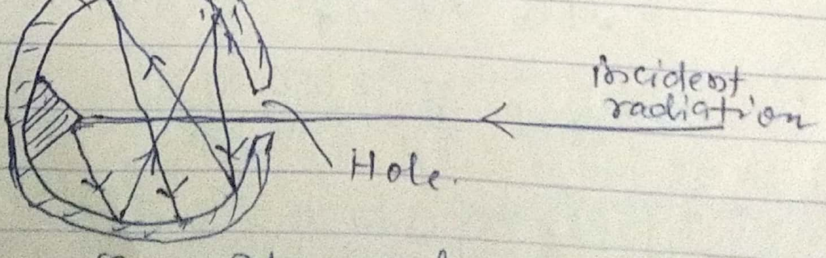
Black Body

A perfectly black body is one which absorbs all the heat radiations corresponding to all wavelengths incident on it. It neither reflects nor transmits any of the incident radiation and therefore, appears black whatever be the colour of incident radiation. When such a body is placed inside an isothermal enclosure, it will emit the full radiation of the enclosure after it is in thermal-equilibrium with the enclosure. These radiations are independent of the nature of the substance. clearly the radiation from an isothermal enclosure is identical with that from the black body at the same temperature. Therefore, the heat radiations in an isothermal enclosure are termed as <u>black body radiation.</u> In practice, a perfectly black body is not available. A body showing close approximation to a perfectly black body can be constructed.

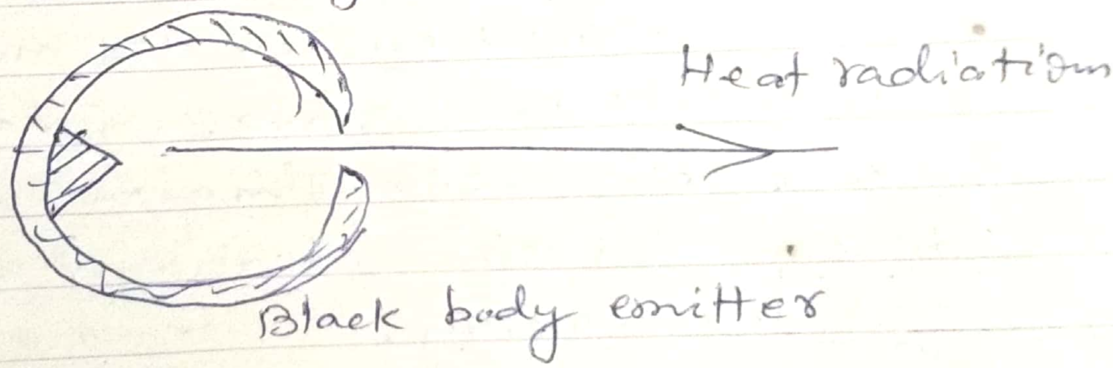
① <u>Ferry's black body.</u> →

It consists of a hollow copper sphere and is coated with lamp black on its inner surface. A fine hole is made and a pointed projection is made just in front of the hole.



(a) Black body absorber

When the radiations enter the hole, they suffer multiple reflections and are completely absorbed. This body acts as a black body absorber. To avoid direct reflection of the radiation from the inner surface, a pointed projection is made infront of the hole. Thus the small hole acts as a black body absorber. When this body is placed in a bath at a fixed temperature, the heat radiation come out of the hole. Now the hole acts as a black body radiator. It ~~should be~~ is to be noted that only the hole and not the walls of the body acts as the black body radiator.



(b)

② Wein's black body

Stefan's law

or

Stefan-Boltzmann law

This law states that the rate of emission of radiant energy by unit area of a perfectly black body is directly proportional to the fourth power of its absolute temperature.

$$E \propto T^4 \text{ or } E = \sigma T^4 \quad \text{---} (1)$$

where σ is called Stefan's Constant.

If the body is not perfectly black and its emissitivity or relative emittance is e, then

$$E = e\sigma T^4 \quad \text{---} (2)$$

e varies between zero and one, depending on the nature of the surface. For a perfectly black body $e = 1$. This law is not only true for emission but also for absorption of radiant energy.

If a perfectly black body at temperature T_1 is surrounded by a wall ~~at a~~ i.e surroundings at a temperature T_2, the net rate of loss (or gain) of heat energy per unit area of the surface is given by,

$$E \propto (T_1^4 - T_2^4)$$

$$\text{or } E = \sigma(T_1^4 - T_2^4) \quad \text{---} (3)$$

If the body has an emissitivity e,

then $$E = e\sigma(T_1^4 - T_2^4) \quad \text{---} (4)$$

Mathematical Derivation of Stefan's law

The fact that black body radiations exert pressure similar to a gas, helps in applying thermodynamics to heat radiation.

Let ψ be the energy density of radiations inside a uniform temperature enclosure at a temp. T. P is the pressure and V is the volume.

