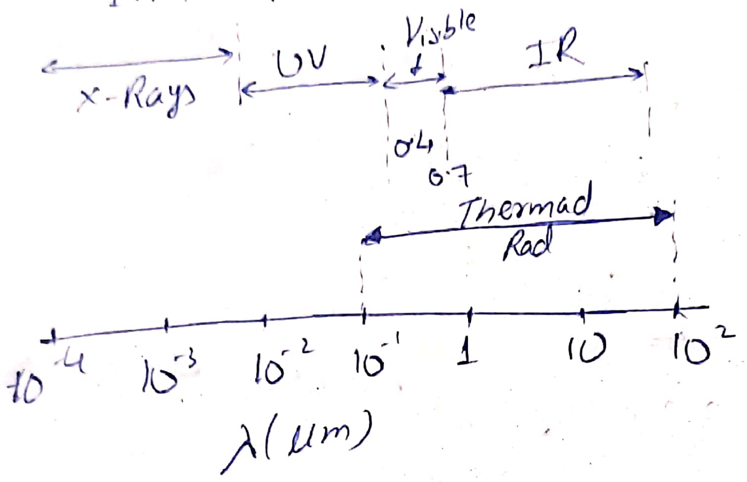
Lec-15

Intro to Radiation heat transfer, blackbodies, blackbody examples

Radiation H.T

Thermal radiation is electromagnetic radiation emitted by a body due to its temperature.

E.M. Spectrum



Black body

(1) It emits maximum possible radiation.

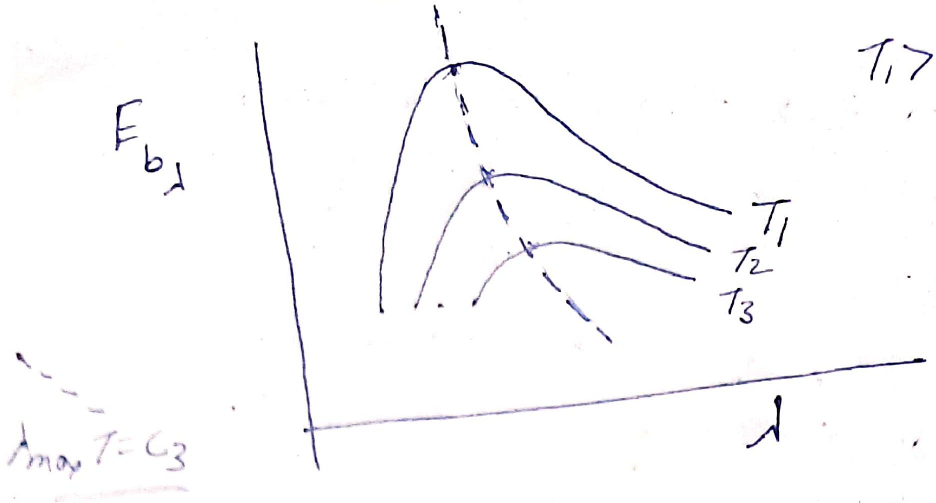
(2) It absorbs all incident radiation.

Plank's Law →

$$\boxed{E_{b\lambda} = \frac{C_1}{\lambda^5\left[\exp\left(\frac{C_2}{\lambda T}\right)-1\right]}}$$

$E_{b\lambda}$ = blackbody spectral emissive power ($W/m^2 . \mu m$)

E = Emissive power, spectral ⇒ wavelength dependent, C_1 & C_2 are constants, T is absolute value



Every curve goes through a maximum and when we connect all max we get Displacement Law

$$\boxed{\lambda_{max} T = C_3}$$

where $C_3 = 2897.6$ ~~μμ~~ μm K

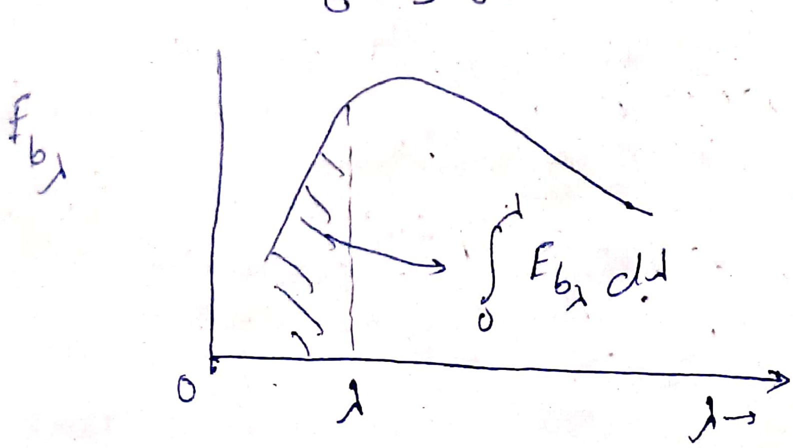
E_b = Total emissive power

$$= \int_0^\infty E_{b_\lambda} \, d\lambda$$

gives $\boxed{E_b = \sigma T^4}$

Stefan boltzman Law.

$\sigma = 5.67 \times 10^{-8}$



The area in above curve is

$$\cancel{E_{b\lambda} = \int_0^{\lambda}} = \int_0^{\lambda} E_{b\lambda}\, d\lambda$$

$$F_{0-\lambda} = \text{fraction of energy emitted} = \frac{\int_0^{\lambda} E_{b\lambda}\, d\lambda}{\int_0^{\infty} E_{b\lambda}\, d\lambda}$$

A table gives

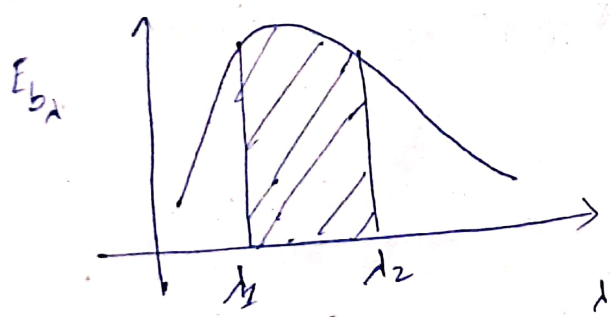
λT	$F_{0-\lambda}$
⋮	⋮

So, we know $F_{0-\lambda}$ & $\int_0^{\infty} E_{b\lambda}\, d\lambda = \sigma T^4$,

then we can get $\int_0^{\lambda} E_{b\lambda}\, d\lambda$

$$F_{0-\lambda} = \frac{\int_0^{\lambda} E_{b\lambda}\, d\lambda}{\sigma T^4}$$

Band Emission



$$F_{\lambda_1-\lambda_2} = \frac{\int_0^{\lambda_2} E_{b\lambda}\, d\lambda - \int_0^{\lambda_1} E_{b\lambda}\, d\lambda}{\int_0^{\infty} E_{b\lambda}\, d\lambda}$$

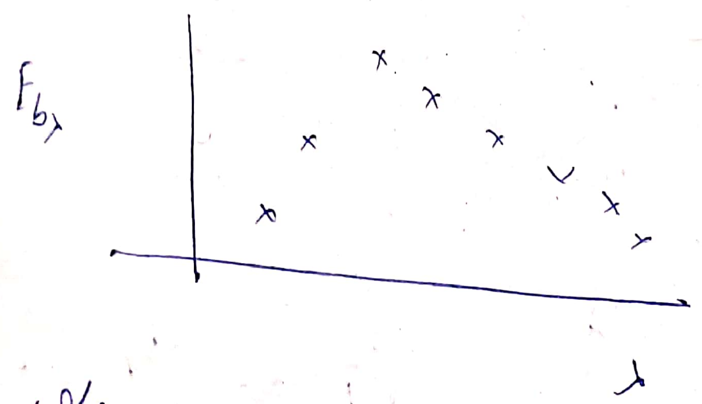
$$F_{\lambda_1-\lambda_2} = F_{0-\lambda_2} - F_{0-\lambda_1}$$

Example

Find fractions of solar energy in UV, visible & infrared. regions.
→ Assume sun behave like a blackbody at 5800 K.

Thermal UV	0.1 to 0.4
Visible	0.4 to 0.7
Infrared	0.7 to 100.

How did people get temp of sun.
⇒ They sent a probe on a satellite with a thermal detector with to the sun with a wavelength filter on it, so only a certain wavelength came into the sensor, and they used different wavelength filters. Then they plot $E_{b\lambda}$ with λ



So, when we connect the points it looks like a blackbody curve. So, sun might be a blackbody. So, when we plot $E_{b\lambda}$ with λ at temperatures we

get that curve nearly fits at 5800 K.
So, the ~~to~~ sun behaves as black body and its temperature is 5800 K.

We find λT. Then from value of λT we get $f_{0-\lambda}$, ~~& then find the total emissive power~~ power. i.e. fraction.

$\lambda = 0.1$ to 0.4

$\lambda T = 0.1 \times 5800 = 580$

$0.4 \times 5800 = 2320$

$0.7 \times 5800 = 4060$

$100 \times 5800 = 580000$

λT	$F_{0-\lambda}$
580	0
2320	0.120
4060	0.495
580000	1

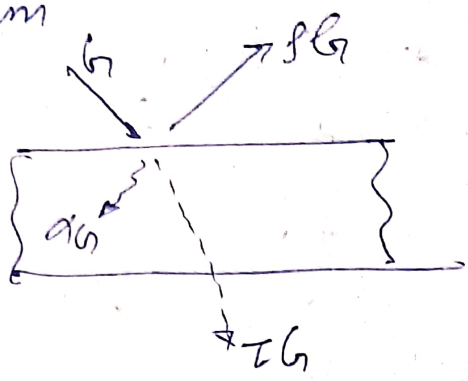
$F_{U-V} = F_{0-\lambda_2} - F_{0-\lambda_1} = 0.120$ (12%)

$F_{visible} = F_{0-\lambda_2} - F_{0-\lambda_1} = 0.495 - 0.120$
$= 0.375$ (37.5%)

$F_{infrared} = 1 - 0.495 = 0.505$ (50.5%)

Lec-16

Consider irradiation G [incident radiation] incident on a semitransparent medium



G = irradiation (W/m^2)

ρG = reflected radiation

ρ = reflectivity $0 \le \rho \le 1$.

