1) Define Heat.

"Heat is 'something' which appears at the boundary when a system changes its state due to a difference in temperature between the system and its surroundings".

It is denoted by Q. Heat is a form of energy. According to the dynamical theory of heat, "Heat flow takes place from higher to lower temperature. The molecules of a substance are in parallel motion. The mean kinetic energy per molecule of the substance is proportional to its absolute temperature".

Heat received by the system = +Q

Heat rejected by the system = −Q.

2) Define Thermodynamics.

"Thermodynamics is an axiomatic science which deals with the relations among heat, work and properties of system which are in equilibrium. It describes state and change in state of physical systems.

Thermodynamics, basically entails four laws;

- First law throws light on concept of internal energy.
- Zeroth law deals with thermal equilibrium.
- Second law indicates the limit of converting heat into work and introduces the principle of increase of entropy.
- Third law defines absolute zero of entropy.

3) Define Heat Transfer.

"The transmission of energy from one region to another as a result of temperature gradient."

In heat transfer the driving potential is temperature difference. The study of heat transfer is carried out for the follows purposes:

1. To estimate the rate of flow of energy as heat through the boundary of a system under study.
2. To determine the temperature field under steady and transient conditions.

4) What is difference between thermodynamics and heat transfer?

THERMODYNAMICS	HEAT TRANSFER
1. It deals with the equilibrium states of matter, and precludes the existence of a temperature gradient.	It is inherently a non-equilibrium process. (Since a temperature gradient must exist for exchange of heat to take place.
2. When a system changes from one equilibrium state to another, thermodynamics helps to determine the quantity of work and heat interactions. It describes how much heat is to be exchanged during a process but does not hint how the same could be achieved.	It helps to predict the distribution of temperature and to determine the rate at which energy is transferred across a surface of interest due to temperature gradients at the surface, and difference of temperature between different surfaces.

To understand the difference between thermodynamics and heat transfer, let us consider the cooling of a hot steel bar which is placed in a water bath. Thermodynamics may be used to pridict the final equilibrium temperature of the steel bar - water combination. However, it will not help us to find out how long it takes to reach this equilibrium condition or what the temperature of the bar will be after a certain length of time before the equilibrium condition is attained. Heat transfer on the other hand, may be used to pridict the temperatures of both the bar and the water as a function of time.

Q5. Give the basic laws governing heat transfer.

The following are the basic laws which govern heat transfer:

1. First law of thermodynamics :- The first law of thermodynamics is merely one statement of this general law with particular reference to heat energy and mechanical work i.e. work, and is stated as follows:

"When a system undergoes a thermodynamic cycle then the net heat supplied to the system from the surroundings is equal to the net work done by the system on its surroundings.

$$\oint dQ = \oint dW$$

Where $\oint$ represents the sum for the complete cycle."

The First law of thermodynamics applies to reversible as well as irreversible transformations.

2. Second law of thermodynamics:

It states that "heat will flow naturally from one reservoir to another at a lower temp, but not in opposite direction without assistance". This law establishes the direction of energy transport as heat and postulates that the flow of energy as heat through a system boundary will always be in the direction of lower temperature.

3. Law of conservation of mass :→ This law is used to determine the parameters of flow.

4. Newton's laws of motion :→ These laws are used to determine fluid flow parameters.

5. The rate equations :→ These equations are made applicable depending upon the mode of heat transfer being considered.

Q6 What is the driving force for heat transfer.

Heat transfer is energy in transit due to temperature difference. Whenever there exists a temperature difference in a medium or between media, heat transfer must occur. The basic requirement for heat transfer is the presence of temperature difference. There can be no net heat transfer between two mediums that are at same temperature. The temperature difference is the driving force for heat transfer, Just as the voltage difference

is the driving force for electric current flow and pressure difference is the driving force for fluid flow. The rate of heat transfer in a certain direction depends on the magnitude of the temperature gradient (the temperature difference per unit length or the rate of change of temperature) in that direction. The larger the temperature gradient, the higher the rate of heat transfer.

Q7. Discuss all modes of heat transfer with suitable examples.

Temperature gradient takes place by the following three modes:

(i) Conduction (ii) Convection (iii) Radiation.

