Molar specific heat

A proportionality constant that relates the amount of heat flow per mole to a material's change in temperature.

$Q = n K \Delta T$

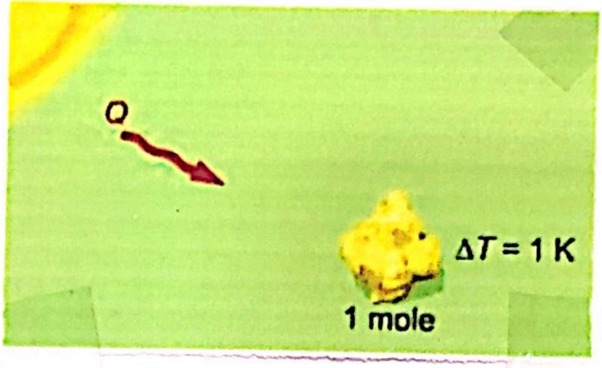
where

Q: heat

K: molar specific heat (J/mol.K)

n: number of moles

ΔT: temperature change in °C or K



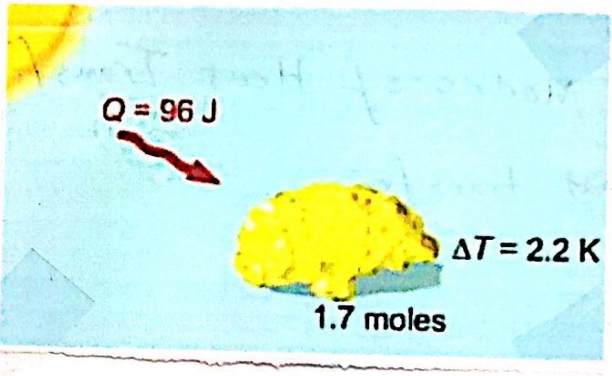
Example: This is a gold nugget. Its temperature increases 2.2 K when 96 J of heat are added. What is the molar specific heat of gold?

Solution:

$Q = n K \Delta T$

$96 = 1.7 K (2.2)$

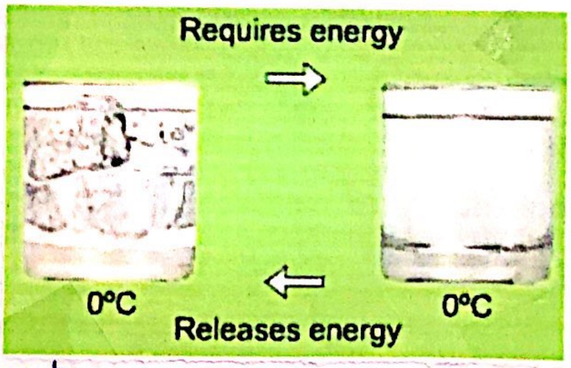
$K = \frac{96}{1.7(2.2)} \Rightarrow K = 26 \text{ J/mol.K}$



Phase changes

Transformation between solid and liquid, liquid and gas, or solid and gas.

- phase change consumes energy or release energy
- under phase change process, temperature stays constant.



Latent heat

Energy required per kilogram to cause a phase change in a given material.

- The latent heat of vaporization is the amount of heat per kilogram consumed when a given substance transforms from a liquid into a gas, or released when the substance transforms from a gas back to a liquid.

The latent heat of fusion is the heat flow per Kilogram during a change in phase between a solid and a liquid.

