1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 02 (Physics Part-2, Class XI)
Module Name/Title	Unit 7, Module 14, Specific Heat Chapter 11, Thermal Properties Of Matter
Module Id	keph_201103_eContent
Pre-requisites	Three states of matter , internal energy , temperature thermometer, internal structure of solids
Objectives	After going through this module, the learners will be able to: • Understand that temperature of bodies rises due to heat • Define heat capacity of a body and specific heat capacity of a material • Know the use of calorimeter to determine specific heat capacity of a given solid / liquid material by method of mixtures • Reason out why there can be infinite specific heat capacities of a gas. • Distinguish between Specific heat capacity at constant volume C_V and Specific heat capacity at constant pressure C_p, for a gas.
Keywords	Rise in temperature, specific heat capacity, heat capacity Molar heat capacity, calorimetry, calorimeter specific heat capacity at constant volume and specific heat capacity at constant pressure.

2. Development Team

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1. UNIT SYLLABUS

1. UNIT 7:

PROPERTIES OF B ULK MATTER: 24 periods

Chapter–9: Mechanical Properties of Solids:

Elastic behaviour, Stress-strain relationship, Hooke's law, Young's modulus, bulk modulus, shear, modulus of rigidity, Poisson's ratio, elastic energy.

Chapter–10: Mechanical Properties of Fluids:

Pressure due to a fluid column; Pascal's law and its applications (hydraulic lift and hydraulic brakes). Effect of gravity on fluid pressure. Viscosity, Stokes' law, terminal velocity, streamline and turbulent flow, critical velocity, Bernoulli's theorem and its applications. Surface energy and surface tension, angle of contact, excess of pressure across a curved surface, application of surface tension ideas to drops, bubbles and capillary rise

Chapter–11: Thermal Properties of Matter:

Heat, temperature, thermal expansion; thermal expansion of solids, liquids and gases, anomalous expansion of water; specific heat capacity; Cp, Cv - calorimetry; change of state - latent heat capacity. Heat transfer-conduction, convection and radiation, thermal conductivity, qualitative ideas of Blackbody radiation, Wien's displacement Law, Stefan's law, Greenhouse effect.

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 17 MODULES

Module 1	• Forces between atoms and molecules making up the bulk matter • Reasons to believe that intermolecular and interatomic forces exist • Overview of unit • State of matter • Study of a few selected properties of matter • Study of elastic behaviour of solids • Stationary fluid property: pressure and viscosity • Stationary liquid property: surface tension • Properties of Flowing fluids • Effect of heat on matter
Module 2	• Idea of deformation by external force • Elastic nature of materials • Elastic behaviour • Plastic behaviour • Tensile stress • Longitudinal Stress and longitudinal strain • Relation between stress and strain • Hooke's law • Young's modulus of elasticity 'Y'
Module 3	• Searle's apparatus • Experiment to determine Young's modulus of the material of a wire in the laboratory • What do we learn from the experiment?
Module 4	• Volumetric strain • Volumetric stress • Hydraulic stress • Bulk modulus K • Fish ,aquatic life on seabed ,deep sea diver suits and submarines
Module 5	• Shear strain • Shear stress • Modulus of Rigidity G • Poisson's ratio

	• Elastic energy • To study the effect of load on depression of a suitably clamped meter scale loaded at i)its ends ii)in the middle • Height of sand heaps , height of mountains
Module 6	• Fluids-liquids and gases • Stationary and flowing fluids • Pressure due to a fluid column • Pressure exerted by solids , liquids and gases • Direction of Pressure exerted by solids , liquids and gases
Module 7	• Viscosity- coefficient of viscosity • Stokes' Law • Terminal velocity • Examples • Determine the coefficient of viscosity of a given viscous liquid by measuring terminal velocity of a given spherical body in the laboratory
Module 8	• Streamline and turbulent flow • Critical velocity • Reynolds number • Obtaining the Reynolds number formula using method of dimensions • Need for Reynolds number and factors effecting its value • Equation of continuity for fluid flow • Examples
Module 9	• Bernoulli's theorem • To observe the decrease in pressure with increase in velocity of a fluid • Magnus effect • Applications of Bernoulli's theorem • Examples • Doppler test for blockage in arteries
Module 10	• Liquid surface • Surface energy • Surface tension defined through force and through energy • Angle of contact • Measuring surface tension

Module 11	• **Effects of surface tension in daily life** • **Excess pressure across a curved liquid surface** • **Application of surface tension to drops, bubbles** • **Capillarity** • **Determination of surface tension of water by capillary rise method in the laboratory** • **To study the effect of detergent on surface tension of water through observations on capillary rise.**
Module 12	• **Thermal properties of matter** • **Heat** • **Temperature** • **Thermometers**
Module 13	• **Thermal expansion** • **To observe and explain the effect of heating on a bi-metallic strip** • **Practical applications of bimetallic strips** • **Expansion of solids, liquids and gases** • **To note the change in the level of liquid in a container on heating and to interpret the results** • **Anomalous expansion of water**
Module 14	• **Rise in temperature** • **Heat capacity of a body** • **Specific heat capacity of a material** • **Calorimetry** • **To determine specific heat capacity of a given solid material by the method of mixtures** • **Heat capacities of a gas have a large range** • **Specific heat at constant volume** C_V • **Specific heat capacity at constant pressure** C_P
Module 15	• **Change of state** • **To observe change of state and plot a cooling curve for molten wax.** • **Melting point, Regelation, Evaporation, boiling point, sublimation** • **Triple point of water** • **Latent heat of fusion** • **Latent heat of vaporisation** • **Calorimetry and determination of specific latent heat**

	capacity
Module 16	• **Heat Transfer** • **Conduction, convection, radiation** • **Coefficient of thermal conductivity** • **Convection**
Module 17	• **Black body** • **Black body radiation** • **Wien's displacement law** • **Stefan's law** • **Newton's law of cooling** • **To study the temperature, time relation for a hot body by plotting its cooling curve** • **To study the factors affecting the rate of loss of heat of a liquid** • **Greenhouse effect**

Module 14

3. WORDS YOU MUST KNOW

Temperature: a measure of the warmth or coldness of an object or substance with reference to some standard/reference value.

