BPT-201 (semester II)
Topic: Blackbody Radiation-part 3
(Radiation Pressure)

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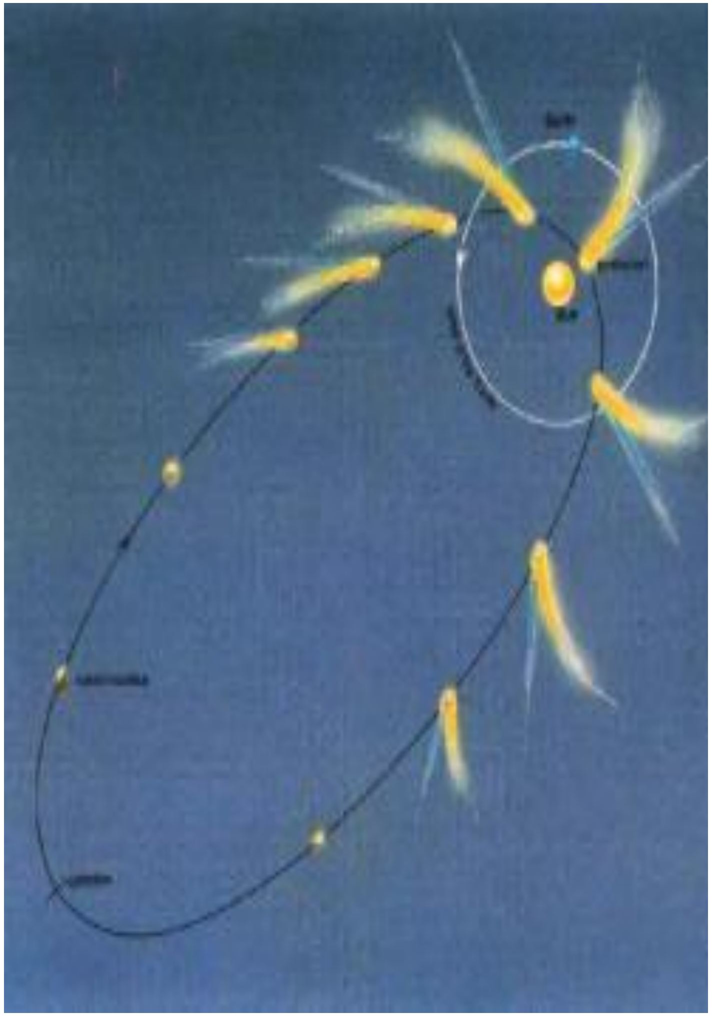
Radiation Pressure

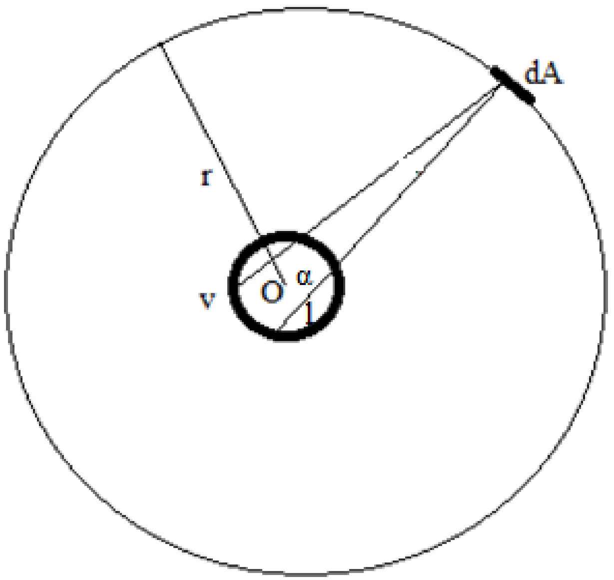
- Radiation pressure came into discussion when kepler observed that comets dust tail bends when they come near to sun
- Radiation being identical to light, it has been thought that it will also exert a pressure on the surface it falls upon.
- Being very small it has been neglected for a long time.