Heat transmission, in majority of real situations, occurs as a result of combinations of these modes of heat transfer.

Conduction :- "Conduction" is the transfer of heat from one part of a substance to another part of the same substance, or from one substance to another in physical contact with it, without appreciable displacement of molecules forming the substance.

In solids, the heat is conducted by the following two mechanism:

(i) By lattice vibration (the faster moving molecules or atoms in the hottest part of a body transfer heat by impacts some of their energy to adjacent molecules).

(ii) By transport of free electrons (Free electrons provide an energy flux in the direction of decreasing temp.

- For metals, especially good electrical conductors, the electronic mechanism is responsible for the major portion of the heat flux expect at low temperature).

Convection :- "Convection" is the transfer of heat within a fluid by mixing of one portion of the fluid with another.

- Convection is possible only in a fluid medium and is directly linked with the transport of medium itself.
- Convection constitutes the macroform of the heat transfer since macroscopic particles of a fluid moving in space cause the heat exchange.
- The effectiveness of heat transfer by convection depends largely upon the mixing motion of the fluid.

This mode of heat transfer is met within situations where energy is transferred as heat to a flowing fluid at any surface over which flow occurs. This mode is basically conduction in a very thin fluid layer at the surface and then mixing caused by the flow. The heat flow depends on the properties of fluid and is independent of the properties of the material of the surface. However, the shape of the surface will influence the flow and hence the heat transfer.

Force or natural convection. natural convection occurs when the fluid circulates by virtue of the natural differences in densities of hot and cold fluids; the denser portions of the fluid move downward because of the greater force of gravity, as compared with the force on the less dense.

Forced convection. When the work is done to pump the fluid, it is said to be forced convection.

Radiation :- "Radiation" is the heat transfer of heat through space or matter by means other than conduction or convection.

Radiation heat is thought of as electromagnetic waves an emanation of the same nature as light and radio waves. All bodies radiate heat; so a transfer of heat by radiation occurs because hot body emits more heat than it receives and a cold body recieves more heat than it emits. Radiant energy requires no medium for propagation and will pass through vaccum.

Example :- The water in a boiler shell receives its heat from the fire bed by conducted, convected and radiated heat from the fire to the shell, conducted heat through the shell and conducted and convected heat from the inner shell wall, to the water. Heat always flows in the direction of lower temperature.

Q8 Define steady state of heat transfer.

If the temperature of a body does not vary with time, it is said to be in a steady state. It means if there is change in time, but there is no change in the temperature. So this type of state is called steady state. In steady state, by definition, the rate of heat transfer does not change with time.

Q9 Define unsteady state of heat transfer.

If there is ~~an~~ an abrupt change in its surface temperature, it attains an equilibrium temp. or steady state after some period, the temp. varies with time and the body is said to be an unsteady state or transient state.

In unsteady state, the rate of heat transfer varies with time. And the transient state and unsteady state moreover same.

Q10 Define transient state of heat transfer.

In transient heat transfer, the rate of heat transfer is changing with time. It is same as in unsteady state. Heat transfer starts out as transient and then approaches steady-state with time until the difference between the actual and the ideal becomes negligible as until thermal equilibrium is approached.

Q11 What are the types of convection? Explain all with examples.

There are many types of convection.

Natural convection :- Natural convection is also called as free convection. It occurs due to temperature differences which affect the density, and thus relative buoyancy, of the fluid. Heavier components will fall, while lighter components rise, leading to bulk fluid movement. Natural convection can only occur, therefore, in a gravitational field. A common example of natural convection is the rise of smoke from a fire it can be seen in a pot of boiling water in which the hot and less dense water on the bottom layer moves upwards in plumes, and the cool and more dense water near of the top of the pot likewise sinks.

Natural convection will be more likely and more

rapid with a greater variation in density between the two fluids, a larger acceleration due to gravity that drives the convection, and a larger distance through the convective medium.