Heat: Energy in transit; gets exchanged because of a difference in temperature.

Thermometer: a device to measure temperature.

Material: any homogeneous system, in any state: solid liquid or gas.

4. INTRODUCTION

We all have some common-sense notions of heat and temperature. Temperature is regarded as an indicator of the 'hotness' of a body. A kettle, with boiling water is hotter than a box containing ice.

Temperature is a relative measure, or indication of hotness or coldness. A hot utensil is said to have a high temperature; ice cube is said to have a low temperature.

An object, that has a higher temperature than another object, is said to be hotter. Note that hot and cold are relative terms, like tall and short. We often perceive temperature through touch.

However, this temperature sense is somewhat unreliable and its range is too limited to be useful for scientific purposes.

We know from experience that a glass of ice-cold water, left on a table on a hot summer day eventually warms up whereas a cup of hot tea on the same table cools down. *However, the heating up and cooling actions seems to stabilize depending upon the temperature of the surroundings.*

It means that when the temperature of a body, (ice-cold water or hot tea in this case), and its surrounding medium are different, heat transfer takes place between the system and the surrounding medium, until the body and the surrounding medium are at the same temperature.

Water in a glass attains a lower temperature as compared to the surrounding in a room. Why?

Why is the sea water cooler as compared to the land during the day?

We also know that in the case of glass tumbler of ice cold water, heat flows from the environment to the glass tumbler, whereas in the case of hot tea, it flows from the cup of hot tea to the environment. **There are many amazing features of heat flow**

So, we can say that

Heat is a form of energy that gets transferred between two (or more) systems or a system and its surroundings, by virtue of temperature difference

The SI unit of heat energy is joule (J) while SI unit of temperature is kelvin (K)

A commonly used unit of temperature is °C (degree Celsius, it is also called degree centigrade).

When an object is heated or cooled, many changes may take place.

- **The temperature of the body changes**
- **It may expand or contract**
- **There may be a change in its state. (solid, liquid or gas)**

In this module we will study change in temperature due to addition or removal of heat.

5. RISE OR FALL IN TEMPERATURE

You may do the activity or observe it at home.

Take some water in a vessel and start heating it on a kitchen burner. This means the burner provides the heat energy to the vessel and the water contained in it. Soon you will notice that air bubbles begin to move upward. As the temperature is raised the number of bubbles increases till it becomes turbulent as water starts boiling. (Hot vessels should not be picked by bare hands.)

THINK ABOUT THIS

You do not have any measuring device just answer from experience.

- **Would the time taken to boil 1 cup of water (at room temperature), be the same as that required for three cups of water. Would your answer change if we heated 3 cups of warm water instead of 3 cups of water at room temperature?**
- **Would the time taken to boil milk be the same as to boil an equal amount of oil?**
- **What are the factors on which the quantity of heat, required to raise the temperature of a substance, by a given amount depend?**

In order to answer these questions, let us first heat a given quantity of water to raise its temperature to boiling point and note the time taken.

Next, double the amount of water and raise its temperature to boiling point using the same source of heat. Note the time taken by using a stopwatch. You will find it takes about twice the time and therefore, double the quantity of heat required to raise the temperature of double the amount of water through the same temperature.

What if we were to just warm the same quantity of water? Would the time be the same?

What if we were to heat oil the same way instead of water? Would the time be the same?

The above observations show that the **quantity of heat or amount of heat (energy)** required to warm a given substance depends on its

- **mass, m,**
- **change in temperature, ΔT and**
- **nature of substance**.

6. HEAT CAPACITY

The above observations show that the quantity of heat required to warm a body or system depends on the change in temperature, (from T to T + ΔT).

The change in temperature of a substance, when a given quantity of heat is absorbed or rejected by it, is characterised by a quantity called the Heat Capacity of that body.

We define heat capacity, S of a body as the amount of heat required or rejected by it to change its temperature by unity.

So if Q is the **heat required by a body to increase its temperature by** ΔT, we have

$$S = \frac{Q}{\Delta T}$$

Or

So if Q is the **heat rejected by a body to decrease its temperature by** ΔT**,** we have

$$S = \frac{Q}{\Delta T}$$

Its unit will be J $(°C)^{-1}$ (joule per degree Celsius)

or

J K^{-1} (joule per kelvin)

Heat capacity ignores the nature of substances; several objects, of different materials and different masses, may have the same heat capacity. This means they would need the same amount of heat to raise their temperature by a unit amount. This is relevant when we have fixtures of mixed materials; say a cooking pan with two compartments, both must heat to the same temperature when placed for cooking.

