BASIC HEAT (PHY 103)

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COURSE CONTENT

- 1. HEAT
- 2. WORK
- 3. ENERGY
- 4. TEMPERATURE
- 5. THERMAL EQUILIBRIUM
- 6. ZEROTH LAW OF THERMODYNAMICS
- 7. SPECIFIC HEAT OF SOLIDS, LIQUIDS AND GASES
- 8. LATENT HEATS

HEAT

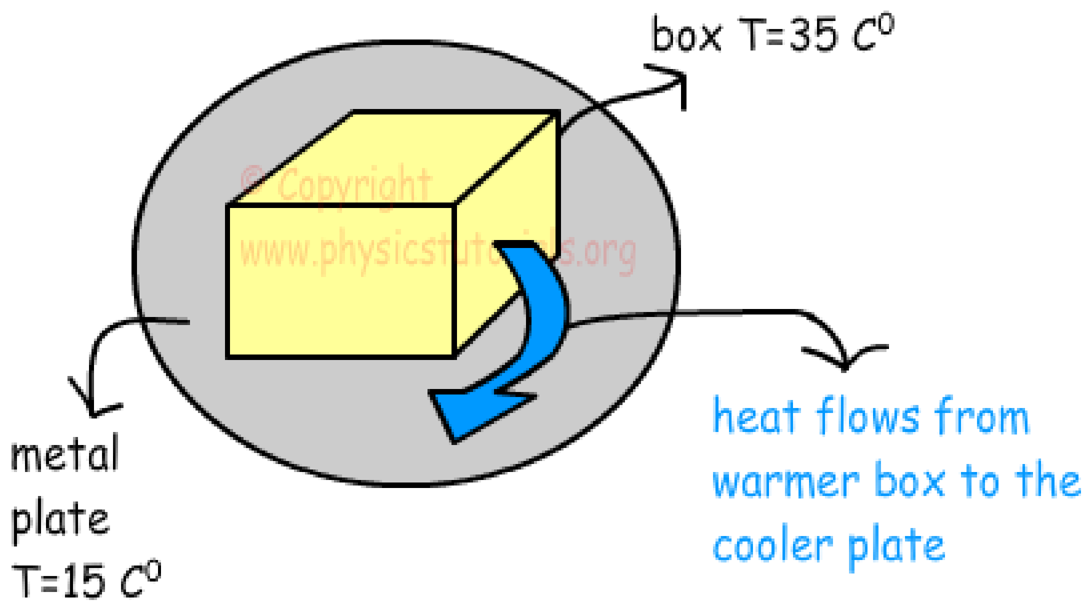
- Two bodies brought in thermal contact will change their temperature until they are at the same temperature. In the process of reaching **thermal equilibrium**, **heat** is transferred from one body to the other.

Heat

Heat is a form of energy that flows from hotter substance to colder one.

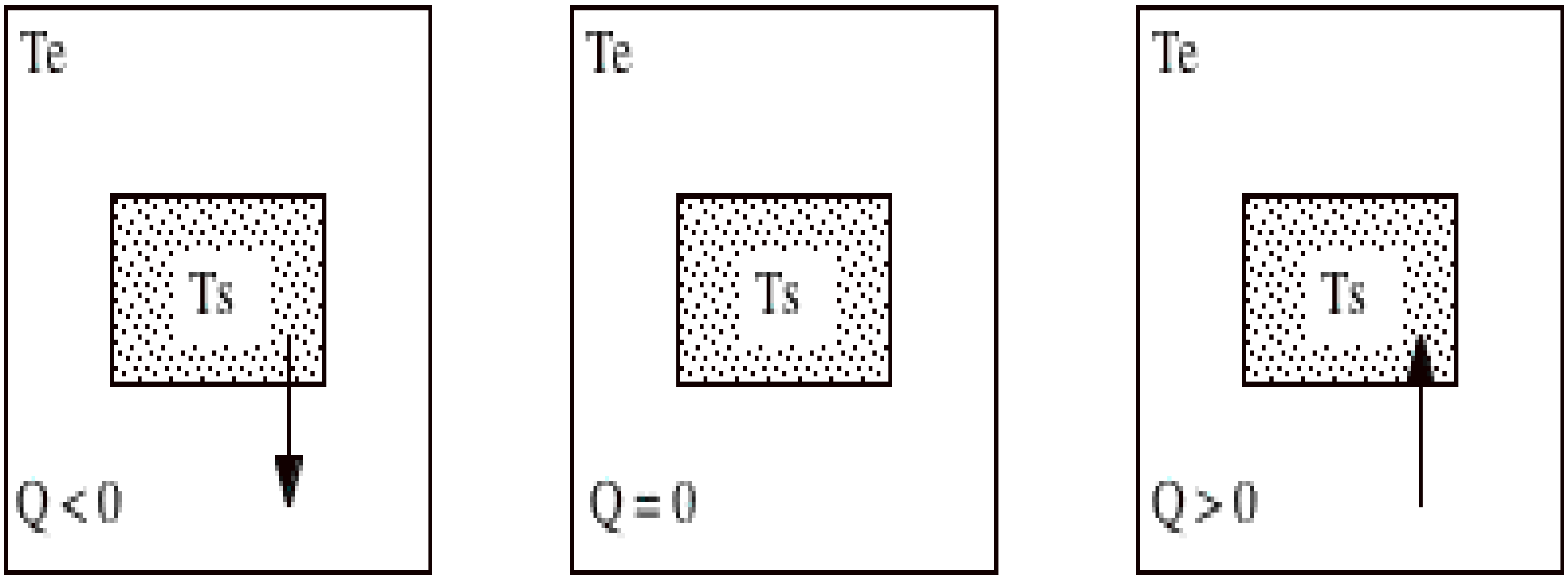
We mean by hotter and colder substance, substance having high temperature and low temperature with respect to a reference matter.