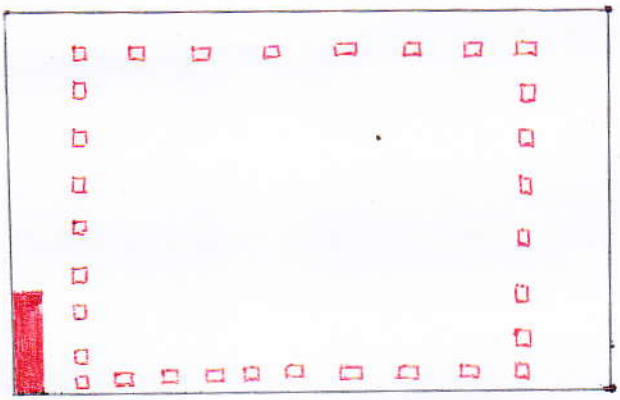
Forced convection :- In forced convection, also called heat advection, fluid movement results from external surface forces such as a fan or pump. Forced convection is typically used to increase the rate of heat exchange. Many type of mixing also utilize forced convection to distribute one substance within another. Forced convection also occurs as a by-product to other processes, such as the action of a propeller in a fluid or aerodynamic heating. Fluid radiator systems, and also heating and cooling of parts of the body by blood circulation, are other familiar examples of forced convection.

Gravitational convection :- It is also called as buoyant convection. It is a type of natural convectional induced by buoyancy variations resulting from one material properties other than temperature. Typically this is caused by a variable composition of the fluid. If the varying property is a concentration gradient, It is known as solutal convection. For example, gravitational convection can be seen in the diffusion of a source of dry salt downward into wet soil due to the buoyancy of fresh water in saline.

Thermomagnetic convection :- It can occurs when an external magnetic field is imposed on a ferrofluid with varrying magnetic susceptibility. In the presence of a temperature gradient this result in a non uniform magnetic body force, which leads to fluid movement. A ferrofluid is a liquid which

becomes strongly magnetized in the presence of a magnetic field. This form of heat transfer can be useful for cases where conventional convention fails to provide adequate heat transfer.

Example :- In miniature microscale devices or under reduced gravity conditions.



Heat source

Q12 Define Fourier Law of Conduction.

Fourier's law of heat conduction is an emperical law based on observation and states as follows:

"The rate of flow of heat through a simple homogenous solid is directly proportional to the area of the section at right angles to the direction of heat flow, and to change of temperature with respect to the length of the path of the heat flow".

$$Q \propto A \cdot \frac{dt}{dx}$$

Q = Heat flow through a body per unit time (W)

A = Surface area of heat flow.

dt = Temperature difference

dx = Thickness of body in the direction of flow.

Thus, $Q = -K.A\frac{dt}{dx}$

K = thermal conductivity of the body.

The temp. gradient $\frac{dt}{dx}$ is always negative along positive x direction and, therefore, the value as Q becomes +ve.

Q13 Define thermal gradient.

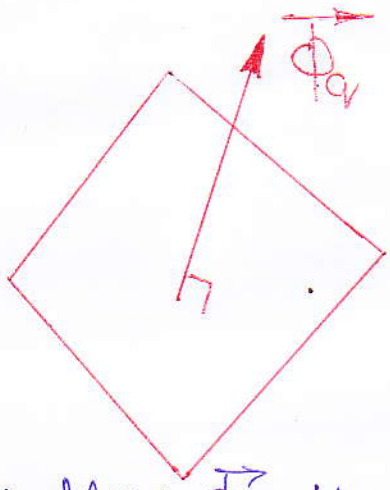
A temperature or thermal gradient is a physical quantity that describes in which direction and at what rate the temperature changes the most rapidly around a particular location. The thermal gradient is a dimensional quantity expressed in units of degrees per unit length. The SI unit is Kelvin per meter (K/m).

Q14 Define heat flux.

Heat flux or thermal flux is the rate of heat energy transfer through a given surface. The SI derived unit of heat rate is Joule per second or watt. Heat flux is the heat rate per unit area. In SI units, heat flux is measured in [W/m^2]. Heat rate is a scalar quantity, while heat flux is a vectorial quantity. To define the heat flux at a certain point in space, one takes the limiting case where the size of the surface

becomes infinitesimally small.

Heat flux is often denoted $\vec{\Phi_q}$, the subscript q specifying heat rate, as opposed to mass or momentum rate.



Heat flux $\vec{\Phi_q}$ through a surface.

