Combining the above equations, we have

$$KA\frac{(\theta_1 - \theta_2)t}{d} = m(\theta_4 - \theta_3)$$

or,

$$K = \frac{md(\theta_4 - \theta_3)}{At(\theta_1 - \theta_2)}$$



Apparatus: Searle's thermal conductivity apparatus, steam generator, four thermometers, a beaker, stopwatch, slide callipers and constant pressure head apparatus

Experimental data:

Diameter of the cylinder = cm

Radius of the cylinder, r = cm

Area of cross-section of the cylinder, A = πr^2 =

= cm^2

Distance between the holes, d = cm

Mass of water collected, m = gm

Time of collection, t = s

Table: Thermometer reading

No. of obs.	Time (min)	θ_1 (℃)	θ_2 (℃)	θ_3 (℃)	θ_4 (℃)
	0				
	5				
	10				
	15				
	20				

Calculations:

Coefficient of thermal conductivity of the given material is

$$K = \frac{md(\theta_4-\theta_3)}{At(\theta_1-\theta_2)}$$

Error Calculation:

$$\text{Percentage error} = \frac{Standard\ value \sim Experimental\ value}{Standard\ value} \times 100\ \%$$

Result:

Discussions:

Experiment no 05: **Date:**

Name of the Experiment: Determination of Latent heat of fusion of ice with radiation correction.

Theory: Latent heat of fusion of ice is defined as the quantity of heat required to melt one gram of ice at 0 ℃ into water at 0 ℃. Let an amount of ice of mass M be added to a mass m of water contained in a calorimeter of mass w and specific heat s. Let t_1℃ be the temperature of the calorimeter and its content before the addition of ice and t_2℃ be the final temperature ,after making due allowance for the gain of heat from the surrounding ,of the mixture after addition and complete melting of ice. Then the heat lost by the calorimeter and water is

$$m(t_1 - t_2) + ws(t_1 - t_2).$$

The heat required to melt the ice is ML where L is the latent heat of fusion of and the heat required to raise the temperature of the water , formed as a result of melting of ice, from 0 ℃ to t_2 ℃ is Mt_2. Therefore, the total heat gained in the experiment is

$$ML + Mt_2 = M(L + t_2)$$

According to the law of colorimetry heat gained is equal to heat lost. So,

$$M(L + t_2) = (m + ws)(t_1 - t_2)$$

or,

$$L = \frac{(m + ws)(t_1 - t_2) - Mt_2}{M}$$

Apparatus: Calorimeter with stirrer, thermometer, blotting paper, stopwatch, ice, balance, etc.

Experimental data:

Mass of calorimeter + stirrer, w =	gm
Specific heat of the calorimeter material, s =	Cal g^{-1}°C^{-1}
Mass of calorimeter + stirrer + water, w_1 =	gm
Mass of water, $m = w_1 - w$ =	gm
Mass of calorimeter + stirrer + water + molten ice, w_2 =	gm
Mass of ice added, $M = w_2 - w$ =	gm
Initial temperature of water, t_1 =	℃
Final temperature of the mixture, t_2 =	℃

Calculations:

Latent heat of fusion of ice is

$$L = \frac{(m + ws)(t_1 - t_2) - Mt_2}{M}$$

Error Calculation:

Percentage error = $\frac{Standard\ value \sim Experimental\ value}{Standard\ value} \times 100\ \%$

Result:

Discussions:

Experiment no 08: **Date:**

Name of the Experiment: Determination of the value of the mechanical equivalent of heat (J) by electrical method

Theory: The mechanical equivalent of heat J is the amount of electrical energy required to generate one calorie of heat. If E volt be the potential difference across a conducting coil (Fig. 8.1) and i ampere be the current flowing through the coil for t seconds, then the electrical energy in the coil is Eit. If this energy is converted into heat H (calories) then the mechanical equivalent of heat J is

$$J = \frac{Eit}{H} \text{ Joules/Calorie} \tag{1}$$

If H is measured by means of a calorimeter with its contents where the temperature raises from θ_1° C to θ_2° C then

$$H = (Ms + W)(\theta_2 - \theta_1), \tag{2}$$

where M is the mass of the water in the calorimeter, s is the specific heat of water and W is the water equivalent of the calorimeter and stirrer. W can be calculated from the mass and specific heat of the calorimeter and stirrer.

