Thermal Properties Of Matter

Temperature and Heat: Measurement of Temperature

- Temperature is the measure of hotness or coldness of a body.
- Heat is the form of energy transfer from one body to another due to their temperature difference.
- Thermometers are used for measuring temperature.
- Ice point and steam point are used as lower and upper fixed points for measurement.
- Conversion of temperature from one scale to another:

$$\frac{\text{Temperature on one scale} - \text{Lower fixed point}}{\text{Upper fixed point} - \text{Lower fixed point}}$$

$$= \frac{\text{Temperature on the other scale} - \text{Lower fixed point}}{\text{Upper fixed point} - \text{Lower fixed point}}$$

$$\therefore \frac{C-0}{100-0} = \frac{F-32}{212-32} = \frac{R-0}{80-0}$$

Where,

C = Temperature in Celsius scale

F = Temperature in Fahrenheit scale

R = Temperature in Reaumur scale

Ideal Gas Equation and Absolute Temperature

- Boyle's law and Charles' law are combined into a single relationship,

$\frac{PV}{T}$ = constant

(Ideal gas law)

- General form which can be applied to any quantity of gas:

$\frac{PV}{T} = \mu R$ [Ideal gas equation]

Where,

P − Pressure

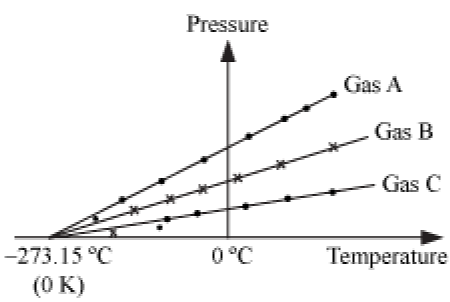
V − Volume

T − Temperature

μ − Number of moles

R− Universal gas constant (8.31 J mol^{-1}K^{-1})

Absolute Temperature



- The absolute minimum temperature of ideal gas is inferred by extrapolating the straight line to the axis. The temperature is −273.15°C, which is called absolute zero.

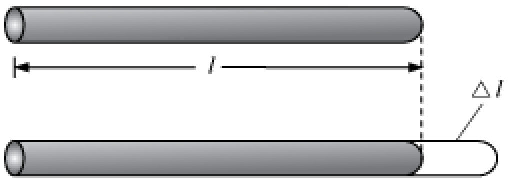
- Absolute zero is the foundation of the Kelvin temperature scale or absolute scale temperature. On this scale, −273.15°C is taken as the zero point i.e., 0 K.

Thermal Expansion

- Effect of heating − Most materials (solid, liquid, and gas) expand on heating and contract on cooling

Thermal expansion − Increase in dimension of a body due to heat

- **Linear expansion (Δ*l*)** − Expansion of length



Linear expansion

Linear expansion ∝ Original length × Temperature change

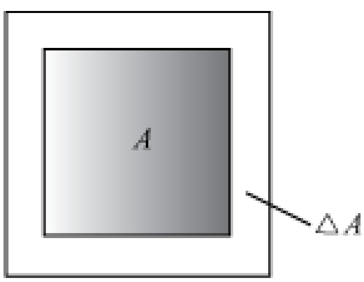
$\Delta l \propto l\Delta T$

$\frac{\Delta l}{l} = \alpha_l \Delta T$

α_l → Coefficient of linear expansion (characteristic property of material)

Generally, metals have high α_l values.

- **Area expansion (Δ*A*)** − Expansion in area



Area expansion

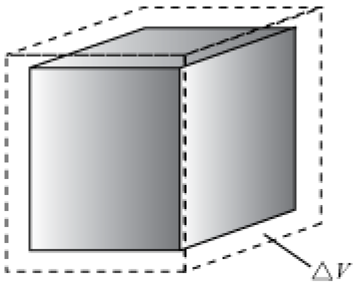
$\Delta A \propto$ Original area × Temperature change

$\Delta A \propto A\Delta T$

$\frac{\Delta A}{A} = \alpha_A \Delta T$

α_A → Coefficient of area expansion

- **Volume expansion (Δ*V*)** − Expansion in complete volume of body



Volume expansion

$\Delta V \propto$ Original volume × Temperature change

$\Delta V \propto V\Delta T$

$$\frac{\Delta V}{V} = \alpha_V \Delta T$$

$\alpha_V \rightarrow$ Coefficient of volume expansion

α_V varies with temperature. It becomes constant at high temperature.

Dependence of α_V on temperature

- For liquids, α_V is relatively independent of temperature.
- For gas, α_V is highly temperature dependent.