Heat capacity is sometimes related to the **water equivalent of an object. This is the amount of water that would require the same amount of heat (as the object) to change its temperature by unity.**

EXAMPLE

8750 J of heat are applied to a piece of aluminium, causing a 56.0 °C increase in its temperature.

- **i) What is the heat capacity of the aluminium piece?**
- **ii) How would the heat capacity change if the aluminium piece were to be shaped like a cup?**
- **iii) How would the heat capacity change if the mass of aluminium cup is doubled?**
- **iv) What can you say about the shape, mass or material of another piece of metal which requires (2 x 8750) J of energy to cause the same change in its temperature?**

SOLUTION

i) Heat capacity of the aluminium piece is = heat supplied / change in temperature.

$$= \frac{8750 J}{56\,°C}$$

=156.25 J/°C

ii) Now if the shape of the material changes its heat capacity will not as neither the material nor its mass has changed.

iii) Heat capacity will get doubled **(= 2 x 156.25 J/ °C=312.50 J/°C)**

iv)

- shape is not important
- mass would be double if the material does not change
- mass and material both could change

7. SPECIFIC HEAT CAPACITY

You may have observed that if equal amount of heat is added to equal masses of different substances, the resulting temperature change in the two will not be the same.

It implies that every substance has a unique value for the amount of heat, absorbed or rejected, to change the temperature of unit mass of it by one unit.

This quantity is referred to as the specific heat capacity of the substance.

The change in temperature of a substance, when a given quantity of heat is absorbed or rejected by it, is characterized by a quantity called the **Specific Heat Capacity of its material.**

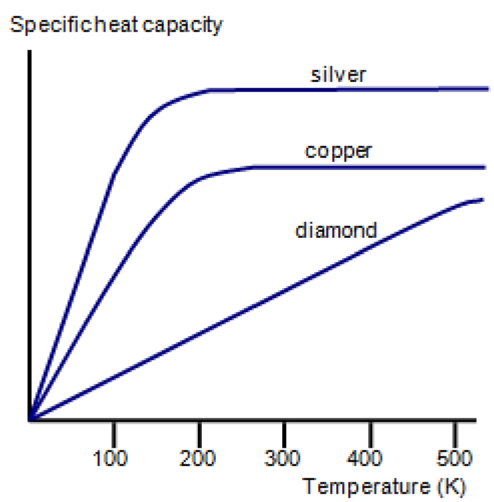
The specific heat capacity is the property of the substance which determines the change in the temperature of the substance (keeping the state same (i.e. solid remains solid, liquid remains a liquid) when a given quantity of heat is absorbed (or rejected) by it.

It is defined as **the amount of heat, absorbed or rejected, by a unit mass of material to change its temperature by one unit.**

It depends on the nature of the material and its temperature.

This may be understood from our molecular picture of the materials. As the kinetic energy of atoms and molecules changes so does its bond length and potential energy, as we are adding or subtracting heat energy. So the heat required by unit mass of substance, for causing a unit change in temperature is not constant for all values of temperature in a particular state. This means specific heat capacity of water at room temperature is different from the specific heat capacity at temperatures close to its boiling point.

Specific heat capacity is because of vibrational, rotational and translation of molecules. If the temperature is increased, all these motions will increase so specific heat capacity also increases.
Specific heat capacity is a measure of the ability of the substance to absorb heat.
The heat goes first into increasing the kinetic energies of the molecules.
Molecules can also store energy in vibrations and rotations. These energies are quantized at low temperatures where collisions do not provide enough energy to get out of the ground states for rotation or vibration.
The average energy increases only from translation. As the substance heats up, the average kinetic energy of the molecules increases.
The collisions impart enough energy to allow rotation energy changes to occur. Rotation then contributes to the internal energy and raises the specific heat capacity.



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We define specific heat capacity, S of a substance as amount of heat required by 1 kg of substance to increase its temperature by 1°C or 1 K

Or

The amount of heat removed from a body of 1 kg mass to decrease its temperature by 1°C.

The above definition allows us to think that the heat required by 1 kg of copper, 1 kg of aluminum or 1 kg of iron, for same change in temperature would be different?

This is because **specific heat capacity here would be governed by nature of material**.

So, the heat required by 1 kg of copper, 1 kg of water or 1 kg of oxygen would be different.

The SI unit of specific heat capacity is J $kg^{-1}(°C)^{-1}$ or J kg^{-1} K^{-1}

Notice the temperature is considered in degree Celsius in the first case and kelvin in the second case, yet the value would be the same

We could also consider the amount of matter as **mole** and the unit would then be

J $mol^{-1}(°C)^{-1}$

Or

J mol^{-1} K^{-1}.

In this case, the specific heat capacity is called **molar specific heat capacity.**

Dimensions = **[$M L^2 T^{-2} K^{-1}$]**

It follows that the heat required to raise the temperature of a sample of metal depends on how many particles the sample contains, and not on the mass of an individual molecule. The specific heat capacity is therefore directly related to the molecular structure of the material.

DULONG AND PETIT RULE

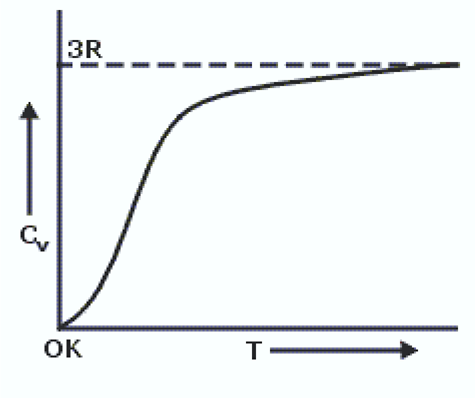
The specific heat capacity of copper is 389 J kg^{-1} K^{-1} and that of lead is only 13 J kg^{-1} K^{-1}

Why are they so different?

The difference is mainly there because specific heat capacity is expressed as energy per unit mass; if you express it as energy per mole, they are very similar.

It is the similarity of the molar specific heats of metals which led to the Law of Dulong and Petit.

They found that the heat capacity of a mole of many solid elements is about 3R, where R is the universal gas constant.



Variation of S with temperature

Dulong and Petit were unaware of the relationship with R, since this constant had not yet been defined on the basis of kinetic theory of gases, at the time of their experimental findings.