From equations (1) and (2), we get

$$J = \frac{Eit}{(Ms + W)(\theta_2 - \theta_1)} \text{Joules/Calories}$$

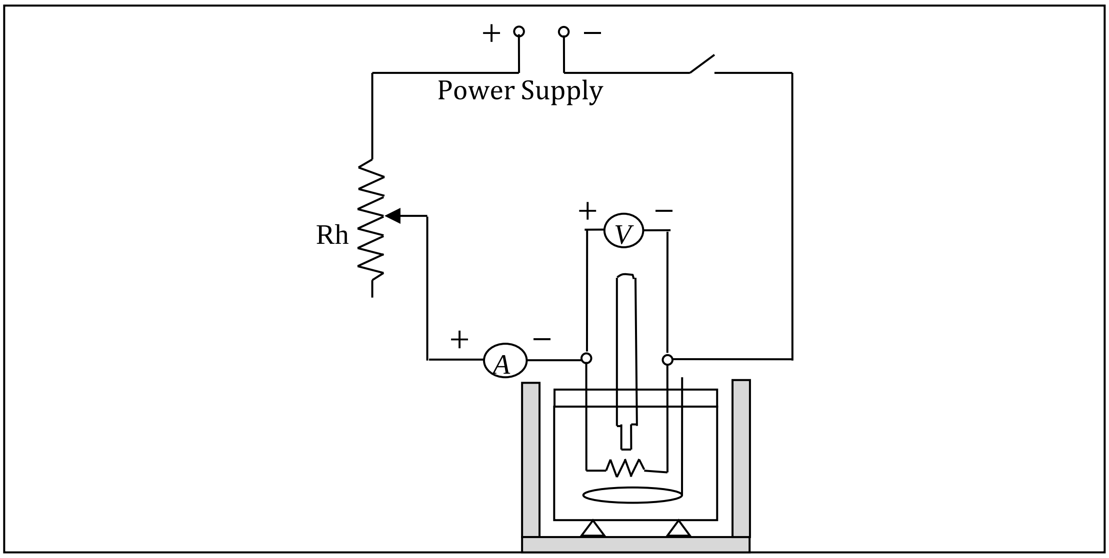


Fig. 8.1: Experimental setup for measuring the mechanical equivalent of heat

Apparatus:

Joule's calorimeter set, Ammeter, Voltmeter, Stopwatch, Thermometer, Balance, Power Supply, Rheostat, Key, etc.

Brief Procedure:

1. Measure the mass (m_1) of the calorimeter and stirrer using a balance.
2. Pour water into the calorimeter which is just enough to dip the heating coil and the bulb of the thermometer. Then measure the total mass (m_2) of the calorimeter, stirrer and water. Calculate the mass (M) of water.
3. Place the heating coil into the calorimeter. Keep the calorimeter with heating coil into its insulating box. Fix the thermometer with holder so that its bulb is in the middle of the water but never touching the coil and the calorimeter.
4. Complete the circuit as shown in Fig.8.1. Switch on the circuit temporarily and adjust the control knob of the power supply until the current is about 2 amperes. Then switch off the circuit and stir the water until a steady temperature is shown by the thermometer. Record this temperature as initial temperature.
5. Switch on the circuit and start the stopwatch simultaneously. Then start recording the temperature, current and voltage in the table at an interval of every 1 minute. Keeping the current supply and stopwatch on, record these values for 10 minutes. Then switch off the circuit but allow the stopwatch to run on and record the temperature for further 10 minutes in the same manner. Stir the water gently during the whole process.
6. Find the maximum and final temperatures. Use them to calculate the radiation correction.
7. Calculate the water equivalent of the calorimeter.
8. Using the given formula, determine the value of the mechanical equivalent of heat.