αG = absorbed radiation

α = absorbtivity $0 \le \alpha \le 1$.

τG = transmitted radiation

τ = transmissivity $0 \le \tau \le 1$.

Energy balance gives

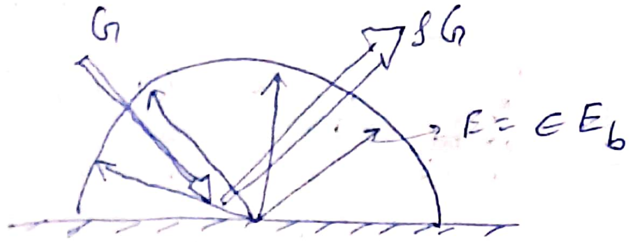
$$G = \rho G + \alpha G + \tau G$$

So, $\boxed{\alpha + \rho + \tau = 1}$

For an opaque surface $\tau = 0$.

So, $\boxed{\alpha + \rho = 1}$

Consider an opaque surface.



J = radiosity (W/m²)
(energy leaving surface)

$J = \varepsilon E_b + \rho G$

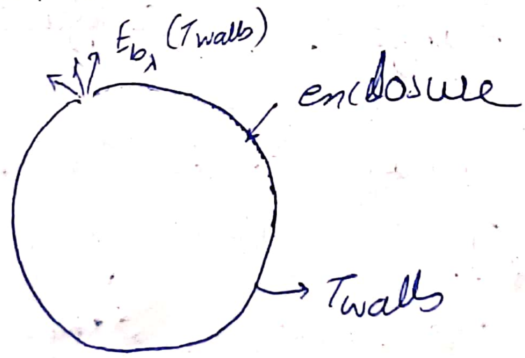
q'' = net radiation heat flux leaving the surface.

$= J - G$

$= \varepsilon E_b + \rho G - G = \cancel{\varepsilon E_b + G(1}$

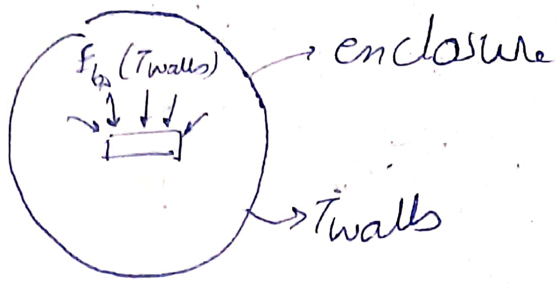
$q'' = \varepsilon E_b - (1-\rho) G$.

One way to obtain a black surface



the radiation emitted by the small hole looks like black body radiation of the walls. $E_{b_\lambda}(T_{walls})$

If we put small object into the enclosure



The radiation that comes to small object from the walls appears to have come from blackbody at the temp of walls. [$E_{b\lambda}(T_{walls})$]

Other relating properties

(Diffuse means spread out)

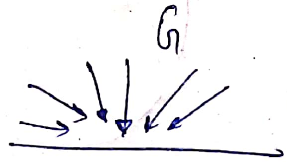
$\varepsilon_\lambda = \alpha_\lambda$ if

① If irradiation is diffuse.

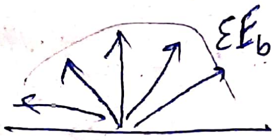
② If surface is diffuse.

[diffuse means its not a ~~fn of~~ dependent on angle].

So, all are same



(irradiation is diffuse)



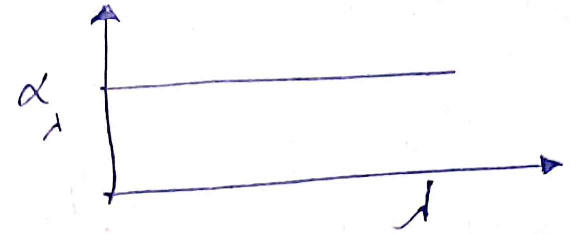
(surface is diffuse)

A real surface will depend on angle.

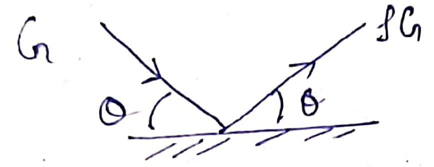
$\varepsilon = \alpha$ if (Total emissivity = Total absorptivity)

① surface is grey.

Grey surface does not depend on λ.



When we polish a surface



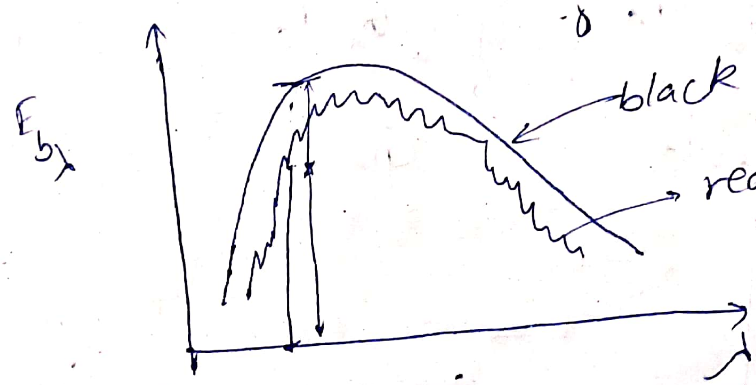
Angle of incidence = Angle of reflection.

Specular reflection (not spectral)

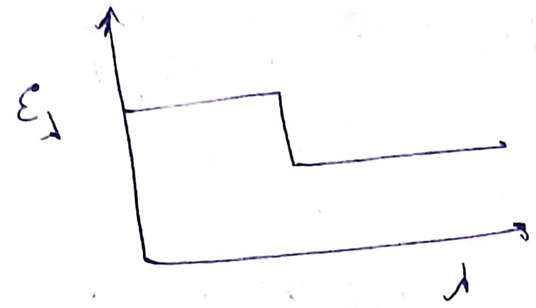
(Specular reflection is more advanced & complex) (ε_λ = spectral emissivity)

Kirchoff's Law

$$\varepsilon = \frac{\int_0^\infty \varepsilon_\lambda E_{b_\lambda}\, d\lambda}{\int_0^\infty E_{b_\lambda}\, d\lambda}$$



Ratio of real surface to black surface



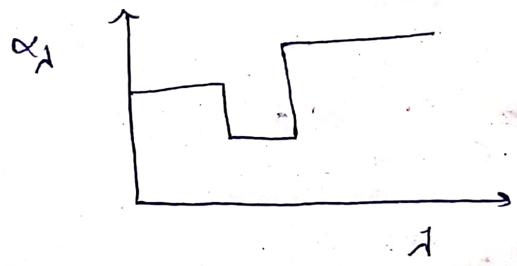
for some material.

ε_λ = spectral emissivity

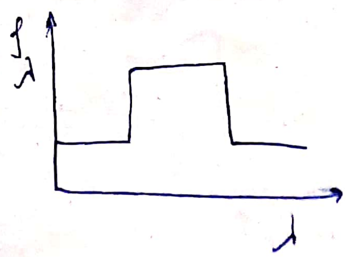
ε = emissivity

$$\varepsilon = \frac{\int_0^\infty \varepsilon_\lambda E_{b_\lambda} \, d\lambda}{\int_0^\infty E_{b_\lambda} \, d\lambda} = \frac{\int_0^\infty \varepsilon_\lambda E_{b_\lambda} \, d\lambda}{\sigma T^4}$$

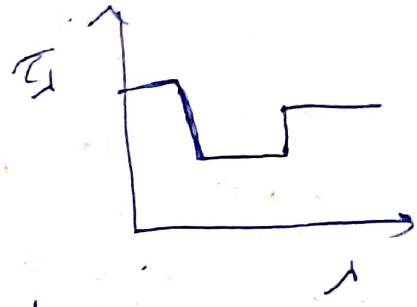
$$\alpha = \frac{\int_0^\infty \alpha_\lambda G_\lambda \, d\lambda}{\int_0^\infty G_\lambda \, d\lambda} = \frac{\int_0^\infty \alpha_\lambda G_\lambda \, d\lambda}{G}$$



$$\rho = \frac{\int_0^\infty \rho_\lambda G_\lambda \, d\lambda}{\int_0^\infty G_\lambda \, d\lambda} = \frac{\int_0^\infty \rho_\lambda G_\lambda \, d\lambda}{G}$$



$$\tau = \frac{\int_0^\infty \tau_\lambda G_\lambda \, d\lambda}{\int_0^\infty G_\lambda \, d\lambda} = \frac{\int_0^\infty \tau_\lambda G_\lambda \, d\lambda}{G}$$

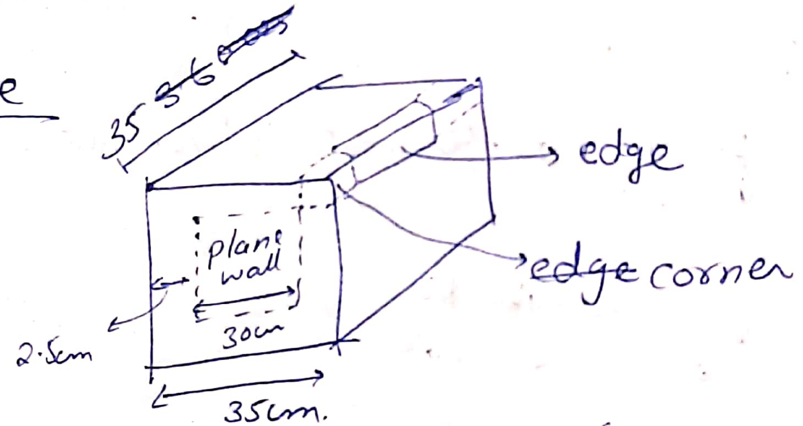


α, ρ & τ depends on what comes in i.e. G.