From Ist law of thermodynamics,

$$dQ = dU + dW$$

$$dQ = dU + PdV \quad \text{--- (1)}$$

From thermodynamical relation

$$\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$$

$$dS = \frac{dQ}{T}$$

$$\left(\frac{\partial Q}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V \quad \text{--- (2)}$$

$$\left(\frac{\partial U + P\partial V}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V$$

$$\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V - P \quad \text{--- (3)}$$

$$p = \frac{1}{3}\rho c^2 = \frac{1}{3}\frac{M}{V}c^2 = \frac{1}{3}\frac{E}{V}$$

Now $U = V\psi$

and $P = \frac{\psi}{3}$

or $\left(\frac{\partial U}{\partial V}\right)_T = \psi$ — (4)

Here ψ is a function of temperature alone.

Putting (4) in (3)

$$\psi = \frac{T}{3}\frac{d\psi}{dT} - \frac{\psi}{3}$$

$$\frac{4\psi}{3} = \frac{T}{3}\cdot\frac{d\psi}{dT}$$

$$\int\frac{d\psi}{\psi} = 4\int\frac{dT}{T}$$

$$\log\psi = 4\log T + \text{Constant}$$

$$\psi = KT^4 \quad \text{--- (5)}$$

Here K is a constant

Also the total rate of emission per unit area of a black body is proportional to the energy density.

$$\therefore E \propto \psi \propto T^4$$

$$\therefore E = \sigma T^4 \quad \text{—} \quad (6)$$

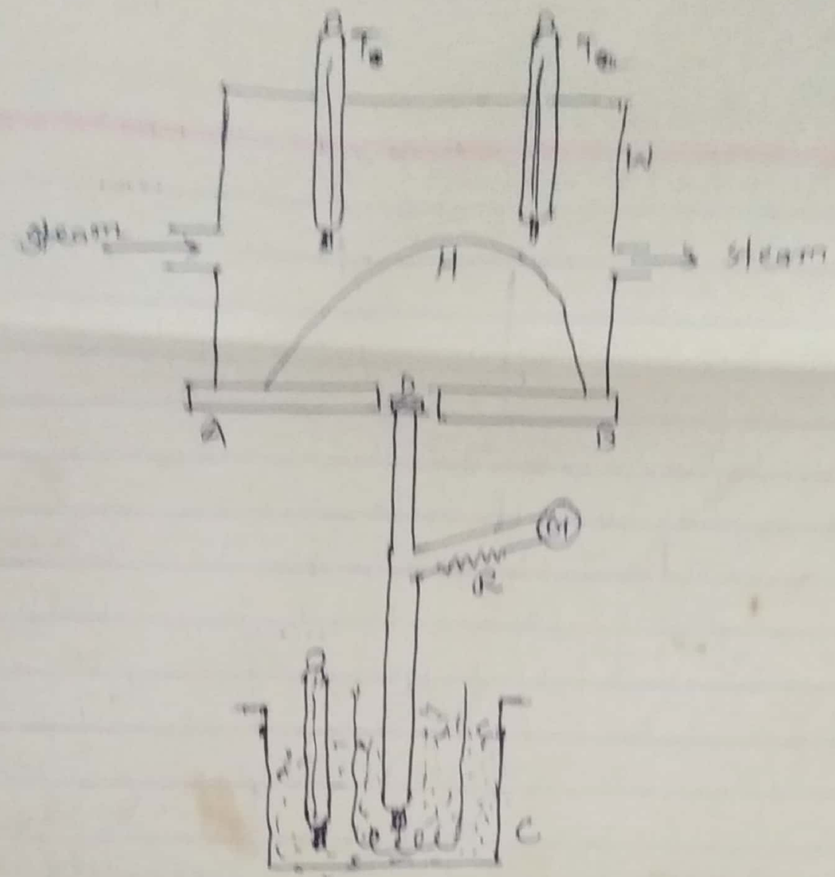
where σ is stefan's Constant

Determination of Stefan's Constant (σ)

The apparatus used for determination of stefan's constant Consists of a hollow metallic hemisphere H blackened inside and placed in a wooden box W, lined with tin plates which serves as a steam chamber. Steam can be passed in the chamber when desired and then in steady state the temperature of hemisphere remains constant, equal to that of steam and may be measured by thermometer T. The hemisphere H rests symmetrically on a Platform AB which has a small hole at its centre.

A small silver disc D blackened at its top surface can be fitted. one junction of the the silver-Constantan Couple is soldered to the lower surface of D; while the other is placed in the water bath or sand Container C.

A sensitive galvanometer (G) is introduced in thermocouple circuit with resistance R in series.



Theory → When the inner surface of H is heated by passing steam, it acts as a black body radiator. The disc D absorbs the radiation emitted by H and its temperature rises continuously, thus causing a difference of temperature in the two junctions of the thermocouple.

If T_1 is the steady state temperature of H and T_2 is that of disc D, when it is just exposed to radiation from H.

Then from Stefan - Boltzmann law,

The net energy gained by the disc per second

$$= EA$$
$$= \sigma (T_1^4 - T_2^4) A \text{ Joule}$$

where A being the area of disc.

$$= \frac{\sigma (T_1^4 - T_2^4) A}{J} \text{ Kil. cal.}$$

If m is the mass of disc, s its specific heat in Kil Cal/°C kg and $\frac{dT}{dt}$ its rate