$$Q = L_f m$$
$$Q = L_v m$$

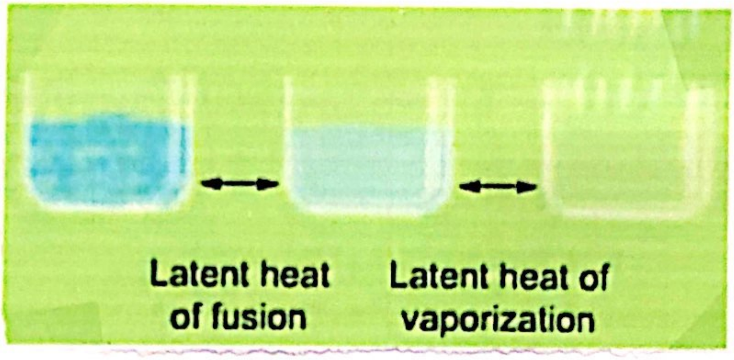
where

Q : heat

m : mass

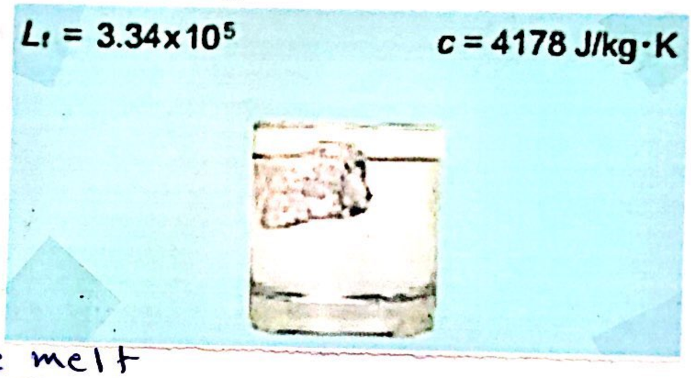
L_f : latent heat of fusion (J/kg)

L_v : latent heat of vaporization (J/kg)



Example: A glass contains 0.0370 kg of ice at 0 °C. How much heat transfers to the ice as it melts without changing temperature?

Solution:



$$Q = L_f m$$
$$Q = 3.34 \times 10^5 (0.0370)$$
$$Q = 1.23 \times 10^4 \text{ J}$$

Sample problem: watching ice melt

The glass contains 0.16 kg of water at 30.0 °C and 0.037 kg of ice at 0.0 °C. what is the resulting temperature of the water at thermal equilibrium after the ice melts?

Solution:

in the insulated container, the only source of the heat to melt the ice is the surrounding water. The water's temperature will decrease as the ice melt. The ice will melt while staying at 0 °C. There is a tricky part to solving this problem: when the ice melts it turns into water, and this extra water must be accounted for when calculating the final temperature.

It is important to distinguish between the two masses of water in the final mixture: the masses that was initially liquid, and the mass that was initially solid ice. we use the subscripts L and S to distinguish these masses of water.

In the section on latent heat, we calculated the heat transferred to the same amount of ice as it melted to be 1.23×10^4 J. Here, we need the heat transferred from the water, not to the ice. Since the water loses heat, we state this as -1.23×10^4 J, with negative sign.

mass of liquid water, $m_L = 0.16$ kg

mass of solid ice, $m_S = 0.037$ kg

heat transferred from water to melt ice, $Q = -1.23\times10^4$ J

initial temperature of liquid water, $T_{Li} = 30$ °C

initial temperature of solid ice, $T_{Si} = 0$ °C

temperature of liquid water after ice melts, T_{Lf}

temperature of ice-melt, $T_{Sf} = 0$ °C

final temperature of liquid water + melted ice, T

heat transferred to melted ice for thermal equilibrium, Q_S

specific heat of water, $C = 4178$ J/kg·K

$Q = mC\Delta T$

As the two masses of water reach thermal equilibrium, the heat transferred from the originally liquid water plus the heat transferred to the the melted ice must sum to zero

$$Q_L + Q_S = 0$$

First we calculate the temperature of the liquid water after it gives up heat to melt the ice

$$Q = mC\Delta T$$

$$-1.23\times10^4 = 0.16\,(4178)\,\Delta T \Rightarrow \Delta T = -18.4\,K = -18.4\ °C$$

Since

$$\Delta T = T_{Lf} - T_{Li}$$

$$T_{Lf} = \Delta T + T_{Li}$$

$$T_{Lf} = -18.4 + 30$$

$$T_{Lf} = 21.6\ ^{\circ}C$$

Now we use the fact that the heat transfers sum to zero as the two masses of water reach thermal equilibrium to calculate the final temperature of the total mass of water

$$Q_L + Q_s = 0$$

$$m_L C (T - T_{Lf}) + m_s C (T - T_{sf}) = 0$$

$$m_L C T - m_L C T_{Lf} + m_s C T - m_s C T_{sf} = 0$$

$$T(m_L C + m_s C) = m_L C T_{Lf} + m_s C T_{sf}$$

$$T = \frac{\cancel{C}(m_L T_{Lf} + m_s T_{sf})}{\cancel{C}(m_L + m_s)}$$

$$T = \frac{0.16(21.6) + 0.037(0)}{0.16 + 0.037}$$

$$T = 17.5\ ^{\circ}C$$

Modes of Heat Transfer

Heat can be transferred in three basic modes as follow:

1- Conduction

2- Convection

3- Radiation

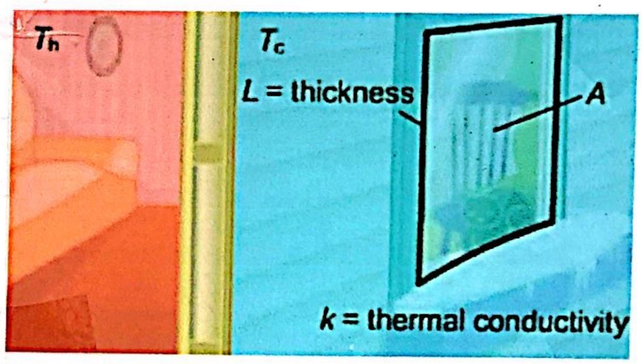
Conduction: The flow of thermal energy directly through a material without motion of the material itself.

Examples on heat conduction

- Heating a metal spoon when it suddenly immersed in a cup of hot tea.
- losing heat from heated room to outside during the winter season.

Rate of heat conduction $\propto \dfrac{(\text{Area})(\text{temp. difference})}{\text{thickness}}$

$$q = K A \frac{\Delta T}{\Delta X}$$



where

q: heat transfer rate, J/s, W

k: thermal conductivity, W/m·K, W/m·°C

A: Area of heat transfer, m2

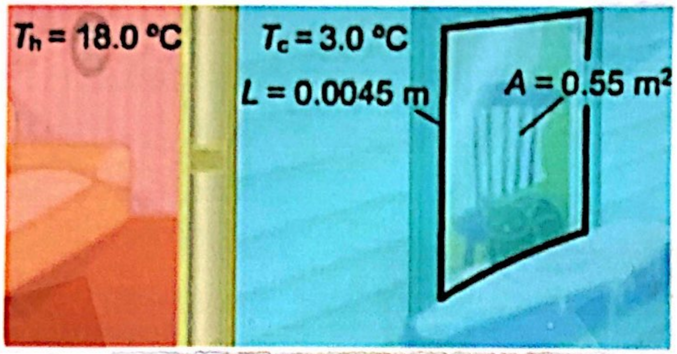
ΔT: temperature difference, °C, K

ΔX: thickness of the plane wall, m

	Thermal conductivity	Thermal resistance (for 1 inch)	
	k (W/m·K)	RSI-value (m²·K/W)	R-value (ft²·F°·h/Btu)
Air, sea level (15° C)	0.025	1.00	5.70
Fiberglass (50° C)	0.04	0.64	3.61
Urethane foam	0.06	0.42	2.40
Plywood	0.11	0.23	1.31
Wood (fir)	0.14	0.18	1.03
Water	0.598	0.04	0.24
Concrete (0° C)	0.8	0.03	0.18
Window glass (0° C)	0.95	0.03	0.15
Ice (0° C)	2.14	0.01	0.07
values approximate for building materials			at 10^5 Pa, 20° C

Example: Heat transfer through the window at a rate of 1700 J/s
What is its thermal conductivity constant? Consider the below figure

Solution:



$$q = K A \frac{\Delta T}{\Delta X}$$

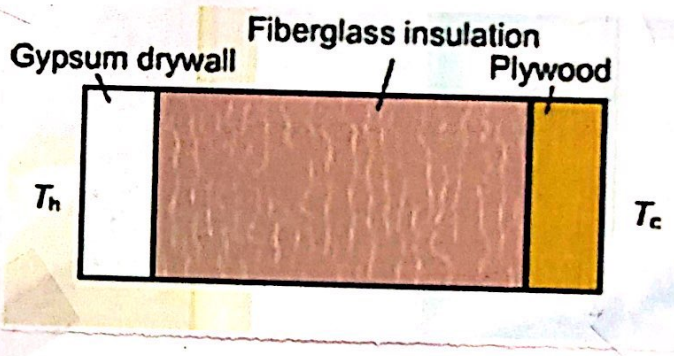
$$1700 = K (0.55) \frac{(18-3)}{0.0045}$$

$$K = 0.93 \ W/m.K$$

Conduction through Composite objects

To calculate the rate of heat flow through this composite object, The overall thermal resistance is calculated by summing the resistance of each object.

$$q = \frac{\Delta T_{overall}}{R_{overall}}$$



where

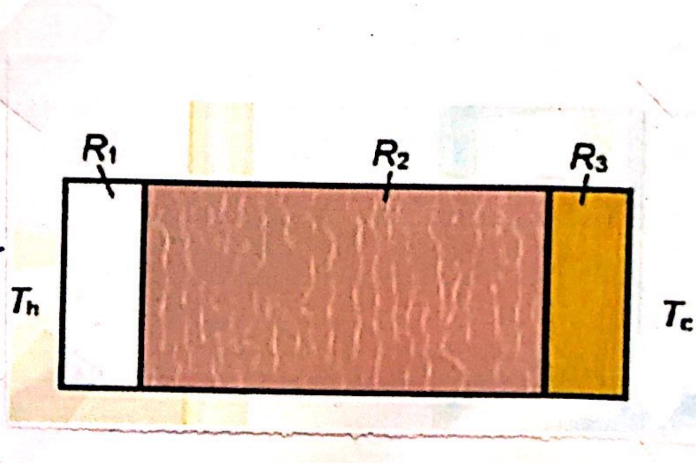
q: overall heat transfer rate (W)

ΔT: temperature difference

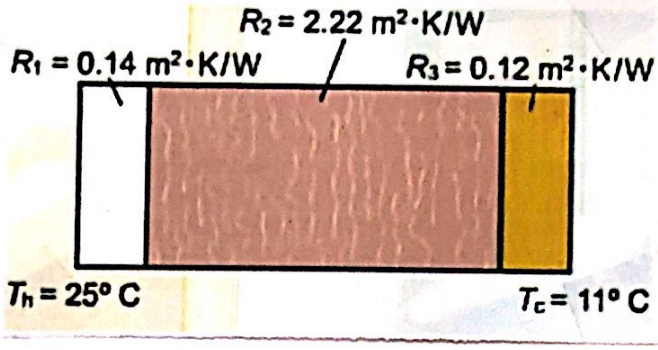
$R_{overall}$: $R_{overall} = R_1 + R_2 + \cdots + R_n$

$$R_1 = \frac{\Delta X_1}{K_1 A_1}, \quad R_2 = \frac{\Delta X_2}{K_2 A_2}$$

R: thermal resistance of each layer



Example: A wall of a house is constructed as shown. What is the rate of heat transfer through a 12.0 m2 area of the wall?



Solution:

$$q = \frac{\Delta T_{overall}}{R_{overall}}$$

$$q = \frac{\Delta T_{overall}}{R_1 + R_2 + R_3}$$

$$q = \frac{(25-11)}{\frac{\Delta X_1}{K_1 A_1} + \frac{\Delta X_2}{K_2 A_2} + \frac{\Delta X_3}{K_3 A_3}}$$

$$A = A_1 = A_2 = A_3$$

$$q = \frac{14}{\frac{\Delta X_1}{K_1 A} + \frac{\Delta X_2}{K_2 A} + \frac{\Delta X_3}{K_3 A}}$$

$$q = \frac{14}{\frac{1}{A}\left[\frac{\Delta X_1}{K_1} + \frac{\Delta X_2}{K_2} + \frac{\Delta X_3}{K_3}\right]}$$

$$q = \frac{A\,(14)}{\left[\frac{\Delta X_1}{K_1} + \frac{\Delta X_2}{K_2} + \frac{\Delta X_3}{K_3}\right]}$$

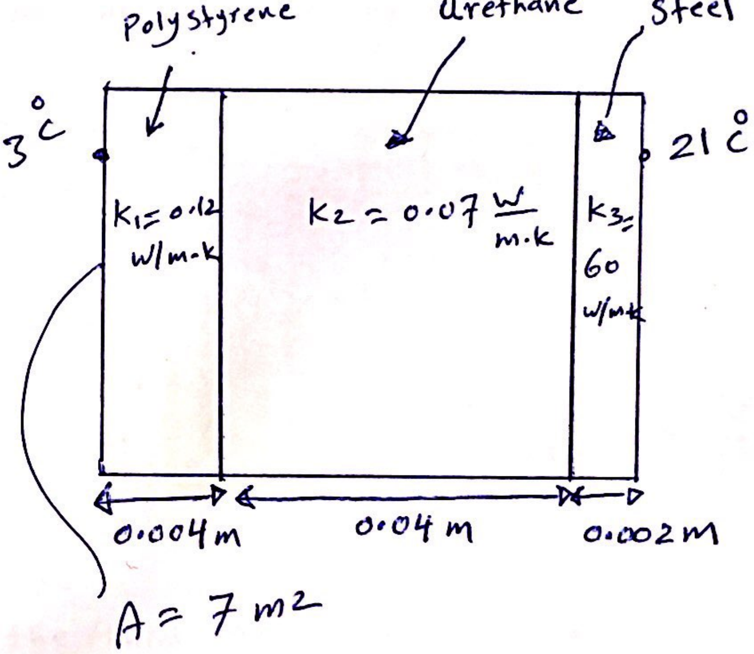
$$q = \frac{12\,(14)}{[0.14 + 2.22 + 0.12]}$$

$$q = 68 \text{ W}$$

Example:

A wall of a cooling room has a surface area of 7 m2. This wall is constructed of layers of polystyrene, urethane foam, and steel, from the inside out. The polystyrene is 0.004 m thick, and has a thermal conductivity of 0.12 W/m.k. The urethane foam is 0.04 m thick, with a thermal conductivity of 0.07 W/m.k. The steel is 0.002 m thick and has a thermal conductivity of 60 W/m.k. The inside temperature of the wall is 3 °C and the outside room temperature is 21 °C. What is the amount of heat transferred through the wall?

Solution:



$$q = \frac{\Delta T_{overall}}{R_{overall}}$$

$$q = \frac{(21-3)}{R_1 + R_2 + R_3}$$

$$q = \frac{(21-3)}{\frac{\Delta X_1}{K_1 A_1} + \frac{\Delta X_2}{K_2 A_2} + \frac{\Delta X_3}{K_3 A_3}}$$

since

$$A = A_1 = A_2 = A_3 = 7 \, m^2$$

$$q = \frac{18}{\frac{0.004}{0.12 * 7} + \frac{0.04}{0.07 * 7} + \frac{0.002}{60 * 7}}$$

$$q = 208 \quad W$$

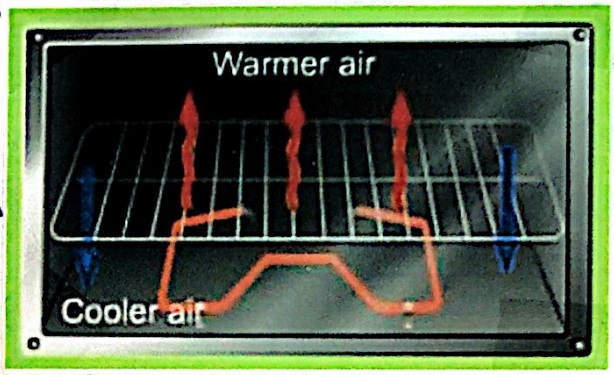
Convection:

Heat transfer through a gas or liquid caused by movement of fluid.

- Convection: Heat transfer due to movement in gases and liquids.