The value of 3R is about 25 joules per kelvin, and Dulong and Petit essentially found that this was the heat capacity of certain solid elements per gram mole.

However, at higher temperatures the value of specific heat capacity of solids changed drastically.

EXAMPLE

A 10 kW drilling machine is used to drill a bore in a small aluminium block of mass 8.0 kg. How much is the rise in temperature of the block in 2.5 minutes, assuming 50% of power is used up in heating the machine itself or lost to the surroundings. Specific heat of aluminium = 0.91 J g^{-1} K^{-1}.

SOLUTION

Power of the machine,

P= 10 kW =$10 \times 10^3 = 10^4 W$;

Time for which the machine is used, t = 2.5 minutes= 2.5×60 s

Therefore, energy used up in drilling up the bore,

Q = P × t = $10^4 \times 2.5 \times 60 = 1.5 \times 10^6 J$

Heat energy transferred to the aluminium block,

$$Q' = Q \times \frac{50}{100} = \frac{1.5\times10^6}{100} \times 50 = 7.5 \times 10^5 J$$

If ΔT is rise in temperature of the aluminium block of mass M, then

$Q' = M\,S\,\Delta T$

Here, M= 8.0 kg;

S = 0.91 $J g^{-1} K^{-1} = 0.91 \times 10^3$ J $kg^{-1}°C^{-1}$

$Q' = 8.0 \times 0.91 \times 10^3 \Delta T = 7.28\ 10^3 \Delta T$

After comparing above equations, we get

$7.28\ 10^3 \Delta T = 7.5 \times 10^5$

Or $\Delta T = \frac{7.5\times10^5}{7.28\times10^3} = \mathbf{103.02}\ °C$

Here the drill machine has transferred heat to the aluminium, and 50 % energy is converted to heat, increasing the temperature of the aluminium block by 103.02 ^{0}C

8. SPECIFIC HEAT CAPACITY OF A GAS-

When a gas is heated its temperature rises; if it is allowed to expand its volume will change significantly. The volume and pressure exerted by a gas, change with rise in its temperature. The amount of heat required to raise the temperature of 1kg of gas through 1°C is, therefore is not fixed. **That is a gas does not possess a unique or single specific heat capacity.**

Limits of specific heat of a gas-

- **Consider a gas, of mass m, enclosed in a cylinder fitted with an airtight and frictionless piston.**
- **Now the gas is heated and allowed to expand such that the rise in temperature of the gas due to the heat supplied is equal to the fall in temperature of the gas due to the expansion of the gas itself.**
- **The specific heat capacity of the gas (= $\frac{\text{Heat supplied}}{\text{mass}\times\text{change in temperature}}$) is, therefore, infinite**.
- **Next imagine the gas to be compressed. The temperature of the gas would then increase even though no heat has been added to it. The specific heat capacity of the gas, in such case, would be zero.**

It follows that the specific heat capacity of a gas can have any value, ranging from 0 to ∞, depending on the way it is being heated.

To limit our choices, we have two conditional, universally accepted, specific heat capacities for gases.

These two specific heat capacities of the gas are defined as follows:

When the gases are heated, we can have an appreciable

- **change in their volume**.
- **change in their pressure.**

We, therefore, talk of two (conditional) specific heat capacities of a gas;

- **specific heat capacity at constant volume and**
- **specific heat capacity at constant pressure.**

(i) **Molar specific heat capacity at constant volume (Cv) –**

It is defined as the amount of heat required to raise the temperature of 1 mole of a gas through 1°C at constant volume.

It is denoted by Cv

(ii) **Molar Specific heat capacity at constant pressure (Cp) –**

It is defined as the amount of heat required to raise the temperature of 1 mole of a gas through 1°C at constant pressure.

It is denoted by Cp.

Thinking about

Heat capacity (also called thermal capacity) as the amount of heat required to raise the temperature of a body / substance through 1°C,

The heat capacity of the body/substance of mass m and of specific heat 's' is = m s

Heat Capacity = mass × Specific Heat capacity

Hence

Heat capacity depends both on the

(i)material of the body
(ii) the mass of the body.

Specific heat capacity, however, depends only upon material

WATER EQUIVALENT

The water equivalent of a body is defined as the mass of water which requires the same amount of heat as is required by the given body for the same rise of temperature.

In the system of units, where the specific heat capacity of water is taken as **1 cal $g^{-1}(°C)^{-1}$**, we have

Water equivalent = mass of the body (in g) × Sp. Heat of the body (in **cal $g^{-1}(°C)^{-1}$**)

$$W = m\,s$$

Its S.I. unit is kg.

NOTE: 1calorie (cal) = 4.184 joules

S.I. unit is (of molar specific heat capacity) J mol^{-1} K^{-1}

Specific heat capacity of some substances, at normal room temperature and normal atmospheric pressure, are listed below.

Substance	Specific heat capacity ($J\ kg^{-1}\ K^{-1}$)	Substance	Specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
Aluminium	900.0	Ice	2060
Carbon	506.5	Glass	840
Copper	386.4	Iron	450
Lead	127.7	Kerosene	2118
Silver	236.1	Edible oil	1965
Tungesten	134.4	Mercury	140
Water	4186.0		

Why are water bodies (water in a bucket ,swimming pools, ponds , rivers, lakes, sea etc) always cooler than the surrounding air?

It's because "specific heat capacity" of water is much larger than that of air, or land or other materials in general.

This means water needs to absorb a lot more of the sun's heat before it begins to warm up.

In fact, 1 kg of water must absorb (nearly) 4186 joules of heat energy before its temperature will rise by 1 °C.