ε depends temperature of object i.e on E_b.

If surface is opaque & diffuse, then our ε_λ equals α_λ.

Example



We need $S_{\text{plane wall}}$, S_{edge}, S_{corner}.

$$S_{\text{plane wall}} = \frac{A}{L} = \frac{0.3 \times 0.3}{0.025} = 3.60$$

$$S_{\text{edge}} = 0.54\,D = 0.54 \times 0.3 = 0.162$$

$$S_{\text{corner}} = 0.15\,L = 0.15 \times 0.025 = 0.00375$$

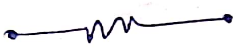
dimension of corner

$(35 - 2.5 - 2.5) = 30 = D$

There are 6 plane walls 12 edges & 8 corners

$$S_{total} = 6 \times S_{plane} + 12 S_{edge} + 8 \times S_{corner}$$
$$= 6 \times 3.6 + 12 \times 0.162 + 8 \times 0.00375$$

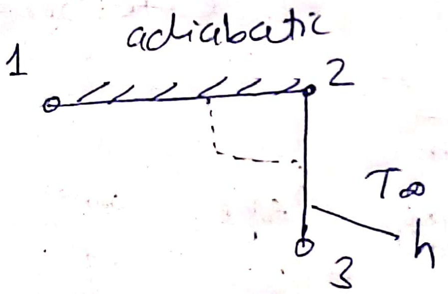
$$q = S_{total} \cdot K \Delta T$$



$1/SK$

Example

Derive finite difference eq^n for corner node



node 2

$$\sum q_{\substack{into \\ node\ 2}} = 0 = q_{cond_{3-2}} + q_{cond_{1-2}} + q_{conv}$$

$$= \frac{KA}{L} \Delta T + \frac{KA \Delta T}{L} + hA\Delta T$$

$$= K \frac{\Delta x/2}{\Delta y} \times (T_3 - T_2) + K \frac{\Delta y/2}{\Delta x} (T_1 - T_2) + h \Delta x \times (T_\infty - T_2) = 0$$

(Area is half)

Lec-17 : Radiation heat transfer surface properties example

We saw the equations:

$$\varepsilon = \frac{\int_0^\infty \varepsilon_\lambda E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda} = \frac{E}{E_b}$$

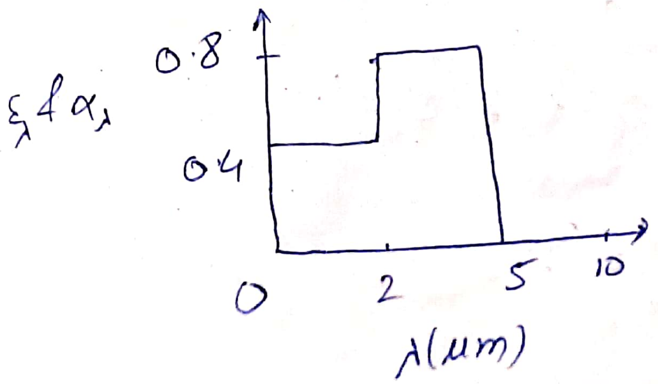
$$\alpha = \frac{\int_0^\infty \alpha_\lambda G_\lambda\, d\lambda}{\int_0^\infty G_\lambda\, d\lambda} = \frac{G_{abs}}{G} \quad \text{(absorptivity)}$$

$$\rho = \frac{\int_0^\infty \rho_\lambda G_\lambda\, d\lambda}{\int_0^\infty G_\lambda\, d\lambda} = \frac{G_{ref}}{G}$$

$$\tau = \frac{\int_0^\infty \tau_\lambda G_\lambda\, d\lambda}{\int_0^\infty G_\lambda\, d\lambda} = \frac{G_{trans}}{G}$$

Problem

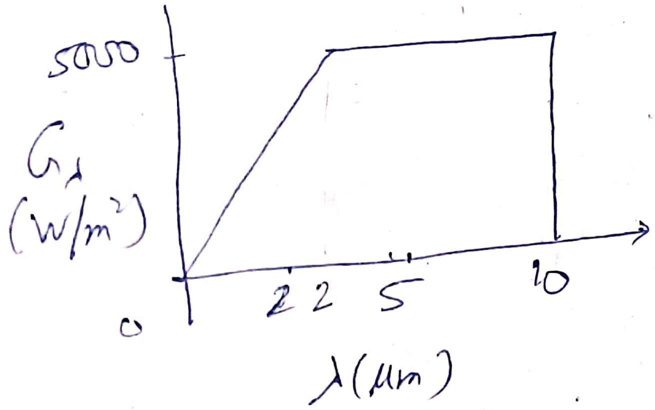
Spectral absorptivity graph given.



Surface is at 1250K.

Surface is diffuse & opaque

Also given a graph of Spectral Irradiation



Find α & E.

$$\alpha = \frac{\int_0^\infty \alpha_\lambda G_\lambda \, d\lambda}{\int_0^\infty G_\lambda \, d\lambda} = \frac{0.4 \times \frac{1}{2} \times 2 \times 5000 + 0.8 \times (5-2) \times 5000 + 0 \times (10-5) \times 5000}{\frac{1}{2} \times 2 \times 5000 + (10-2) \times 5000}$$

$$= 0.311$$

$$\int_0^\infty \alpha_\lambda G_\lambda \, d\lambda = 0.4 \times \int_0^2 G_\lambda \, d\lambda + 0.8 \times \int_2^5 G_\lambda \, d\lambda + \int_5^{10} \underset{0}{\alpha_\lambda} G_\lambda \, d\lambda + \int_{10}^\infty \underset{0}{\alpha_\lambda} \underset{0}{G_\lambda} \, d\lambda$$

Diffuse, opaque surface

$$\varepsilon_\lambda = \alpha_\lambda \quad , \quad \tau = 0$$

$$G = \frac{1}{2} \times 2 \times 5000 + 8 \times 5000 = 45{,}000$$

To find E. $E = \varepsilon E_b$

$$\varepsilon = \frac{\int_0^\infty \varepsilon_\lambda E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda}$$

for diffuse, opaque surface

$\varepsilon_\lambda = \alpha_\lambda$ $\quad \tau = 0$

$$\frac{\int_0^2 \varepsilon_\lambda E_{b\lambda}\, d\lambda + \int_2^5 \varepsilon_\lambda E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda}$$

$$= 0.4 \frac{\int_0^2 E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda} + 0.8 \frac{\int_2^5 E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda} + 0 + 0$$

$$= 0.4 \times F_{0-2} + 0.8 \times F_{2-5}$$

(We will use table)

$\lambda_1 T = 2 \times 1250 = 2500$

given temp surface

$F_{0-2} = .162$ (From table)

$\lambda_2 T = \cancel{10\times}\ 5 \times 1250 = 6250$

$\cancel{F_{2-5}}\ F_{0-5} = 0.757$

$= 0.4 \times 0.162 + 0.8(0.757 - 0.162)$

$\varepsilon = 0.540.$

So, $E = \varepsilon E_b = \varepsilon \sigma T^4$

$= 0.54 \times 5.67 \times 10^{-8} \times (1250)^4$

$$E = \varepsilon E_b$$
$$= \varepsilon \sigma T_s^4$$
$$= 0.54 \times 5.67 \times 10^{-8} \times (1250)^4$$
$$= 74,750 \ W/m^2$$

We have $\varepsilon \neq \cancel{\alpha}\alpha$, but we had

$\varepsilon_\lambda = \alpha_\lambda$ (for

$\varepsilon = \alpha$ if we have grey surface.

We know that

$$\alpha + \rho + \tau = 1$$
$$\tau = 0, \Rightarrow \rho = 1 - \alpha$$
$$= 1 - 0.311$$
$$\rho = 0.689$$

So, $\varepsilon = 0.54$

$\alpha = 0.311$

$\tau = 0$

$\rho = 0.689$

$E = 74,750 \ W/m^2$

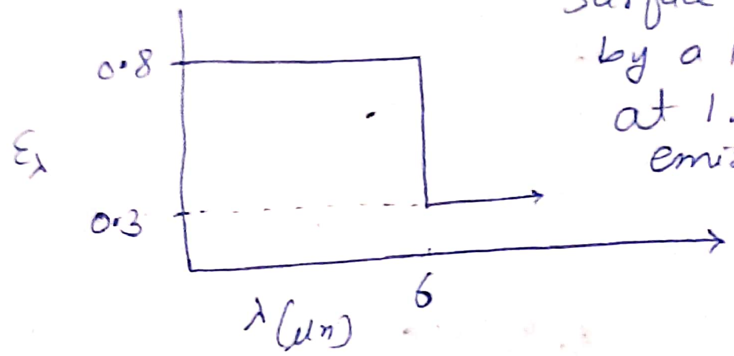
$G = 45,000 \ W/m^2$

$$J = E + \rho G = 74750 + 0.689 \times 45000$$
$$= 105,750 \ W/m^2$$

$q''_{net} = J - G$
(Net heat flux leaving the surface)
$$= 105750 - 45000$$
$$= 60750 \ W/m^2$$

Example

Opaque, diffuse surface at 1000 K.



