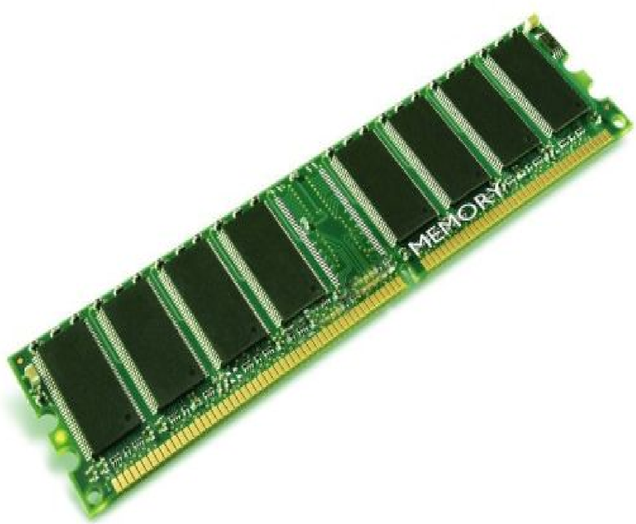
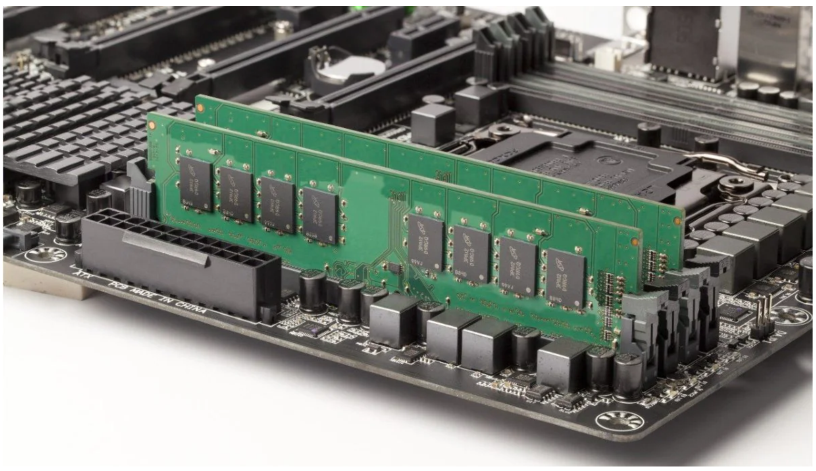
Thermal Analysis of RAM Module

What is RAM Module :

The RAM module in a computer system is like the computer's short-term memory. It's a piece of hardware that **stores data and information** temporarily while the computer is running. When you open a program or work on a document, the computer loads the necessary data into RAM so that it can access it quickly. RAM is much faster than the computer's long-term storage (like the hard drive or SSD), so it allows the computer to work efficiently by providing quick access to the data it needs. **When you turn off or restart your computer, the data in RAM is erased** because it's only meant for temporary storage, unlike the long-term storage devices where your files are saved even when the computer is powered off.





Problem 🙂

Power requirement (TDP) of a 136 mm long 49 mm tall DDR4 RAM in a computer is 3 W. Assuming the RAM to be thin, estimate its surface temperature if a fan blows 50˚C air along the length of the RAM at 100 km/hr.

Objective 😃

- **Power Requirement** : Identify and quantify the power dissipation of the DDR4 RAM module, which is typically referred to as its Thermal Design Power (TDP). In this case, the TDP is specified as 3 watts.

- **Geometry and Assumptions** : Make necessary geometric assumptions, such as considering the RAM module as a thin flat surface, to simplify the analysis while retaining reasonable accuracy.

- **Heat Transfer Analysis**: Apply principles of heat transfer to determine how heat generated by the RAM module is transferred to the surrounding air. Consider the three primary modes of heat transfer: conduction, convection, and radiation.

- **Convection Analysis** : Specifically, focus on convective heat transfer, as air is blowing over the surface of the RAM module. Estimate the temperature rise (ΔT) of the RAM module due to this convective cooling effect.

- **Environmental Conditions** : Take into account the environmental conditions, including the air temperature of 50°C and the air velocity of 100 km/hr, as these factors play a significant role in determining the cooling effectiveness.

- **Surface Temperature Estimation** : Finally, estimate the surface temperature of the RAM module under the specified conditions. This estimation will help assess whether the RAM module operates within a safe temperature range and whether additional cooling measures might be necessary.

Basic concepts :

- Heat is the form of energy that can be transferred from one system to another due to a temperature difference or gradient.
- The science which deals with the rates of such energy transfer is known as “heat transfer”.
- Heat is a vector quantity, flowing in the direction of decreasing temp, with a negative temp gradient.

Thermodynamics vs. Heat Transfer

TD	HT
TD is concerned with the **amount** of heat and work transfer and it gives no indication about the **rate(how long).**	It helps to determine the rate at which energy is transferred to or from a system due to temp. difference.
The science of TD deals with the equilibrium states of matter and precludes the existence of a temp. gradient.	For HT, temp. gradient must exist and such HT is a non equilibrium process.
TD does not provide any information on the nature of interactions and the time rate at which interactions occur. Eg:- **Cooling of a hot steel bar in water.**	HT helps to predict the temp. distribution within the regions of matter.

