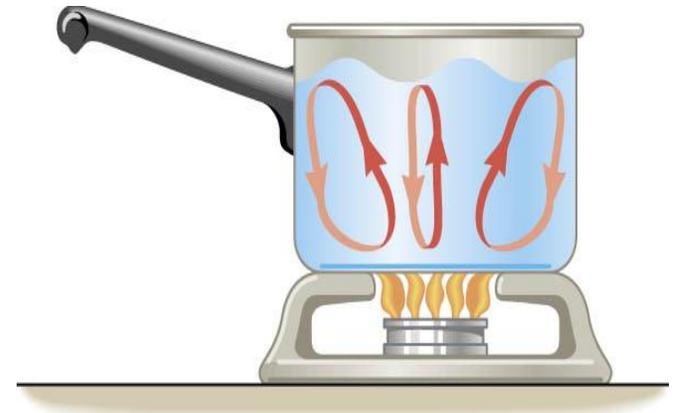


Physical Mechanism of Convection

- “ **Conduction and convection** are similar in that both mechanisms require the **presence of a material medium**.
- “ But they are different in that convection requires the **presence of fluid motion**.
- “ Heat transfer through **a liquid or gas** can be **by conduction** or **convection**, depending on the presence of **any bulk fluid motion**.

Convection is the process in which heat is carried from place to place by the bulk movement of a fluid.

Convection currents are set up when a pan of water is heated.

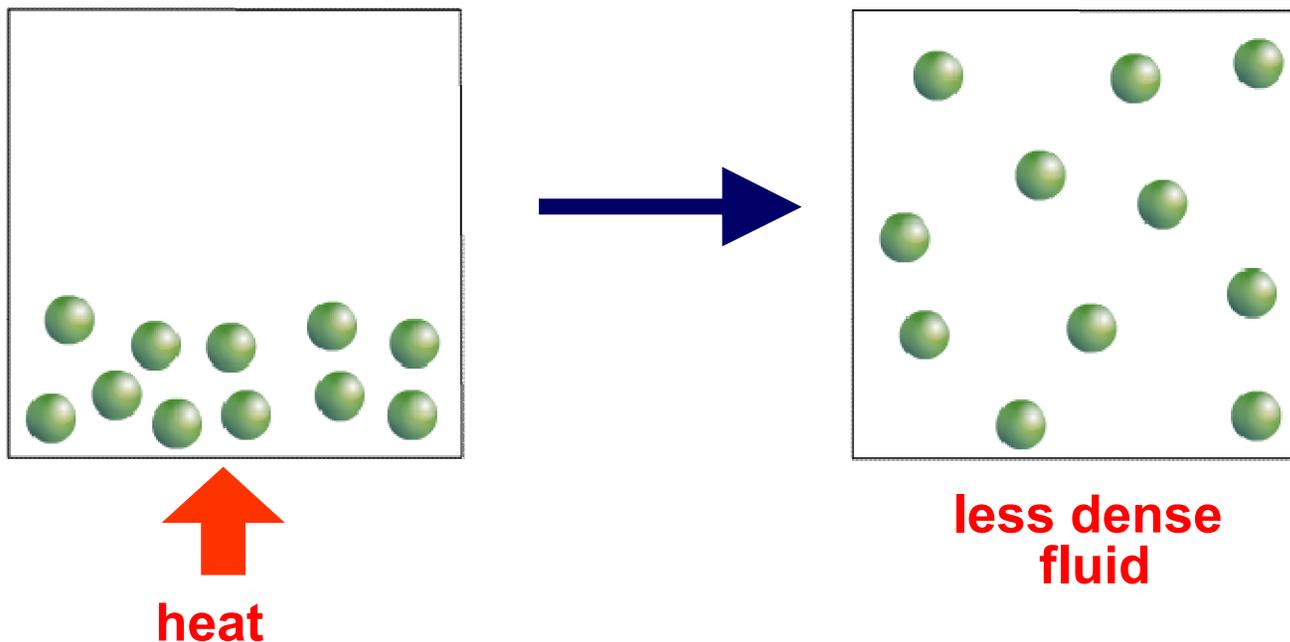


how?

What happens to the particles in a liquid or a gas when you heat them?

