14. Measurement and Effects of Heat

Can you recall?

1. Which sources do we get heat from?
2. How is heat transferred?
3. Which effects of heat do you know?

Some effects of heat are shown in figure 14.1 What are they?

We have seen in previous standards that heat is a form of energy which flows from an object at high temperature to an object at low temperature. Temperature of an object tells us how hot or cold that object is. The temperature of a cold object is lower than the temperature of a hot object. Thus, the temperature of ice cream is less than the temperature of tea.

14.1 Various effects of heat

We have also seen that when we give heat to an object it expands and it contracts on cooling. Also, the state of matter changes due to heat.

The unit of heat in SI system is Joule while that in CGS units is calorie. One calorie is equivalent to 4.18 Joule. One calorie heat is the heat required to increase the temperature of 1 gm of water through 1^0C.

Solved examples

1. How much heat will be needed to raise the temperature of 1.5 kg of water from 15 ^{0}C to 45 ^{0}C ? Give the answer in calories as well as in Joule.

Given : mass of water = 1.5 kg = 1500 gm.
Change in temperature = 45 ^{0}C - 15 ^{0}C = 30 ^{0}C.
Heat required for temperature change = ?
Heat required for temperature change = mass of water (gm) x change in temperature (^{0}C) cal.
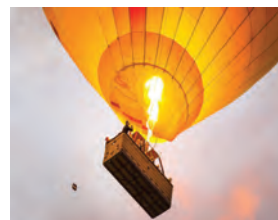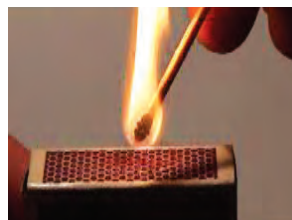= 1500 × 30 cal = 45000 cal
= 45000 × 4.18 J = 188100 J

2. If the temperature of water changes by 10 ^{0}C on giving 300 cal of heat, what is the mass of water?

Given : Amount of heat given to water = 300 cal, change in temperature = 10 ^{0}C, mass of water = m = ?
Amount of heat given (cal) = mass of water (gm) x change in temperature (^{0}C)
300 = m × 10
m = 300 / 10 = 30 gm.

Sources of heat

1. Sun : The Sun is the biggest source of heat received by the earth. A large amount of heat is generated due to the nuclear fusion taking place in its centre. In this process hydrogen nuclei fuse together to form helium nuclei, generating heat in the process. Some of it reaches the earth in the form of light and heat.

2. Earth : As the temperature at the centre of the earth is high, the earth is also a source of heat. This heat is called geothermal energy.

3. Chemical energy : When fuels like wood, coal, petrol etc, burn, there is chemical reaction between the fuel and oxygen. Heat is generated in these reactions.

4. Electrical Energy : In your daily life, you have seen several equipments which produce heat with the help of electricity e.g. electric press, electric heater etc. Thus, electricity is a source of heat.

5. Atomic energy : A huge amount of heat is produced in a very short time when the nuclei of some elements like uranium, thorium etc undergo fission. This is used in atomic energy projects.

6. Air : A large amount of heat is present in the air around us.

Temperature : We can find out how hot or cold an object is by touching the object. However, our sense of 'hot' or 'cold' is relative. This can be understood from the following experiment.

Try this

1. Take three similar vessels. Let us call them 'A', 'B'and 'C'(see figure 14.2)
2. Fill A with hot water and B with cold water. Put some water from A and B in C.
3. Dip your right hand in A and left hand in B, and keep them immersed for 2 to 3 minutes.
4. Now dip both the hands in C. What do you feel?
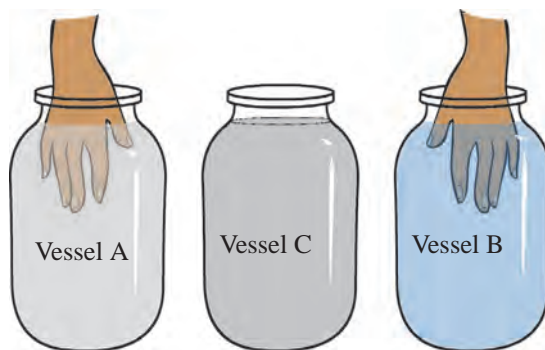
14.2 Relative sensation

Even though, both the hands are dipped in water in the same vessel i.e. water at the same temperature, your right hand will find the water to be cold while the left hand will find it to be hot. What is the reason for this? Think about it.