Modes of Heat Transfer

There are basically three modes:

1. Conduction 2. Convection and 3. Radiation.

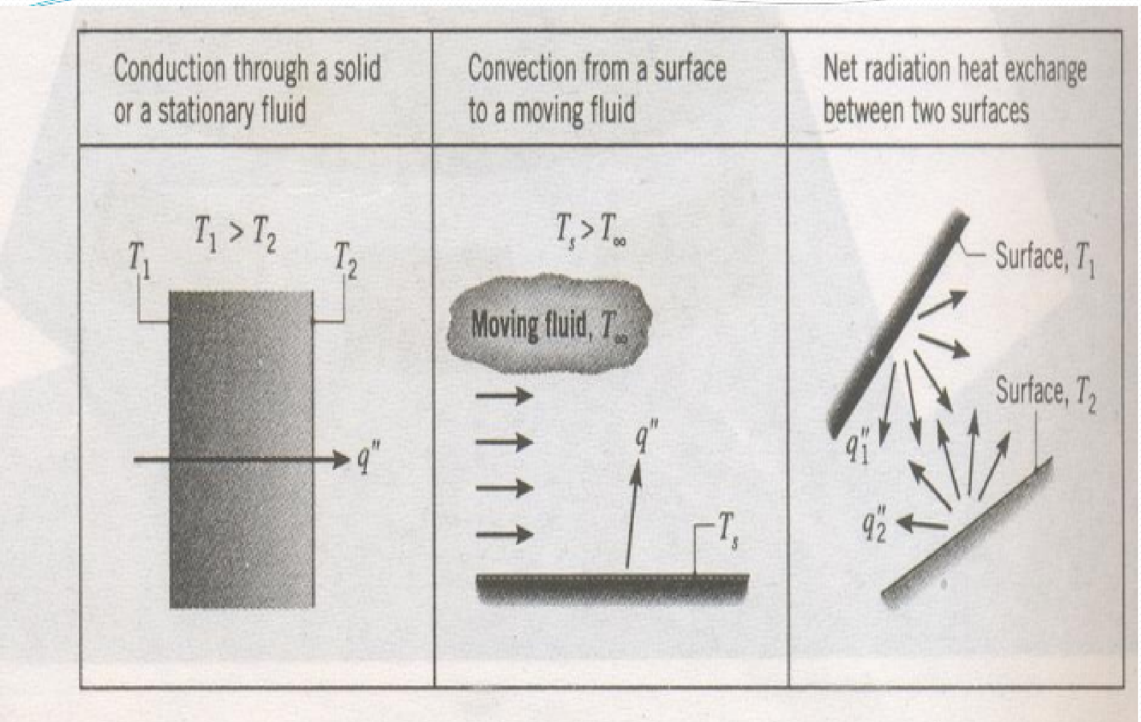
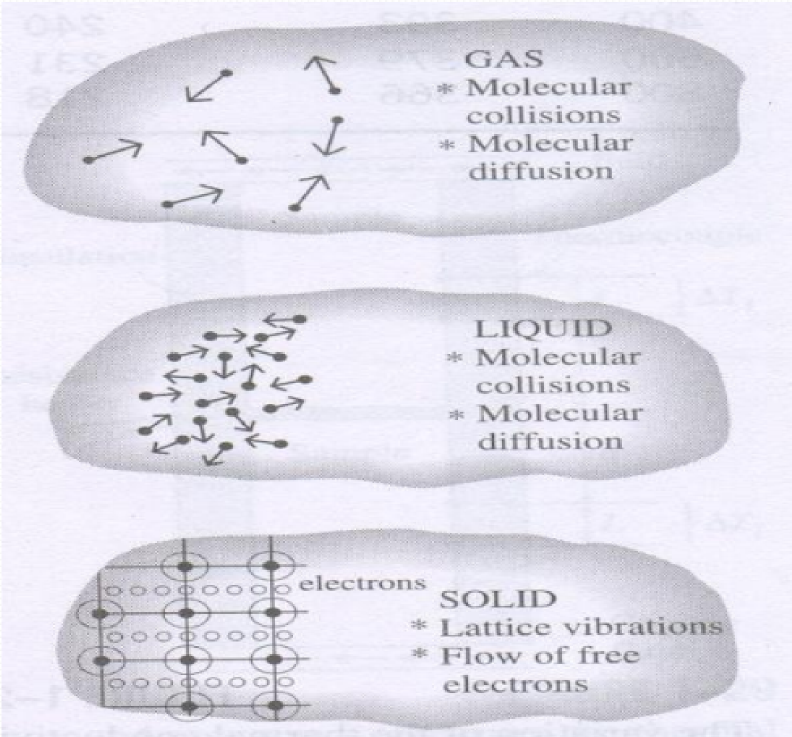


FIGURE 1.1 Conduction, convection, and radiation heat transfer modes.

CONDUCTION :

- Thermal conduction is the transfer of thermal energy from the high energetic to the low energetic particles of a stationary medium(solids, liquids or gas) due to interactions between the particles.
- In solids ,conduction may be attributed to atomic activity in the form of lattice vibrations and energy transport by the free electrons.

