EXPERIMENT – 3

Aim of the experiment: Determination of **electrical equivalent** of heat

Apparatus required: 30V, 2A adjustable, regulated DC power supply, 10V voltmeter, 3A ammeter, calorimeter with heating coil and stirrer, 0 to 50°C thermometer, connecting wires.

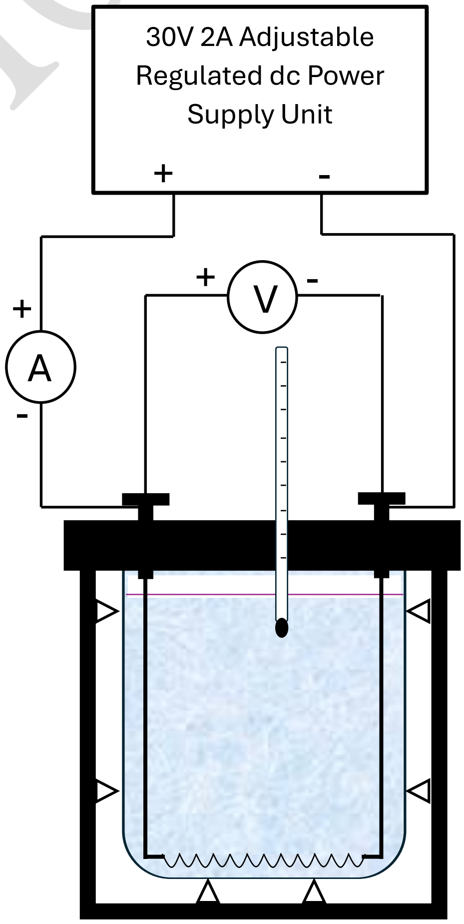
Prelude: It is typically possible to convert the work done on a system into heat energy. The work may be done on a system, either by electrical or mechanical methods. Our primary task is to determine the inherent conversion efficiency i.e., how much work (electrical or mechanical) gets effectively converted into heat energy.

James Joule discovered that there exists a proportionality between mechanical work done on a system and the heat produced in it. Hence, the constant of proportionality is referred to as the Joule equivalent of heat and is designated by J .

It is a dimensionless quantity as both the quantities bear the unit of energy, nonetheless, the conversion may be expressed in meaningful units, $J\ cal^{-1}$. The value of J does not depend on, whether the work is done using electrical methods or mechanical methods.

For this experiment we utilize a thermally isolated system on which the work is done electrically, and the heat produced in that system is then measured. Water is chosen as the working liquid for this experiment due to its high specific heat capacity. As this makes the task of obtaining measurable temperature rise, a lot easy.

Principle: An arrangement is made as shown in fig-1, for the determination of electrical equivalent of heat. A dc power supply is used for powering the coil inside the calorimeter. A voltmeter is used for measuring the voltage across the coil and an ammeter for measuring the current through it. A thermometer is used for measuring the temperature of water in the calorimeter. The electrical equivalent of heat may be written as,



$$J = \frac{W}{H}$$

where, W is the electrical work done on the system (liquid inside calorimeter, metal vessel of calorimeter and stirrer and H is the heat produced due to the electrical work.

We may also write the expression in terms of the experimentally measurable parameters as,

$$J = \frac{V\ I\ \Delta t}{m\ s\ (\theta_f - \theta_i)}$$

where,

V voltage applied across the heating coil.

I current through the heating coil

Δt duration for which the current passes through the coil

m mass of the system

s specific heat of the system

θ_i initial temperature of the system

θ_f final temperature of the system

Assumption is that the entire mass of the calorimeter vessel assumes the same temperature as the water in it. For this purpose, the calorimeter vessel is thermally isolated from the exterior.