Picture of comet tail moving away from sun

- Quantum theory says that radiation consists of photons having energy $h\nu$ and moving with velocity of light
- Where ν is the frequency of photon
- So by mass-energy relation $E= h\nu=mc^2$
- So mass of photon $=m= h\nu/c^2$
- So it will have a momentum $= h\nu/c$
- So if it falls on a surface and get absorbed then it will create an impulse $h\nu/c$
- Hence the pressure $p= \sum h\nu/c=I/c$
- Where I is the intensity of radiation
- The summation includes photons of all frequencies

Energy density of diffuse radiation



- Let us find the energy density from uniformly heated enclosure of any size/shape.
- Let us consider a small elemental volume 'v' inside the enclosure.
- Let us now consider a sphere of radius 'r' around the volume with its center at 'O'.
- Sphere is large in comparison to volume 'v'.
- All the radiation may be supposed to come from the surface of sphere.

- Let us start from the elemental area ‘dA’ of sphere.
- The radiation coming from it travels a length ‘l’ in volume ‘v’
- Let us consider an elementary cone having vertex at dA and radial line as its axis.
- The solid angle of cone will be given as $d\omega=\alpha/r^2$
- Where α is the area of cross-section perpendicular to axis.
- Time taken by the radiation to traverse the volume v is $t=l/c$

- Amount of radiation contained in volume v due to elementary cone is =K dA α l/cr^2
- Where k is the specific intensity of radiation i.e. radiation/sec per unit area per unit solid angle
- So the total radiation contained in v due to dA

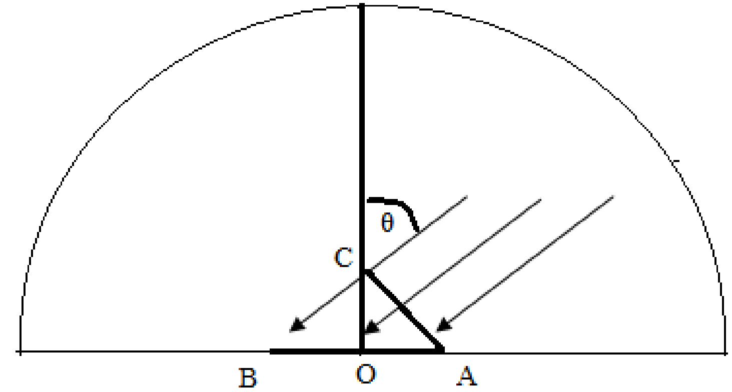
$$\sum K\, dA \frac{\alpha l}{cr^2} = \frac{K dA}{cr^2} \sum \alpha l = \frac{K dA}{cr^2} v$$

- Now to get the value of radiation due to complete sphere will be

$$\sum \frac{K dA}{cr^2} v = \frac{Kv}{c} \sum \frac{dA}{r^2} = \frac{Kv}{c} 4\pi$$

- So the energy density $u = \dfrac{4\pi K}{c}$

Pressure and energy density



- To get an relation between energy density and pressure for diffused radiation, let us consider a surface AB on which radiation is falling
- Angle of radiation with normal at AB is θ
- Intensity of radiation in the enclosure due radiation coming from the direction enclosed in a small solid angle $d\omega$ will be $I = K\, d\omega$
- So the pressure on 'AC' due to radiation from direction given be θ, ϕ will be $K d\omega / c$,
- Where $d\omega = \sin\theta \, d\theta \, d\phi$

- So force on AC will be given as $\frac{K d\omega}{c} AC$
- The normal component of above force = $\frac{K d\omega}{c} AC\cos\theta$
- This is the force on AB surface,
- Hence pressure on surface AB due to normal component of radiation will be given by $\frac{K d\omega}{c}\frac{AC}{AB}\cos\theta$ or $\frac{K d\omega}{c}\cos^2\theta$
- Integrating this value over the entire hemisphere, the total pressure can be obtained.
- $$p = \int_0^{\pi/2}\int_0^{2\pi}\frac{K}{c} Sin\theta\cos^2\theta\, d\theta\, d\,\phi = \frac{1}{3} 2\pi\frac{K}{c} = \frac{u}{3}$$
- Here energy density u is taken as $u = \frac{2\pi K}{c}$
- As here radiation is being received from hemisphere not from complete sphere.