Q15 Define Thermal Conductivity. Also give its unit. How it differs with temperature?

Thermal conductivity is the property of a material to conduct heat. It is evaluated primarily in terms of Fourier's law for heat conduction.

Heat transfer occurs at a higher rate across material of high thermal conductivity than across materials of low thermal conductivity. If material of high thermal conductivity are widely used in heat sink application and materials of low thermal conductivity are used as thermal insulation. Thermal Conductivity of material is temperature dependent. The reciprocal of thermal conductivity is called thermal resistivity.

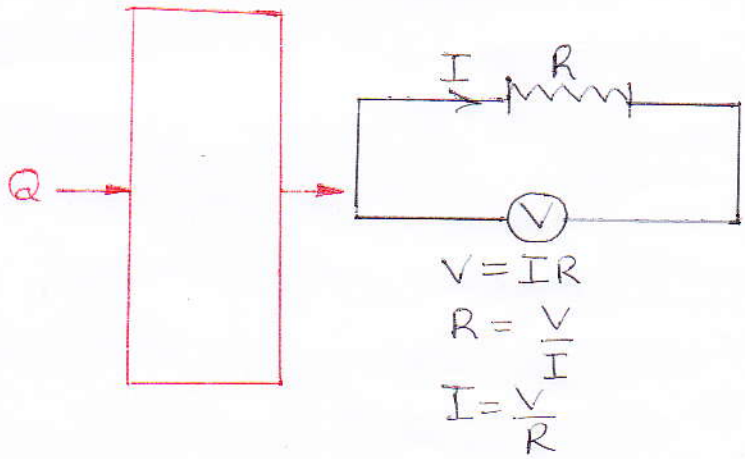
UNITS OF THERMAL CONDUCTNITY :-

The dimension of thermal conductivity is $M^1L^1T^{-3}\Theta^{-1}$. These variables are (M) mass, (L) length, T (Time), and (Θ) temperature. In SI units, thermal conductivity is measured in Watts per meter Kelvin. (W/m-K).

It differs with temperature due to the effect of temperature on thermal conductivity is different for metal and non-metals. In metals conductivity is primarily due to free electrons. Thus the thermal conductivity increases with increase with temperature. Because thermal conductivity increases on related to electrons.

Q16 Define thermal conduction resistance.

Thermal conduction may be defined as the ratio of heat flow temperature difference to the heat flow.



we know

$$Q = KA\frac{dt}{dx}$$

$$\frac{dx}{KA} = \frac{dt}{Q}$$

$$Q = \frac{dt}{\left(\frac{dx}{KA}\right)}$$, Here the quantity dx/KA is called thermal conduction resistance.

$$\therefore \frac{dx}{KA} = \frac{dt}{Q}$$, dt – Temperature difference and Q – heat flow.

Q17 Define Newton Law of cooling.

Newton's Law of cooling states that the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient temperature. (i.e. the temperature of its surroundings.

Newton's law makes a statement about an instantaneous rate of change of the temperature,

i.e. $\frac{dT}{dt} \propto (T - T_\alpha)$

Q18 Give the unit of heat convection coefficient.

The unit of heat convection coefficient W/m^2K.

Q19 Define thermal convection resistance.

It is defined as the temperature difference to the heat flow.

In convection we know,

$$Q = hA(t_1 - t_2)$$

$$Q = \frac{(t_1 - t_2)}{1/hA}$$

$$\frac{1}{hA} = \frac{(t_1 - t_2)}{Q}$$

Here $\frac{1}{hA}$ be the thermal convection resistance.

Q20 Define Stefan Boltzmann Law.

The law states that the emissive power of a black body is directly proportional to the fourth power of its absolute temperature.