For comparison sake,

it only takes 800 joules of heat to raise the temperature of 1 kg of dry soil by 1 °C, and

1005 joules to do so for dry air.

If you've ever burned your feet walking on the banks of a river leading up to a body of water, then you've experienced how fast heat is moved through these substances. Not so with water. It will certainly warm up, but it won't get anywhere near steaming or boiling hot. Good for us!!

There is another reason and we will consider it in the upcoming modules.

EXAMPLE

Calculate the heat energy required to heat a beaker of water at 18 °C to its boiling point. The mass of the water is 70.0 g.

SOLUTION

Heat Energy required = mass x specific heat capacity x change in temperature

$$= 0.07\ \text{kg}\ \times 4186\ \text{J kg}^{-1}{}^{\circ}\text{C}^{-1} \times (100 - 18)^{\circ}\text{C} = \mathbf{24027.84\ joules}$$

EXAMPLE

A water heater warms 35 liters of water from a temperature of 22.7 °C to a temperature of 83.7°C. Determine the amount of energy (in joules) required.

SOLUTION

35 liters of water = 35 kg [1 liter = 1000cm^3 =10^{-3} m^3, density of water = 1000kg m^{-3}]

Heat Energy required = mass x specific heat capacity x change in temperature

$$= 35 \times 4186 \times (86.7 - 22.7) = \mathbf{9376640joules}$$

EXAMPLE

Determine the temperature change that will occur when 250J of heat energy is supplied to 20 g of silver

SOLUTION

$$\text{temperature change} = \frac{\text{heat supplied}}{\text{mass} \times \text{specific heat}}$$

$$= \frac{250\text{j}}{0.020\text{kg} \times 236\text{jkg}^{-1}\text{C}^{-1}} = \mathbf{52.97\ ^0C}$$

EXAMPLE

When 895J of heat is supplied to a sample of iron metal, the temperature increases by 55.0 °C. Determine the mass of the metal sample.

SOLUTION

$$\text{mass} = \frac{\text{heat supplied}}{\text{specific heat capacity } \times \text{change in temperature}}$$

$$= \frac{895\text{J}}{450\text{Jkg}^{-1}(°\text{C})^{-1} \times 55°\text{C}}$$

= 0.036kg or 36 g

TRY ThESE

- **A silver ring has a mass of 138.45 g. How many joules of heat are required to increase the temperature from 11.8 °C to 162.5 °C?**
- **A heat energy of 645 J is supplied to a sample of glass with a mass of 28.4 g. Its temperature increases from –11.6 °C to 15.5 °C. Calculate the specific heat capacity of glass.**

NOW TRY THESE

- What is the mass of copper that increases its temperature by 285 °C when 186,000 J of heat energy is supplied to it?
- How much energy (in kJ) is lost by a 348kg iron statue that goes from a temperature of 299 K to a temperature of 280 K?
- When 5800 joules of energy are supplied to a 15.2 kg piece of lead metal, how much does temperature change?
- How many joules of heat are required to raise the temperature of 550 g of water from 12.0 ^{0} C to 18.0 ^{0}C?
- How much heat is lost when a 64 g piece of copper cools from 375 ^{0}C to 26 ^{0}C

  Express your answer in kJ.

- How much heat is transferred when a 4.7 kg piece of iron is cooled from 180 ^{0}C to 13 ^{0}C?

  Remember you must use the same system of units throughout.

9. CALORIMETRY

The branch of physics that deals with the measurement of heat is called calorimetry.

The name is from the earlier unit (calorie) used for measuring heat.

PRINCIPLE- The heat gained by the cold body must be equal to the heat lost by the hot body, provided there is no exchange of heat with the surroundings.

Heat gained = Heat lost

CALORIMETER: A device in, used in heat measurement experiments is called the calorimeter.

It consists of a metallic vessel and stirrer of the same material, usually copper.

What is the reason for choosing the same material for both the calorimeter and the stirrer?

The vessel is kept inside a wooden box.

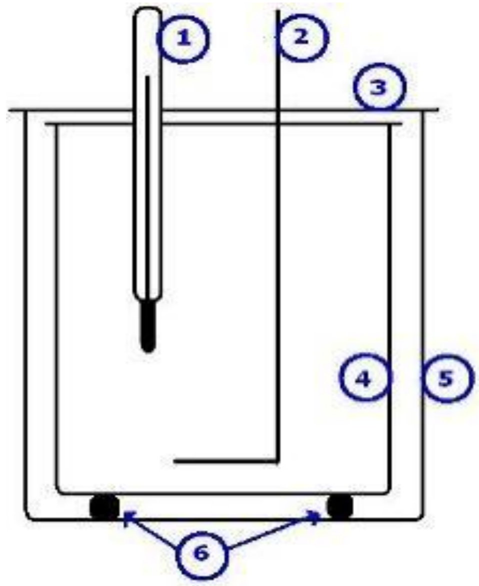
What could be the reason to place it in a wooden box?

The space, between the calorimeter and the jacket is packed with a heat insulating material like glass, wood etc.

Why?

Thus the calorimeter gets (almost) thermally isolated from the surroundings. The lid is provided with holes for inserting a thermometer and a stirrer into the calorimeter. The calorimeter set up, therefore, has a

1. Cylindrical copper container
2. Lid
3. Outer insulated case
4. Insulated base to avoid flow of heat
5. Stirrer
6. Thermometer



https://upload.wikimedia.org/wikipedia/commons/thumb/0/0d/Calorimeter.svg/82px-Calorimeter.svg.png

10. DETERMINATION OF SPECIFIC HEAT CAPACITY OF A SOLID MATERIAL –

Principle

Solid of known mass is heated to a known temperature, it is then transferred to a known mass of liquid for which the specific heat capacity is known. The solid should not dissolve in or react with the chosen liquid. The 'mixture' is maintained in isolation and transfer of heat is considered only between the solid, the liquid and the container in which the liquid is kept.