There must be a difference in temperatures of the substance to have heat or energy transfer. Heat is related to the quantity of matter also. If the object has big mass it also has big thermal energy and consequently amount of transferred energy increases. Since it is a type of energy we use Joule or Calories as unit of heat.



HEAT

- Suppose we have a system of interest at temperature T_S surrounded by an environment with temperature T_E.
- If $T_S > T_E$ heat flows from the system to the environment. If $T_S < T_E$ heat flows from the environment into the system.
- Heat, presented by the symbol Q and unit Joule, is chosen to be positive when heat flows into the system, and negative if heat flows out of the system (see Figure).
- Heat flow is a results of a temperature difference between two bodies, and the flow of heat is zero if $T_S = T_E$.



Ts > Te   Ts = Te   Ts < Te

HEAT

- Heat is not the only way in which energy can be transferred between a system and its environment.
- Energy can also be transferred between a system and its environment by means of **work** (W).
- The unit of work is the Joule.
- Another commonly used unit is the calorie. The calorie is defined as the amount of heat that would raise the temperature of 1 g of water from 14.5 ^{O}C to 15.5 ^{O}C. The Joule and the calorie are related as follows: **1 cal = 4.1860 J**

Heat Capacity

- When heat is added to an object, its temperature increases. The change in the temperature is proportional to the amount of heat added

$$Q = c\,m\left(T_f - T_i\right)$$

- The constant C is called the **heat capacity** of the object. The heat capacity of an object depends on its mass and the type of material of which it is made.

Heat Capacity

- The heat capacity of an object is proportional to its mass, and the **heat capacity per unit mass**, c, is commonly used.
- In that case where m is the mass of the object.

$$Q = C\left(T_f - T_i\right)$$

molar heat capacity

- The **molar heat capacity** is the heat capacity per mole of material. For most materials the molar heat capacity is 25 J/mol K.
- In order to determine the heat capacity of a substance we not only need to know how much heat is added, but also the conditions under which the heat transfer took place.
- For gases, adding heat under constant pressure and under constant temperature will lead to very different values of the specific heat capacity.

Heat of Transformation

- When heat is added to a solid or a liquid, the temperature of the sample does not necessarily rise.
- During a phase change (melting, boiling) heat is added to the sample without an increase in temperature.
- The amount of heat transferred per mass unit during a phase change is called the **heat of transformation** (symbol L) for the process.
- The amount of heat needed/released is given by

$$Q = L\,m$$

- where m is the mass of the sample.

PROBLEM

1. What mass of steam of $100^{O}C$ must be mixed with 150 g of ice at $0^{O}C$, in a thermally insulated container, to produce liquid water at $50^{O}C$

SOLUTION

We start with calculating the heat required to transform 150 g of ice at $0^{O}C$ to 150 g of liquid at $0^{O}C$.

The heat of transformation of water is 333 kJ/kg.

ANSWER

- The transformation of ice into water therefore requires a total heat given by

$$Q = L\,m = 50\ \mathrm{kJ}$$

- The heat required to change the temperature of 150 g of water from $0^{O}C$ to $50^{O}C$ is given by

$$Q = c\,m\left(T_f - T_i\right) = 31.5\ \mathrm{kJ}$$

- The total heat that needs to be added to the system is therefore equal to 81.5 kJ. This heat must be supplied by the steam.
- Heat will be released when the steam is transformed into liquid, The heat of transformation for this process is 2260 kJ/kg.

SOLUTION

- Suppose the mass of the steam is m. The total heat released in the conversion of steam into water is given by

$$Q = L\,m = 2260\ m\,kJ$$

- The heat released when the steam cools down from 100^{O}C to 50^{O}C is given by

$$Q = c\,m\left(T_f - T_i\right) = 210\ m\,kJ$$

- The total heat released by the cooling of the steam is therefore equal to 2470 m kJ.
- The total heat required is 81.5 kJ, and we therefore conclude that the mass of the steam must be equal to 33 g.

HEAT TRANSFER

- There are three ways to transfer heat:
  - conduction
  - convection
  - radiation

CONDUCTION

- Let’s consider what happens when you are cooking. You can’t find a wooden spoon, so you grab a metal spoon to start stirring your dinner.

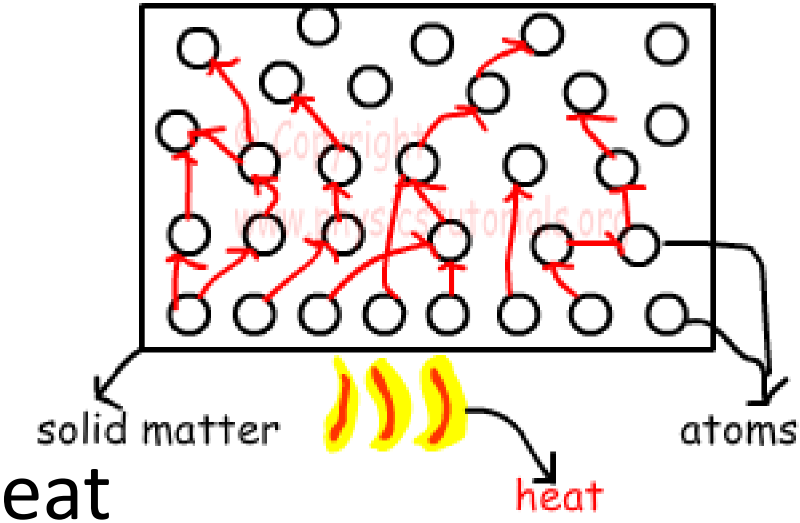
- After a few moments, you realize that your hand is getting very warm. But your hand is not in contact with the food in the pot, or the pot, or the stove. Why is your hand warm?

- This is the process of conduction. Let’s think about the spoon. One end of the spoon is at a higher temperature than the other end of the spoon. So if this end of the spoon is at a higher temperature, on average the molecules in this end are moving faster than those in the other end.