$E_b = \sigma T^4$

E_b = Emissive power of a black body,

σ = Stefan - Boltzmann Constant
$= 5.67 \times 10^{-8}\ W/m^2K^4$

$$E_b = 5.67 \left(\frac{T}{100}\right)^4$$

Q21 Give the unit of heat radiation coefficient.
The unit of heat radiation coefficient $= W/m^2K^4$

Q22 Define thermal radiation Resistance.
Thermal radiation resistance may be defined as the ratio of driving force to the heat flow.

$$Q = F\alpha A (T_1^4 - T_2^4)$$
$$= F\alpha A (T_1^2 - T_2^2)(T_1^2 + T_2^2)$$
$$= F\alpha A (T_1 - T_2)(T_1 + T_2)(T_1^2 + T_2^2)$$

$$Q = \frac{T_1 - T_2}{\dfrac{1}{F\alpha A (T_1+T_2)(T_1^2+T_2^2)}}$$

$$\frac{1}{F\alpha A (T_1+T_2)(T_1^2+T_2^2)} = \frac{T_1 - T_2}{Q}.$$

Q23 Define Wein Law.
For a black body emissive spectrum the wavelength λ_{max}, giving the maximum emissive power at a particular temp, may be found by differentiating equation with respect to λ and setting it to zero.

$$\lambda_{max} T = \frac{C_2}{5} \frac{1}{1 - \exp(-C_2/\lambda_{max} T)}$$

$$\lambda_{max} T = C_3$$

which is one form of Wein's law with the value of constant.

$C_3 = 0.289 \times 10^{-2}\ mK.$

Alternately the value of $\lambda_{max} \cdot T$ can be found at the peak of the distribution curve in which we also see that for a given value of λT, the ratio of $\frac{E_{b\lambda}}{T^5}$ is the same for all temperatures.

Another form of Wien's law, therefore, is:

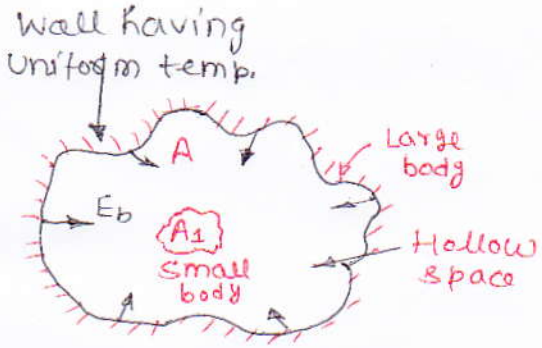
$$\frac{E_{b\lambda max}}{T^5} = \text{Constant},$$

$$E_{b\lambda_{max}} = C_4 T^5$$

$$C_4 = 1.307 \times 10^{-5}\ W/m^2K^5$$

Q24 Define Kirchhoff Law.

The law states that at any temperature the ratio of total emissive power E to the total absorptivity α is a constant for all substances which are in thermal equilibrium with their environment.



energy emitted E_1 per unit surface.

$$A_1 E_1 = \alpha_1 A_1 E_b$$

Now we remove body (1) and replace it by body (2) having absorptivity α_2.

$$A_2 E_2 = \alpha_2 A_2 E_b$$

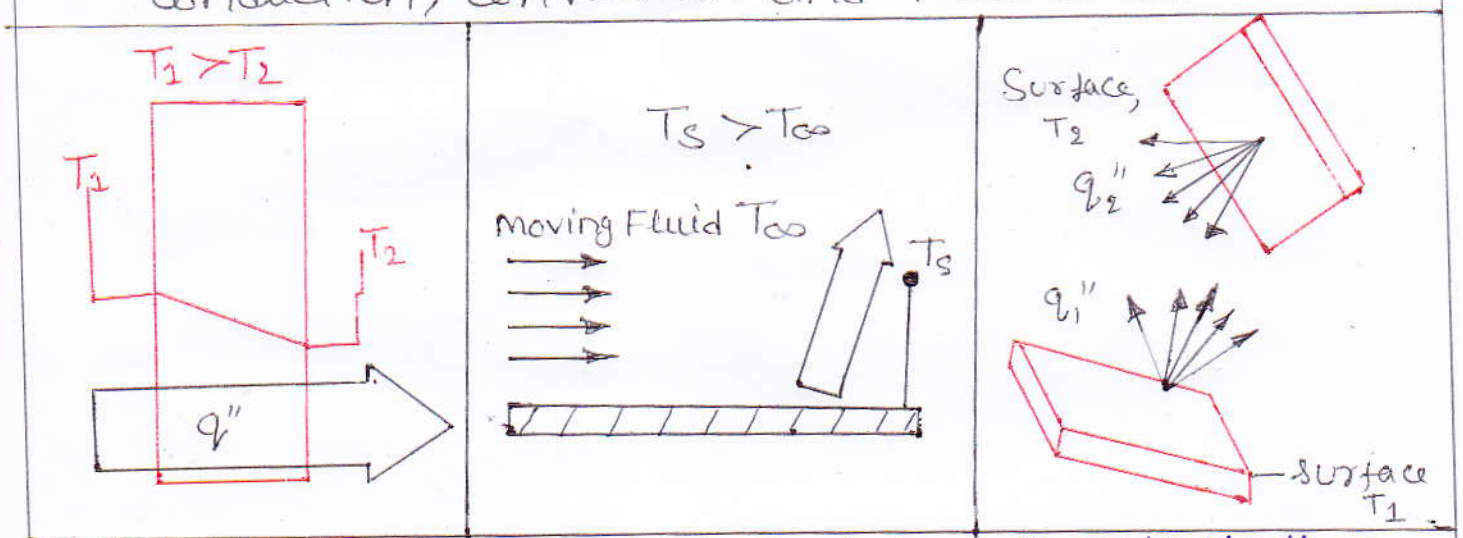
$$E_b = \frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E}{\alpha}$$