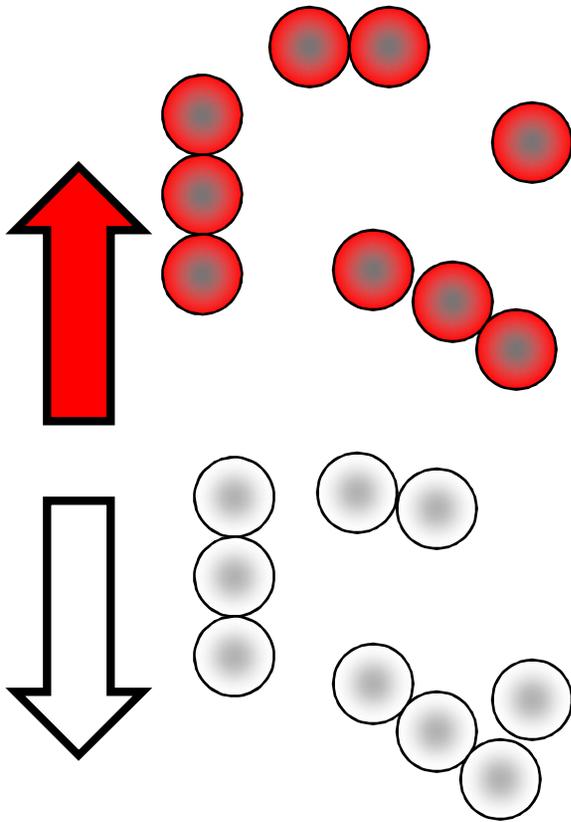
Liquids and gases can both flow and behave in similar ways, so they are called **fluids**.

What happens to the particles in a fluid when it is heated?



The heated fluid particles gain energy, so they move about more and spread out. The same number of particles now take up more space, so the fluid has become **less dense** (i.e. The particles spread out and become less dense)

Fluid Movement



Cooler (**more dense**) fluids sink through warmer (**less dense**) fluids.

In effect, **warmer liquids and gases rise up.**

Cooler liquids and gases sink.

Convection

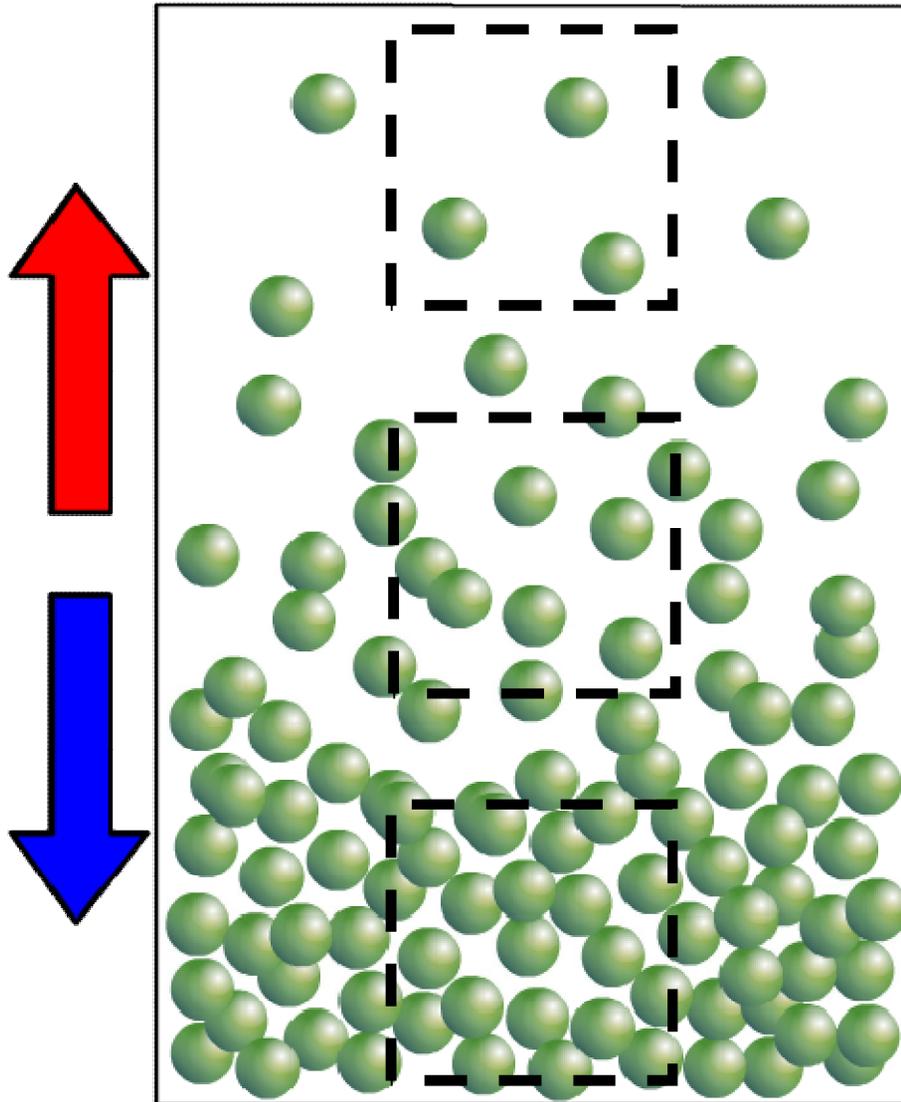
Convection is a process involving **mass movement of fluids.**