- In fluids, conduction occurs due to the collisions and diffusion of the molecules during their random motion. It is a microscopic form of heat transfer



- The basic equation for thermal conduction is the **Fourier's law**.
- It states that the heat flux(Heat Transfer rate per unit area) is directly proportional to the temperature gradient.

$$q \infty dT/dx \quad \text{or}$$

$$q = -k \; dT/dx$$

- Where, k - thermal conductivity (W/m.K)

  dT/dx - temperature gradient

  q - heat flux (W/sq. m)

$$\boxed{Q = -kA\frac{dT}{dx}}$$

Assumptions of Fourier's Law

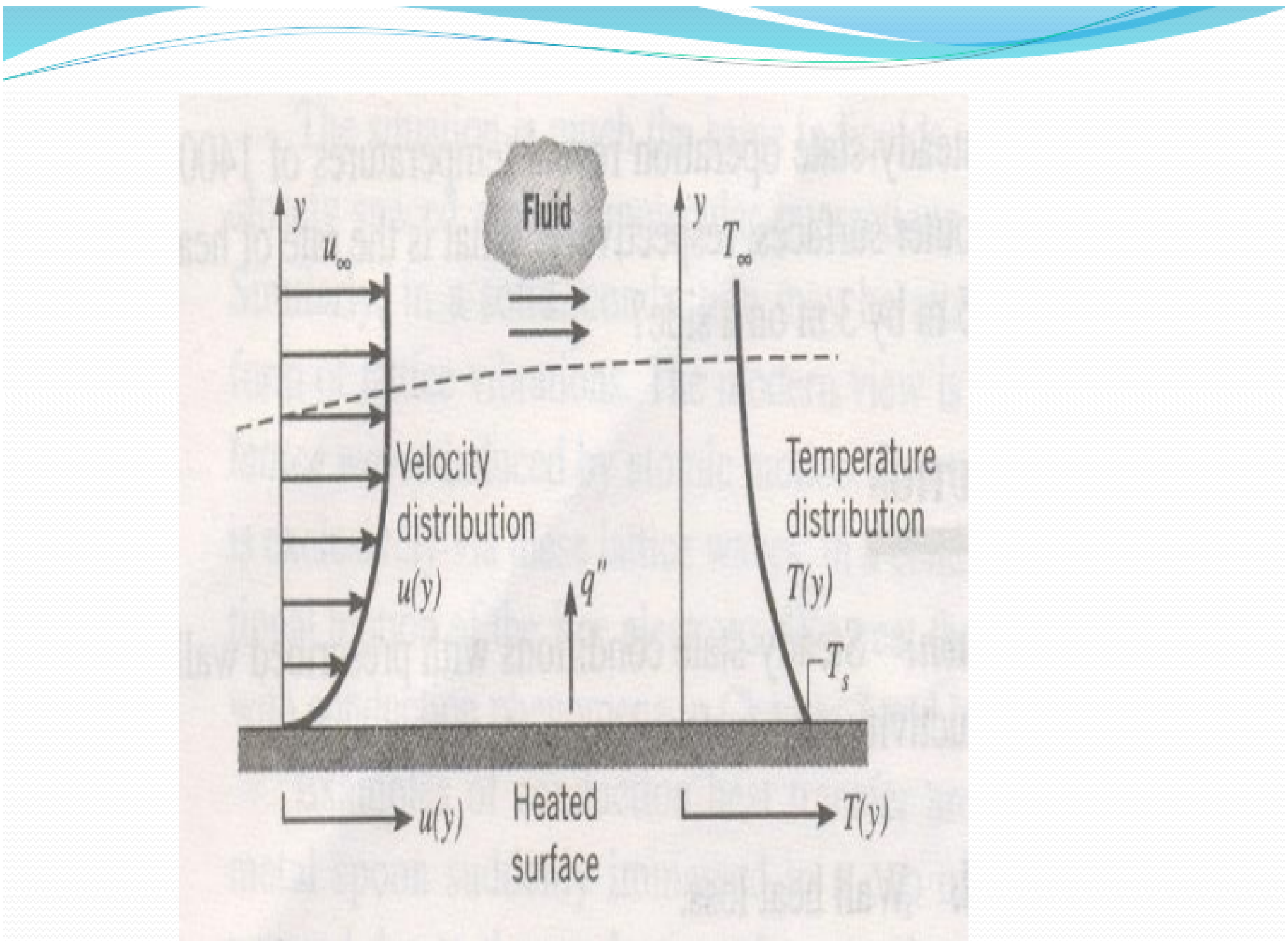
1. Steady state conduction – temp. does not change with time.
2. Uni-directional heat flow.
3. Constant temp. gradient and linear temp. profile.
4. No internal heat generation.
5. Bounding surfaces are isothermal in character.
6. Isotropic and homogeneous material.

Thermal Conductivity(k)

- It is the measure of the ability of a material to conduct heat.
- It is one of the transport properties of a material.
- Its unit is W/m°C or W/m. K
- For Solids and Liquids, $k = f(T)$
- For gases/vapor, $k = f(p, T)$

CONVECTION :

- Convection refers to the thermal energy transfer between a solid surface and a moving fluid when they are at different temperature levels.
- It involves the combined effect of conduction and fluid motion.
- Heat is transferred from the solid surface to the fluid layer which is in contact with it by conduction.
- Then to the adjacent layers heat will transfer by the random molecular motion.



- Due to the fluid-surface interaction, a hydrodynamic boundary layer is developed with zero velocity at the wall and a finite velocity level at the boundary.

- Since the free stream temperature of the fluid and the temperature at the wall are different, a thermal boundary layer will also be developed as shown above.