You must have understood from the above activity that we cannot determine the temperature of an object accurately by simply touching it. Also you may hurt yourself by touching very hot or cold objects. So we feel the need of some device for measuring temperature. Thermometer is a device for measuring temperature. You have read about thermometer in the previous class. In this lesson you are going to learn about the construction of a thermometer.

Can you recall?   What are potential and kinetic energies?

Heat and Temperature : What is the difference between heat and temperature? We know that a substance is made of atoms. The atoms in a substance are always in motion. The total kinetic energy of the atoms in a substance is a measure of the heat contained in that substance, while the temperature of a substance is related to the average kinetic energy of atoms. If the average kinetic energy of atoms in two objects is equal then their temperatures will also be equal.

Figure 14.3 'a'and 'b' show the velocities of atoms in a gas at high and low temperature, respectively. The direction and the length of the arrows attached to the atoms show the direction and magnitude of the velocity of the atoms. The velocity of atoms in the gas at higher temperature is larger than the velocity of atoms in the gas at lower temperature.
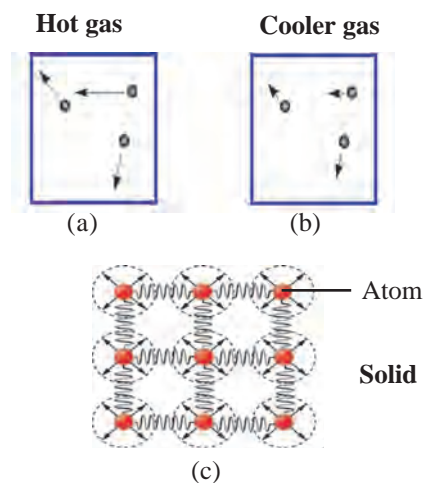
14.3 Motion of atoms in gas and solid

The velocities of atoms in a solid object are shown by arrows in figure 14.3(c). The atoms in a solid object are tied to one another because of the forces acting between them. So they cannot be displaced from their places. Because of heat, they oscillate around their fixed position. Higher the temperature of the solid, faster is their velocity of oscillation.

Suppose A and B are two objects made from the same substance. The mass of A is twice the mass of B which means that the number of atoms in A is twice the number of atoms in B. Even if the temperatures of A and B are equal, i.e. the average kinetic energy of atoms in A is same as that in B, the total kinetic energy of atoms in A is twice that in B. Thus, the heat content of A is twice that of B even though, they both have the same temperature.

Try this   1. Take two steel vessels A and B of the same size.

2. Fill some water in A and double that amount in B. Make sure that the water in both vessels are at the same temperature.

3. Raise the temperatures of water in both vessels by $10\,^0$ C using a spirit lamp. Did it take the same time to increase the temperature in the two vessels?

You must have required more time to raise the temperature of water in B. This means that for the same increase in temperature, you had to give more amount of heat to B. Thus, even though the water in A and B have the same temperature, the amount of heat in B is more than that in A.

Temperature is measured in units of Celsius (^{0}C), Fahrenheit (^{0}F) and Kelvin (K). Kelvin is used in scientific experiments, while the other two are used in daily life. The relation between the three units is shown by the following formulae.

$$\frac{(F-32)}{9} = \frac{C}{5} \quad --------(1)$$

$$K = C + 273.15 \quad -------(2)$$

Some specific temperatures are given in the three scales in the following table. Verify that they satisfy the above relations and fill appropriate numbers in the blanks.

Description	^{0}F	^{0}C	K
Boiling point of water	212	100	373.15
Freezing point of water	32	0	273
Room temperature	72	23	296
Boiling point of mercury		356.7	
Freezing point of mercury		-38.8	

Sloved examples

1. How much will the temperature of 68 ^{0}F be in Celsius and Kelvin?

Given : Temperature in Fahrenheit = F = 68, Temperature in Celsius = C= ?, Temperature in Kelvin = K = ?

According to formula (1), $\dfrac{(F-32)}{9} = \dfrac{C}{5}$

$$\frac{(68-32)}{9} = \frac{C}{5}$$

$C = 5 \times \dfrac{36}{9} = 20\,^0$C According to formula (2)

$K = C + 273.15 = 20 + 273.15 = 293.15$

Thus, the temperature in Celsius = 20 ^{0}C and in Kelvin = 293.15 K

2. At what temperature will its value be same in Celsius and in Fahrenheit?

Given : If the temperature in Celsius is C, then the temperature in Fahrenheit (F) will be same, i.e. F= C.