The mechanism of convection is the transfer of heat energy by actual physical movement of fluid molecule from one place to another in which there exists a temperature gradient.

This mode of heat transfer is comprised of two mechanism

- “ energy transfer due to **random molecular motion (diffusion)**
- “ and **bulk motion of fluid**

What is Convection?



Warmer regions of a fluid are **less dense** than **cooler regions** of the same fluid.

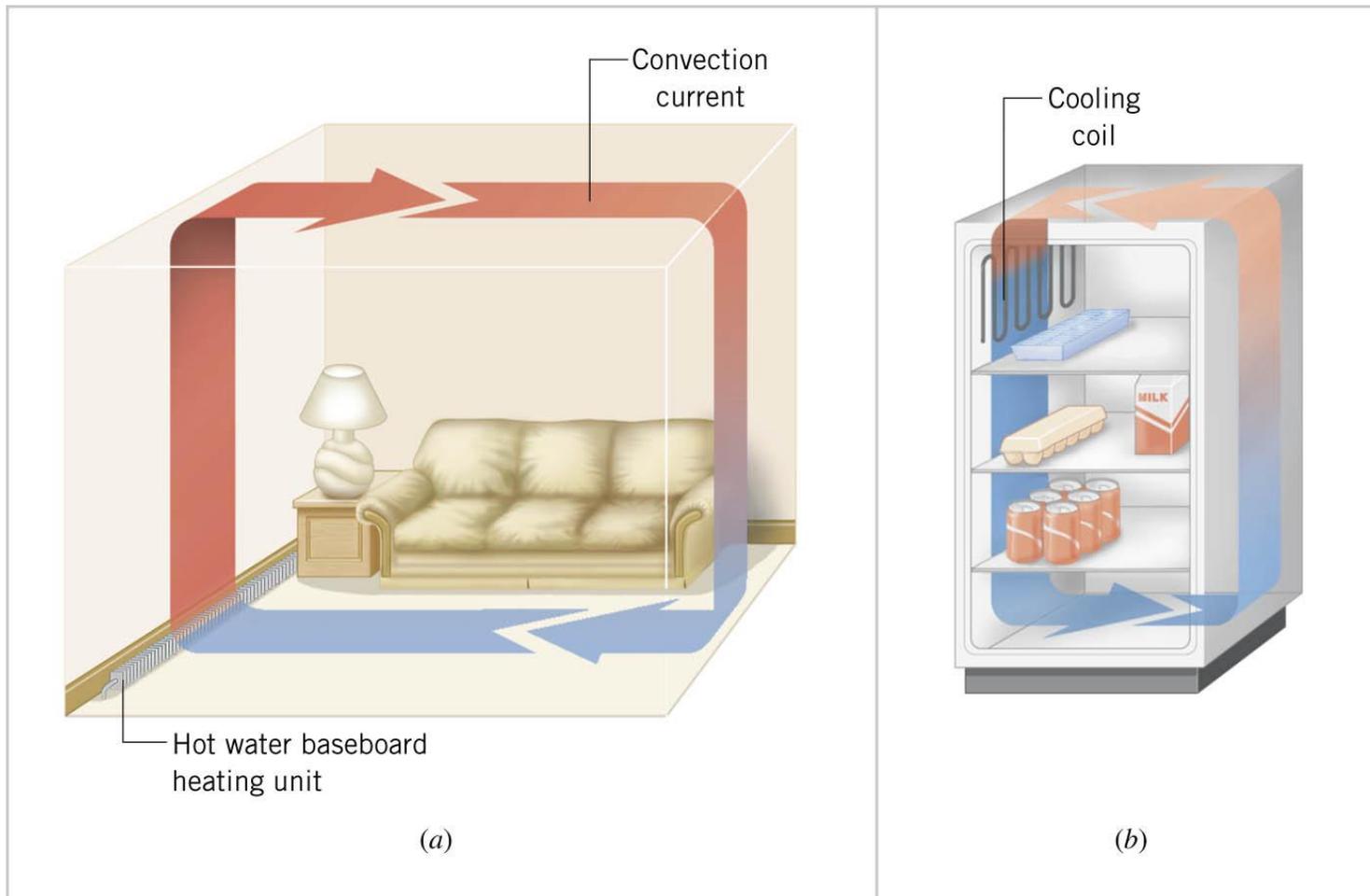
The **warmer** regions will **rise** because they are **more dense**.