- Gases and liquids usually decrease in density when they are heated. When part of a body of liquid or gas is heated, the warmed component rises because of its decreased density, while the cooler part sinks. This occurs in homes, where heat sources near the floor heat the nearby air, which rises and moves throught the room. The warmer air displaces cooler air near the ceiling, causing it move near the heat source, where it's heated in turn. This transfer of heat by the movement of gas or liquid is called convection.

- Convection heat transfer can be classified according to the nature of the flow for the fluid as follows



1. Forced convection: This type of convection occurs when the fluid is forced to flow over the heated surface by external means such as fan, pump, or wind.

2. Natural Convection (free convection):

This kind of convection occurs when the fluid motion is caused by buoyancy forces that are induced by density differences due to the variation of temperature in the fluid.

The rate of heat transfer by convection between a surface and a fluid (i.e., gas or liquid) can be calculated from the following equation:

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

where

q: rate of heat transfer by convection, W

h: heat transfer coefficient, W/m2-°C

A: surface area, m2

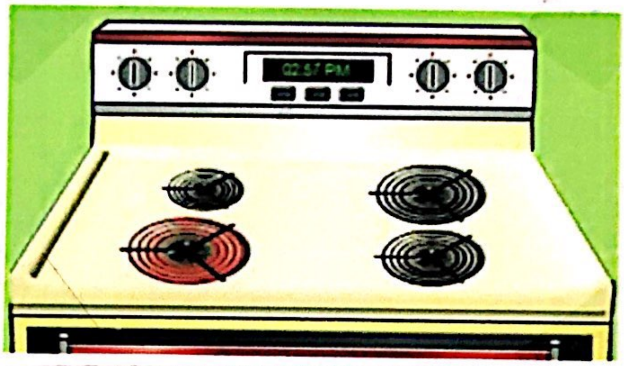
T_s: Surface temperature, °C, K

T_∞: Fluid temperature at some specified location, °C, K

Radiation: Heat transfer by electromagnetic waves.

The energy emitted by matter in the form of electromagnetic waves (or photones) as a result of the changes in the electronic configuration of atoms or molecules.

- Unlike conduction and convection, the transfer of heat by radiation does not require the presence of an intervening medium (i.e., radiation occurs most efficiently in a vacuum).
- Any object above 0 K / −273 °C emits heat. However, it will also absorb heat radiation.
- All solid, liquid, and gases emit, absorb, or transmit radiation to varying degree.

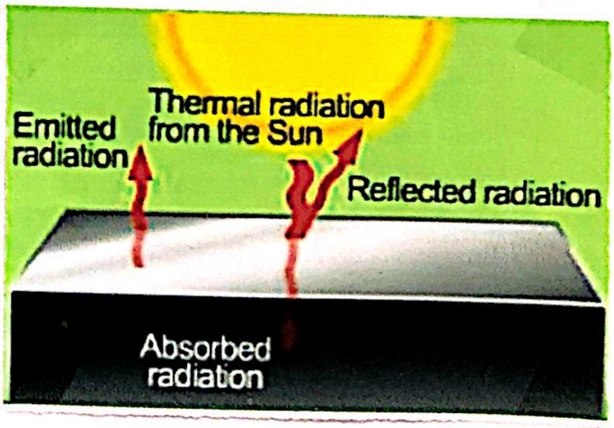


Example on radiation heat transfer.

If you place your hand near a red-hot heating element and feel your hand warm up, you are experiencing thermal radiation: the transfer of energy by electromagnetic waves.

Radiation quantified:

When radiation reach the surface of an object, it is either absorbed or reflected. Any ordinary object (i.e., not black body) absorbs some of the incident radiation, and reflects some back. A material's emissivity is the ratio of absorbed radiation to incident radiation.



An object called a black body will absorb all the radiation that strikes it. No real object is a perfect black body, but the ideal object is the theoretical limit of bodies that absorb almost all the radiation that hits them. A black body has an emissivity of one because it absorb all radiation. A material that reflected all radiation would have an emissivity of zero.