- Thermal energy transfer by convection is classified as:

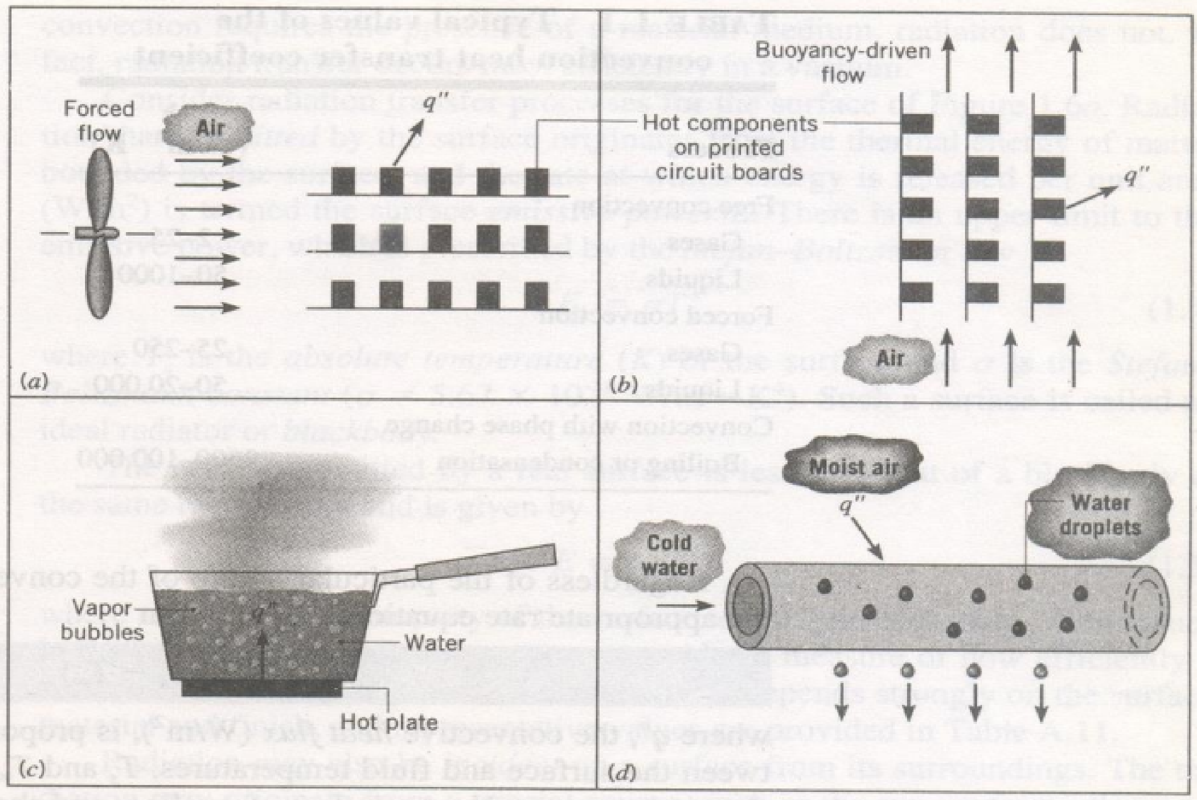
1. Natural (Free) convection and
2. Forced convection.

- **Forced convection** is the transfer of thermal energy when the flow is caused by external means, such as a fan, a pump or atmospheric winds.

- **Natural convection** is induced by buoyancy forces due to density variations as a result of temperature differences.

- There are thermal energy convection by **latent heat exchange**. This latent heat is due to change of phase from liquid to vapor or vice-versa.

- Boiling and condensation are examples for such processes.



- The basic equation for convection heat transfer is known as **Newton's law of cooling**:

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

Where,

T_S is the surface temperature,

T_∞ is the fluid temperature and

A is the surface area of the solid.

h is the convection heat transfer coefficient in $({}^{W}/_{m^2K})$

- h is also called **film heat transfer coefficient** or **surface conductance**.

The value of ‘h’ depends upon:

- Surface condition: roughness and cleanliness
- Geometry and orientation of the surface: plate, cylinder or sphere, placed vertically or horizontally.
- Thermophysical properties of the fluid: density, viscosity, specific heat, thermal conductivity etc.
- Nature of fluid flow: laminar or turbulent
- Boundary layer configuration
- Prevailing temperature conditions.

RADIATION :

- ➢ Thermal energy transfer by radiation is caused by electromagnetic waves(or photons).
- ➢ Thermal radiation is emitted by all surfaces which are kept at a finite temperature level.
- ➢ This happens from solids, liquids and gases. Rate of emission increases with temp.
- ➢ Radiant energy does not require a material medium for its transport. Moreover, radiation transfer will occur effectively in vacuum.

- The mechanism of heat flow by radiation consists three distinct phases:

1. **Conversion of thermal energy of the hot source into electromagnetic waves.**
   - Photons are propagated through the space as rays.

2. **Passage of wave motion through intervening space**
   - Photons travel with unchanged frequency in straight paths with speed equal to that of light.