The **cooler** regions will **sink** as they are **less dense**.

This is how heat transfer takes place in fluids and is called **convection**.

The steady flow between the warm and cool sections of a fluid, such as air or water is called a **convection current**.

Conceptual Example 1. Hot Water Baseboard Heating and Refrigerators



Hot water baseboard heating units are frequently used in homes, where they are **mounted on the wall next to the floor**.

In contrast, the **cooling coil in a refrigerator** is mounted **near the top of the refrigerator**.

The locations for these heating and cooling devices are different, yet **each location is designed to maximize the production of convection currents**.

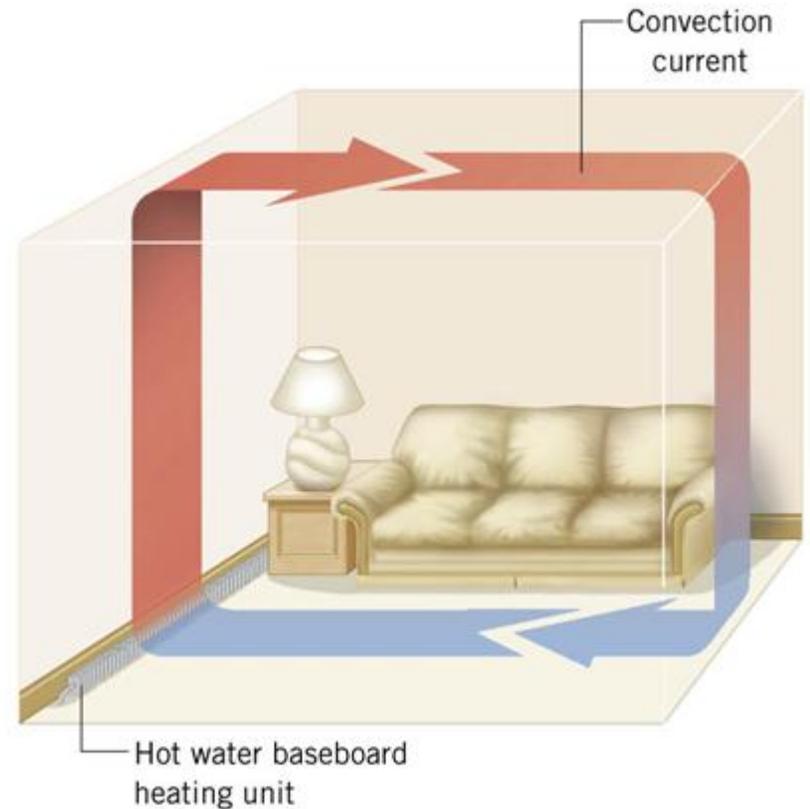
How?

The air above the baseboard unit is heated, like the air above a fire.

Buoyant forces from the surrounding cooler air push the warm air upward.

Cooler air near the ceiling is displaced downward and then warmed by the baseboard heating unit, leading to the convection current.

Had the heating unit been located near the ceiling, the warm air would have remained there, with very little convection to distribute the heat.