Proof:

Ideal gas equation

$PV = \mu RT$

$P \rightarrow$ Pressure

$V \rightarrow$ Volume

$T \rightarrow$ Temperature

$\mu \rightarrow$ Number of moles

$R \rightarrow$ Gas constant

(At constant pressure)

$P\Delta V = \mu R\Delta T$

$$\frac{\Delta V}{V} = \mu R\frac{\Delta T}{T}$$

For ideal gas,

$\alpha_V = \frac{1}{T}$

Relation between α_l, α_A, and α_V

For a solid cube of length (l),

Volume, $V = l^3$

Area, $A = l^2$

∴ Change in volume, $\Delta V = (l + \Delta l)^3 - l^3$

$= 3l^2\Delta l$ [In eq.$\Delta l^2$and Δl^3 have been neglected]

Since Δl is small compared to l,

$\Delta V = \frac{3V\Delta l}{l} = 3V\alpha_l \Delta T$

Which gives,

$$\boxed{\therefore \alpha_V = 3\alpha_l}$$

Change in area, $\Delta A = (l + \Delta l)^2 - l^2$

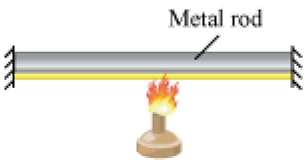
$= 2l\Delta l$

$\Delta A = \frac{2A\Delta l}{l}$

$\Delta A = 2A\alpha_l$

$$\boxed{\therefore \alpha_A = 2\alpha_l}$$

- Thermal stress generates when thermal expansion is prevented.



Specific Heat Capacity

- Heat required to warm a substance depends on:
- Mass (m)
- Change in temperature (Δt)
- Nature of substance
- Heat capacity (S): The change in temperature (Δt) of a substance when heat is absorbed or rejected (ΔQ) by it is characterised by a quantity called the heat capacity.

$$\therefore S = \frac{\Delta Q}{\Delta t}$$

- Specific heat capacity (s) of a substance determines the change in temperature when a given amount of heat is absorbed or rejected per unit mass of the substance.

$$s = \frac{1\Delta Q}{m\Delta t}$$

SI unit is J $kg^{-1}K^{-1}$

- Molar specific heat (C): When the amount of substance is specified in moles (μ) instead of mass

$$C = \frac{1\Delta Q}{\mu\Delta t}$$

SI unit is J $mol^{-1}K^{-1}$

- Heat transfer at constant pressure is called molar specific heat capacity at constant pressure (C_p).
- Heat transfer at constant volume is called molar specific heat capacity at constant volume (C_v).
- The specific heat capacity of water is high, so it is used as a coolant in automobiles.

Calorimeter

Principle of Calorimetry

Calorimetry means measurement of heat. When a body at higher temperature is brought in contact with a body at lower temperature, the heat lost by the former is equal to the heat gained by the latter (no heat should escape to the surroundings).

Calorimeter

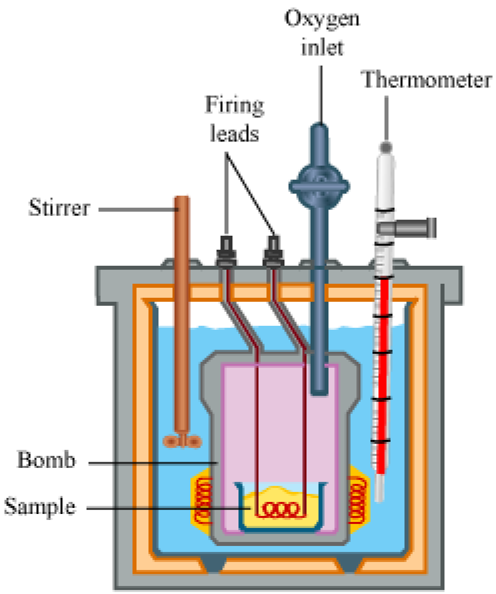
A device used for heat measurement is called a calorimeter.

Construction of a Calorimeter

- It consists of a metallic vessel and stirrers. They are made of copper or aluminium.
- The vessel is then kept inside a wooden jacket which contains heat-insulating materials.
- The outer wooden jacket acts as a heat shield, and reduces the heat loss from the inner vessel.
- The outer jacket has an opening through which a mercury thermometer is inserted into the calorimeter.

Determination of Specific Heat by a Calorimeter

- Consider a calorimeter of known water equivalent containing water.
- Note the initial temperatures of the water and the calorimeter.
- Heat the substance whose specific heat is to be determined to a particular temperature.
- Put this substance in the calorimeter, and stir the mixture.
- The substance at higher temperature will lose heat, which will in turn be gained by the water and the calorimeter.
- Stir the mixture and note the constant temperature.
- Weigh the mixture to find the mass of the added substance.