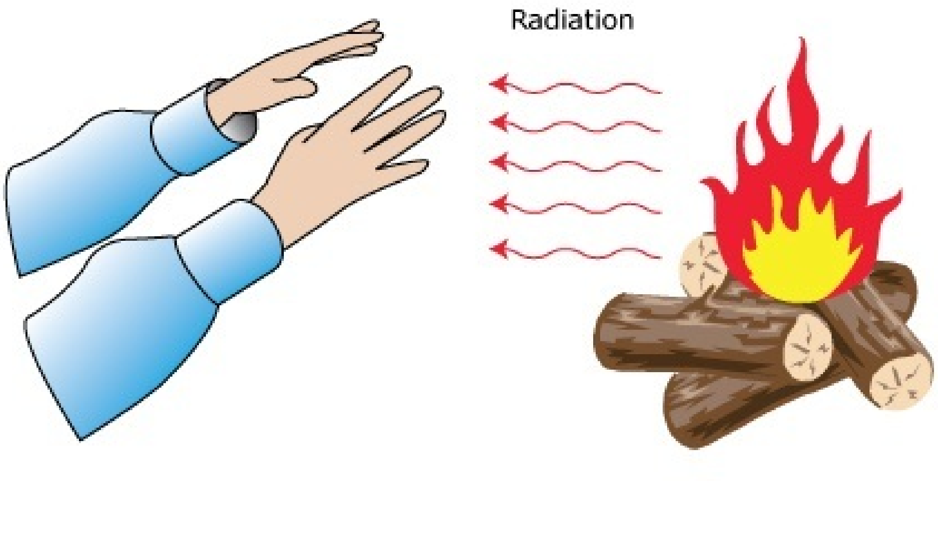
3. **Transformation of waves into heat.**
   - Reconversion of wave motion into energy occurs in the receiving surface which may partly absorbed, reflected or transmitted through.

- The basic rate equation for radiation HT is the **Stefan-Boltzman law**:

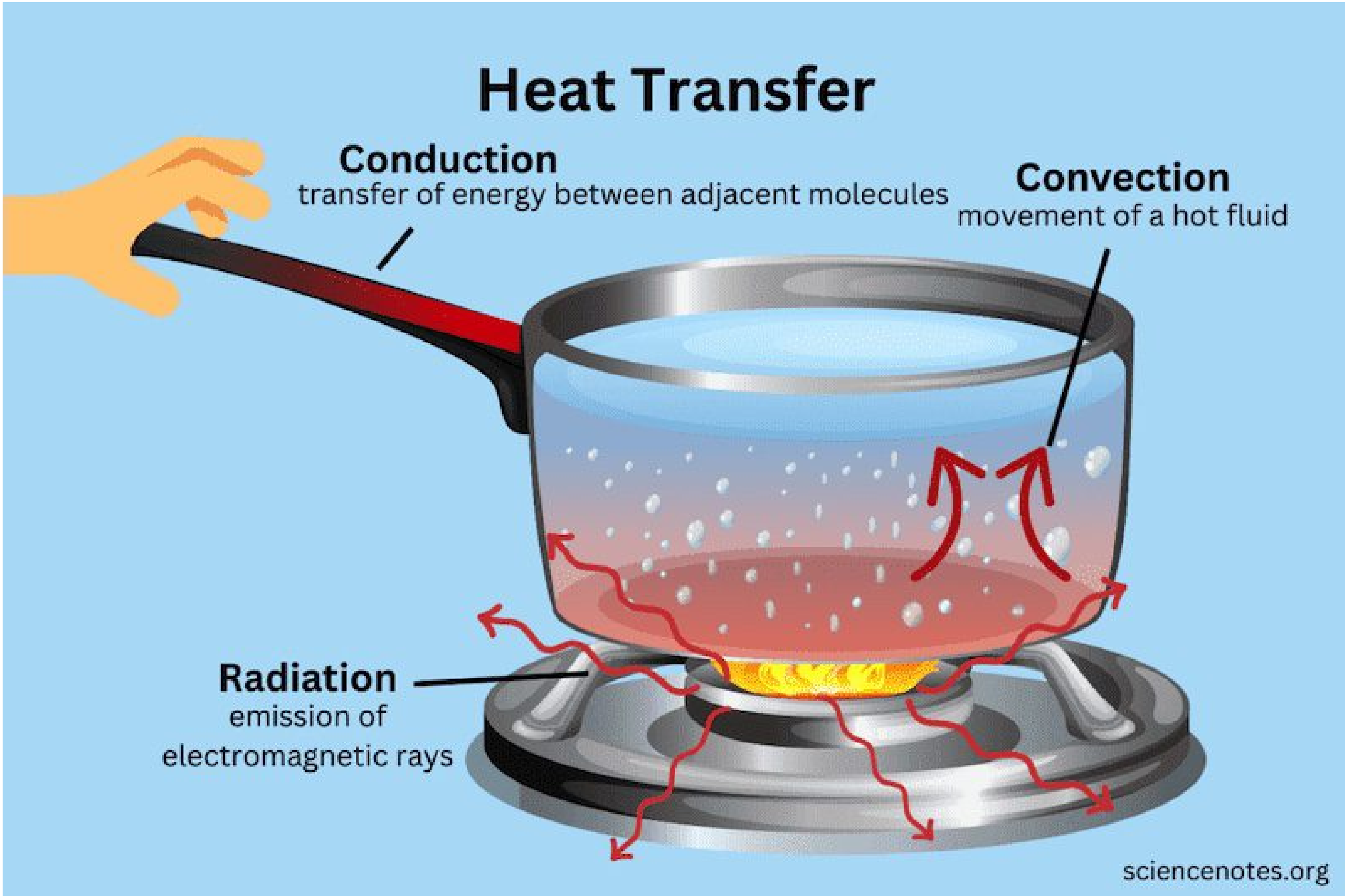
$$\boxed{\boldsymbol{E_b = \sigma_b A T^4}}$$