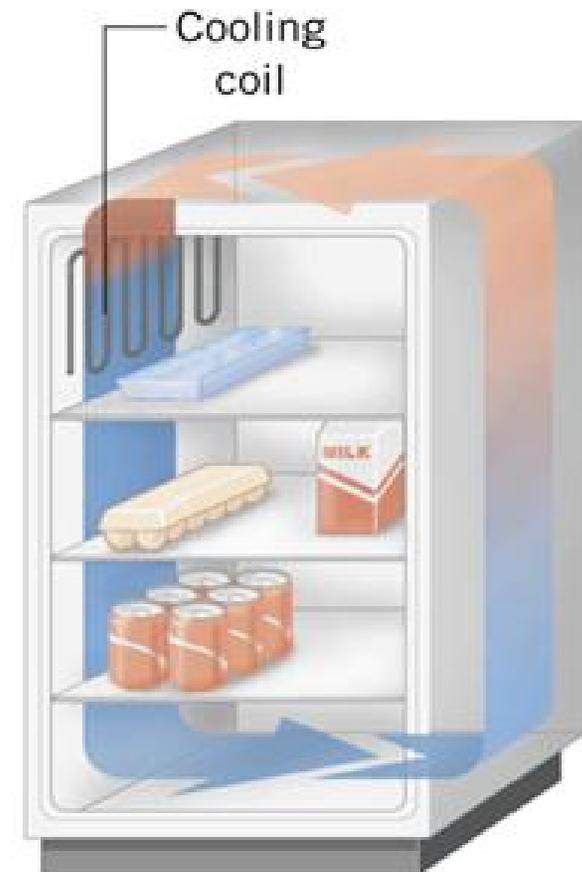


The air in contact with the top-mounted coil is cooled, its volume decreases and its density increases.

The surrounding warmer and less dense air cannot provide sufficient buoyant force to support the colder air which sinks downward.

In the process, warmer air near the bottom is displaced upward and is then cooled by the coil, establishing the convection current.

Had the cooling coil been placed at the bottom of the refrigerator, stagnant, cool air would have collected there, with little convection to carry the heat from other parts of the refrigerator to the coil for removal.



Convection

Heat transfer engineering is the predication of the rate of heat transfer between a fluid and solid boundary surface.

This take place in various steps.

Suppose the solid surface is at higher temperature than the fluid.

First, heat will flow by conduction from the surface to adjacent particles of fluid.

The energy thus transferred will serve to increase the temperature and the internal energy of these fluid particles.

Thus the fluid particles will move to a region of cold fluid (lower temperature in the fluid) where they will mix with and transfer a part of their energy to other fluid particles.

The energy is actually stored in the fluid particle and due to mass motion of fluid particles, it is also carried away.

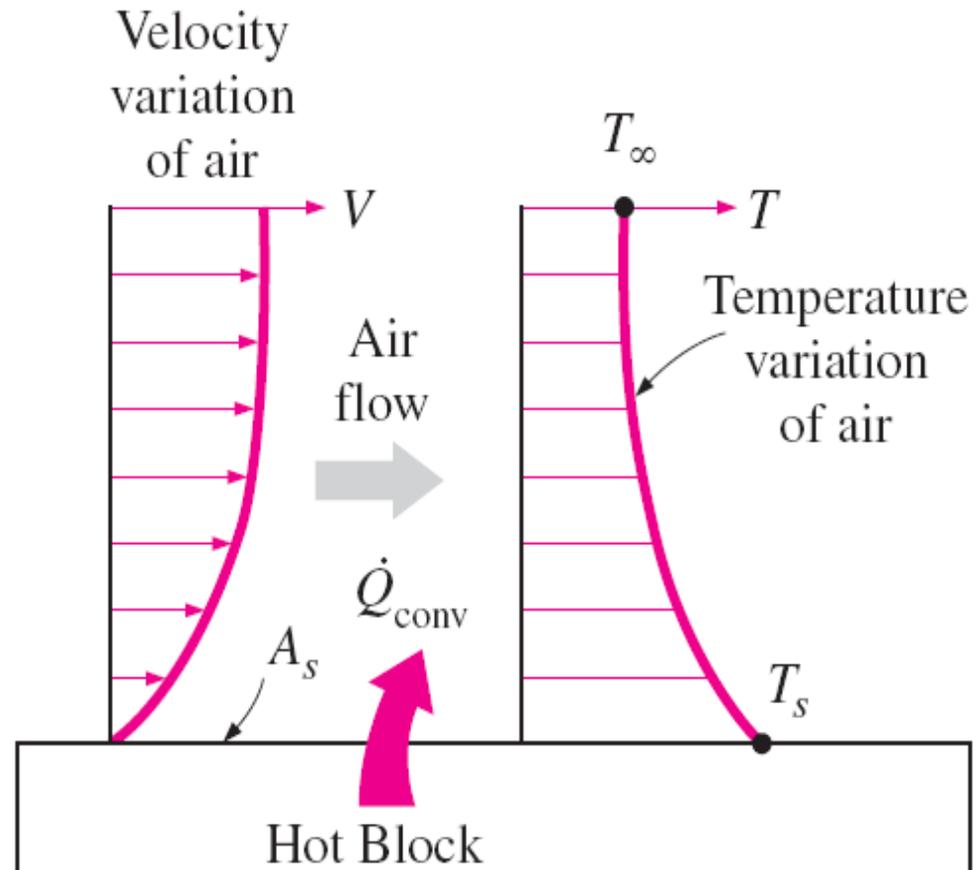
Thus the heat transfer between a solid surface and fluid is due to conduction as well as convection.