Also as per definition of emissivity ε, we have

$$\varepsilon = \frac{E}{E_b} \quad \text{or,} \quad E_b = \frac{E}{\varepsilon} \Rightarrow \boxed{\varepsilon = \alpha}$$

Thus, Kirchhoff's law also ~~also~~ states that the emissivity of a body is equal to its absorptivity when the body remains in thermal equilibrium with its surroundings.

Q25 Explain the electrical analogy of heat conduction, convection and radiation.



Conduction through a solid or a stationary fluid.	Convection from a surface to a moving fluid	No radiation heat exchanges between surfaces.

There exists an analogy between the diffusion of heat and electrical charge. Just as an electrical resistance is associated with the conduction of heat. Defining resistance as the ratio of a driving potential to the corresponding transfer rate.

$$R_{cond} = \frac{T_{s,1} - T_{s,2}}{q_x} = \frac{L}{KA}$$

As the electric resistance from ohm's law

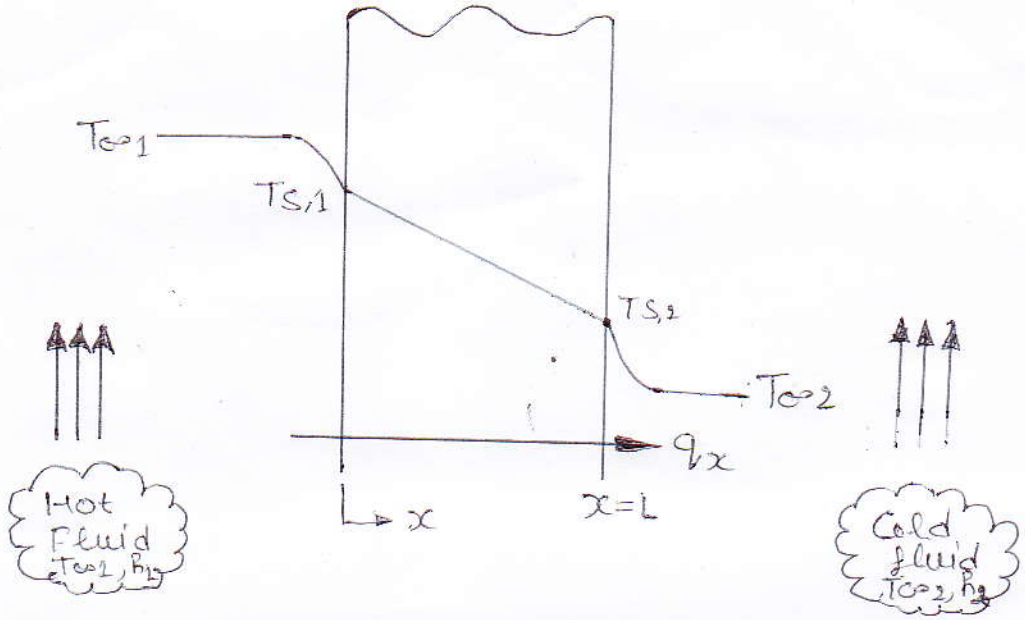
$$R_e = \frac{E_{s,1} - E_{s,2}}{I} = \frac{L}{\sigma A}$$