Let a calorimeter of water equivalent w contain water of mass m_1, at temperature T_1. A solid, of mass m_2, heated to a, temperature T_2, is 'dropped' into the water in the calorimeter.

Let T be the final temperature of the mixture.

Heat gained by water and calorimeter = $(m_1 + w) \times S_w \times (T - T_1)$

S_w is the specific heat of water and id S is the specific heat capacity of the material of the solid .

Heat lost by the solid = $m_2 \times S \times (T_2 - T)$

According to principle of method of mixtures, if no heat is lost to surroundings, we have,

Heat lost = Heat gained

$$m_2 \times S \times (T_2 - T) = (m_1 + w) \times S_w \times (T - T_1)$$

Knowing all the other factors, S can be calculated.

The following example will help you understand the method better.

EXAMPLE

A sphere of aluminium, of mass 0.047 kg, is placed for sufficient time in a vessel containing boiling water, so that the sphere is at 100 °C. It is then immediately transferred to a 0.14 kg copper calorimeter containing 0.25 kg of water at 20 °C. The temperature of water rises and attains a steady value of 23 °C.

Calculate the specific heat capacity of aluminium.

SOLUTION

In solving this example, we shall use the fact that at the steady state, heat given by the aluminium sphere will be equal to the heat absorbed by the water and calorimeter.

Mass of aluminium sphere (m_1) = 0.047 kg

Initial temp. of aluminium sphere = 100 °C

Final temp. = 23 °C

Change in temp (ΔT) = (100 °C - 23 °C) = 77 °C

Let specific heat capacity of aluminium be S_{Al}

The amount of heat lost by the aluminum sphere = $m_1 S_{Al} \Delta T = 0.047kg \times S_{Al} \times 77\ ^0C$

Mass of water (m_2) = 0.25 kg

Mass of calorimeter (m_3) = 0.14 kg

Initial temp. of water and calorimeter = 20 °C

Final temp. of the mixture = 23 °C

Change in temp. (ΔT_2) = 23 °C – 20 °C = 3 °C

Specific heat capacity of water (S_w)

= 4.18×10^3 J kg^{-1} K^{-1}

Specific heat capacity of copper calorimeter

$= 0.386 \times 10^3$ J kg^{-1} K^{-1}

The amount of heat gained by water and calorimeter = $m_2\ S_w\ \Delta T_2 + m_2\ S_{cu}\ \Delta T_2$

$= (m_2\ S_w + m_3\ S_{cu})\ (\Delta T_2)$

$= [0.25$ kg $\times 4.18 \times 10^3$ J kg^{-1} K^{-1} + 0.14 kg $\times 0.386 \times 10^3$ J kg^{-1} K^{-1}] (23 °C – 20 °C)

In the steady state,

heat lost by the aluminum sphere = heat gained by water + heat gained by calorimeter.

So,

0.047 kg $\times S_{Al} \times$ 77 °C

= (0.25 kg $\times 4.18 \times 10^3$ J kg^{-1} K^{-1} + 0.14 kg $\times 0.386 \times 10^3$ J kg^{-1} K^{-1})(3 °C)

$\therefore S_{Al} = 0.911\times10^3$ J kg^{-1} K^{-1}

EXAMPLE

In an experiment on the specific heat of a metal, a 0.20 kg block of the metal at

150 °C is dropped in a copper calorimeter (of water equivalent 0.025 kg) containing

150 cm^3 of water at 27 °C. The final temperature is 40 °C.

a) Compute the specific heat of the metal.

b) If heat losses to the surroundings are not negligible, is your answer greater or smaller than the actual value for specific heat of the metal?

SOLUTION

a) **We know that** mass of the block, $M_1 = 0.20\ kg$;

Temperature of metal block, $T_1 = 150$°C

Temperature of the calorimeter and water, $T_2 = 27$°C

Final temperature of the mixture, T = 40 °C

Water equivalent of calorimeter, w = 0.025 kg

Volume of water in the calorimeter = 150 cm^3 = $150\times 10^{-6} m^3$

Therefore, mass of water in the calorimeter

$$M_2 = 150 \times 10^{-6} \times 10^3 = 150 \times 10^{-3} kg$$

Let $S_1 (Jkg^{-1}K^{-1})$ be the specific heat of metal block.

Then, heat lost by the metal block

$= M_1 S_1 \times (T_1 - T) = 0.20 \times S_1 \times (150 - 40) = 22\, S_1$

Also, specific heat of water

$S_2 = 4.2 \times 10^3 Jkg^{-1}K^{-1}$

Then, heat gained by water and calorimeter

$= (M_2 + w) \times S_2 \times (T - T_2)$

$= (150 \times 10^{-3} + 0.025) \times 4.2 \times 10^3 \times (40 - 27)$

$= 0.175 \times 4.2 \times 10^3 \times 13 = 9.555 \times 10^3 J$

Now, **heat lost = heat gained**

$22 S_1 = 9.555 \times 10^3$

$$\mathbf{S_1 = \frac{9.555 \times 10^3}{22} = 434\ Jkg^{-1}K^{-1}}$$

EXAMPLE

An electrical immersion heater with a power of 50 W is used to heat a glass beaker of mass 75 g containing 200 g of water.

If the initial temperature of the beaker and the water is 15^0 C,

Calculate the temperature after 4 minutes of heating.

You can assume that no heat energy is lost to the surroundings.