Using formula (1), $\dfrac{(F-32)}{9} = \dfrac{C}{5}$

or, $\dfrac{(C-32)}{9} = \dfrac{C}{5}$

$(C-32) \times 5 = C \times 9$

$5C - 160 = 9\,C$

$4\,C = -160$

$C = F = -40$ The temperatures in Celsius and in Fahrenheit will be same at -40^0


Thermometer : You must have seen the thermometer that is used when someone at home has fever. That thermometer is called clinical thermometer. Different thermometers are used for different purposes. Let us first learn about the working of a thermometer.

A thermometer is shown in figure 14.4 a. It has a narrow glass tube which has a bulb at one end. The bulb and part of the tube is filled with a liquid. Earlier, mercury was used but, as it is harmful for us, it has been replaced with alcohol. The rest of the volume of the tube has vacuum and its other end is closed. The bulb is kept in contact with the object whose temperature is to be measured so that its temperature becomes same as that of the object. Because of the increased temperature the alcohol inside it expands and its level in the tube rises. Using the properties of the expansion of alcohol (to be discussed below), the temperature can be obtained from the level of the alcohol. The tube of the thermometer is marked accordingly.

Figure 14.4 (b) shows a clinical thermometer. As the body temperature of a healthy person is $37\,^0C$, clinical thermometers are designed to measure temperatures between $35\,^0C$ and $42\,^0C$. These days, instead of the above type, digital thermometers are used for clinical puroses. One such thermometer is shown in figure 14.4 c.

This does not use the expansion of liquid due to heat. Instead, it has a sensor which can measure the heat coming out from the body directly and from that can measure the temperature of the body.

The thermometers used in laboratory are similar to the one shown in figure 14.4 a except that the range of temperatures that it can measure is large spanning $40\ ^0C$ to $110\ ^0C$ or even larger. A special type of thermometer is used to measure the minimum and maximum temperatures in a day. It is called the maximum minimum thermometer. It is shown in figure 14.4 d.
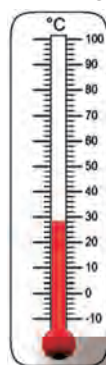
a. A thermometer
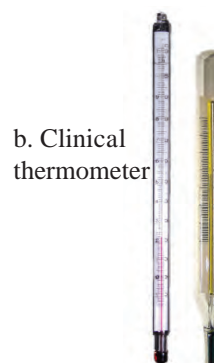
b. Clinical thermometer

c. Digital thermometer

d. Maximum - minimum thermometer

14.4 : Different thermometers

When a hot object is kept in contact with a cold object they both exchange heat. The hot object gives away heat while the cold object absorbs heat. Thus, temperature of the hot object decreases, while that of the cold object increases. This means that the kinetic energy of atoms in the cold object goes on incresing while that in the hot object goes on decreasing. A time comes when the average kinetic energies of atoms in both objects become equal, which means that the temperatures of both objects become equal.

Specific heat : The specific heat of an object is the amount of heat required to increase the temperature of unit mass of that substance through one degree. This is represented by the symbol 'c'. Its unit in SI is Joule /(kg ^{0}C) and in CGS is cal/(gm ^{0}C). Suppose Q amount of heat is required to increase the temperature of an object of mass m and specific heat c, from T_i to T_f This amount depends on the mass and specific heat of the object as well as on the increase in temperature and can be written as.

$$Q = m \times c \times (T_f - T_i) \quad .... (3)$$

Different substances have different specific heats. We are going to learn more about it in future classes. The specific heats of a few substance are given in the following table.

Substances	Specific heat cal/(gm ^{0}C)	Substance	Specific heat cal/(gm ^{0}C)
Aluminium	0.21	Iron	0.11
Alcohol	0.58	Copper	0.09
Gold	0.03	Mercury	0.03
Hydrogen	3.42	Water	1.0

Calorimeter : We have seen that a thermometer is used to measure the temperature of an object. A calorimeter is used to measure the heat content of an object. Using this equipment, we can measure the heat produced or absorbed in a physical or chemical process.