Where, E_b is the energy radiated per unit time.
T is the absolute temp of the surface
σ_b is the Stefan-Boltzman constant

$$\sigma_b = 5.67 \; x \; 10^{-8} \; W/m^2K^4$$



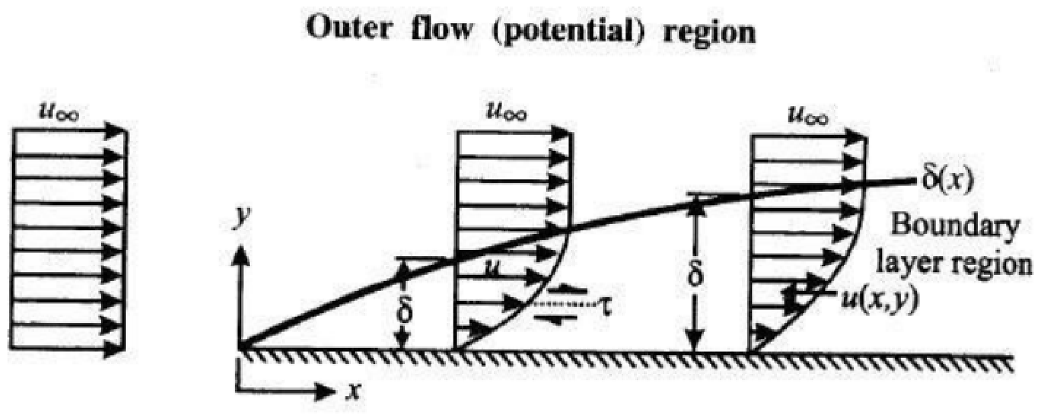
ALL IN ONE


Heat Transfer
Conduction
transfer of energy between adjacent molecules
Convection
movement of a hot fluid
Radiation
emission of
electromagnetic rays
sciencenotes.org

Concepts and basic relations in boundary layers:

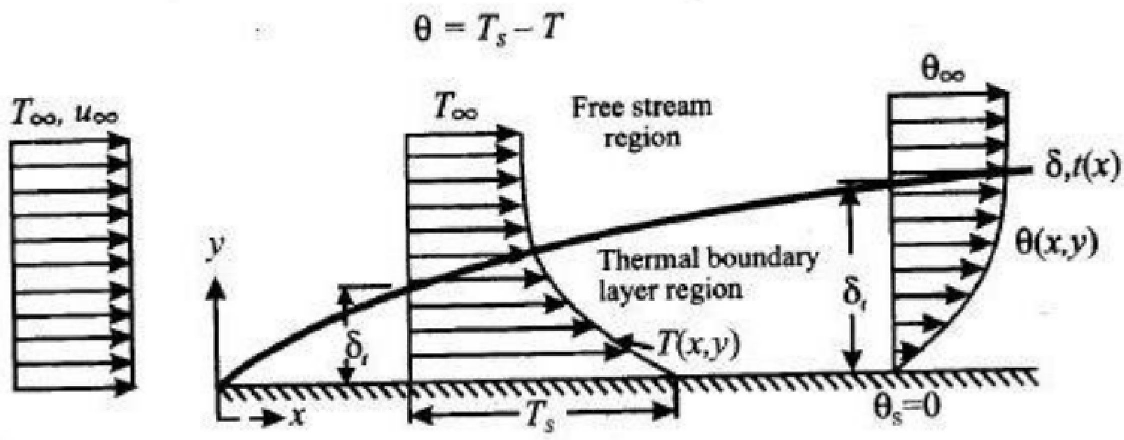
Convection Boundary Layers:

1) Velocity Boundary Layer:



Velocity Boundary Layer on a Flat Plate

2) Thermal boundary Layer:



Thermal Boundary Layer on a Flat Plate

Nusselt Number (Nu).

It is defined as the ratio of the heat flow by convection process under a unit temperature gradient to the heat flow rate by conduction under a unit temperature gradient through a stationary thickness (L).