Surface is irradiated by a large surrounding at 1500 K and emissivity of 0.8

Find ε & α.

$$\varepsilon = \frac{\int_0^\infty \varepsilon_\lambda E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda}$$

$$= \frac{\int_0^6 \varepsilon_\lambda E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda} + \frac{\int_6^\infty \varepsilon_\lambda E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda}$$

$$= 0.8 \frac{\int_0^6 E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda} + 0.3 \frac{\int_6^\infty E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda}$$

$$= 0.8\, F_{0-6} + 0.3\, F_{6-\infty}$$

$\lambda_1 T = 6 \times 1000 = 6000$

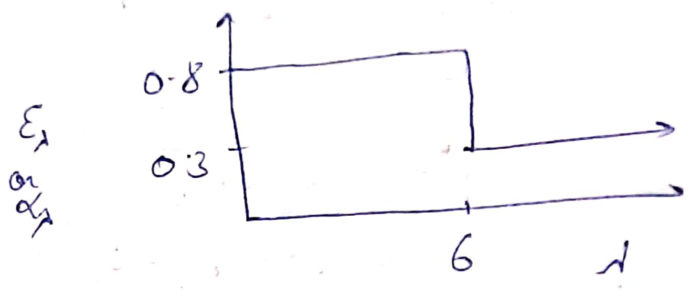
$F_{0-6} = 0.7378$

$F_{6-\infty} = 1 - F_{0-6} = 0.2622$

$\varepsilon = 0.8 \times 0.7378 + 0.3 \times 0.2622$

$= 0.6689$

For diffuse, $\alpha_\lambda = \varepsilon_\lambda$

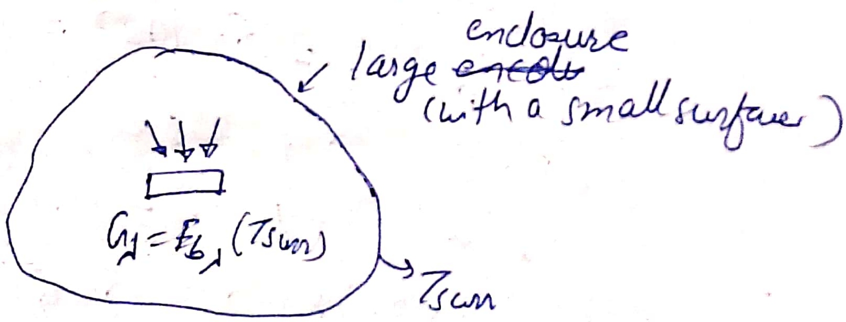


$$\alpha = \frac{\int_0^\infty \alpha_\lambda G_\lambda \, d\lambda}{\int_0^\infty G_\lambda \, d\lambda}$$

$$= \frac{\int_0^6 \alpha_\lambda G_\lambda \, d\lambda}{\int_0^\infty G_\lambda \, d\lambda} + \frac{\int_6^\infty \alpha_\lambda G_\lambda \, d\lambda}{\int_0^\infty G_\lambda \, d\lambda}$$

$$= 0.8 \frac{\int_0^6 G_\lambda \, d\lambda}{\int_0^\infty G_\lambda \, d\lambda} + 0.3 \frac{\int_6^\infty G_\lambda \, d\lambda}{\int_0^\infty G_\lambda \, d\lambda}$$

Given surface is irradiated by a large surrounding and 1500 K & emissivity of 0.8.



The irradiation appears to come from a blackbody at temperature of surroundings so, we can replace with $E_{b\lambda}$

$$\alpha = 0.8 \frac{\int_0^6 E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda} + 0.3 \frac{\int_6^\infty E_{b\lambda}\, d\lambda}{\int_0^\infty E_{b\lambda}\, d\lambda}$$

$$= 0.8 \times F_{0-6} + 0.3 \times F_{6-\infty}$$

(fraction of energy from 0-6)

$= \cancel{0.8 \times 0.7378 + 0.3(1-0.7378)}$

We have a surface temperature at 1000K and enclosure wall temperature at 1500K.

Our irradiation comes from enclosure wall temp at 1500K

$$\lambda T = \cancel{0.6}\ 6 \times 1500 = 9000\,K$$

$= \cancel{0.8 \times 0.890}$ $F_{0-6} = 0.890$ (from table)

$$\alpha = 0.8 \times 0.890 + 0.3 \times (1 - 0.890)$$

$$\alpha = 0.745$$

So, $\alpha = 0.745$, $\varepsilon = 0.669$.

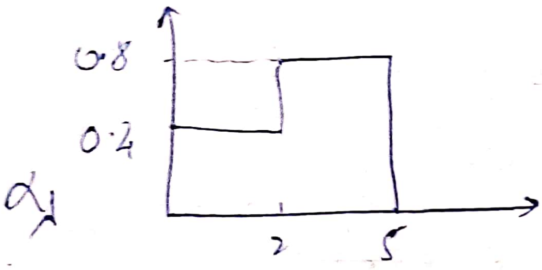
$$\rho = 0.255$$

We were given emissivity of walls but was of ~~not~~ use. Emissivity of walls be 8/10 or 1/10, it did not affect the problem.

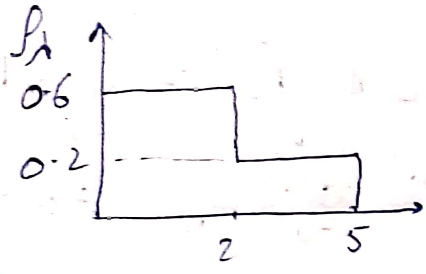
$$E = \varepsilon E_b = \varepsilon \sigma T^4 = 0.669 \times 5.67 \times 10^{-8} \times (1000)^4$$

$$= 37932.3\ W/m^2$$

For a given opaque surface if we are give α_λ graph we can get ρ_λ graph by just ~~doo~~ $\rho_\lambda = 1 - \alpha_\lambda$



given



found $\rho_\lambda = 1 - \alpha_\lambda$

Intensity of Radiation (I)

It is directional.
(We will not use this)

Surface Properties can be

Directional (depend on angle)	Spectral (depend on wavelength)
Hemispherical (Over all angles)	total (over all wavelength)

$\varepsilon \rightarrow$ hemispherical total emissivity

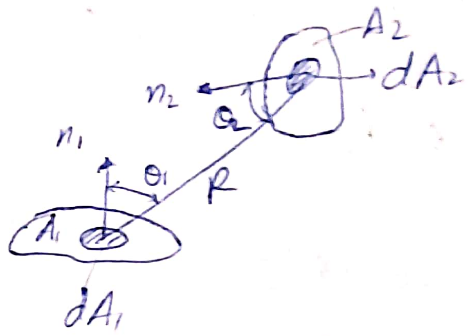
$\varepsilon_\lambda \rightarrow$ hemispherical spectral emissivity

$\varepsilon_{\theta,\lambda} \rightarrow$ directional spectral emissivity

(hemispherical means integrating over all angles)

Lec-18 (View factor, simple view factor example)

Radiation exchange b/w surfaces



we want to find how much energy leaves surface A_1 that reaches A_2

$$q_{A_1-A_2} = F_{A_1-A_2} A_1 J_1 \text{ and}$$

$$q_{A_2-A_1} = F_{A_2-A_1} A_2 J_2$$

J = radiosity → surface energy leaving surface

where $F_{A_1-A_2}$ = (view factors) fraction of ~~energy~~ radiation energy leaving A_1 that is intercepted or received by A_2.

$$F_{A_1-A_2} = \frac{1}{A_1} \int_{A_1} \int_{A_2} \frac{\cos\theta_1 \cos\theta_2}{\pi R^2} dA_2 \, dA_1$$

same

also going from A_2 to A_1

$$F_{A_2-A_1} = \frac{1}{A_2} \int_{A_2} \int_{A_1} \frac{\cos\theta_2 \cos\theta_1}{\pi R^2} dA_1 \, dA_2$$

So, $\boxed{A_1 F_{A_1-A_2} = A_2 F_{A_2-A_1}}$

$F_{A_1 - A_2} = F_{1-2} = F_{12}$

F_{12} : F from surface 1 to surface 2.

So, $\boxed{A_1 F_{12} = A_2 F_{21}}$

Reciprocity relation.

For an enclosure with N surfaces

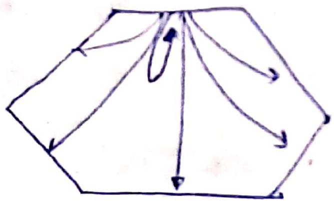
$\boxed{\sum_{j=1}^{N} F_{ij} = 1.}$ for each surface A_i in the enclosure

Enclosure law

It is ~~we get by~~ energy balance on surface A_i.