A calorimeter is shown in figure 14.5 Similar to a thermosflask, a calorimeter has two vessels, an inner and an outer one. This way, no heat can be transferred from the inner to the outer vessel or from the outer to the inner vessel. Thus, the inner vessel is thermally isolated from the surroundings. The inner vessel is made of copper. A thermometer for measuring the temperature and a stirrer for stirring the liquid in the calorimeter are fitted in it.

Use your brain power

1. Why does your mother put folded cloth strips soaked in cold water on your forehead when you have high fever?
2. Why is the calorimeter made of copper?

Water at a fixed temperature is placed inside the calorimeter. This means that the temperature of the inner vessel and that of the water in it are the same. When a hot object is placed in water, heat is exchanged between the hot object, water and the calorimeter and all three reach the same temperature. As the calorimeter is thermally isolated from the surroundings, the total heat lost by the hot object is equal to the total heat absorbed by the calorimeter and water inside it.
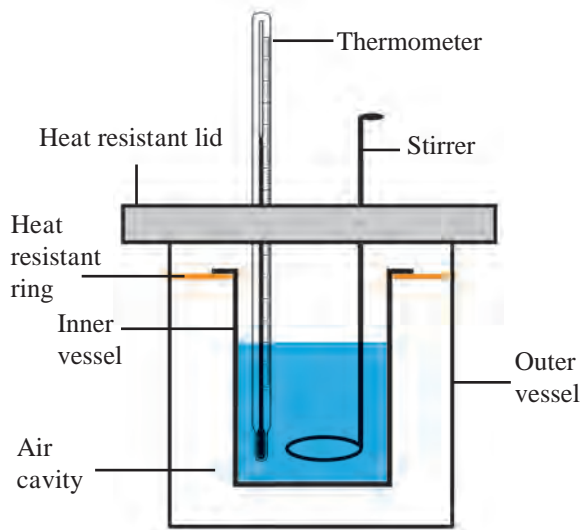
Similarly if we put a cold object in the calorimeter, the cold object will receive heat from the water and its temperature will increase, while water and calorimeter will lose heat and their temperature will decrease.

Suppose the mass of the inner vessel in the calorimeter is 'm_c' and its initial temperature is 'T_i' and the mass of the water in the calorimeter is 'm_w'. The temperature of water will also be 'T_i'. Suppose we place an object of mass 'm_o' and temperature 'T_o' in the calorimeter. If 'T_o' is higher than T_i the object will give away heat to the calorimeter and water. Soon the temperature of all three will become the same.

14.5 Caloriemeter

Let us call this final temperature 'T_f'. The total heat given away by the object ('Q_o') will be equal to the sum of the heat gained by the calorimeter ('Q_c') and by water ('Q_w'). We can write this as.

$$Q_o = Q_C + Q_W \quad ....\ (4)$$

As seen above Q_o, Q_c and Q_w depend on mass, specific heat and change in temperature ΔT. If the specific heats of the material of calorimeter, water and the object are c_c, c_w and c_o respectively, we can write using formula (3),

$$Q_O = m_O \times \Delta T_O \times C_O, \quad \Delta T_O = T_O - T_f$$
$$Q_W = m_W \times \Delta T_W \times C_W, \quad \Delta T_W = T_f - T_i$$
$$Q_C = m_C \times \Delta T_C \times C_C, \quad \Delta T_C = T_f - T_i = \Delta T_W$$

Using (4), $m_o \times \Delta T_o \times c_o = m_w \times \Delta T_w \times c_w + m_c \times \Delta T_c \times c_c$ ....(5)

We can measure all the masses and temperatures. If we know the specific heats of the material of the calorimeter i.e. copper and that of water, we can calculate the value of the specific heat of the object using formula (5). We will learn about this in more details in higher standards.

Solved Examples

1. Suppose the masses of the calorimeter, the water in it and the hot object made up of copper which is put in the calorimeter are the same. The initial temperature of the calorimeter and water is 30 °C and that of the hot object is 60 °C. The specific heats of copper and water are 0.09 cal / (gm °C) and 1 cal / (gm °C) respectively. What will be the final temperature of water?

Given : $m_w = m_o = m_c = m$, $T_i = 30$ °C, $T_o = 60$ °C $T_i = ?$

Using formula (5), $m \times (60 - T_f) \times 0.09 = m \times (T_f - 30) \times 1 + m \times (T_f - 30) \times 0.09$

$(60 - T_f) \times 0.09 = (T_f - 30) \times 1.09$

$60 \times 0.9 + 30 \times 1.09 = (0.09 + 1.09) T_i$

$T_1 = 32.29$ °C

The final temperature of water wil be 32.29 °C.