$$Nusselt\ Number\ = q_{convection}/q_{conduction}$$

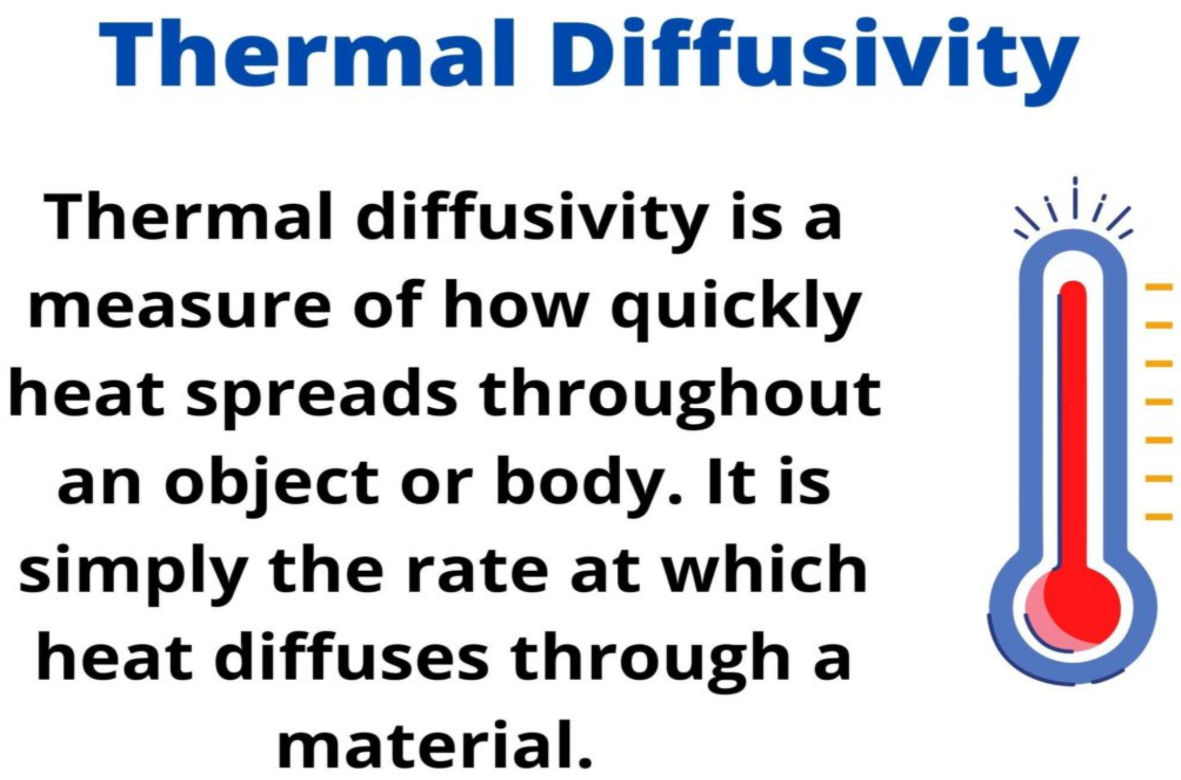
Prandtl number (Pr) :

It is the ratio of the momentum diffusivity to the thermal diffusivity.

$$Prandtl\, number\ =\ Momentum\ diffusivity\ /\ Thermal\ diffusivity$$

$$Pr = \frac{Momentum\ Diffusivity}{Heat\ Diffusivity} = \frac{v}{\alpha} = \frac{(\frac{\mu}{\rho})}{(\frac{k}{\rho c_p})} = \frac{c_p \mu}{k}$$

Diffusivity :



Problem 🙂

Power requirement (TDP) of a 136 mm long 49 mm tall DDR4 RAM in a computer is 3 W. Assuming the RAM to be thin, estimate its surface temperature if a fan blows 50˚C air along the length of the RAM at 100 km/hr.

Objective 😃

- **Power Requirement** : Identify and quantify the power dissipation of the DDR4 RAM module, which is typically referred to as its Thermal Design Power (TDP). In this case, the TDP is specified as 3 watts.

- **Geometry and Assumptions** : Make necessary geometric assumptions, such as considering the RAM module as a thin flat surface, to simplify the analysis while retaining reasonable accuracy.

- **Heat Transfer Analysis**: Apply principles of heat transfer to determine how heat generated by the RAM module is transferred to the surrounding air. Consider the three primary modes of heat transfer: conduction, convection, and radiation.

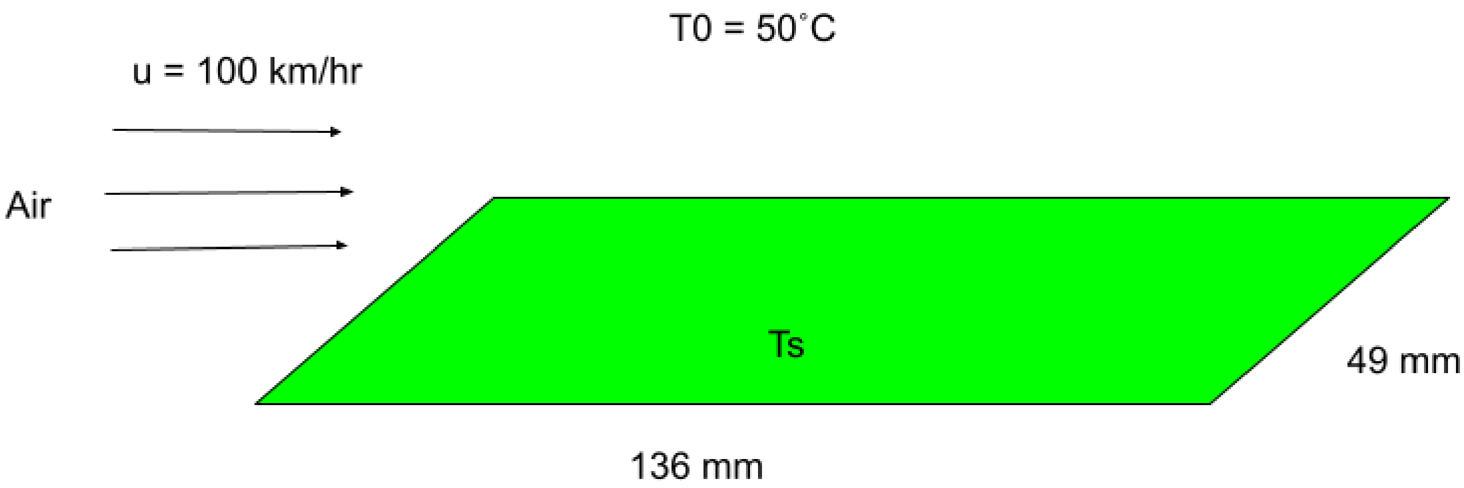
- **Convection Analysis** : Specifically, focus on convective heat transfer, as air is blowing over the surface of the RAM module. Estimate the temperature rise (ΔT) of the RAM module due to this convective cooling effect.