Radiated and absorbed energy

$$q_{rad} = \sigma \epsilon A T^4$$

$$q_{abs} = \sigma \epsilon A T_{env}^4$$

	Emissivity
Polished silver, gold, aluminum	0.02-0.04
Mercury (the element)	0.09-0.12
Venus	0.24
Earth average	0.67
White enamel paint	0.87-0.91
Mercury (the planet)	0.9
Flat black lacquer	0.92-0.96
Candle soot	0.95

where

q_{rad}: energy radiated (emitted), W

q_{abs}: energy absorbed, W

ϵ: emissivity $0 < \epsilon \leq 1$

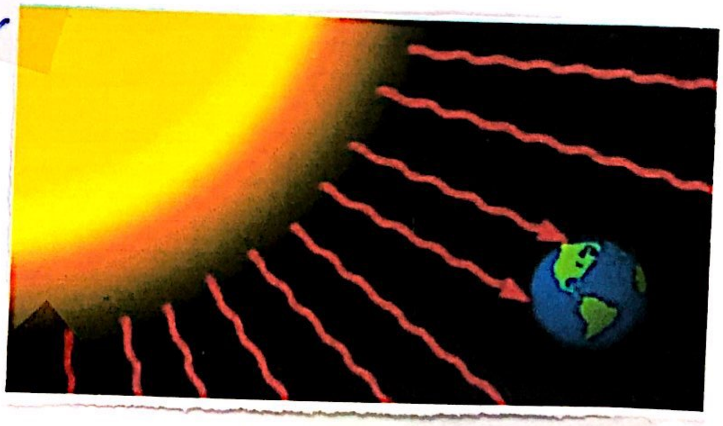
A: surface Area, m2

T: temperature of object, K

T: temperature of environment, K

σ: 5.67×10^{-8} W/m2.K4 (Stefan-Boltzmann constant)

Example: Estimate the Earth's equilibrium surface temperature by modeling the Earth as a black body. In this idealization the Earth does not reflect any sunlight, so the intensity of the incident sunlight equals the solar constant, 1370 W/m2.



Solution:

$$q_{In} = q_{out}$$

$$q = q'' \times A$$

where

q'': heat flux, W/m2

$$q = q'' \pi R_e^2 = \sigma \epsilon A T^4 \Rightarrow q'' \cancel{\pi} \cancel{R_e^2} = \sigma \epsilon 4 \cancel{\pi} \cancel{R_e^2} T^4$$

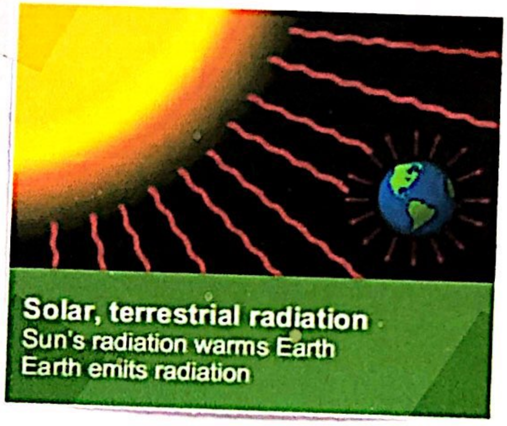
$$T^4 = \frac{q''}{4 \sigma \epsilon} \Rightarrow T = \sqrt[4]{\frac{q''}{4 \sigma \epsilon}} \Rightarrow T = \sqrt{\frac{1370}{4(5.67 \times 10^{-8})(1)}}$$

$$\underline{\underline{T = 279 \text{ K}}}$$

Global warming and greenhouse effect

Global warming: A gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide and other pollutants.

Greenhouse gas: A greenhouse gas is a gas that absorb and emits radiant energy within the thermal infrared range. Greenhouse gases cause the greenhouse effect. The primary greenhouse gases in Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide and ozone. without greenhouse gases, the average temperature of Earth's surface would be about $-18\,^{\circ}C$ rather than the present average of $15\,^{\circ}C$.



What causes global warming?

Global warming occurs when carbon dioxide (CO_2) and other air pollutants and greenhouse gases collect in the atmosphere and absorb sunlight and solar radiation that have bounced ارتدت off the earth's surface. Normally, this radiation would escape into space but these pollutants trap the heat and cause the plant to get hotter. That is what is known as the greenhouse effect.