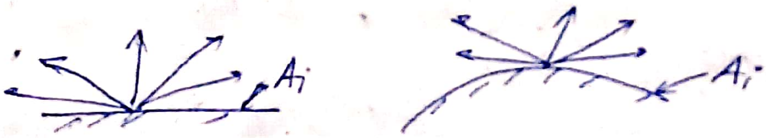
So, for surface A_1 with $N = 6$.

$$F_{11} + F_{12} + F_{13} + F_{14} + F_{15} + F_{16} = 1$$



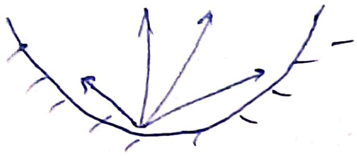
(Here $F_{11} = 0$)
(Radiation doesn't do U-turn.)

For a plane or convex surface



$F_{ii} = 0$ $\quad$ $F_{ii} = 0.$

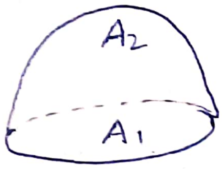
For a concave surface



$F_{ii} \neq 0$

Number of $F's = N^2$.
N = number of surface

Example



Here $N = 2$.
Number of view factors $= 2^2 = 4$.

$$\begin{bmatrix} F_{11} & F_{12} \\ F_{21} & F_{22} \end{bmatrix}$$

$F_{11} = 0 \qquad F_{12} = 1$

(100% energy from surface 1 reaches surface 2)

Every row sums upto 1. (Enclosure Law)

$F_{11} + F_{12} = 1$

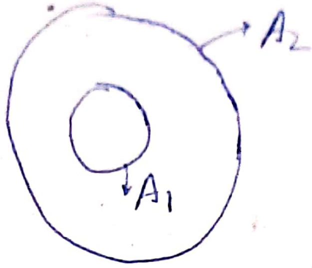
$\Rightarrow F_{12} = 1.$

$$F_{21} = \frac{A_1}{A_2} F_{12} \quad \text{(Reciprocity relation)}$$

$$F_{21} = \frac{\pi D^2/4}{\pi D^2/2} F_{12} = \frac{F_{12}}{2}$$

$F_{22} = 1 - F_{21}$

Ex



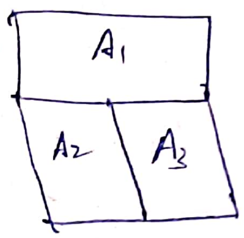
It is an enclosure

$F_{11} = 0 \qquad F_{12} = 1$

$$F_{21} = \frac{A_1}{A_2} F_{12}$$

$$F_{22} = 1 - \frac{A_1}{A_2} F_{12}$$

Ex:-



$\cancel{A_1 F_{1-2,3} = A_2 F_{12}}$

$$A_1 F_{1-2,3} = A_1 F_{1-2} + A_1 F_{1-3}$$

$$\Rightarrow \quad F_{1-2,3} = F_{1-2} + F_{1-3}$$

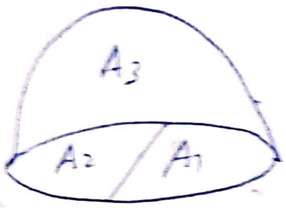
– to

, and

Fraction of energy leaving 1 and going to 2 and 3 is : $F_{1-2,3}$.

$$A_{2,3} F_{2,3-1} = A_2 F_{2-1} + A_3 F_{3-1}$$

Fraction of energy leaving 2 & 3 & going to 1.



$N = 3$

$\# F's = N^2 = 3^2 = 9$

$$\begin{bmatrix} F_{11} & F_{12} & F_{13} \\ F_{21} & F_{22} & F_{23} \\ F_{31} & F_{32} & F_{33} \end{bmatrix}$$

$F_{11} = F_{22} = 0$. (plane surfaces)

$F_{12} = F_{21} = 0$ (both on a ~~sa~~ same plane)

Every row is an enclosure

$\cancel{F_{11}} + \cancel{F_{12}} + F_{13} = 1$
$0 \quad 0$

$F_{13} = 1$

similarly $\cancel{F_{21}} + \cancel{F_{22}} + F_{23} = 1$
$0 \quad 0$

$F_{23} = 1$

$A_3 F_{3-1} = A_1 F_{1-3}$

$F_{3-1} = \frac{A_1}{A_3}$

$A_3 F_{3-2} = A_2 F_{2-3}$

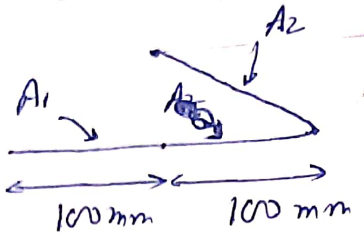
$F_{3-2} = \frac{A_2}{A_3}$

$$F_{3-3} = 1 - \frac{A_1}{A_3} - \frac{A_2}{A_3} = \frac{A_3 - A_1 - A_2}{A_3}$$

We have all the view factors.

We get all Fs by observations.

Example



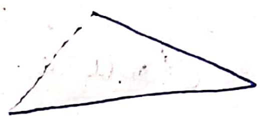
(Long inclined planes)

Find F_{1-2} & F_{2-1}.

Not an enclosure

$$F_{1-2} = 0.5$$

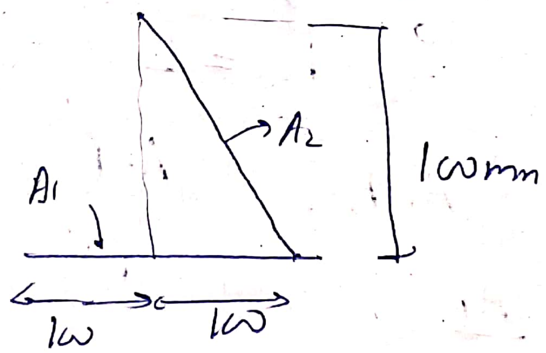
Half energy leaving surface A_1 will hit surface A_2.
Other half goes through dashed line



$$F_{2-1} = \frac{A_1 F_{1-2}}{A_2}$$

$F_{11} = 0$ $F_{22} = 0$ (by plane surfaces)

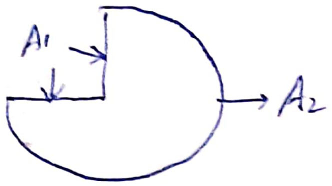
Example



Again $F_{1-2} = 0.5$.

Since half energy leaving A_1 will hit surface A_2.

Example



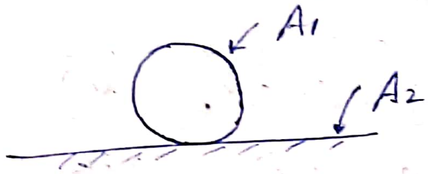
Long Duct

$F_{11} = 0 \quad F_{12} = 1$

$$F_{21} = \frac{A_1}{A_2} F_{12} \qquad 1 - F_{21} = F_{22}$$

Example

Sphere lying on an infinite plane



~~$F_{11} = 0$~~ ~~F_{12}~~

This is not an enclosure.

$F_{1-2} = 0.5$

Half goes down the sphere &
half goes above it.

$$F_{21} = \frac{A_1}{A_2} F_{1-2}$$

(Considering every surface is diffuse)

We looked at

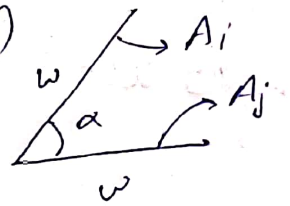
Reciprocity
$$A_i F_{ij} = A_j F_{ji}$$

Enclosure Law
$$\sum_{j=1}^{N} F_{ij} = 1$$

Plane or convex wall
$$F_{ii} = 0$$

To find F we generally look at table. Example given in table -

(2D geometries)

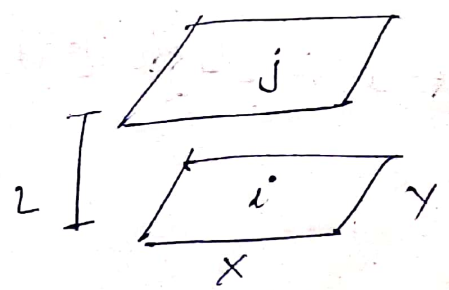


$$F_{ij} = 1 - \sin\left(\frac{\alpha}{2}\right)$$

other cases are similar.

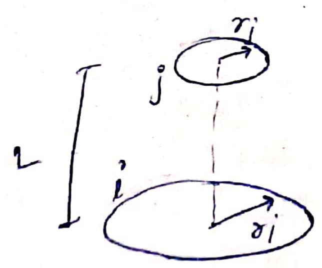
Similarly we have table for 3D geometries (3D-geometries)

①



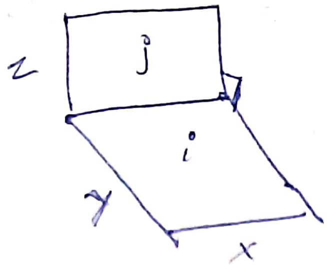
$F_{ij} = \text{----}$

②



$F_{ij} = \text{--}$

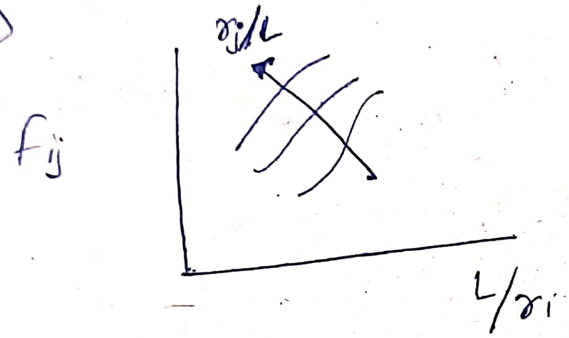
We have eq^ns for each case.

3


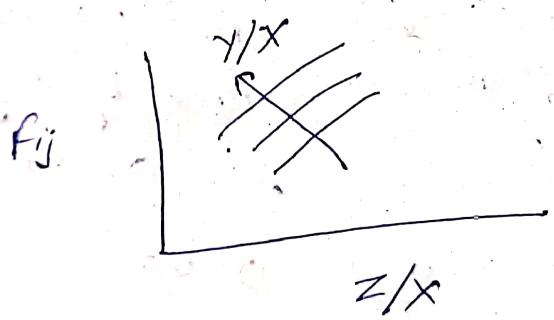
$f_{ij} = \cdots$

we also have graph other than equations
for case 1 we have a graph like -

Case 2 =>

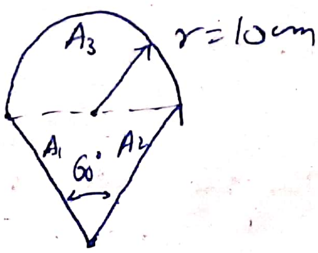


Case 3 =>



we have graphs & equations for each case. So, we can use any.

Example Long Duct Find all f's.



$N = 3$ surfaces

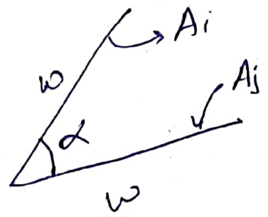
$\#\ F's = N^2 = 3^2 = 9$

$$\begin{bmatrix} F_{11} & F_{12} & F_{13} \\ F_{21} & F_{22} & F_{23} \\ F_{31} & F_{32} & F_{33} \end{bmatrix}$$

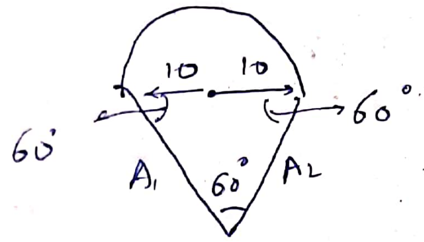
It is long duct, so we are supposed to use 2D geometry.

$F_{11} = 0 \quad F_{22} = 0$

For 2D geometry, we have



$F_{ij} = 1 - \sin(\alpha/2)$



$A_1' = 20$ cm

('Area' by length)

$A_2' = 0.2$ m

$A_3' = \frac{\pi (0.2)}{2} = 0.10\pi$.

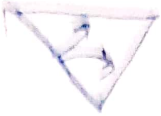
$F_{12} =$ We have equal sides & angle b/w is 60°.

$F_{12} = 1 - \sin\left(\frac{60}{2}\right) = 1 - \sin 30 = 1 - \frac{1}{2}$

$= \underline{\underline{\frac{1}{2}}}$

$F_{12} = 0.5$

For equilateral triangle we have F_{12} as 50%..



Similarly $F_{21} = 0.5$.

From enclosure law we have

$$F_{11}' + F_{12} + F_{13} = 1$$

$$0 + 0.5 + F_{13} = 1$$

$$\therefore F_{13} = 0.5$$

Also, $F_{23} = 0.5$.

$$\cancel{F_{13} = A_3}\ F_{31} = \frac{A_1'}{A_3'} F_{13}$$

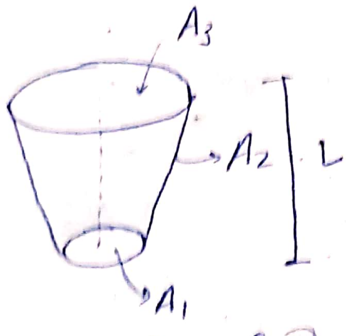
$$F_{31} = \frac{0.2}{0.1\pi} \times 0.5 = \frac{1}{\pi}$$

$F_{31} = F_{32}$ (Symmetry)

$$F_{32} = \frac{1}{\pi} = 0.318$$

$$F_{33} = 1 - \frac{1}{\pi} - \frac{1}{\pi} = 1 - \frac{2}{\pi} = 0.364.$$

Example: Truncated cone



$r_1 = 5\text{cm}$
$r_3 = 20\text{cm}$
$L = 10\text{ cm}$

$$\begin{bmatrix} F_{11} & F_{12} & F_{13} \\ F_{21} & F_{22} & F_{23} \\ F_{31} & F_{32} & F_{33} \end{bmatrix}$$

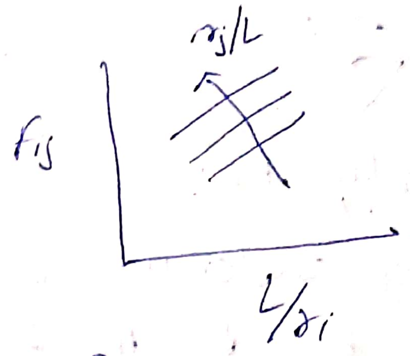
$F_{11} = 0 = F_{33}$

Now, we will use graph.

$i = 1,\ j = 3$, we find F_{13}.

$\frac{L}{r_1} = \frac{10}{5} = 2$

$\frac{r_3}{L} = \frac{20}{10} = 2$



We get F_{13} from graph $= 0.80$.

or We can also use equation.

$$F_{ij} = \frac{1}{2}\left\{ S - \left[S^2 - 4\left(\frac{r_j}{r_i}\right)^2 \right]^{1/2} \right\}$$

where $R_i = \frac{r_i}{L}$ and $R_j = \frac{r_j}{L}$

and $S = 1 + \frac{1+R_j^2}{R_i^2}$

$R_1 = \frac{5}{10} = 0.5 \quad R_j = \frac{20}{10} = 2.0$

$S = 1 + \frac{1+4}{(0.5)^2} = 1 + \frac{5}{(1/2)^2} = 21$

$F_{ij} = \frac{1}{2}\left\{ 21 - \left[441 - 4\times\left(\frac{20}{5}\right)^2 \right]^{1/2} \right\}$

$= \frac{1}{2}\left\{ 21 - [441 - 64]^{1/2} \right\}$

$= \frac{1}{2}\{21 - 19.41\} = 0.7917$

$\simeq 0.8.$

$F_{13} = 0.8$

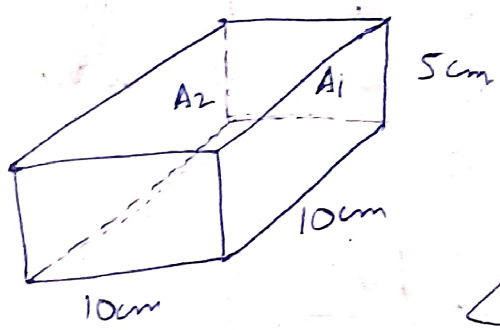
$F_{12} = 1 - F_{13} - \underbrace{\cancel{F_{11}}}_{0} = 1 - 0.8 = 0.2$

$F_{31} = \frac{A_1}{A_3} F_{13} = \frac{\pi r_1^2}{\pi r_3^2} \times F_{13} = \left(\frac{5}{20}\right)^2 \times F_{13}$

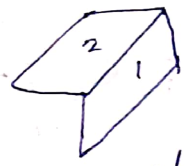
$F_{31} = \frac{1}{16} \times 0.8 = 0.05$

$F_{32} = 1 - F_{33} - F_{31} = 1 - 0.05 = 0.95$

Example



2 → Top
1 → Side



Find F_{21}. We solve from graph.

$i = 2$, $j = 1$

We need Z/X & Y/X

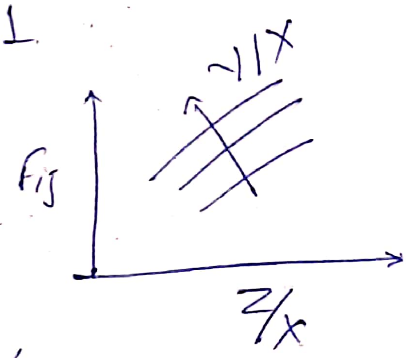
X = common edge where 2 touch = 10cm.

Y = 10cm

Z = 5cm

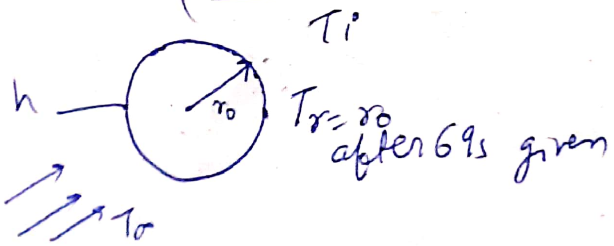
$\frac{Z}{X} = \frac{5}{10} = 0.5 \qquad \frac{Y}{X} = 1$

From graph $F_{21} = 0.15$



We have N^2 view factors for this box.

Example (Transient problems)



$$B_i = \frac{h L_c}{K} < 0.1$$

If < 0.1 we use LHC.

As we can't use B_i, but we can assume that LHC can work as it is easy approach.

$$\frac{\theta}{\theta_i} = \exp\left[-\frac{h A_s}{\rho C_p V} t\right]$$

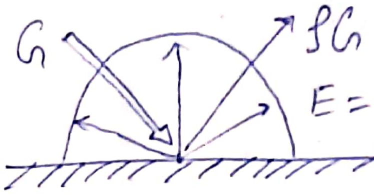
$\theta_i = T_i - T_\infty \qquad \theta = T - T_\infty$

From this, we find h. And check if $B_i < 0.1$, then our answer is good.

Else, we use formula when $B_i > 0.1$.