Experimental data:

Mass of the calorimeter + stirrer, m_1 = g

Mass of the calorimeter + stirrer + water, m_2 = g

Mass of the water, $M = m_2 - m_1$ = g

Specific heat of the water, s = 1 Cal g^{-1}°C^{-1}

Specific heat of the material of the calorimeter (Aluminum), s_1= 0.2096 Cal g^{-1}°C^{-1}
(Copper), s_1= 0.0909 Cal g^{-1}°C^{-1}

Table 1: Table for current, voltage and temperature

No of observations	Times (min)	Current, *i* (amp.)	Voltage, *E* (Volt)	Temperature, *T* (°C)
1	00	0	0	θ_i =
2	01			
3	02			
4	03			
5	04			
6	05			
7	06			
8	07			
9	08			
10	09			
11	10			
Current Stopped				
12	11	0	0	
13	12	0	0	
14	13	0	0	
15	14	0	0	
16	15	0	0	
17	16	0	0	
18	17	0	0	
19	18	0	0	
20	19	0	0	
21	20	0	0	θ_f =

Calculations:

Water equivalent of the calorimeter, $W = m_1 s_1$ = g

Initial temperature of the calorimeter + contents, θ_i= ℃

Maximum temperature of the calorimeter + contents, θ_m = ℃

Final temperature of the calorimeter + contents, θ_f = ℃

Rise of temperature, $\theta = (\theta_m - \theta_i)$ ℃

Radiation correction, $\theta_r = (\theta_m - \theta_f)/2$ = ℃

Corrected rise of temperature $(\theta_2 - \theta_1) = (\theta + \theta_r)$ = ℃

Time during which the current is passed, t = sec

Mean current during the interval t, i = amp.

Mean voltage during the interval t, E = volt

Mechanical equivalent of heat,

$$J = \frac{Eit}{(Ms+W)(\theta_2 - \theta_1)} \text{ Joules/Calories}$$

Error Calculation:

Standard value of the mechanical equivalent of heat, J is 4.2 Joules/Calories

Percentage error = $\dfrac{Standard\ value \sim Experimental\ value}{Standard\ value} \times 100\ \%$

Result:

Discussions:

Experiment no 10: **Date:**

Name of the Experiment: Determination of temperature co-efficient of the resistance of the material of a wire.

Theory: The temperature co-efficient of the resistance of the material of a wire may be defined as the change in resistance per unit resistance per degree rise in temperature.

If R_2 and R_1 are the resistances of a coil at temperatures t_2°C and t_1°C respectively, then

$$R_2 = R_1(1 + \alpha t)$$

Where α, the mean temperature co-efficient between the temperature t_2 and t_1, is given by

$$\alpha = \frac{(R_2 - R_1)}{R_1(t_2 - t_1)} \ ^\circ\text{C}^{-1}$$

Apparatus:

Metre bridge, dc power supply, rheostat, commutator, galvanometer, hypsometer etc.

Experimental data:

Table: Reading for R_1 and R_2

Temperature	No. of obs.	Resistance (ohm)		Null points (cm)		Mean null point (cm)	Unknown resistance (ohm)	Mean Resistance (ohm)
		Left gap	Right gap	Direct current	Reverse current			
t_1 =	1							
	2							
	3							
	4							
	5							
	6							

<table>
<tr><th rowspan="2">Temperature</th><th rowspan="2">No. of obs.</th><th colspan="2">Resistance (ohm)</th><th colspan="2">Null points (cm)</th><th rowspan="2">Mean null point (cm)</th><th rowspan="2">Unknown resistance (ohm)</th><th rowspan="2">Mean Resistance (ohm)</th></tr>
<tr><th>Left gap</th><th>Right gap</th><th>Direct current</th><th>Reverse current</th></tr>
<tr><td rowspan="6">t_2 =</td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="6"></td></tr>
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</table>

Calculations:

$$\alpha = \frac{(R_2 - R_1)}{R_1(t_2 - t_1)}\ {}^{\circ}\mathrm{C}^{-1}$$

Result:

Discussions: