RADIATION

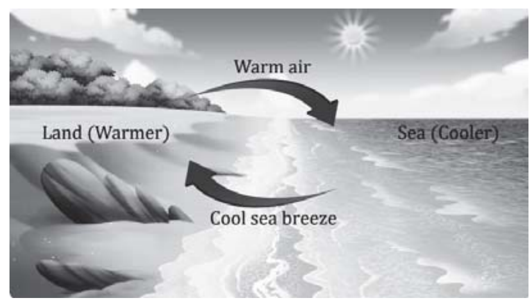
Convection

Convection is the heat transfer process characterized by the movement of particles resulting from increased kinetic energy due to supplied heat. When molecules contact a hot surface, they absorb heat energy and disperse, causing a decrease in fluid density. Cooler molecules replace these heated ones, ascending due to their lower density. This cycle continues, with molecules receiving heat from the hot surface until the entire fluid heats up. Essentially, convection involves heat transfer through the movement of molecules, driven by heat currents.

Applications

Land breeze and Sea breeze

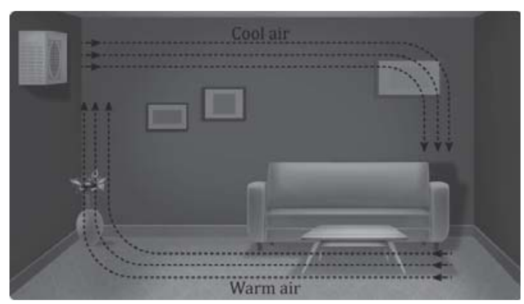
During daylight hours, the sun heats both the sea and land surfaces. However, the sea surface warms up more slowly compared to the land surface. As the temperature rises over the land, it warms the adjacent air, causing it to expand and become less dense, leading to its upward movement. This creates areas of low pressure over the land. Conversely, the temperature increase over the sea surface is relatively mild compared to the land. Consequently, the air above the sea remains cooler and denser, resulting in the formation of high-pressure zones. This pressure disparity prompts air movement from the high-pressure region (sea surface) to the low-pressure region (land surface), known as a sea breeze.



At night, the pattern reverses. As the sun sets, both the land and sea surfaces begin to cool. The land surface cools rapidly, leading to the formation of a low-pressure area over the sea surface, where temperatures remain relatively higher than over land. Consequently, air flows from the land to the sea, resulting in what is known as a land breeze.

Air conditioner

The following diagram explain how air conditioner cool the entire room:



The cooler air from the air conditioner descends because of its greater density. Warmer air near the surface, being lighter, rises, establishing a convection current. This process effectively cools the entire room.

Types of Convection

Natural

Convection occurs due to temperature discrepancies, leading to density variations in the fluid. The fluid's velocity is minimal, and the process is primarily driven by gravity, facilitating heat transfer from the bottom to the top.

Forced

Forced convection occurs as a result of external influences. The velocity of fluid particles and the direction of heat flow are entirely determined by these external factors.

Heat Transfer by Convection

The rate of heat transfer by convection is given by,

$$q = \frac{Q}{t} = hA(T - T_0)$$

Where,

h = Convection coefficient　　A = Surface area of the body

T = Temperature of the body　　T_0 = Temperature of the surrounding

Convection coefficient (h) mainly depends on fluid density, viscosity, specific heat, and thermal conductivity.

$$q = \frac{Q}{t} = hA(T - T_0)$$
$$q = \frac{T - T_0}{\left(\frac{1}{hA}\right)} = \frac{T - T_0}{R}$$

$R = \frac{1}{hA} =$ Thermal resistance

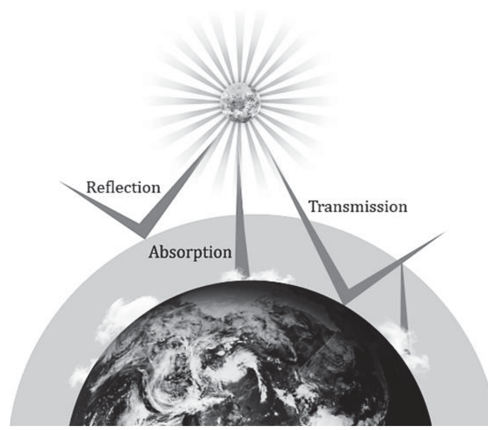
Ex. Why does convection occur when fluids are heated from the bottom?

(A) The molecular motion of fluids gets aligned.
(B) Molecular collisions within the fluid increase.
(C) The heated fluid becomes denser than the cold fluid above it.
(D) The heated fluid becomes less dense than the cold fluid above it.

Sol. The density of a fluid decreases as the molecules of the fluid move away from each other. It happens to the molecules that are at the bottom. This leads to convection current. So, the heated fluid at the bottom becomes less dense than the cold fluid above it.
Thus, option (D) is the correct answer.

Radiation

When energy strikes a surface, three simultaneous processes occur: absorption, transmission, and reflection, often remembered as the RAT (Reflection Absorption Transmission) analogy. On a hot day, a boy standing in an open space experiences both high temperatures and intense brightness. The heat energy from the Sun travels to the Earth through radiation.



Radiation refers to the transfer of heat from one location to another without the need for a medium. In this process, heat energy is conveyed through electromagnetic (EM) waves, which do not rely on any material medium for transmission. Radiation itself is a form of emitted energy, with light and thermal radiation being common examples of EM waves.

Electromagnetic (EM) Waves

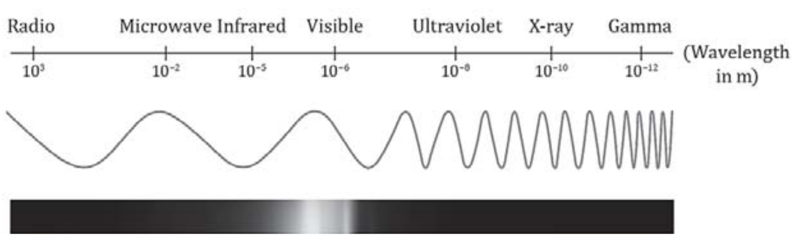
Here are several significant traits of electromagnetic waves:

- They propagate at the speed of light.
- They travel in a linear trajectory.
- They adhere to the principles of reflection and refraction.
- They can traverse through a vacuum.

Electromagnetic (EM) Spectrum

EM Spectrum

The spectrum provided includes sunlight, which consists of thermal radiation comprising infrared, visible, and ultraviolet rays. Thermal radiation falls within the electromagnetic spectrum and encompasses wavelengths starting from 7.8×10^{-7}m to 4×10^{-4}m.

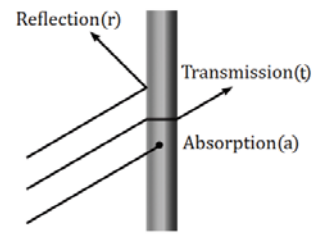


Do we emit radiation?

Yes, the answer to this question is affirmative. According to Prevost's theory of heat exchange, any object at a temperature above absolute zero (0 K) emits heat to its surroundings while simultaneously absorbing heat from them. When an object with a temperature T is placed in an environment with a higher temperature T_0 (where $T_0 > T$), the object absorbs more radiation from the surroundings than it emits. Conversely, when an object with a temperature T is placed in an environment with a lower temperature T_0 (where $T_0 < T$), the object emits more radiation into the surroundings than it absorbs. When the temperatures of the object (T) and the surroundings (T_0) are equal ($T_0 = T$), the amount of radiation emitted by the object matches the amount absorbed from the surroundings. Consequently, humans do emit energy in the form of infrared radiation. Here are a few observed instances of infrared images:

An entity with a temperature higher than 0 K emits thermal radiation.

Interaction of Radiation with Matter



When thermal radiation strikes a surface, it undergoes partial reflection, partial absorption, and partial transmission.

If $a = t = 0$ and $r = 1$, then the body is a perfect reflector.

If $r = t = 0$ and $a = 1$, then the body is a perfect absorber.

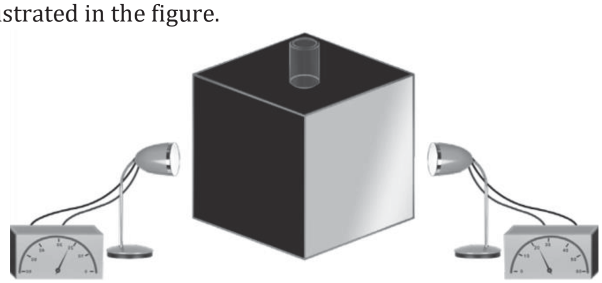
If $a = r = 0$ and $t = 1$, then the body is a perfect transmitter.

Also, $r + a + t = 1$

Leslie's Cube Experiment

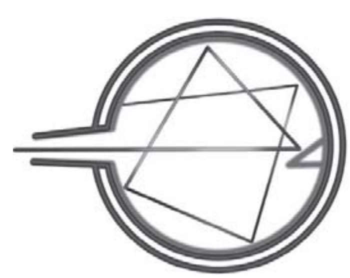
This experiment aims to determine whether a proficient absorber also excels as an emitter.

Two faces of a cube are examined in this experiment: one face is polished with silver while the other is polished with a black coating. Two infrared (IR) detectors are positioned equidistant from the respective faces to gauge the heat radiation emitted by each. The faces are heated by filling the cube with water heated to 100°C. The intensity of radiation is subsequently measured by the IR detectors, as illustrated in the figure.



This experiment confirms that black color serves as both an effective absorber and emitter of heat. Consequently, materials that excel at absorbing heat also excel at emitting it. This principle holds true for all substances.

Black body



A black body is a theoretical physical object that absorbs all incoming electromagnetic radiation, without regard to wavelength or angle of incidence. It serves as an ideal absorber and emitter of radiation across all wavelengths. ($r = t = 0$ and $a = 1$). A black body releases radiation across a continuous spectrum corresponding to its temperature. Put simply, it absorbs all the energy it receives.

Sun as a black body

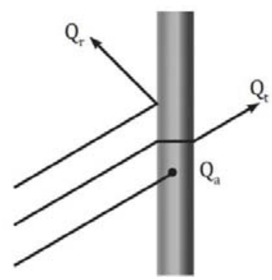
The Sun's temperature is extremely high, causing it to emit and absorb all available radiations, thereby meeting the criteria of a black body.

Ferry's black body

It's a spherical cavity with two walls, the inner surface of which is blackened and it features a small hole on its surface. When radiation enters through this hole, it becomes trapped due to multiple reflections inside the sphere, resulting in complete absorption.

Absorptive power

It represents the proportion of heat absorbed by a surface during a specified duration to the total amount of heat incident on the surface within the same timeframe.



$$Q = Q_a + Q_r + Q_t$$

$$a = \frac{Q_a}{Q} = \text{ Absorptance}$$

For a perfectly black body, absorptive power $a = 1$, while $r = t = 0$.
Similar reflected power is defined as

$$r = \frac{Q_r}{Q} = \text{ Reflectance}$$

Transmittance or transmitting power is given by,

$$t = \frac{Q_t}{Q} = \text{ Transmittance}$$

$$\text{And, } a + r + t = 1$$

Emissive power

Emissive power is the energy emitted per unit surface area per unit time in all directions perpendicular to the surface at a given temperature. Therefore, the formula for emissive power is,

$$E = \frac{Q}{\Delta A \Delta t}$$

Ex. The emissive power of a spherical body of area 200 cm^2 is 2100 $Jm^{-2}s^{-1}$. What is the amount of thermal energy radiated by the body in 20 s?

(a) 840 J (b) 420 J (c) 1680 J (d) 210 J

Sol. $A = 200cm^2 = 0.02m^2, E = 2100Jm^{-2}s^{-1}, t = 20$ s

$$Q = E \times A \times t$$

$$Q = 2100 \times 0.02 \times 20$$

$$Q = 840 \text{ J}$$

Thus, option (A) is the correct answer.

Emissivity

It represents the ratio of the emissive power exhibited by a real body at temperature T to that of a black body at the identical temperature.

$$\varepsilon = \frac{E}{E_b}$$

Kirchhoff's law

The law asserts that at a specific temperature, the ratio of emissive power to absorptive power remains constant across all bodies, equaling the emissive power of a black body at that temperature.

$$E(\text{ blackbody }) = \frac{E(\text{ body })}{a(\text{ body })}$$