Radiation heat exchange b/w surfaces

Consider diffuse, grey, opaque surface



$E = \varepsilon E_b = \varepsilon \sigma T^4$

recall. $J = \varepsilon E_b + \rho G$

and recall $\rho = 1 - \alpha = 1 - \varepsilon$

opaque surface $\tau = 0$.

we solve for G.

$$G = \frac{J - \varepsilon E_b}{1 - \varepsilon}$$

next

$$q'' = \frac{q}{A} = \text{net radiation leaving surface}$$

$$= J - G$$

$$q'' = J - \left(\frac{J - \varepsilon E_b}{1 - \varepsilon} \right)$$

$$= \frac{\varepsilon (E_b - J)}{1 - \varepsilon}$$

$$q = \frac{\varepsilon A (E_b - J)}{1 - \varepsilon} = \frac{E_b - J}{\left(\frac{1 - \varepsilon}{\varepsilon A} \right)}$$

(In chapter 3 we had $q = \frac{T_1 - T_2}{R_{cond}}$)

$$q = \frac{E_b - J}{\left(\frac{1-\varepsilon}{\varepsilon A}\right)}$$

For conduction

$T_1 \xrightarrow{q} T_2$

$1/KA$

$$\boxed{R_{surface} = \frac{1-\varepsilon}{\varepsilon A}}$$

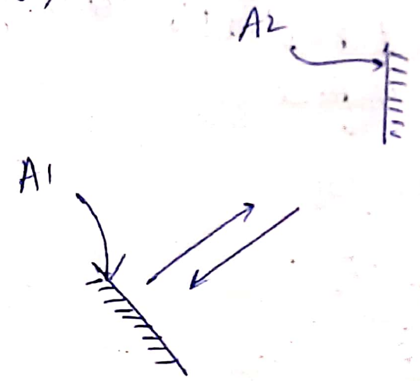
$E_{b1} \xrightarrow{q} J_1$

$$\frac{1-\varepsilon}{\varepsilon A}$$

For black surface. $\cancel{\varepsilon = 0}$. $\varepsilon = 1 \Rightarrow R = 0$.

So, this means we get maximum heat flow.

Next, look at two surfaces exchanging radiation.



$$q_{1-2} = F_{12} A_1 J_1 - F_{21} A_2 J_2$$

(Net heat b/w 1 to 2)

from reciprocity $A_1 F_{12} = A_2 F_{21}$

$$q_{1-2} = A_1 F_{12} (J_1 - J_2)$$

$$q_{1-2} = \frac{J_1 - J_2}{\left(\frac{1}{A_1 F_{12}}\right)}$$

$$\boxed{\frac{1}{A_1 F_{12}} = \text{space Resistance}} = R_{space}$$

$$\boxed{R_{space} = \frac{1}{A_1 F_{12}}}$$

$$J_1 \xrightarrow[\frac{1}{A_1 F_{12}}]{q} J_2$$

In the enclosure every surface has surface resistance and every pair of surface has space resistance.

Example

Consider a 2-surface enclosure like .

Each surface has surface resistance

$$E_{b1} \xrightarrow[\frac{1-\varepsilon_1}{\varepsilon_1 A_1}]{q} J_1$$

Now there is ~~sect~~ resistance b/w two surfaces.

$$J_1 \xrightarrow[\frac{1}{A_1 F_{12}}]{q_{12}} J_2$$

Now surface 2 has surface resistance

$$J_2 \xrightarrow[\frac{1-\varepsilon_2}{\varepsilon_2 A_2}]{q} E_{b2}$$

It looks as

$$E_{b1} \xrightarrow[\frac{1-\varepsilon_1}{\varepsilon_1 A_1}]{q_1} J_1 \xrightarrow[\frac{1}{A_1 F_{12}}]{q_{12}} J_2 \xrightarrow[\frac{1-\varepsilon_2}{\varepsilon_2 A_2}]{q_2} E_{b2}$$

Three resistances are in series

$$q_1 = q_{12} = q_2$$

$$q_{12} = \frac{E_{b_1} - E_{B_2}}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1 F_{12}} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2}}$$

For infinite plane surfaces (i.e spacing is small b/w them)

$$q'' = \frac{q}{A} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

For two black surfaces $\varepsilon_1 = \varepsilon_2 = 1$.

$$q_{12} = A_1 \varepsilon_1 \sigma (T_1^4 - T_2^4)$$

For enclosure with $F_{12} = 1$

$$q = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \cancel{\frac{1}{\varepsilon_2}} - 1 + \frac{A_1}{A_2}\left(\cancel{\frac{1-\varepsilon_2}{\varepsilon_2 A_2}}\right)}$$

$$q = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} - 1 + 1 + \frac{A_1}{A_2}\left(\frac{1-\varepsilon_2}{\varepsilon_2}\right)}$$

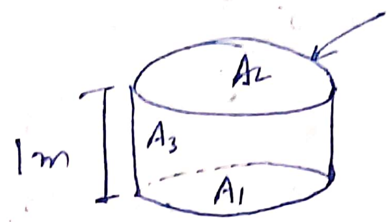
1 2

if ~~$A_2 \ggg A_1$~~ $A_2 \ggg A_1$

$$\boxed{q = \varepsilon_1 A_1 \sigma (T_1^4 - T_2^4)}$$

(for small object in an enclosure)

Consider a 3 surface enclosure (127)



$\varepsilon_1 = 1$ $T_1 = 1000K$
$\varepsilon_2 = 1$ $T_2 = 325K$
$\varepsilon_3 = 1$ $T_3 = 448K$

$A_1 = \pi(2^2) = A_2$ $A_3 = \pi D \times 1 = \pi \times 4 \times 1 = 4\pi$
$A_1 = 4\pi = A_2$

Find $q_1, q_2, q_3, q_{12}, q_{13}, q_{23}$:

We need view factor for space resistance

$F_{11} = 0 = F_{22}$

For coaxial circular disc separated by a distance d

$$\frac{L}{r_1} = \frac{1}{2} = 0.5$$

$$\frac{r_2}{L} = \frac{2}{1} = 2.0$$

From graph we get $F_{12} = 0.8$
We need F_{13}. (By enclosure laws)
$F_{13} = 1 - F_{11} - F_{12} = 1 - 0.8 = 0.2$.
We get same for F_{23} as symmetrical.
$F_{23} = 0.2$ $F_{21} = 0.8$.

$\cancel{F_{33} = 1 - F_{31} - F_{32}}$

$A_1 F_{13} = A_3 F_{31}$ $F_{31} \cancel{A_{31}} = \frac{A_1}{A_3} F_{13} = 1 \times 0.2$

$F_{32} = 0.2$

$\Rightarrow$ $F_{33} = 1 - 0.2 - 0.2 = 0.6$.

We have all view factors.

$\varepsilon_1 = 1$ | $T_1 = 1050\ K$ | $E_{b_1} = \sigma T_1^4 = 56{,}700$

$\varepsilon_2 = 1$ | $T_2 = 325\ K$ | $E_{b2} = \sigma T_2^4 = 633$

$\varepsilon_3 = 1$ | $T_3 = 448\ K$ | $E_{b_3} = \sigma T_3^4 = 2284$

$F_{11} = 0 \quad F_{12} = 0.8 \quad F_{13} = 0.2$ | $A_1 = 4\pi$

$F_{21} = 0.8 \quad F_{22} = 0 \quad F_{23} = 0.2$ | $A_2 = 4\pi$

$F_{31} = 0.2 \quad F_{32} = 0.2 \quad F_{33} = 0.6$ | $A_3 = 4\pi$

$$R_1 = \frac{1-\varepsilon_1}{\varepsilon_1 A_1} = 0 = R_2 = R_3$$

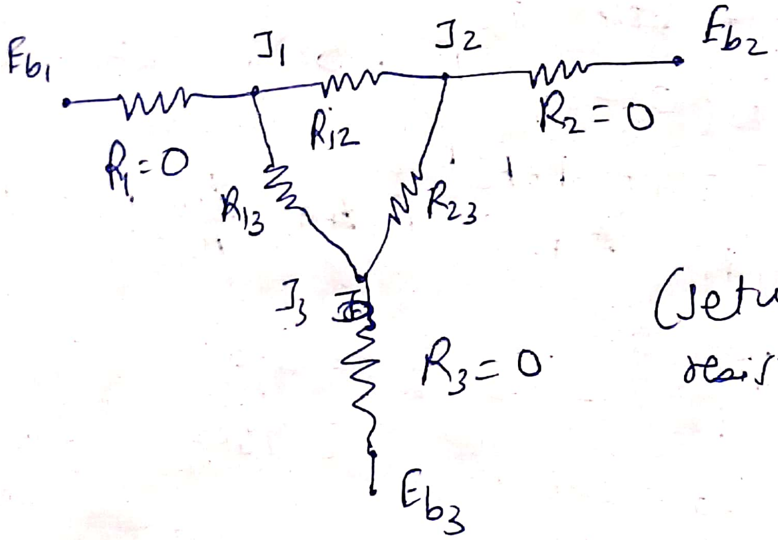
All surface resistances are 0.

$$R_{12} = \frac{1}{A_1 F_{12}} = \frac{1}{4\pi \times 0.8} = 0.0994$$

$$R_{13} = \frac{1}{A_1 F_{13}} = \frac{1}{4\pi \times 0.2} = 0.3978$$

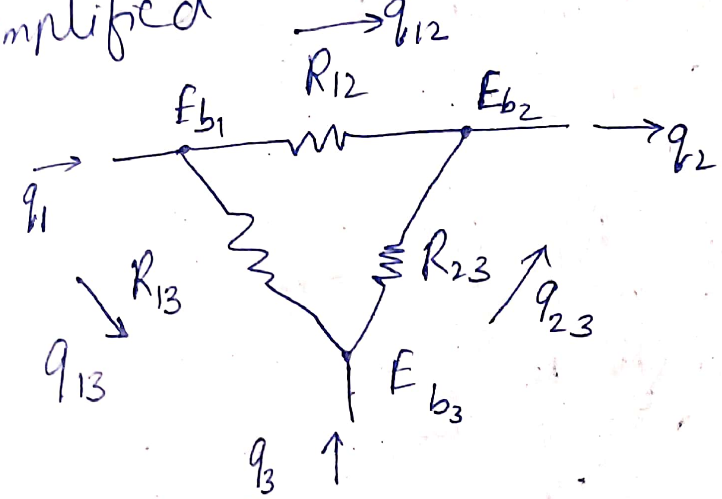
$$R_{23} = \frac{1}{A_2 F_{23}} = \frac{1}{4\pi \times 0.2} = 0.3978$$

Now we construct circuit.