SOLUTION

Electrical energy input = VI t = Power x time = 50 x 4 x 60J = 12000 J

Heat energy gained by the glass and the water = 0.075 x 840 x (T – 15) + 0.20 x 4186 x (T – 15)

= (0.075×840 +0.20×4186) (T-15)

Therefore: (63 + 837.2) (T-15) =12000

Or T-15 = 12000 /900.02

T-15=13.33

T=13.33+15

∴T = 28.33 °C

EXAMPLE

A mother wants to prepare warm water at 40 ^{0}C to bathe her baby. How much boiling water should be added to 20 liters of water at 30 ^{0}C to make the required water?

SOLUTION

Let the water required be L liter

Heat lost by hot water at 100 ^{0}C= L x 4186 x (100-40) J

Heat gained by cold water =20 x 4186 x (40 -30) J

Heat gained = heat lost

∴L x 60 = 20 x 10

∴L = 3.33 liter

Or approximately 3 liters

Most mothers do this calculation in their heads.

TRY THESE

i) A 15.75-g piece of iron absorbs 1086.75 joules of heat energy, and its temperature changes from 25°C to 175°C. Calculate the specific heat capacity of iron.

ii) How many joules of heat are needed to raise the temperature of 10.0 g of aluminum from 22°C to 55°C, if the specific heat capacity of aluminum is 0.90 J/g°C?

iii) To what temperature will a 50.0 g piece of glass rise if it absorbs 5275 joules of heat and its specific heat capacity is 0.50 J/g°C? The initial temperature of the glass is 20.0°C.

iv) **Calculate the specific heat capacity of a piece of wood if 1500.0 g of the wood absorbs 6.75×10^4 joules of heat, and its temperature changes from 32°C to 57°C.**

v) **The specific heat capacity of ethanol is 2.46 J/g °C. Find the heat required to raise the temperature of 193 g of ethanol from 19°C to 35°C.**

vi) **An alloy of unknown composition is heated to 137 °C and placed into 100.0 g of water at 25.0 °C. If the final temperature of the water was 36.4 °C, and the alloy weighed 2.71 g, what is the specific heat capacity of the alloy? The specific heat capacity of water is 4.184 J/g° C.**

vii) **A 45.0 g rock is heated to 97.2 °C and placed into 75.3 g of water originally at 32.0 °C. If the final temperature of the water was 46.2 °C, what is the specific heat capacity of the rock?**

viii) **Given that the specific heat capacity of gold is 0.129 J/g°C, calculate the final system temperature if a 200.0 g block of gold at 100.0 °C is placed in a copper calorimeter, of mass 100 g, containing 50.0 g of water at an initial temperature of 25.0 °C**

ix) **When 165 mL of water at 22 °C, is mixed with 85 mL of water at 82 °C, what is the final temperature? (Assume that no heat is lost to the surroundings; density of water is 1.00 g/mL.)**

x) **A 505g piece of copper tubing is heated to 99.9 °C and placed in an insulated vessel containing 59.8 g of water at 24.8 °C. Assuming no loss of water and a heat capacity for the vessel of 10.0 J/K, what is the final temperature of the system (specific heat capacity of copper = 0.387 J/g·K)?**

11. LABORATORY METHOD TO DETERMINE THE SPECIFIC HEAT CAPACITY OF A GIVEN A) SOLID B) GIVEN LIQUID BY THE METHOD OF MIXTURES.

APPARATUS AND MATERIAL REQUIRED

- Copper calorimeter with lid, stirrer and insulating cover (the lid should have provision to insert thermometer in addition to the stirrer),
- Two thermometers (0 °C to 100 °C or 110 °C with a least count of 0.5 °C),
- A solid (preferably metallic (brass/copper/steel/ aluminium), which is insoluble in given liquid and water,
- Given liquid,
- Two beakers (100 mL and 250 mL),
- A heating device (heater/hot plate/gas burner);

- physical balance, spring balance with weight box (including fractional weights),
- a piece of strong nonflexible thread (25-30 cm long),
- water,
- laboratory stand, tripod stand and wire gauze.

PRINCIPLE / THEORY

For a body of mass m and specific heat capacity s, the amount of heat Q lost/gained by it when its temperature falls/rises by Δt is given by $\Delta Q = m\, s\, \Delta t$.

Specific heat capacity: It is the amount of heat required to raise the temperature of unit mass of a substance through 1°C. Its S.I unit is $Jkg^{-1}\, K^{-1}$.

Principle of Calorimetry: If bodies at different temperatures, are brought in thermal contact, the amount of heat lost by the body at higher temperature is equal to the amount of heat gained by the body at lower temperature, at thermal equilibrium, provided no heat is lost to the surrounding.

PROCEDURE

(i) Set the physical balance/spring balance and make sure there is no zero error.

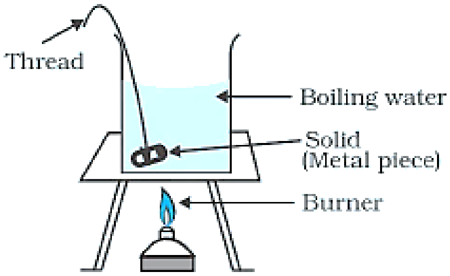
(ii) Weigh the empty calorimeter with stirrer and lid with the physical balance/spring balance. Ensure that calorimeter is clean and dry.

- Note the mass m_1 of the calorimeter.
- Pour water in the calorimeter. Make sure that the quantity of water taken would be sufficient to completely submerge the given solid in it.
- Weigh the calorimeter with water along with the stirrer and the lid
- note its mass m_2.
- Place the calorimeter in its insulating cover.