- **Environmental Conditions** : Take into account the environmental conditions, including the air temperature of 50°C and the air velocity of 100 km/hr, as these factors play a significant role in determining the cooling effectiveness.

- **Surface Temperature Estimation** : Finally, estimate the surface temperature of the RAM module under the specified conditions. This estimation will help assess whether the RAM module operates within a safe temperature range and whether additional cooling measures might be necessary.

Assumptions :

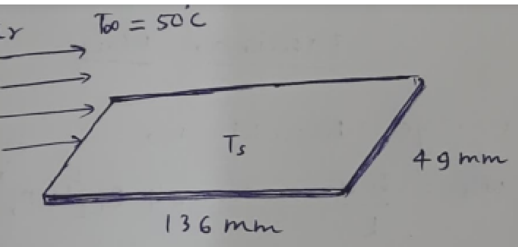
- ➔ Steady state
- ➔ Air is an ideal gas
- ➔ Atmospheric pressure is 1 atm
- ➔ Thermal properties are constant
- ➔ Critical Reynold's number is $R_c = 5 * 10^5$
- ➔ Radiation effect is negligible
- ➔ RAM Module to be an isothermal flat plate
- ➔ Air is blown in one side only



$V = u_\infty = 100 \, km/hr$

$L_c = 136 \, mm$

$T_\infty = 50°C$



surface area, $A_s = (49 \, mm) \times (136 \, mm) = 6.664 \times 10^{-3} \, m^2$

the properties of air @ 50°C & 1 atm.

$\nu = 1.798 \times 10^{-5} \, m^2/s$, $P_r = 0.7228$ $(P_r > 0.6)$

$k = 0.02735 \, W/mK$

$$Re_L = \frac{u_\infty L}{\nu} = 2.1 \times 10^5 < Re_{cr}$$

$\therefore$ Laminar flow

$\because$ Average Nusselt no. for flow over an isothermal flat plate are: (for laminar flow)

$$Nu = \frac{hL}{k} = 0.664 \, Re_L^{1/2} \, P_r^{1/3} \quad \{ P_r > 0.6 \text{ \& } Re_L < 5 \times 10^5$$

$$\Rightarrow \quad h = \frac{k}{L}\left(0.664 \, Re_L^{1/2} \, P_r^{1/3}\right) = 54.9164 \, W/m^2.K$$

Now

$$\because \quad Q = h A_s (T_s - T_\infty)$$

$$T_s = \frac{Q}{h A_s} + T_\infty = \frac{3}{54.9164 \times 6.664 \times 10^{-3}} + 50$$

$$\boxed{T_s = 58.19°C}$$

Now for 2nd iteration,

$$T_f = \frac{T_s + T_\infty}{2} = \frac{58.2 + 50}{2} = 54.1°C$$

$\because$ properties of air @ 54.1°C & 1 atm.

$k = 0.02765 \, W/mK$, $\nu = 1.8382 \times 10^{-5} \, m^2/s$

$P_r = 0.7217$

$$\therefore Re_L = \frac{u_\infty L}{\nu} = 2.055 \times 10^5 < Re_{cr}$$

$\therefore$ Laminar flow.

Average Nusselt no.

$$Nu = \frac{hL}{k} = 0.664 \, Re_L^{1/2} \, P_r^{1/3}$$

$$h = \frac{0.02765}{0.136} \times 0.664 \times (2.055 \times 10^{5})^{1/2} \times (0.7217)^{1/3}$$

$$\therefore \quad h = 54.8928 \ W/m^2K$$

$$Q = hA_s(T_s - T_\infty)$$

$$\therefore \quad T_s = \frac{Q}{hA_s} + T_\infty = \frac{3}{54.8928 \times 6.664 \times 10^{-3}} + 50$$

$$\boxed{T_s = 58.201\ ^\circ C}$$

error in T_s after 2^{nd} iteration is less than 0.01%.

Hence, surface temp. $\boxed{T_s = 58.2^\circ C}$

Conclusion :

- ➢ **Temperature Rise Due to Power Dissipation:** Temperature of RAM module increases by 8.2˚C as a result of its power dissipation (TDP). This information is essential for assessing whether the RAM module operates within its specified temperature limits.

- ➢ **Impact of Airflow:** It helps to understand the cooling effect of airflow. We can conclude how efficiently the air blowing over the RAM module dissipates heat and keeps the temperature in check.
- ➢ **Need for Additional Cooling** : If the estimated surface temperature of the RAM module exceeds safe operating limits,

we can conclude that additional cooling measures, such as improved airflow or heatsinks, may be necessary to ensure the RAM's reliability and performance

- **Real-World Relevance** : The project demonstrates the real-world relevance of thermal analysis in electronic device design. It provides insights into how electronic components, like RAM modules, behave in various operating conditions, which can inform decisions in system design and component selection.
- **Safety and Reliability** : By estimating the RAM module's temperature, we can conclude whether it operates safely within its specified temperature range, ensuring the long-term reliability of the component and the overall computer system.

Thank You