Convection

Convection: The mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion and it involves the combined effects of **conduction** and **fluid motion**.

The faster the fluid motion, the greater the convection heat transfer.

In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction.



Heat transfer from a hot surface to air by convection.

Types of Convection

Natural (or free) convection: If the fluid motion is caused by buoyancy forces that are induced by density differences due to the variation of temperature in the fluid.

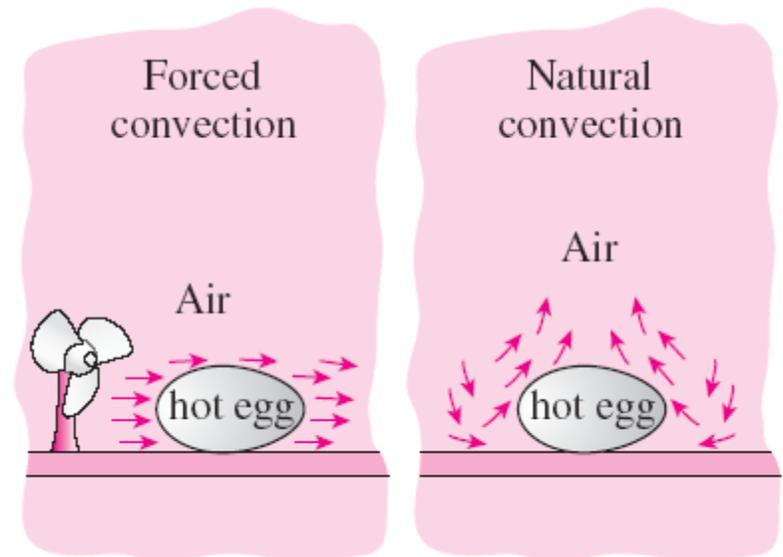
e.g. Heat flow from a hot place to atm

Heating a room by a stove

Forced convection: If the fluid is forced to flow over the surface by external means such as a fan, pump or the wind.

e.g. Heat exchange in condenser

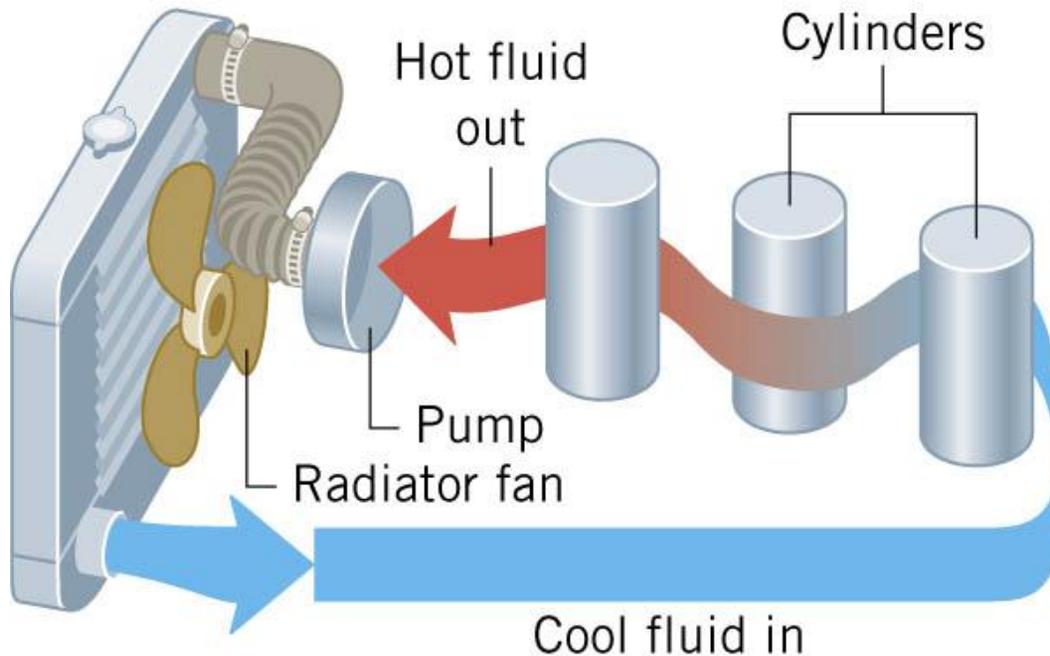
Air conditioning equipments



The cooling of a boiled egg by forced and natural convection

Heat transfer processes that involve **change of phase** of a fluid are also considered to be convection because of the fluid motion induced during the process, such as the rise of the vapor bubbles during **boiling** or the fall of the liquid droplets during **condensation**.