So, we may write,

$$J = \frac{V\ I\ \Delta t}{m_w\ s_w\ (\theta_f - \theta_i) + m_v\ s_v\ (\theta_f - \theta_i)}$$

or,

$$J = \frac{V\ I\ \Delta t}{(m_w\ s_w + m_v\ s_v)\ (\theta_f - \theta_i)}\ .$$

where,
m_w the mass of water
s_w specific heat capacity of water
m_v mass of vessel
s_v specific heat capacity of vessel
θ_i initial temperature of water as recorded using the thermometer
θ_f final temperature of water as recorded using the thermometer

Procedure and precautions:

1. As a first step we take some tap water in a pet bottle and store it so that it comes to nearly room-temperature before we start the experiment. <u>Otherwise, the change in temperature of the water due to the difference in its temperature and room temperature will adversely affect the results of the experiment.</u>
2. <u>Ensure that the calorimeter coil is close to the bottom of the vessel and is just not touching it (maintain a separation of 5 mm approximately).</u>
3. Weigh the metal vessel inside the calorimeter using a weighing machine for this purpose. <u>Any weighing machine will not be suitable for this purpose, so make sure you are using the right machine.</u>
4. Take sufficient water (5 to 8 mm below the brim) in the vessel and again weigh it. This way we have the mass of the vessel as well as mass of water in it.
5. We wire the circuit as shown in fig.-1.
6. We push a thermometer through a rubber plug at the center of the calorimeter top lid, so that its sensing bulb is dipped fully inside water. <u>Do not push it to the extent that the bulb touches the bottom of the vessel or the coil itself, which is close to the bottom.</u>
7. The initial temperature of water is recorded.
8. We switch on the power supply to ensure that all components of the circuit, including the meters, are working properly. We also ensure that the current through the calorimeter coil is appropriately set (anywhere between 1 A and 2 A, as desired). Voltage across the coil will solely depend on its resistance and the current through it. We need not try to adjust the voltage. *It is the current that heats!*
9. Once these settings are made quickly, we start the stopwatch immediately.
10. We may observe the temperature rise gradually. Once we have a sufficient rise in temperature (4°C to 6°C) we may simultaneously switch off the current and stop the stopwatch.
11. The temperature may further rise slightly before stabilizing. We allow some time and record the final temperature.
12. By now we must have recorded all the relevant data. Next, we proceed with the calculations.

Observations:

Trial no. #1:

V = ___________ (V)
I = ____________ (A)
t_i = __________
t_f = __________
Δt = __________ (s)
m_w = __________ (kg)
m_v = __________ (kg)
s_w = __________ (Joule kg^{-1} K^{-1})
s_v = __________ (Joule kg^{-1} K^{-1})
$\Delta\theta$ = __________ °C

Trial no. #2:

V = ___________ (V)
I = ____________ (A)
t_i = __________
t_f = __________
Δt = __________ (s)
m_w = __________ (kg)
m_v = __________ (kg)
s_w = __________ (Joule kg^{-1} K^{-1})
s_v = __________ (Joule kg^{-1} K^{-1})
$\Delta\theta$ = __________ °C

Trial no. #3:

V = ___________ (V)
I = ____________ (A)
t_i = __________
t_f = __________
Δt = __________ (s)
m_w = __________ (kg)
m_v = __________ (kg)
s_w = __________ (Joule kg^{-1} K^{-1})
s_v = __________ (Joule kg^{-1} K^{-1})
$\Delta\theta$ = __________ °C

Calculations:

Substituting the values measured experimentally into the following relation

$$J = \frac{VI\Delta t}{(m_w\, s_w + m_v\, s_v)\left(\theta_f - \theta_i\right)}$$

We get,

$$J = (4.7 \pm 0.5)\, Joule/cal$$

Results and discussion: The values of J obtained from all the trials can be averaged out to get a final result.

Viva questions

1. What is a calorimeter? What must be its features?
2. What is the difference between mechanical equivalent of heat and electrical equivalent of heat?
3. Which one takes less energy to raise the temperature of its one gram through one degree Celsius; water or aluminum?
4. What precautions would you observe during this experiment.
5. Is there anything else that heats up besides the water and the cup? If so, what? Does this affect your results?
6. What are some good conductors of heat? Name them.
7. What are some bad conductors of heat? Name them.
8. Usually, good conductors of heat are good conductors of electricity as well. Are there any good conductors of heat that are bad conductors of electricity?