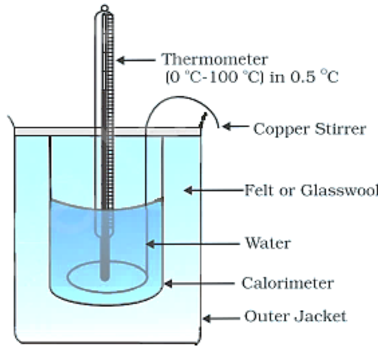
(iii) Tie a thread to the solid.

(iv) Now shake it to remove extra water sticking to its surface.
Weigh the wet solid using a spring balance and note down its mass m_3.

- Place a 250 mL beaker on the wire gauze kept on a tripod stand as shown in the fig (a)
- Let the water in the beaker boil for about 5-10 minutes.
- Now measure the temperature t_2 of the water with the other thermometer and record the same.
- Holding the solid with the thread tied to it, remove it from the boiling water, shake it to remove water sticking on it and quickly
- Put it in the water in the calorimeter and replace the lid immediately Fig. (b)



(a)



(b)

(v) Stir the water with the stirrer.

(vi) Measure the temperature of the water once equilibrium is attained, that is, temperature of the mixture becomes constant. Record this temperature as t_3.

OBSERVATIONS

Mass of the empty calorimeter with stirrer (m_1) = ... g

Mass of the calorimeter with water (m_2) = ... g

Mass of solid (m_3) = ... g

Initial temperature of the water (t_1) = ... °C = ... K

Temperature of the solid in boiling water (t_2) = ... °C = ... K

Temperature of the mixture (t_3) = ... °C

Specific heat capacity of material of calorimeter s_1 = ... Jkg^{-1} $(°C)^{-1}$ [Jkg^{-1} K^{-1}]

Specific heat capacity of water (s) = ... Jkg^{-1} K^{-1}

CALCULATIONS

- Mass of the water in calorimeter ($m_2 – m_1$) = ... g = ... kg
- Change in temperature of liquid and calorimeter ($t_3 – t_1$) = ... °C
- Change in temperature of solid ($t_2 – t_3$) == ... °C

Heat given by solid in cooling from t_2 to t_3 =

Heat gained by water in raising its temperature from t_1 to t_3 + heat gained by calorimeter in raising its temperature from t_1 to t_3.

Hence

$$m_3 s_0 (t_2 - t_3) = (m_2 - m_1)\, s(t_3 - t_1) + m_1 s_1 (t_3 - t_1)$$

This can be used to calculate s_o.

RESULT

The specific heat of the given solid is ... J kg^{-1} K^{-1} within experimental error.

How can we use the method of mixtures to find the specific heat of a liquid?

We can verify the principle of calorimetry, if specific heat capacity of the solid and the liquid are known.

PRECAUTIONS

- -Physical balance should be in proper working condition and ensure that there is no zero error.
  - The two thermometers used should be of the same range and least count.
- .-The solid used should not be chemically reactive with the liquid used or water.
  - The calorimeter should always be kept in its insulated cover and at a sufficient distance from the source of heat and should not be exposed to sunlight so that it absorbs no heat from the surroundings.
  - The solid should be transferred quickly so that its temperature is same as recorded when it is dropped in the liquid.
  - Liquid should not be allowed to splash while dropping the solid in it in the calorimeter. It is advised that the solid should be lowered gently into the liquid with the help of the thread tied to it.
- -While measuring the temperature, the thermometers should always be held in vertical position. The line of sight should be perpendicular to the mercury level while recording the temperature.

SOURCES OF ERROR

- Radiation losses cannot be completely eliminated.
- Heat loss that takes place during the short period while transferring hot solid into

calorimeter, cannot be accounted for.

- Though mercury in the thermometer bulb has low specific heat capacity, it does absorb some heat.
- There may be some error in measurement of mass and temperature.

THINK ABOUT THESE

- **There may be some heat loss while transferring the solid, from boiling water to the liquid kept in the calorimeter. Heat loss may also occur due to time lapsed between putting of hot solid in calorimeter and replacing its lid.**
- **The insulating cover of the calorimeter may not be a perfect insulator.**
- **Error in measurement of mass of calorimeter, calorimeter with liquid and that of the solid may affect the calculation of specific heat capacity of the liquid.**
- **Calculation of specific heat capacity of the liquid may also be affected by the error in measurement of temperatures.**
- **Even though the metal piece is kept in boiling water, it may not have exactly the same temperature as that of boiling water.**
- What is water equivalent? Will this remain the same over a wide range of temperatures
- **Why do we generally use a calorimeter made of copper?**
- **Why is it important to stir the contents before taking the temperature of the mixture?**
- **Is specific heat capacity a constant quantity for a given material?**
- **What is thermal equilibrium?**

13.SUMMARY

In this module you learnt the following

- The temperature of a body increases or decreases on addition or subtraction of heat
- Heat capacity equals the amount of heat required to raise the temperature of a body by 1 ^{0}C
- Specific heat capacity equals the amount of heat required by 1 kg or 1 mole of substance to raise the temperature by 1 ^{0}C
- Specific heat capacity depends upon the material of the sample
- Specific heat capacity of a material is not constant; it changes with temperature.

- Molar specific heat of metallic solids is (nearly) constant at room temperature. It equals (nearly) 3R where R is the universal gas constant

- Gases can have specific heat capacities, ranging from 0 to ∞, depending upon how much of additional heat is used for expansion

- Specific heat capacity at constant volume, for a gas, equals the amount of heat required by unit mass of the gas to increase its temperature by 1^0 C keeping its volume constant- (C_v)

- Specific heat capacity at constant pressure, for a gas equals the amount of heat required by unit mass of the gas to increase its temperature by 1^0 C keeping its pressure constant- (C_p)