- When the molecules move around, they engage in collisions. Momentum is always conserved.

- In some collisions, the faster moving molecules will impart some of their momentum to the slower moving molecules, causing the slower
- molecules to move around more. These in turn hit other, colder molecules, and eventually, the whole spoon is heated up.

CONDUCTION



- **Conduction cannot occur without a difference in temperature.**
  In fact, the rate at which heat flows is found experimentally to be directly proportional to the temperature difference.

$$\frac{\Delta Q}{\Delta t} = KA\,\frac{\Delta T}{l}$$

where l is the length of the object, A is the cross-sectional area and K is a proportionality constant called the **thermal conductivity**. The units of k are kcal/s-m-°C or J/s-m-°C.

CONDUCTION

- ΔQ is a rate of energy transfer Δt
- $\Delta T/l$ represents a temperature gradient – how the temperature varies along the length of the object.
- If one end is at a very high temperature and the other is at a lower temperature, conduction will occur at a higher rate than if the ends are at similar temperatures.
- If the material has a large cross sectional area, the rate is higher. K tells us that some materials are better conductors than others.

DIRECTION OF HEAT TRANSFER
Heat is the energy transferred to an object and is measured in **joules**. If two objects at different temperatures are placed in contact, heat will flow from the higher to the lower temperature object. This is called **Conduction**.

This is sometimes not obvious: Like when you shake hands with a person with cold hands. The conclusion that many people make is that cold has travelled from that person to you. It is only heat that travels. The coldness that you feel is simply the heat leaving your hand.

Simple Experiment: Put a block of wood and a bowl of water in the fridge. Allow the water to freeze. Then take both of them out and feel them. Which feels "colder"? Most will say the ice. So which has the lowest temperature. If you say the ice, then you are **wrong**! They both have the same temperature. It feels colder because the ice conducts heat faster than wood. What you feel as "colder" simply means there is more heat leaving your hand every second than when touching the wood.

So our concept of hot or cold does not just depend on temperature but also on how fast heat travels in different materials.

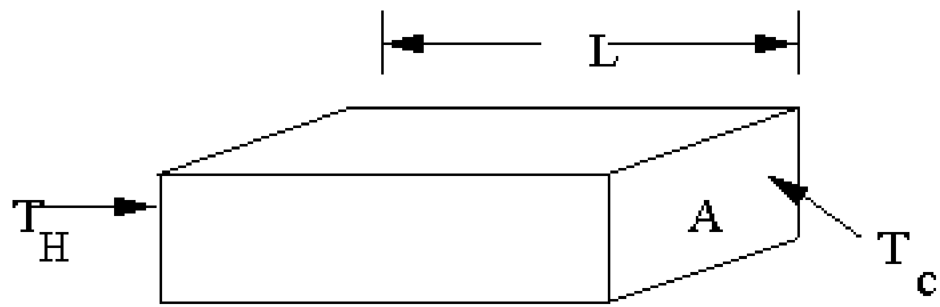
SO HOW FAST DOES HEAT TRAVEL?

Heat travels at different rates in different materials. The quantity of heat transferred per unit time (in other words the rate of heat transfer) is given by:

$$H = \frac{Q}{t}$$

$$H = kA\frac{(T_H - T_C)}{L}$$

where k is the thermal conductivity, A is the cross-sectional area, L is the length of the object, T_H is the higher temperature at one end of the solid, T_c is the lower temperature at the other end.



Demonstration: Three metal strips of the same length are heated by the same flame at the same time. Matches placed at the end of these strips do not light up at the same time. The reason is that the three metal strips are made from 3 different materials: stainless steel (k=14 W/mK), copper (k=401 W/mK) and Brass 220 (W/mK). Since copper is the most conducting, the match on it will light up first and so on.

WHEN IS SOMETHING NEITHER HOT NOR COLD?

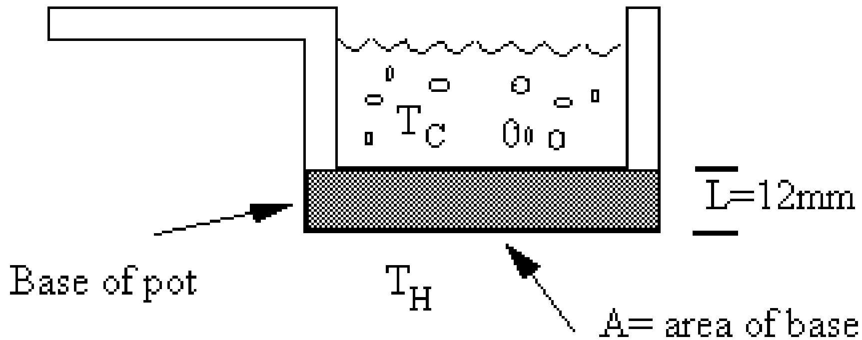
Answer: When there is no heat transfer between you and the object. That is when H = 0 i.e when the object is at the same temperature as your hand.

Example: The "Wonder Defrosting Board" is made of metal that conducts heat towards the food faster than a block of wood.

Example: An aluminium pot contains water that is kept steadily boiling (100 ºC). The bottom surface of the pot, which is 12 mm thick and in area, is maintained at a temperature of by an electric heating unit. Find the rate at which heat is transferred through the bottom surface. Compare this with a copper based pot. The thermal conductivities for aluminium and copper are k_{Al} = 235 $Wm^{-1}K^{-1}$ and k_{Cu} = 401 $Wm^{-1}K^{-1}$ respectively.

SOLUTION:

The following is a schematic diagram of the pot.



The rate of heat conduction across the base is given by equation 7.

$$H = kA\frac{(T_H - T_C)}{L}$$

For the aluminium base:

T_H = 102 ºC, T_C = 100 ºC, L=12 mm = 0.012 m, k = k_{Al} = 235 $Wm^{-1}K^{-1}$

Base area = A = **=** 0.015 m^2.