Types of Convection



Natural convection, in which a temperature difference causes the density at one place in a fluid to be different from that at another.

The **forced convection** generated by a pump circulates radiator fluid through an automobile engine to remove excess heat.

Types of Convection

In **forced convection**, the **fluid velocity is much higher** than that of **free convection**, hence **heat exchange rate is more** in the case of **forced convection**.

Typical values of convection heat transfer coefficient

Type of convection	$h, \text{W/m}^2 \cdot ^\circ\text{C}^*$
Free convection of gases	2–25
Free convection of liquids	10–1000
Forced convection of gases	25–250
Forced convection of liquids	50–20,000
Boiling and condensation	2500–100,000

$$\dot{Q}_{\text{conv}} = hA_s (T_s - T_\infty) \quad (\text{W}) \quad \text{Newton's law of cooling}$$

h	convection heat transfer coefficient, $\text{W}/\text{m}^2 \cdot ^\circ\text{C}$
A_s	the surface area through which convection heat transfer takes place, m^2
T_s	the surface temperature (solid surface), $^\circ\text{C}$
T_∞	the temperature of the fluid sufficiently far from the surface (fluid free stream), $^\circ\text{C}$

Sir Isaac Newton (1642–1727) was an English mathematician, physicist, and astronomer, born in Lincolnshire, England. Newton is regarded as one of the greatest scientists and mathematicians in history. His contributions to mathematics include the development of the binomial theorem, the differential calculus, and the integral calculus. He is said to have conceived the idea of the law of gravity upon the observation of the fall of an apple in 1665. With the three fundamental laws that bear his name and are described in *Philosophiae Naturalis Principia Mathematica*, Newton is known as the father of classical mechanics. Newton showed that each of Kepler's three laws on the motion of planets and stars could be derived from the single law of gravity. Newton is also credited for the discovery of the composite nature of white light and the separation of different colors by a prism. The law of cooling that governs the rate of heat transfer from a hot surface to a cooler surrounding fluid is also attributed to Newton.



Convection heat transfer coefficient (h)

The convection heat transfer coefficient h is not a property of the fluid.

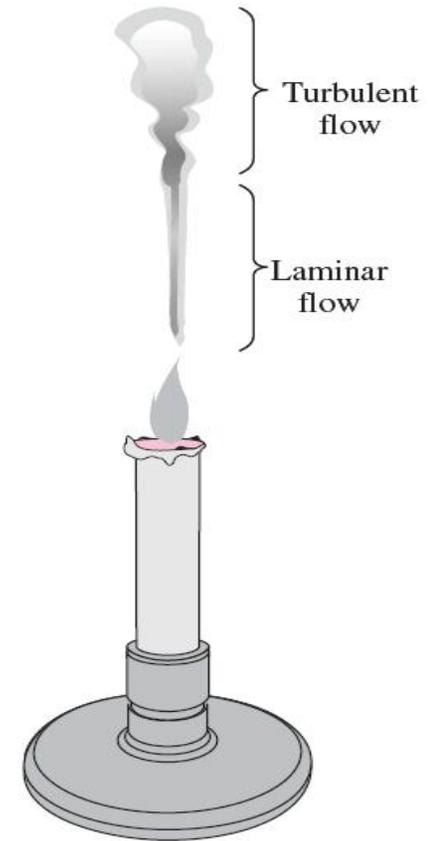
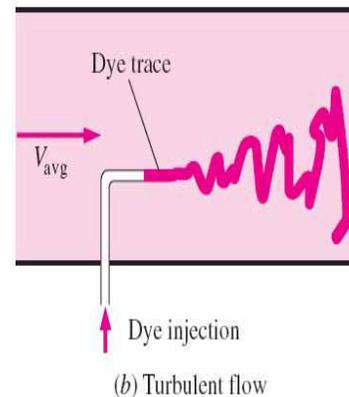
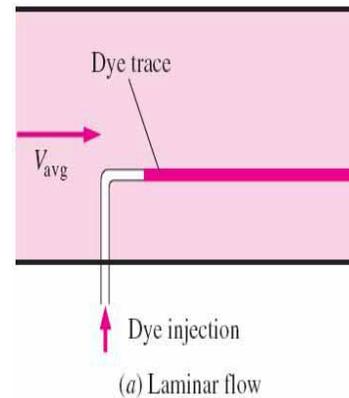
It is an experimentally determined parameter whose value depends on following parameters