Effects of heat

In previous standards, we have studied two effects of heat on matter : 1. expansion and contraction and 2. change of state. In this lesson, we are going to learn more about expansion. You will learn about change of state of matter in higher standards.

Expansion

When heat is given to any substance, its temperature increases and it expands. Its expansion depends on the increase in its temperature. Solids, liquids and gases, all expand on receiving heat.

Expansion of solids

Linear expansion : The linear expansion of a solid is the increase in length of a wire or a rod of a solid due to increase in its temperature.

When we increase the temperature of a rod of length l_1 from T_1 to T_2, its length becomes l_2. The change in length is proportional to the original length and the increase in temperature, $(\Delta T = T_2 - T_1)$. So we can write the change in length as follows.

Change in length α original length x change in temperature

$l_2 - l_1 \, \alpha \, l_1 \times \Delta T$

$l_2 - l_1 = \lambda \times l_1 \times \Delta T$ .... (6)

$l_2 = l_1 (1 + \lambda \Delta T)$ .... (7)

Here λ (lambda) is the constant of proportionality and it is called the coefficient of linear expansion of the solid substance.

The expansion coefficients of different substances are different. From the above formula we can see that if we take two rods of different substances, both having the same length, and increase their temperatures by the same amount, the rod of the substance having higher expansion coefficient will expand more. Thus, the increase in its length will be larger.

From formula (6), we can write the expansion coefficient as

$\lambda = (l_2 - l_1) / (l_1 \Delta T)$ .... (8)

Thus, the expansion coefficient is the change in length of a rod of unit length when its temperature is increased by 1 degree. From formula (8) we can see that the unit of expansion coefficient is the inverse of the unit of temperature, i.e. $1/^0C$. The expansion coefficients of some substances are given in the following table.

Solid	Coefficient of linear expansion x 10^6 $(1/^0C)$	Liquid	Coefficient of volume expansion x 10^3 $(1/^0C)$	Gas	Expansion coefficient x 10^3 $(1/^0C)$
Copper	17	Alcohol	1.0	Hydrogen	3.66
Aluminium	23.1	Water	0.2	Helium	3.66
Iron	11.5	Mercury	0.2	Nitrogen	3.67
Silver	18	Chloroform	1.3	Sulphur dioxide	3.90

14.6 : Coefficient of expansion of some substances
Solved Examples

Example : What will be the increase in length of a steel rod of length 0.5 m, when its temperature is increased by 60 ^0C? The coefficient of linear expansion of steel is 0.000013 $(1/^0C)$.

Given : Initial length of the rod = 0.5 m, change in temperature = 60 ^0C, change in length = Δl = ?

Using formula (6), $\Delta l = \lambda \times l_1 \times \Delta T = 0.000013 \times 0.5 \times 60 = 0.00039$ m

Increase in length = 0.039 cm

Areal expansion of solids : Similar to linear expansion, the area of a sheet of a solid material also increaes on heating. This is called the areal expansion of solids. This is given by the following formula.

$A_2 = A_1 (1 + \sigma \Delta T)$ .... (9)

Here, ΔT is the change in temperature and A_1 and A_2 are the initial and final areas of the sheet. σ **is the coefficient of areal expansion of the solid**.

Volumetric expansion of solids : Similar to a sheet, a three dimensional piece of solid expands on all sides when heated and its volume increases. This is called the volumetric expansion of a solid. This is given by the following formula.

$V_2 = V_1 (1 + \beta \Delta T)$ .... (10) Here, ΔT is the change in temperature and and V_1 and V_2 are the initial and final volumes of the solid. β **is the volumetric expansion coefficient of the solid**.

Expansion of liquids

A liquid does not have a definite shape but it has a definite volume. So we can define a volumetric expansion coefficient for a liquid as follows.

$V_2 = V_1 (1 + \beta \Delta T)$ .... (11)

Here, ΔT is the change in temperature and V_1 and V_2 are the initial and final volumes of the liquid. β is the volumetric expansion coefficient of the liquid.

Use your brain power

Which use of the expansion of liquids in daily life do you know?