Substituting these into the above equation:

$$H_{Al} = 235 \times 0.015 \times \frac{(102 - 100)}{0.012} = 588$$

For the copper base k = k_{Cu} = 401 $Wm^{-1}K^{-1}$. So the rate of heat conduction across the base is

$$H_{Cu} = 401 \times 0.015 \times \frac{(102 - 100)}{0.012} = 1003$$

Js^{-1} (or Watts)

So the copper based pot transfers 1.7 times more energy every second compared with the aluminium pot. Generally copper bottom pots are more expensive.

QUESTION

- What is the rate of heat flow along a copper bar 1.5 m long having a cross sectional area of $0.50 cm^2$ if one end of the bar is at 25°C and the other is at 110°C?
  Using K = 380 J/m-s-°C and applying the equation
- $\underline{\Delta Q} = KA\ \underline{\Delta T}$
- $\Delta t \qquad\qquad l$

SOLUTION

- = ((380 X J / $ms^{o}C$) ($0.50cm^2$)) X ((110°C – $25^{o}C$) /150 cm)

- =108 Jcm2°C/ ms°C cm
-
- = (108 Jcm/ ms) (1m/ 100cm)

- = 1 . 1 J/s

CONDUCTION QUESTION

- Determine the heat transfer rate per unit area, by means of conduction for a furnace wall made of fire clay. Furnace wall thickness is 6" or half a foot. Thermal conductivity of the furnace wall clay is 0.3 W/m·K. The furnace wall temperature can be taken to be same as furnace operating temperature which is 650^0C and temperature of the outer wall of the furnace is 150^0C.

For heat transfer by conduction across a flat wall, the heat transfer rate is expressed by following equation,
Large Rectangle

$\underline{\Delta Q}$ = KA $\underline{\Delta T}$
Δt $\quad\quad\quad\quad$ l
$Q = - KA\ dt/dx = KA\ (T_1 - T_2)/\ L$

For the given sample problem,
$T_1 = 650^0C$
$T_2 = 150^0C$
$L = 12" = 12 \times 0.0254\ m = 0.3048\ m$
$k = 0.3\ W/m{\cdot}K$

Hence,
Heat transfer rate per unit area of the wall is calculated as,
$Q/A = k \times (T_1 - T_2)/L$
$Q/A = 0.3\times(650\text{-}150)/0.3048\ W/m^2 = 492.13\ W/m^2$
This figure multiplied by the area of the furnace wall, will determine the total heat transfer rate in Joules/sec i.e. Watt.

WINDOWS

- Windows - There is cold air outside and warm air inside. The glass conducts the heat to the outside (or the cold to the inside, depending how you look at it).
  - What happens if we instead double the thickness of the glass? The answer is that the heat flow will occur at half the rate ($\Delta Q/\Delta t$ proportional to $1/l$).

- The difference in thermal conductivity also helps explain things like why a tile floor is colder than carpet - the tile has a higher thermal conductivity, so it pulls the heat away from your foot faster than the carpeting would.

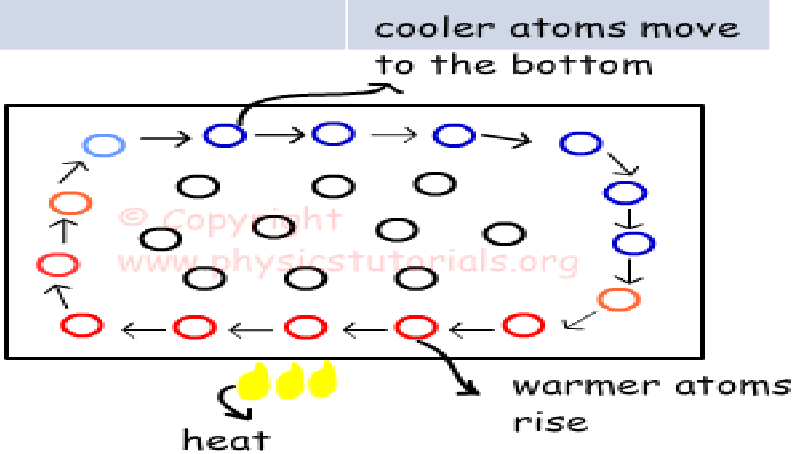
CLOTHING

- Clothing is also much more insulating than just the effect of the material. Clothing can trap air and prevent breezes. Layers of clothing are especially good at this.
  - Polar bears have – in addition to all the fat – an underlayer of hollow hairs that are very good at trapping air, thus keeping the bears warm.
  - \- This is similar idea to why women wear nylons in the winter – the nylons keep you warmer than slacks by trapping air close to your legs.

Convection

- In conduction, heat is transmitted through a solid (or a liquid or gas); however, there is no motion of the molecules themselves. In liquids and gases, the molecules themselves can actually move, which we call convection.
  - One place in which convection occurs is in heating water. The water molecules at the bottom of the pan are heated by conduction through the pan.
  - As they are heated, their density decreases and the warm water becomes less dense than the colder water above it. The warmer molecules rise and the colder molecules fall to the bottom of the pan where they are then heated.
  - This is the same phenomena responsible for the phrases, "warmer near the lake" and "cooler near the lake".

Other examples of where convection is important are in forced-air heating and cooling systems. IN a refrigerator, the coolant gas or liquid moves through the inside of the refrigerator and removes	



CONVECTION

- heat from the inside of the refrigerator, transferring it to the outside. The coolant must be colder when it passes through the inside of the refrigerator so that heat will flow from the inside of the refrigerator to the coolant. Your blood cools your body the same way - it moves heat from the inside of the body to the skin, where it can be exhausted to the air.
- • Question: Air is a good thermal insulator; however, you often find that a polymer foam insulation is blown into the spaces between the walls of a house? Why would you do this?
- Answer: Although air is a poor conductor, is it still subject to heat transfer by convection. The polymer foam is a solid and therefore doesn't transmit heat by convection.