Consider,

m_1 = Mass of water

t_1 = Initial temperature of the water and the calorimeter

w = Water equivalent of the calorimeter and the stirrer

m_2 = Mass of the substance

s = Specific heat of the substance

t_2 = Temperature of the substance

t = Common temperature of the mixture

Rise in the temperature of the water and the calorimeter = $(t - t_1)$

Fall in the temperature of the substance = $(t_2 - t)$

Heat gained by the water and the calorimeter = $(m_1 + w)(t - t_1)$

Heat lost by the substance = $s.\, m_2 (t_2 - t)$

According to calorimetry principle,

$(m_1 + w)(t - t_1) = s.m_2 (t_2 - t)$

$$\therefore s = \frac{(m_1 + w)(t - t_1)}{m_2(t_2 - t)}$$

Note

Rise in the temperature of a body may not be equal to the fall in the temperature of another body.

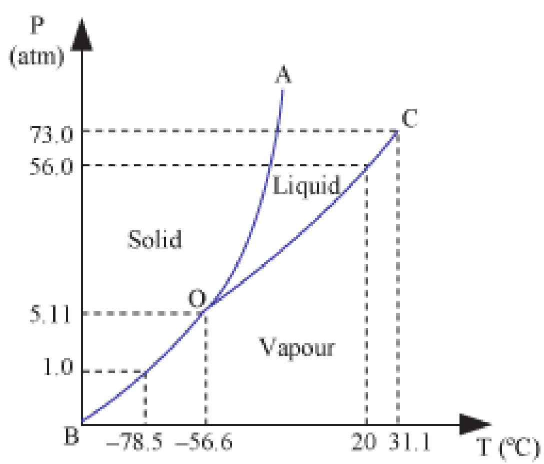
Change in State: Latent Heat

- Change in state: Transition from one state to another

$$\text{Solid} \xrightarrow{\text{melting}} \text{Liquid}$$
$$\text{Solid} \xrightarrow{\text{sublimation}} \text{Vapour}$$
$$\text{Liquid} \xrightarrow{\text{fusion}} \text{Solid}$$
$$\text{Liquid} \xrightarrow{\text{vaporisation}} \text{Vapour}$$

- Temperature at which the solid and liquid states of a substance are in thermal equilibrium with each other is called its melting point.
- Temperature at which the liquid and vapour states of a substance co-exist is called its boiling point.

Triple Point



- Graph is a $P - T$ diagram/phase diagram of CO_2
- $P - T$ plane is divided into the solid region, the vapour region and the liquid region
- Sublimation curve (BO) − solid and vapour phases coexist

- Fusion curve (AO) − solid and liquid phases coexist
- Vaporisation curve (CO) − liquid and vapour phases coexist
- Temperature and pressure at which the fusion curve, vaporisation curve and sublimation curve meet, and all the three phases coexist, is called the triplepoint.

Latent Heat

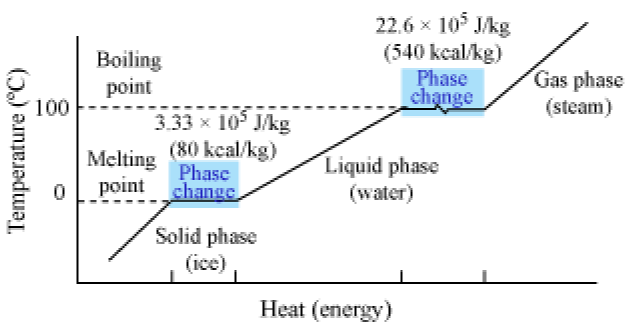
- It is the amount of heat energy required to change the state of a unit mass of a substance from solid to liquid or from liquid to vapour, without a change in temperature.
- Heat required during a change of state depends on:
- Mass of the substance undergoing change *(m*)
- Heat transformation
- Quantity of heat required,

$$Q = mL$$
$$\boxed{L = Q / m}$$

Where,

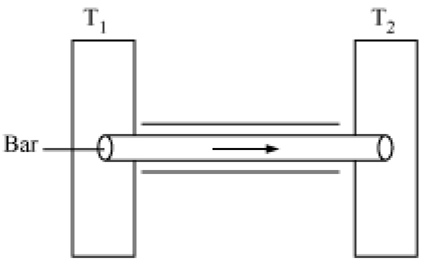
$L \longrightarrow$ Latent heat

- SI unit is J/kg
- $\text{Solid state} \xrightarrow{\text{latent heat of fusion } (L_f)} \text{Liquid state}$
- $\text{Liquid state} \xrightarrow{\text{latent heat of vaporisation } (L_v)} \text{gas state}$
- A plot of temperature versus heat energy for a quantity of water is shown in the figure.