The effect if heat on water is somewhat different from that for other liquids. This is called anomalous behaviour of water. We are going to learn about it in higher standard.

Expansion of gases

A gas does not even have a fixed volume. Gas expands on heating but if the gas is kept in a closed box, its volume cannot increase but its pressure increases. This is shown in figure 14.7

Observe figure 14.7 and find out answers to the questions.
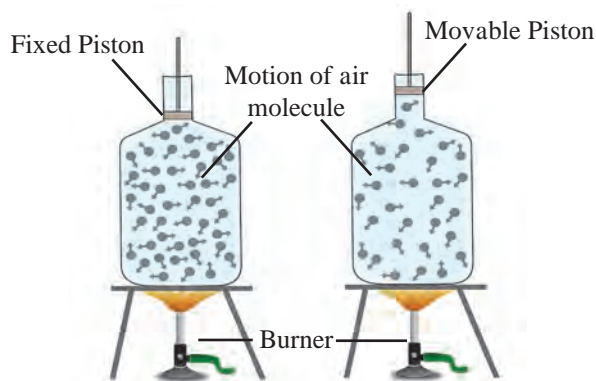
14.7 Effect of heat on a gas

1. Using the formula density = mass / volume, explain what will be the effect of heat on the gas kept in a closed bottle.

2. If the bottle is not closed but has a movable piston attached to its open end (see the figure), what will be the effect of heating the gas in the bottle?

Therefore, the expansion of a gas is measured by keeping its pressure constant. This volumetric expansion coeffcient is called the constant pressure expansion coefficient and is given by the following formula.

$V_2 = V_1 (1 + \beta \Delta T)$ .... (12)

Here, ΔT is the change in temperature and V_1 and V_2 are the initial and final volumes of the gas at costant pressure. β is the constant pressure expansion coefficient of the gas.

The density of a gas decreases on heating. Which of the pictures in figure 14.1 makes use of this?

Exercises

1. A. Whom should I pair with?

Group A	Group B
a. Temperature of a healthy human body	i. 296 K
b. Boiling point of water	ii. 98.6 ^{0}F
c. Room temperature	iii. 0 ^{0}C
d. Freezing point of water	iv. 212 ^{0}F

B. Who is telling the truth?

a. The temperature of a substance is measured in Joules.

b. Heat flows from an object at higher temperature to an object at lower temperature.

c. Joule is the unit of heat.

d. Objects contract on heating.

e. Atoms of a solid are free.

f. The average kinetic energy of atoms in a hot object is less than the average kinetic energy of atoms in a cold object.

C. You will find if you search.

a. A thermometer is used to measure..........

b. The apparatus used to measure heat is called a ....

c Temperature is the measure of the .... kinetic energy of the atoms in a substance.

d. The heat contained in a substance is the measure of the .... kinetic energy of atoms in the substance.

2. Nishigandha kept a vessel containing all the ingredients for making tea in a solar cooker. Shivani kept a similar vessel on a stove. Whose tea will be ready first and why?

3. Write brief answers.

a. Describe a clinical thermometer. How does it differ from the thermometer used in laboratory?

b. What is the difference between heat and temperature? What are their units?

c. Explain the construction of a calorimeter. Draw the necessary figure.

d. Explain why rails have gaps at specific distances.

e Explain with the help of formulae the expansion coefficients of liquid and gas.

4. Solve the following examples.

a. What must be the temperature in Fahrenheit so that it will be twice its value in Celsius?

(Ans. 320 ^{0}F)

b. A bridge is made from 20 m long iron rods. At temperature 18 ^{0}C, the distance between two rods is 0.4 cm. Up to what temperature will the bridge be in good shape?

(Ans. 35.4 ^{0}C)

c. At 15 ^{0}C the height of Eifel tower is 324 m. If it is made of iron, what will be the increase in length in cm, at 30 ^{0}C?

(Ans. 5.6 cm)

d. Two substances A and B have specific heats c and 2 c respectively. If A and B are given Q and 4Q amounts of heat respectively, the change in their temperatures is the same. If the mass of A is m, what is the mass of B?

(Ans. 2 m)

e. When a substance having mass 3 kg receives 600 cal of heat, its temperature increases by 10 ^{0}C. What is the specific heat of the substance?

(Ans.0.0033 cal /(gm ^{0}C))

Project :

Collect information about bimetallic strips and discuss in your class how a fire alarm is made using it.

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