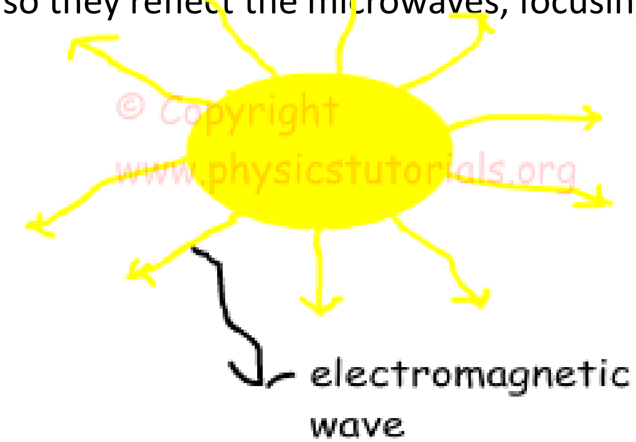
TYPES OF CONVECTION TYPES OF CONVECTION

- We can distinguish two types of convection :
- (a) Forced convection: This is a process in which a material is forced to move by a blower or pump leading to transfer of heat.
- (b) National or free convection:- this is a process in which a material flows due to differences in density.

RADIATION

- Radiation often has a bad connotation; however radiation is a very important method of energy transfer.
- Conduction and convection require the presence of a medium -solid, gas or liquid.
- Radiation is the method of energy transfer that can take place without a medium - in a vacuum.
- This is important because there is a vacuum between the sun and the Earth and if we could only get heat from conduction and convection, we'd be in big trouble.
- If you stand in front of a fireplace, you feel heat through radiation. Although some of the heat is
- from visible radiation, quite a bit of the heat you feel is from infrared radiation. Infrared lamps are
- used to heat food in cafeterias.
- People emit infrared radiation and it turns out that the patterns of blood vessels in your face are
- very unique. Infrared cameras are being developed that use these patterns of blood vessels as a means of identification.

- The rate at which an object radiates energy is determined by Stefan's Law:
- $P = \sigma AeT4$
  where P is the power (energy per unit time), σ is a constant, e is the emissivity (ranging from 0 to 1) that tells you how efficiently the object radiates or absorbs. T is the temperature.
- • Microwave ovens use microwaves (a form of radiation) that are easily absorbed by the water in the food. The metal walls have a high emissivity, so they reflect the microwaves, focusing them back into the food.



RADIATION

Energy is transferred by electromagnetic radiation. All of the earth's energy is transferred from the Sun by radiation. Our bodies radiate electromagnetic waves in a part of the spectrum that we can't see called the infra-red. However, there are some cameras that can actually see this radiation.

The colour and texture of different surfaces determines how well they absorb the radiation.

(1) Black objects absorb more radiation than white objects.

(2) Matt and rough surfaces absorb more than shiney and smooth surfaces.

If you are ever in the snow, take a black and a white piece of cardboard, both the same size. Lay them down on the snow side by side. Over time you will notice that the black cardboard sinks deeper into the snow because it absorbs more heat from the sun and therefore melts more snow underneath it. You will notice this effect if you wear a black jumper and sit in the sun. You become warm more quickly than if you wore other coloured jumpers.

Curiosity: It is interesting to note that aluminium foil has two different surfaces. One side is shiney and the other is matt. If you want to heat something evenly and quickly then you wrap it up with the matt side on the outside. If you want to keep something cold then the shiney side must be on the outside to lessen the effect of heating by radiation. Do you think that's what the manufacturers intended? Is it really that important, or is it a small effect?

Temperature

All matters are formed from atoms and molecules. In microscopic view we see that all particles in a matter are in random motion, they are vibrating, colliding randomly

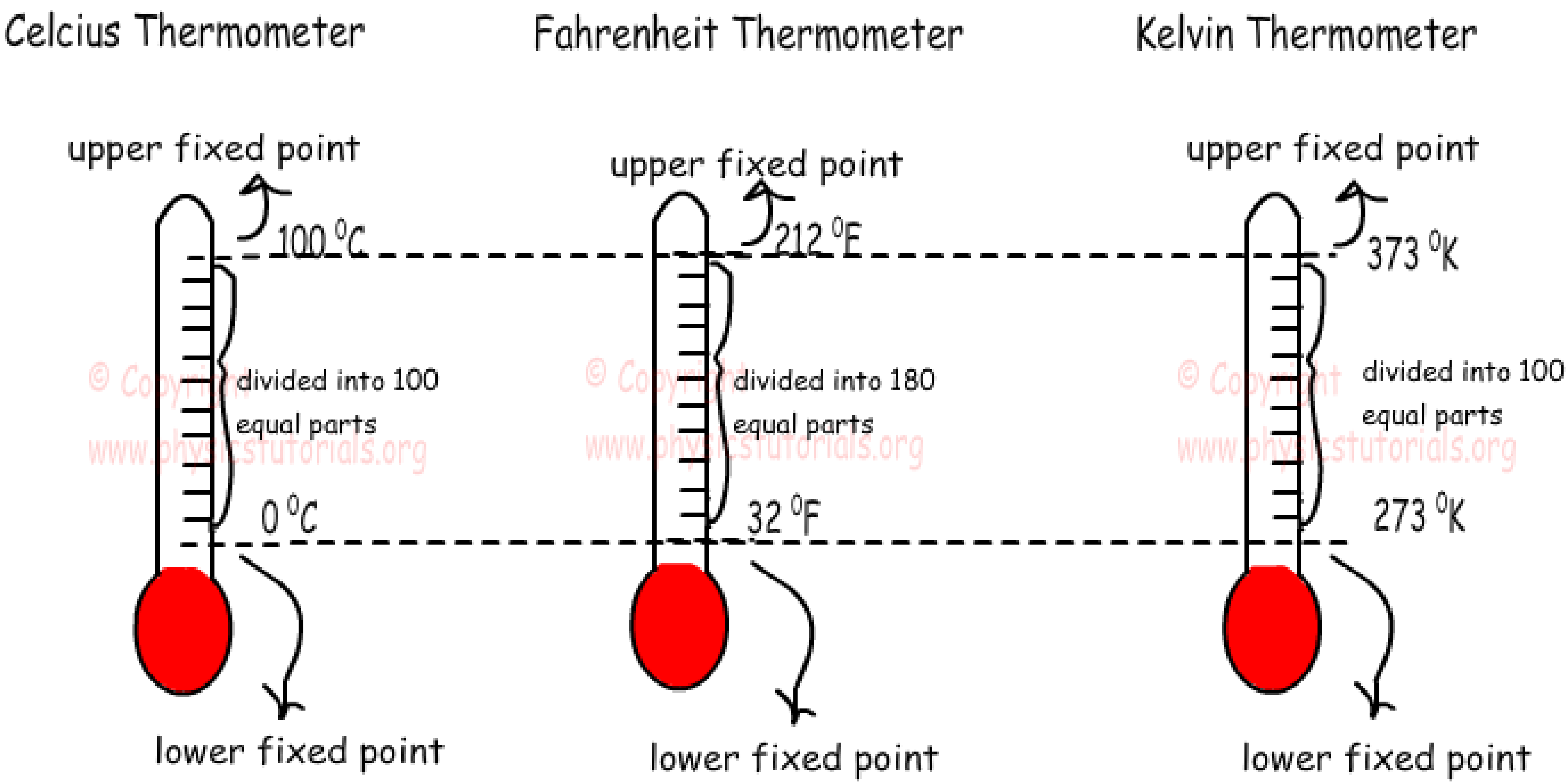
In an object all particles have kinetic energies because of their random motions.