Conduction

- Conduction is the mechanism of heat transfer due to temperature difference between two adjacent parts of a body.



Heat flows by conduction in the bar.

Consider,

L → Length of metallic bar

A → Area of cross-section

T_1 and T_2 → Different temperature of the two ends of the bar ($T_1 > T_2$)

Assume that no heat is lost to the atmosphere. After sometime, a steady state is reached.

At steady state, the temperature decreases uniformly with distance from T_1 to T_2.

In this steady state, the rate of heat (H) flow depends on

- temperature difference ($T_1 - T_2$)
- area of cross-section
- length of bar

$$\therefore H \propto A\frac{T_1 - T_2}{L}$$

$$H = KA\frac{T_1 - T_2}{L}$$

Where K → Thermal conductivity

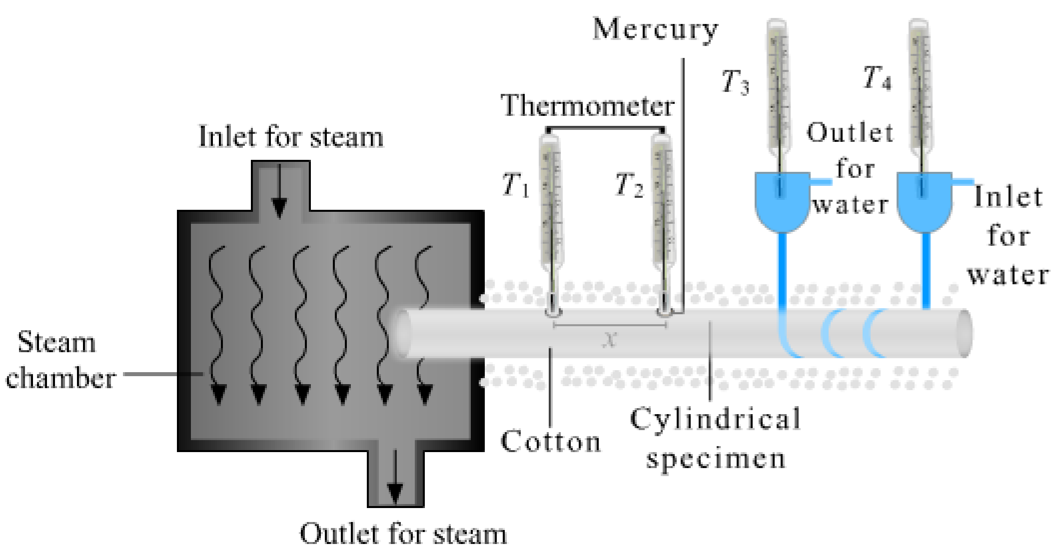
- Thermal conductivity − Metals have high thermal conductivity whereas non-metals and gases have low thermal conductivity.

Applications

- Cooking pots have copper coating. Copper helps in uniform distribution of heat over the bottom of a pot as it is a good conductor.
- Concrete roof gets warm during summer. Therefore, a layer of hay (bad conductor) forms an insulating layer and the heat transfer through the ceiling into the roof is prohibited.

Searle's Experiment

Searle's experiment is used to determine the thermal conductivity of an unknown specimen using Searle's apparatus. The apparatus is shown below.



Construction: It consists of a steam chamber in which some portion of the cylindrical specimen resides. The other end of the specimen is wrapped around with copper tubes through which cold water flows around the speicmen.

Two thermometers are placed in holes in the specimen to measure the temperature gradient; the holes may be filled with mercury to increase thermal contact. The whole apparatus is covered with heat insulators, such as cotton, so as to minimise the loss of heat. Two thermometers are also inserted in the copper tubes as shown above.

Principle: The heat given out by the steam flows through the specimen and is absorbed by the water flowing through the tubes. Thus, the heat lost by the steam will be equal to the heat gained by the water.

Working: Steam is sent into the steam chamber through the inlet pipe. The heat given out by the steam interacts with the specimen. The heat, then, flows though the specimen and is then absored by the water circulating around the specimen. Then the hot water coming out of the outlet water pipe is collected in some beaker. Thus, the heat given by the steam must be equal to the heat absorbed by the water at steady state.