- (i) **Fluid flow:** Laminar or turbulent, boundary layer configuration etc.
- (ii) **Thermo physical properties of the fluid:** such dynamic viscosity μ , thermal conductivity k , density ρ , specific heat c_p , fluid velocity V and coefficient of expansion
- (iii) **Surface condition:** roughness and cleanliness
- (iv) **Geometry and orientation of the surface:** Plate, tube etc. Placed horizontally or vertically

Laminar and Turbulent flow

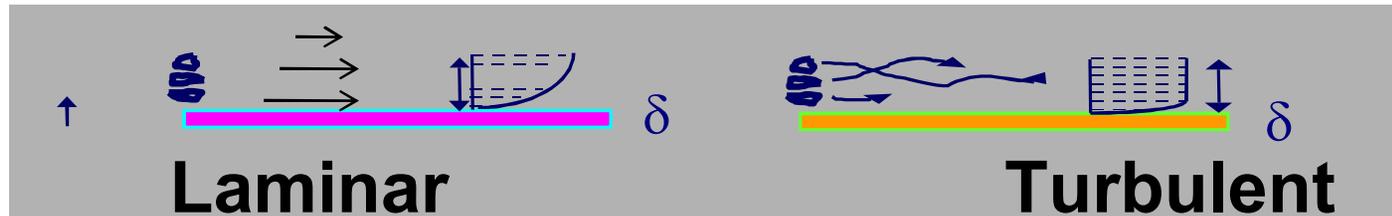
Laminar flow (Streamline flow): the flow is characterized by smooth streamlines and highly-ordered motion (In this type of flow, the fluid moves in layers, each fluid particle follow a smooth and continuous path. The fluid particles in each layer remain in orderly sequence without mixing with each other).

Turbulent flow: the flow is characterized by velocity fluctuations and highly disordered motion (the flow is no more a streamlined flow and eddies of various size are formed in the flow)



The **transition from laminar** to turbulent flow does not occur suddenly.

Laminar and Turbulent flow



Reynolds showed that the nature of fluid flow is governed by the following parameter:

- “ Flow velocity, v
- “ Density of fluid,
- “ Dynamic viscosity of fluid, μ
- “ Diameter D i.e. dimension of flow passage

The grouping of above variables results into a dimensionless quantity called the Reynolds number.

$$Re = v D \rho / \mu$$

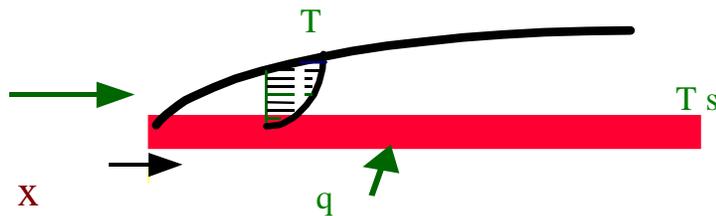
Nature of flow	Range of Re
Laminar	$Re < 2100$
Transition	$2100 < Re < 4000$
Turbulent	$Re > 4000$

Boundary Layer

The concept of boundary layer was introduced by **Prandtl in 1904**.

When a real fluid (viscous fluid) flows past a stationary solid boundary a layer of fluid which comes in contact with the boundary surface adheres to it (on account of viscosity) and condition of **no slip** occurs (the no slip condition implies that the velocity of fluid at a solid boundary must same as that of boundary itself).

Thus the layer of fluid which cannot slip away from the boundary surface undergoes retardation.



Boundary Layer

This retarded layer further causes retardation for the adjacent layers of the fluid, thereby developing a small region in the immediate vicinity of the boundary surface in which the velocity of the flowing fluid increases rapidly from zero at the boundary surface and approaches the velocity of main stream. The layer adjacent to the boundary is known as boundary layer.

Boundary layer is formed whenever there is relative motion between the boundary and the fluid.

Two types of boundary layer

- (1) Hydrodynamic boundary layer
- (2) Thermal boundary layer

Boundary Layer

(1) Hydrodynamic boundary layer

The fluid velocity decreases as it approaches the solid surface, reaches to zero in the fluid layer immediately next to the surface. This thin layer of stagnant fluid has been called hydrodynamic boundary layer.

Its thickness δ is defined as the distance from the plate surface at which the velocity approach 99% of free stream velocity.

(2) Thermal boundary layer

A region of fluid motion near the plate which temperature gradient exist is thermal boundary layer and its thickness δ_t is defined as the value of y from the plate surface at which

$$\frac{t_s - t}{t_s - t_\alpha} = 0.99$$

Boundary Layer