Temperature is the quantity which is directly proportional to the average kinetic energy of the atoms of matter. it is not energy, it just show the quantity of average kinetic energy of one atom or one molecule.

In daily life we use some terms like hot, cold or warm. All these terms are used with respect to another reference matter. For example, you say that a glass of boiling water is hotter than the ice cream. Be careful, ice cream is our reference matter.

TEMPERATURE

- We measure temperature of matters with a device called ***thermometer.*** There are three types of thermometer, Celsius Thermometer, Fahrenheit Thermometer and Kelvin Thermometer. Look at the given picture to see how we scale thermometer

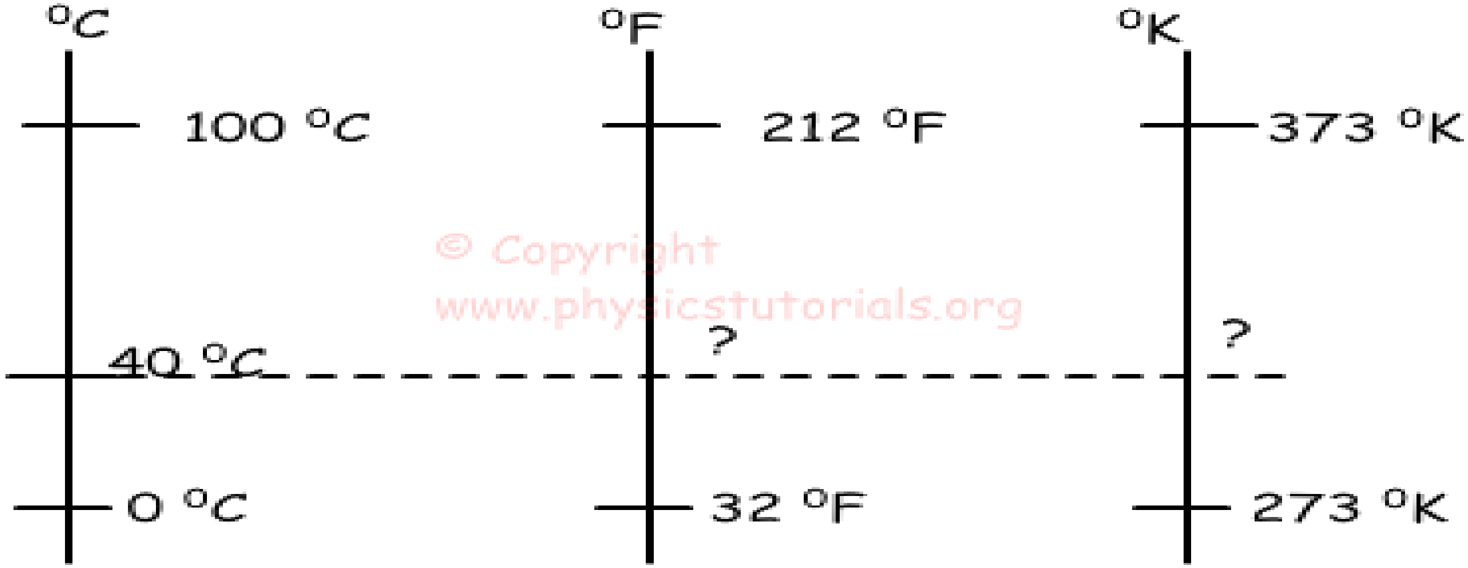

Celcius Thermometer
Fahrenheit Thermometer
Kelvin Thermometer
upper fixed point
100 ^{0}C
divided into 100
equal parts
0 ^{0}C
lower fixed point
upper fixed point
212 ^{0}F
divided into 180
equal parts
32 ^{0}F
lower fixed point
upper fixed point
373 ^{0}K
divided into 100
equal parts
273 ^{0}K
lower fixed point

In Celsius thermometer, lower fixed point is 0 ºC and upper fixed point is 100 ºC, in Fahrenheit thermometer lower fixed point is determined as 32 ºF and upper fixed point as 212 ºF and finally, lower fixed point of Kelvin thermometer is 273 ºK and upper fixed point is 373 ºK.