So, the rate of flow of heat through the specimen is

$$\frac{dQ}{dt} = \frac{KA(T_1 - T_2)}{x} \quad .....(i)$$

where, K = Coefficient of thermal conductivity of the specimen

A =Area of cross-section of the specimen

x = Seperation between the two thermometers placed in the specimen

Thus, the heat lost by the steam is

$$dQ = \frac{KA(T_1 - T_2)}{x} dt \quad .....(ii)$$

Now, the heat gained by the water is

$$dQ' = mC(T_3 - T_4) \quad .....(iii)$$

where, m = Mass of the water

C = Specific heat of water

Equating (ii) and (iii), we get

$$mC\left(T_3 - T_4\right) = \frac{KA(T_1 - T_2)}{x} dt$$

or

$$K = \frac{mC(T_3 - T_4)x}{A(T_1 - T_2)dt}$$

Convection and Radiation

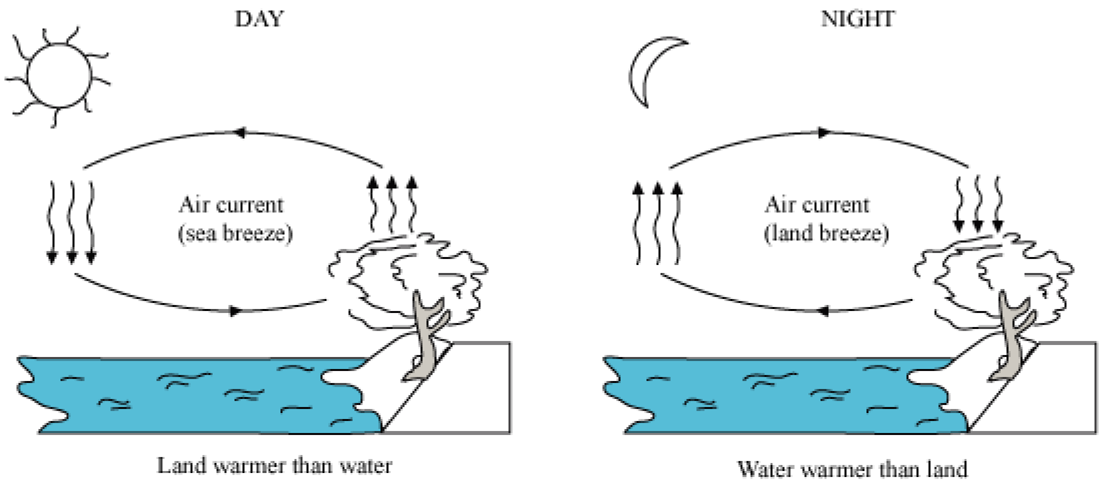
Convection

- In this process, heat is transferred from one point to another by the actual movement of the material particles from a region of high temperature to a region of low temperature.
- Possible only in fluids.
- Convection involves bulk transport of different parts of a fluid.
- Convection can be natural or forced. In natural convection, gravity plays an important role. In forced convection, material is forced to move by a pump or by some other physical means.

Various Phenomena Based on Convection

- Land breeze and Sea breeze: Land absorbs heat from the sun faster than the sea (water). Specific heat of the sea (water) is more than that of land. So during daytime, the rise in temperature of land is higher than that of the sea (water). The hotter air above land rises, and the cold air above the sea (water) flows towards land. This is called sea breeze.

During night time, the hot air above the sea rises, and the cold air above land blows towards the sea (water). This is called land breeze.



- Trade winds: Prevailing winds that blow towards the Equator from the Northeast and the Southeast. Trade winds are caused by hot air rising at the Equator and the consequent movement of the air from the North and the South to take its place. The winds are deflected towards the West because of the Earth's West-to-East rotation.

Radiation

- Conductionand convection require some material as a transport medium.
- These modes of heat cannot transfer heat between two bodies placed in vacuum.
- Radiation is the mechanism for heat transfer that requires no medium.
- It is the manner of heat transfer to the earth from the sun through vacuum.
- Energy emitted by a body in the form of radiation by virtue of its temperature is called thermal radiation.
- Black bodies absorb and emit radiant energy better than bodies of lighter colours.

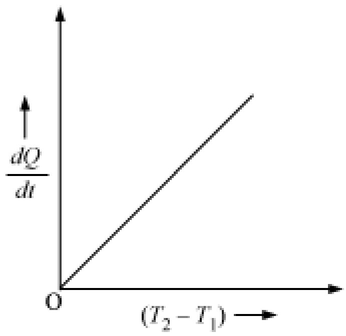
Newton's Law of Cooling

- Rate of cooling of a body is directly proportional to the temperature difference between the body and surroundings ($T_2 - T_1$) [provided the temperature difference is small]

$$\therefore -\frac{dQ}{dt} = k(T_2 - T_1) \qquad (1)$$

Where, $k \rightarrow$ a positive constant

- k depends on area and nature of the surface of the body.