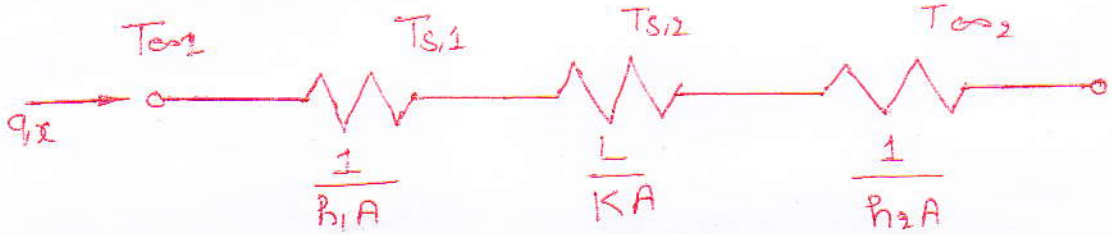
As there is a conduction resistance also there is a convection resistance.

$$q = hA(T_s - T_\infty)$$

$$\therefore R_{t,conv} = \frac{T_s - T_\infty}{q} = \frac{1}{hA}$$

Series circuits :- In the series circuits of heat transferred in a series of stages that aren't necessary of the same heat transfer mode.





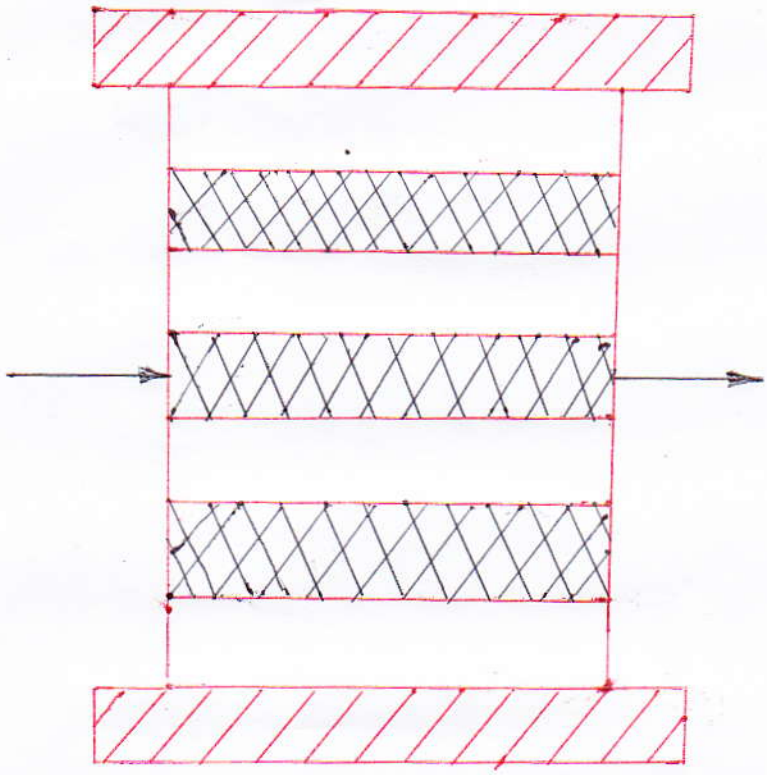
In this figure a plane wall subjected at its end to convective heat transfer. So in this case the heat is first transformed from the hot fluid to the wall surface by convection, then through the wall by conduction, and finally by convection from the second wall surface to the cold fluid. Here the heat quantity in each phase is the same so as current flowing in a series of electric resistances. Then from this analogy we may conclude that;