These temperatures are determined with considering the freezing point and boiling point of water.

We can convert the measurements of Celsius to Kelvin or Fahrenheit to Kelvin, Celsius by using following equations.

$$\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100}$$



We use the equation given below to find corresponding values of 30 °C in Kelvin and Fahrenheit Thermometers

$$\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100}$$

$$\frac{C}{100} = \frac{F-32}{180}$$

$$\frac{40\ ^{\circ}C}{100} = \frac{F-32}{180}$$

$$F = 104\ ^{\circ}F$$

$$\frac{C}{100} = \frac{K-273}{100}$$

$$\frac{40\ ^{\circ}C}{100} = \frac{K-273}{100}$$

$$K = 313\ ^{\circ}K$$

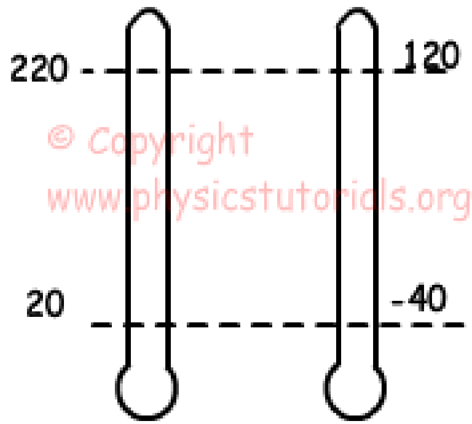
DIFFERENCES BETWEEN HEAT AND TEMPERATURE

- Heat is a type of energy, but temperature is not energy.

- Heat depends on mass of the substance, however; temperature does not depend on the quantity of matter. For example, temperature of one glass of boiling water and one teapot of boiling water are equal to each other; on the contrary they have different heat since they have different masses.

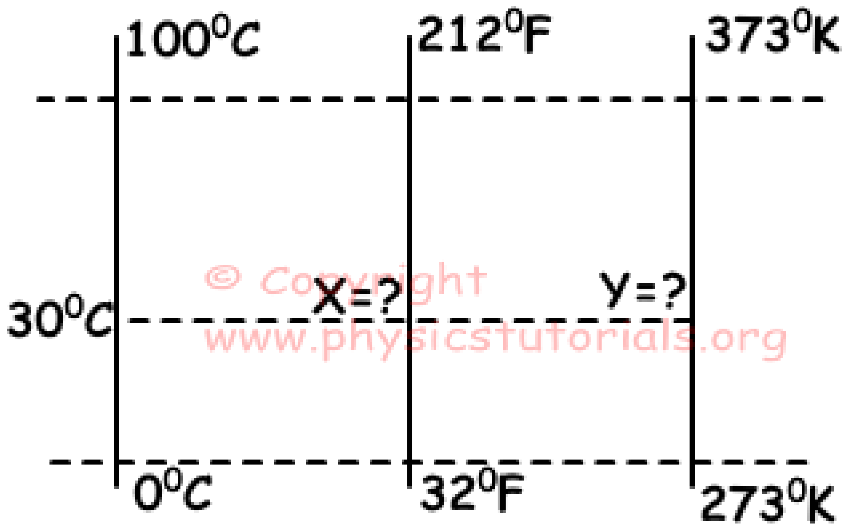
- You can measure temperature directly with a device called thermometer but heat cannot be measured with a device directly. You should know the mass, temperature and specific heat capacity of that matter.
- If you give heat to a matter, you increase its temperature or change its phase.
-

1. Two thermometer X shows boiling point of water 220X and freezing point of water 20X and Y shows boiling point of water 120 Y and freezing point of water -40Y. If thermometer X shows 100X, find the value that thermometer Y shows.



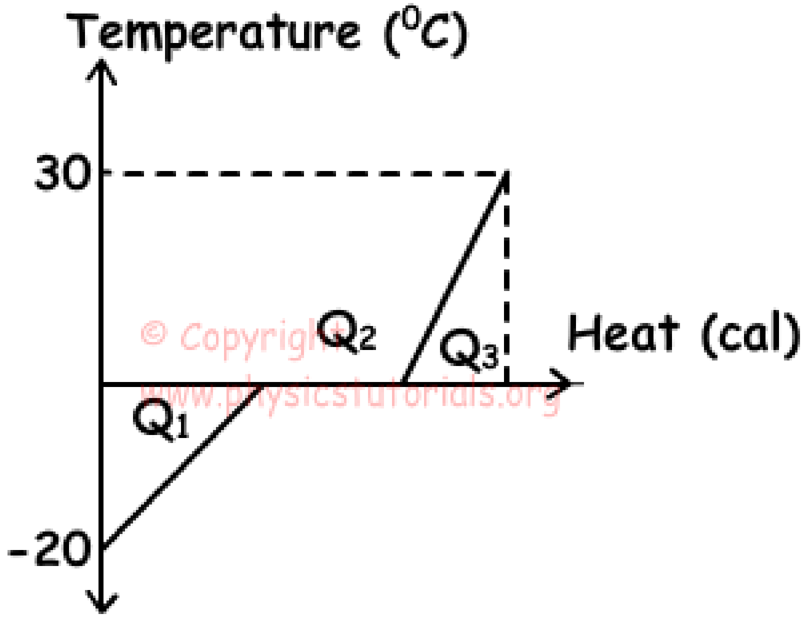
(X-20)/200=(Y-(-40))/160
(X-20)/20=(Y+40)/16
Y=24^{0}Y

2. If Celsius thermometer shows the temperature of air 30^0C, find the temperature of air in Fahrenheit thermometer.



$T(K)=T(C)+273$
$T=30+273=303^0K$
$C/100=(F-32)/180$
$30/100=(F-32)/180$
$F=86^0F$

3. Find heat required to make 5g ice at -20^0C to water at 30^0C. ($c_{ice}=0{,}5cal/g.^0C$, $L_{ice}=80cal/g$, $c_{water}=1cal/g.^0C$)