- **Proof**

Let us consider,

$m \rightarrow$ Mass of a body

$s \rightarrow$ Specific heat capacity

$T_2 \rightarrow$ Temperature of the body

$T_1 \rightarrow$ Temperature of the surrounding

$dT_2 \rightarrow$ Fall in temperature of the body in time dt

Amount of heat lost, $dQ = ms\, dT_2$

∴Rate of heat loss, $\frac{dQ}{dt} = ms\frac{dT_2}{dt}$ (2)

From equations (1) and (2),

$$-ms\frac{dT_2}{dt} = k(T_2 - T_1)$$

$$\frac{dT_2}{T_2 - T_1} = \frac{-k}{ms}dt$$

Where, $\frac{k}{ms} =$ constant = K

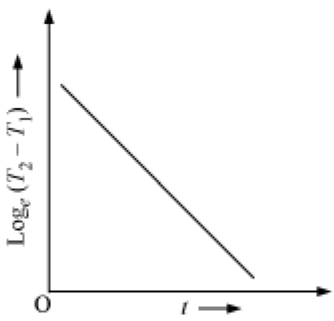
$$\therefore \frac{dT_2}{T_2 - T_1} = -Kdt$$

Integrating both sides,

$$\log_e (T_2 - T_1) = -Kt + C$$

Where, C is constant of integration

If we plot a graph between t and $\log_e (T_2 - T_1)$, then we obtain a straight line having slope K and making an intercept C on Y-axis. Hence, Newton's law of cooling is verified.



Newton's law of cooling

Stefan's Law and Wein's Law

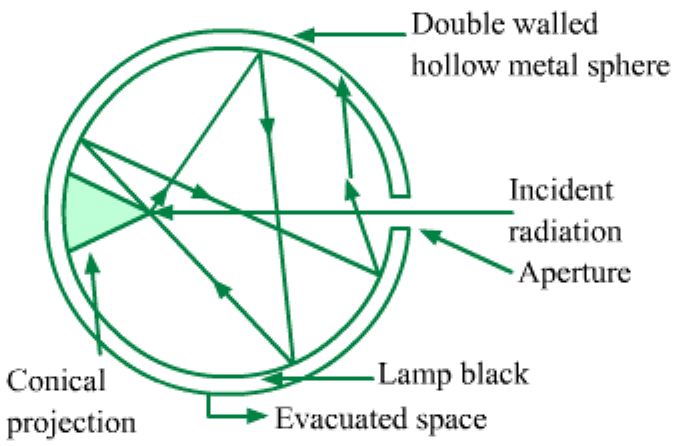
Black and grey bodies:

A body that absorbs the entire radiation incident on it is called a perfect black body. At a given temperature, the radiation emitted by a perfect black body is greater than that of any other body maintained at the same temperature. A body that is not a black body is called a grey body.

Ferry's black body

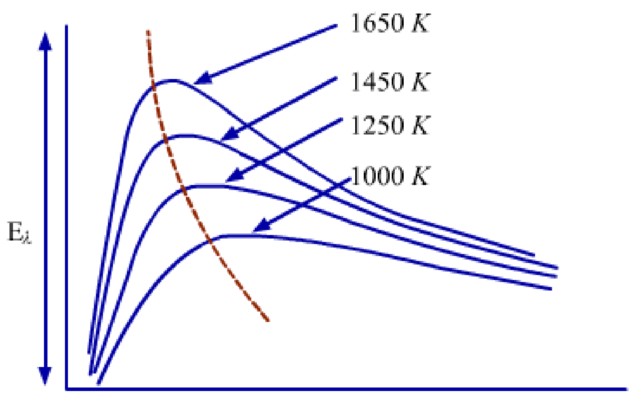
Ferry's black body is an artificial black body. It consists of a double-walled hollow metal sphere blackened inside with a small fine hole O on the surface. Its outer surface is polished with nickel. The space between the two walls is evacuated, so that there is no heat loss by conduction and convection.

When the heat radiation enters the hole, it is reflected many times on the inner wall of the sphere until it is completely absorbed. To avoid direct reflection of the radiation from the inner surface, a pointed projection is made in front of the hole, as shown in the figure. Thus, the small hole acts as a black body absorber.



Perfect black body

Spectrum of black body radiation
Lummer and Pringsheim carried out an experiment to study the spectrum of black body radiation. They performed the experiment by heating the body to different temperatures and drew curves for the observations made at the different temperatures.



Energy Distribution Spectrum of a Black Body

The curves show that:

(1) energy is not uniformly distributed in the radiation spectrum of the black body.

(2) at a given temperature, the intensity of radiation increases with increase of wavelength and becomes maximum at a particular wavelength. On increasing the wavelength further, the intensity of heat radiation decreases.

(3) an increase in temperature causes a shift in the peak value of E towards left.

(4) an increase in temperature causes an increase in energy emission for all wavelengths.