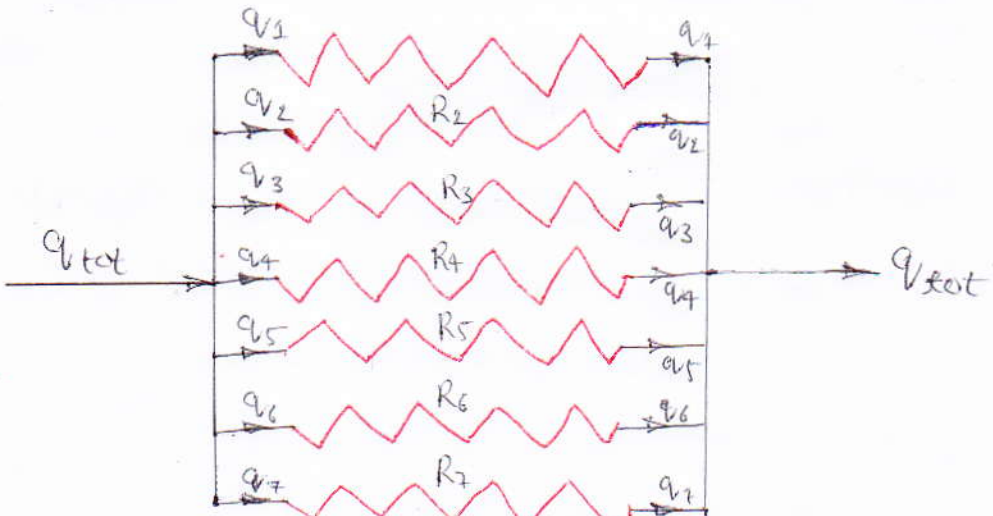
$$q = \frac{\Delta T_{overall}}{\Sigma R_t} = \frac{T_{\infty 1} - T_{\infty 2}}{(R_{t,conv}) + (R_{t,cond}) + (R_{t,conv})} = \frac{T_{\infty 1} - T_{\infty 2}}{\left(\frac{1}{h_1 A}\right) + \left(\frac{L}{KA}\right) + \left(\frac{1}{h_2 A}\right)}$$

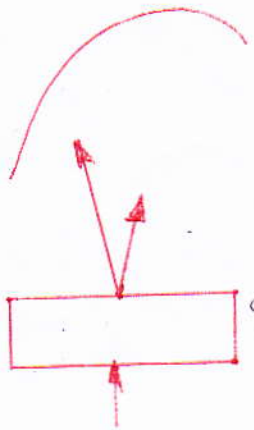
$$i = \frac{\Delta E}{\Sigma R_e} = \frac{E_1 - E_2}{(R_{e,1}) + (R_{e,2}) + (R_{e,3})}$$

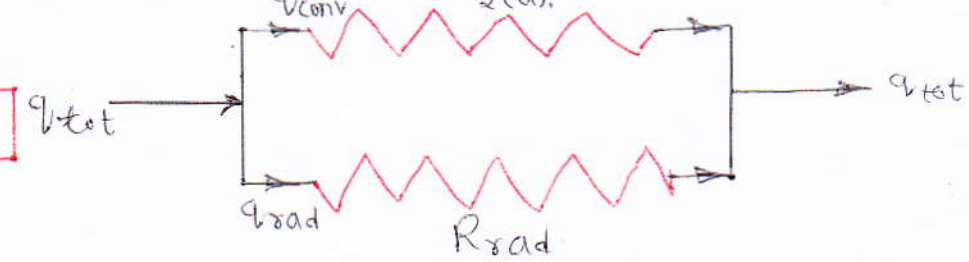
Parallel circuit :→

In this case, heat is transferred in parallel through several heat transfer conduits. These conduits may be of various heat transfer mod.









2(b)

Now considering the case in fig 2(a),

$$q_i = K_i A_i \frac{\Delta T}{L_i} = \frac{\Delta T}{R_{t,i}}$$

And

$$q_{tot} = \Sigma q_i = \Delta T\left(\frac{1}{R_{t,1}} + \frac{1}{R_{t,2}} + \frac{1}{R_{t,3}} + \frac{1}{R_{t,4}} + \frac{1}{R_{t,5}} + \frac{1}{R_{t,6}} + \frac{1}{R_{t,7}}\right)$$

$$= \frac{\Delta T}{R_{t,tot}}$$

This means that like electric circuits in parallel, the equivalent total thermal resistance would be:

$$\frac{1}{R_{t,tot}} = \Sigma \frac{1}{R_{t,i}}$$