Heat required to make ice at -20^0C to ice at 0^0C ;

$Q_1=m.c_{ice}.\Delta T=5.0{,}5.20$

$Q_1=50cal.$

Heat required to make it melt;

$Q_2=m.L_{ice}=5.80$

$Q_2=400cal.$

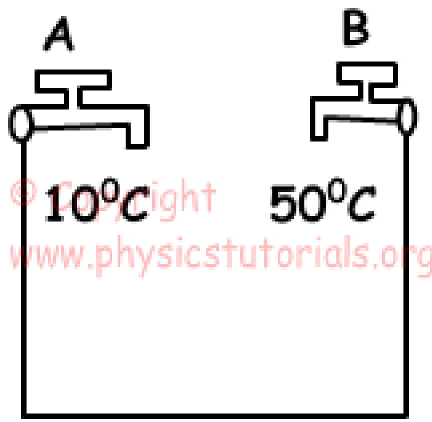
Heat to make it water at 30^0C;

$Q_3=m.c_{water}.\Delta T=5.1.30$

$Q_3=150cal$

$Q_{total}=Q_1+Q_2+Q_3=50+400+150=600cal$

4. Two taps fill the water tank with different flow rates. Tap A fills the tank in 1 hour and tap B fills the tank in 3 hour If we open two taps together, find the final temperature of the water in the tank.



Flow rates of taps; $V_A=3V_B$
3m.c.(T-10)=m.c(50-T)
$T=20^0C$

Calculation with Heat Transfer with Examples

Calculations of Heat Transfer

Conservation of energy theorem is also applied to heat transfer. In an isolated system, given heat is always equal to taken heat or heat change in the system is equal to zero. If two objects having different temperatures are in contact, heat transfer starts between them. The amount of heat given is equal to the amount of heat taken. Object one has mass **m1**, temperature **t1** and specific heat capacity **c1**, object two has mass **m2**, temperature **t2** and specific heat capacity **c2**.
Calculation with Heat Transfer with Examples

$$Q_{gained}=Q_{lost}$$
$$m_1.c_1.\Delta T_1=m2.c2.\Delta T_2$$

Example: Find the final temperature of the mixture, if two cup of water having masses m1=150g and m2=250g and temperatures T1= 30 ºC and T2=75 ºC are mixed in an isolated system in which there is no heat lost. (cwater=1cal/g.ºC)

$Q_{gained} = Q_{lost}$

$m_1 . c_1 . \Delta T_1 = m2 . c2 . \Delta T_2$

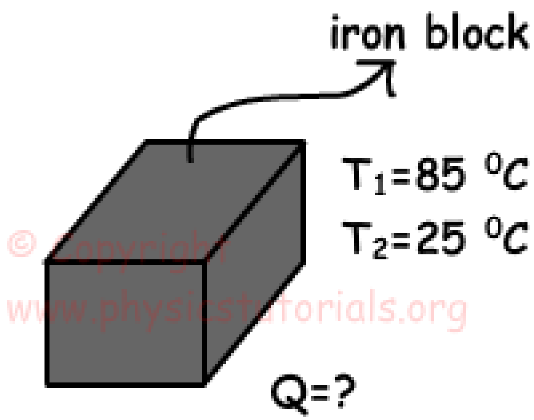
$150g . 1 . (Tf - 30\ ^oC) = 250g . 1 . (75\ ^oC - Tf)$

$3Tf - 90\ ^oC = 375\ ^oC\ - 5Tf$

$8Tf = 465\ ^oC$

$Tf = 58,1\ ^oC$ is the final temperature of the water mixture

Example: Temperature of the iron block decreases from 85 ºC to 25 ºC. If the mass of the block is 1,2kg, calculate the heat lost by the block. (c_{iron}=0.115cal/g.ºC)



Q_{lost}==$m_{iron}.c_{iron}.\Delta T$

Q_{lost}=1200g.0,115cal/g.^0C.(85 ^0C-25 ^0C)

Q_{lost}=8280 Calorie is the heat lost by the block

THERMAL EQUILIBRIUM

Thermal equilibrium is simply another way of saying that two or more objects are at the same temperature.

Example: You and I have never met. Not even shaken hands. Yet if we are in good health you can bet that our body temperatures are at 37 $^{\circ}$C. We are both in thermal equilibrium. Ignoring the fact that our extremities (e.g hands, feet and nose!) may be colder than the rest of our body.

This is sometimes called the **zeroth law of thermodynamics**. The reason for this is that physicists first found the first and second laws, then realised that there is a more fundamental law so they decided to give it the number zero. More formally the law can be quoted as follows:

zeroth law of thermodynamics: If object A and object B are in thermal equilibrium with object C, then they are in thermal equilibrium with each other.

1) Temperature is related to the average kinetic energy of the particles (atoms or molecules).
(2) Heat is the amount of energy transferred to a system of particles

1 calorie is the heat required to raise the temperature of 1 gram of water by 1 degree Celsius.

The Zeroth Law of Thermodynamics:

If two objects are in thermal equilibrium with a third, then they are in thermal equilibrium with each other.

Absolute Temperature scale

There is a physical lower temperature limit of matter. Nothing can be cooled below -273.15 °C. So for convenience, scientists have devised the absolute temperature scale which starts with -273.15 °C and called it 0 Kelvin (**not** degrees Kelvin!). So the relationship between Celsius and Kelvin is:

$$T_K=T_C+273.15 \qquad (1)$$

where T_K is the temperature in Kelvin, and T_C is the temperature in Celsius.

Example: Ice freezes at 0 °C or T_K= 0 +273.15= 273.15 Kelvin.
Normal room temperature is at 20 °C or T_K = 20 + 273.15 = 293.15 Kelvin