Wein's Displacement Law:

The radiation emitted by a body has wavelengths ranging from zero to infinity. However, the intensity (spectral emissive power) of all the wavelengths is not same. The spectral distribution of radiation with corresponding emissive power is shown in the figure.

It can be seen that for a higher temperature T_1, the wavelength at which the maximum power is emitted is lower than the corresponding wavelength for a lower temperature T_2.

Wein established a relation between the temperature and wavelength at which the maxima of emissive power occurs. According to this law,

$$\lambda_{max.}T = b$$,

where 'b' is a constant. Its value is 2.89×10^{-3} mK.

Absorptive Power:
Absorptive power of a surface is defined as the ratio of the radiant energy absorbed by it in a given time to the total radiant energy incident on it in the same time.

Since a perfect black body absorbs all radiation incident on it, its absorptive power is unity. For a grey body, it is less than one.

$$a = \frac{\text{energy absorbed}}{\text{energy incident}}$$

Emissive Power:
It is defined as the radiant energy emitted per second, per unit area of the surface. If this is given for a particular wavelength instead of all wavelengths, it is called spectral emissive power and is represented by e_λ .
If Q = amount of radiant energy emitted,
A = surface area of a body,

t = time for which the body radiates energy, then

E = Q/At

S.I. unit of emissive power is J/m^2s or W/m^2. Its dimensions are $[M^1L^0T^{-3}]$.

Coefficient of emission (emissivity):
It is the ratio of emissive power of a body at a given temperature to the emissive power of a black body at the same temperature.

Coefficient of emission $e = E/E_b$

Here, E = Emissive power of an ordinary body at a given temperature
E_b = Emissive power of a perfect black body at the same temperature

For a perfect black body, $e = 1$
For a perfect radiator, $e = 0$

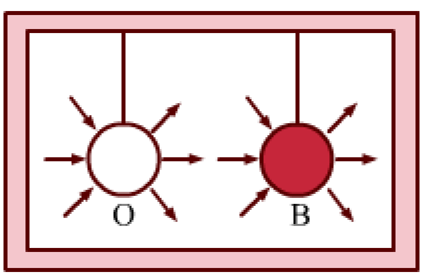
For ordinary bodies, $e < 1$

Kirchhoff's Law:
It states that the coefficient of absorption of a body is equal to its coefficient of emission at any given temperature.
$a = e$

But coefficient of emission $e = \frac{E}{E_b}$
$\therefore a = \frac{E}{E_b}$
$\Rightarrow \frac{E}{a} = E_b$

Hence, Kirchoff's Law can be stated thus: " At any given temperature, the ratio of emissive power (E) to the coefficient of absorption (a) is constant for all bodies and this constant is equal to emissive power (E_b) of a perfect black body at the same temperature."
Thus, all good absorbers are also good emitters.

Proof of Kirchhoff's Law:
To prove Kirchhoff's Law, take an ordinary body O and a perfect black body B of same surface area A. Initially, let they be placed in a uniform temperature enclosure. Body O's emissive power is E, coefficient of emission is e, coefficient of absorption is a and body B's emissive power is E_b.



Constant temperature enclosure

According to the Zeroth law of thermodynamics, the ordinary body O and the perfect black body B will attain the same temperature by thermal exchange.

If Q be the amount of radiant energy incident per unit time per unit area of each body, then radiant energy incident per unit time on body B is AQ. As it is a perfect black body, it absorbs all this radiant energy per unit time. Energy emitted per unit time by the perfect black body B is AE_b.

Energy emitted per unit time by the black body = Energy absorbed per unit time by the black body

So,
$AE_b = AQ$
$E_b = Q$ ...(1)

Energy incident per unit time on body O will be *AQ* and energy absorbed per unit time by body O is *aAQ*.
Energy emitted per unit time by body O = Energy absorbed per unit time by body O
So,

$AE = aAQ$
$E = aQ$
$\frac{E}{a} = Q$ ...(2)
From equations (1) and (2), we have:
$\frac{E}{a} = E_b$
$\therefore \frac{E}{E_b} = a$

Also, $\frac{E}{E_b} = e =$ coefficient of emission
$\therefore a = e$
Coefficient of absorption = Coefficient of emission
This proves Kirchhoff's Law.

Prevost's Law of Exchange:
Every physical body radiates and absorbs heat simultaneously. The heat radiated by it depends upon its own temperature, while the heat absorbed by it depends upon the temperature of the surroundings.

If a body at temperature T is in an environment of temperature T_0 ($< T$), the body loses energy by emitting radiation at a rate $P_1 = eA\sigma T^4$ and it receives energy by absorbing radiation at a rate $P_2 = eA\sigma {T_0}^4$.

So, net rate of loss of energy by the body through radiation,
$P = P_1 - P_2 = eA\sigma\left(T^4 - {T_0}^4\right)$.

Stefan's Law:
According to this law, the radiant energy emitted by a perfect black body per unit area per second (i.e. emissive power or radiance or intensity of black body radiation) is directly proportional to the fourth power of its absolute temperature, i.e.
$E \propto T^4$ or $E = \sigma T^4$,

where σ is a constant called Stefan's constant of dimensions $[MT^{-3}\theta^{-4}]$ and value 5.67×10^{-8} W/m^2K^4.

If the body is not a perfect black body, $E = e\sigma T^4$

Where e is called emissivity or relative emittance and has value $0 < e < 1$, depending on the nature of the surface. It has no units and dimensions.

So, the energy radiated per second by a body of area A is

$P = EA = eA\sigma T^4$

Newton's Law from Stefan's Law:
According to this law, the rate of cooling of a body is directly proportional to the temperature difference of the body and its surroundings, if temperature difference is small.

From Stefan's Law,
$\Delta P = eA\sigma(T^4 - T_0^4)$,

where A = surface area of a body

T= absolute temperature of the body

T_o = temperature of surroundings
If the temperature difference is small,
$T = T_0 + \Delta T$

$$T = T_0 + \Delta T$$
$$T^4 - {T_0}^4 = (T_0 + \Delta T)^4 - {T_0}^4$$
$$T^4 - {T_0}^4 = {T_0}^4 \left(1 - \frac{\Delta T}{T_0}\right) - {T_0}^4$$
$$\Rightarrow T^4 - {T_0}^4 = {T_0}^4 \left(1 + 4\frac{\Delta T}{T_0} + \ldots\right) - {T_0}^4$$

We neglect the higher power of $\frac{\Delta T}{T_0}$.

$$\Rightarrow T^4 - {T_0}^4 = {T_0}^4 \left(1 - \frac{\Delta T}{T_0}\right) - {T_0}^4$$
$$\Rightarrow T^4 - {T_0}^4 = {T_0}^4 \left(1 + \frac{4\Delta T}{T_0}\right) - {T_0}^4$$
$$\Rightarrow T^4 - {T_0}^4 = {T_0}^4 + 4{T_0}^3 \Delta T - {T_0}^4$$
$$\Rightarrow T^4 - {T_0}^4 = 4{T_0}^3 (T - T_0)$$

So,

$$\Delta P = eA\sigma \left(T^4 - {T_0}^4\right)$$
$$\Rightarrow \Delta P = 4eA\sigma {T_0}^3 (T - T_0)$$
$$\Rightarrow \Delta P_1 = b_1 A (T - T_0)$$

The body may also lose energy due to convection in the surrounding air. It also depends on surface area and temperature difference of the body.

$\Delta P_2 = b_2 A(T - T_0)$

The net rate of loss of thermal energy due to convection and radiation,

$$\Delta P = \Delta P_1 + \Delta P_2$$
$$\Rightarrow \Delta P = (b_1 + b_2) A (T - T_0)$$

Rate of fall of temperature:

$$-\frac{dT}{dt} = \frac{\Delta P}{ms} \ [\Delta Q = ms dT],$$

where m= mass of object

s = specific heat capacity

$$-\frac{dT}{dt} = \frac{b_1 + b_2}{ms} A (T - T_0)$$
$$\Rightarrow \frac{dT}{dt} = -bA (T - T_0),$$

which is Newton's Law of Cooling.

Limitation of Newton's Law of Cooling:

(1) Newton's Law of Cooling is applicable only when the excess temperature of the body over its surroundings is small.

(2) This law is not valid for radiation.

Greenhouse Effect:
It is a natural phenomenon that keeps the earth's atmosphere warm.

- Without this phenomenon, the temperature of the earth would be too low for living beings to survive.

  The greenhouse gases (CO_2, methane, etc.) absorb the heat of the sun and the earth and emit it back to the earth's surface.

- Thus, these gases prevent a part of the heat rays from escaping to the atmosphere.
- This cycle is repeated many times to maintain the earth's temperature at an optimum 15ºC.
- The concentration of these gases has increased due to increased industrialisation, leading to heating of the earth's surface (global warming).
- This has increased the overall temperature of the earth, resulting in changes in the earth's climate. During the last century, the temperature of the earth has increased by 0.6ºC.
- This increase in temperature has led to melting of polar ice caps, rise in sea levels and flooding of coastal areas.
- Greenhouse effect can be controlled by reducing the use of fossil fuels that produce greenhouse gases on burning, afforestation, efficient energy usage, etc.