(setup of resistors)

Simplified



(Heat comes in from hottest & goes out from coldest)

We know which way q_1 & q_2 goes but do not know where q_3 goes.

Solve for all q's

$$q_{1\text{-}2} = \frac{E_{b_1} - E_{b_2}}{R_{12}} = \frac{56700 - 633}{0.0944} = 593930$$

$$q_{13} = \frac{E_{b_1} - E_{b_3}}{R_{13}} = \frac{56700 - 2284}{0.3978} = 136792.4$$

$$q_{32} = \frac{E_{b_3} - E_{b_2}}{R_{23}} = \frac{2284 - 633}{0.3978} = 4150.3$$

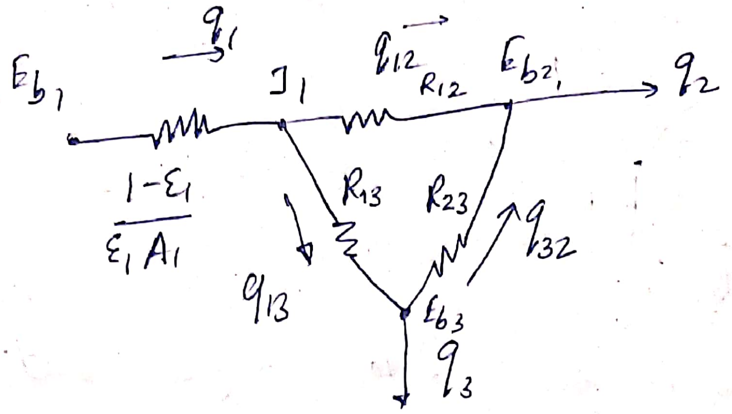
$$q_1 = q_{1\text{-}2} + q_{13} = 593930 + 136{,}792.4$$
$$= 730{,}722.4$$

$$q_2 = q_{12} + q_{32} = 598080.3$$

$$q_3 = q_{13} - q_{23} = 589779.7$$

(goes out)

If we have value for $\varepsilon_1 < 1$. Then we will have J_1



$$\frac{E_{b_1} - J_1}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1}} = \frac{J_1 - E_{b_2}}{R_{12}} + \frac{J_1 - E_{b_3}}{R_{13}}$$

We know all values, so we get J_1.

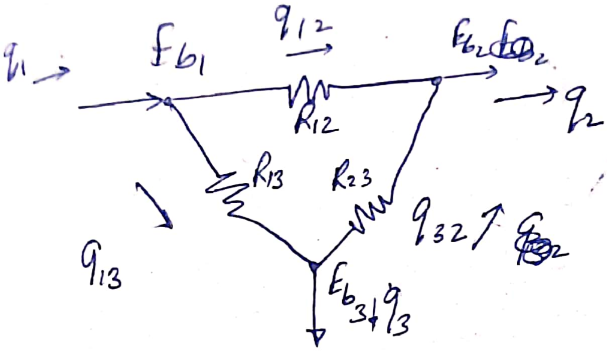
Once we get J_1, we get all values of q.

Lec-21 (Radiation network example)

(V) In our previous example, now we consider that all are black surfaces but A_3 is reradiating.

We still have $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 1$.

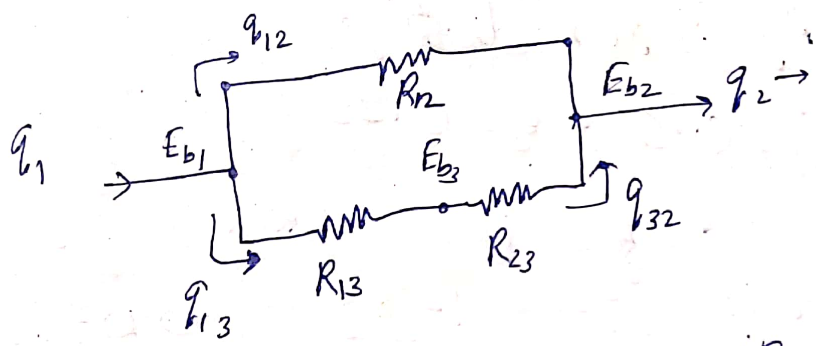
So, $R_1 = R_2 = R_3 = 0$.



As eit is reradiating $q_3 = 0$.

So, $q_{13} = q_{32}$

So, our diagram looks as→



So ~~It~~ Now it has resistances in parallel

$$q_1 = \frac{E_{b_1} - E_{b_2}}{\frac{(R_{12}) \times (R_{13} + R_{23})}{(R_{12}) + (R_{13} + R_{23})}} = q_2$$

$$q_{12} = \frac{E_{b_1} - E_{b_2}}{R_{12}}$$

$$q_{13} = \frac{E_{b_1} - E_{b_2}}{(R_{13} + R_{23})} = q_{32}$$

We have 5 qs. ($q_1, q_2, q_{12}, q_{13}, q_{23}$)

We are not given T_3, so we do not know E_{b_3}

$$q_{13} = \frac{E_{b_1} - E_{b_3}}{R_{13}}$$

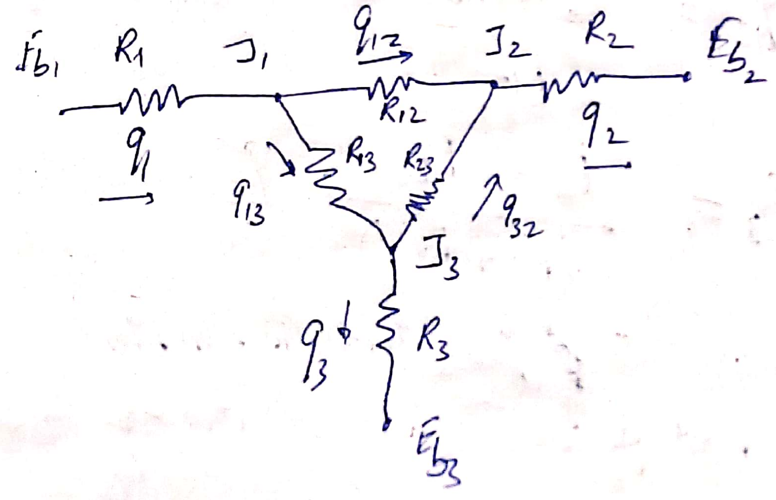
$$q_{13} = \frac{E_{b_1} - \sigma T_3^4}{R_{13}}$$

We now get T_3.
So, we can solve & get $q_1, q_2, q_3, q_{13}, q_{32}, T_3$.

(III) Now we consider non-black surface but A_3 is reradiating.
$\epsilon_1 = \epsilon_2 = 0.5$ & $\epsilon_3 = 0.25$
So, each surface has surface resistance $\frac{1-\epsilon_1}{\epsilon_1 A_1} = \frac{1-0.5}{0.5 \times (4\pi)} = 0.0796$
$= R_2$

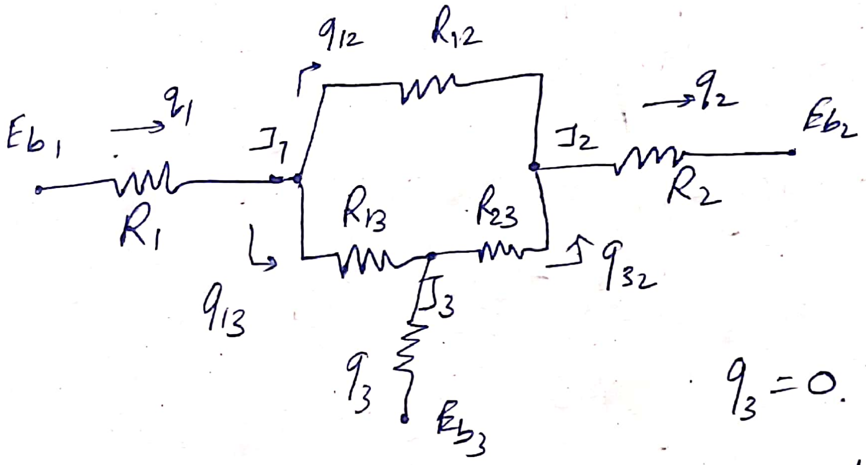
$$R_3 = \frac{1-0.25}{0.25 \times (4\pi)} = 0.239$$

So, we have 3 surface resistances



Reradiating, so $q_3 = 0$

$$q_{13} = q_{23}$$



$q_3 = 0.$

As $q_3 = 0$, we can remove the part from J_3 to E_{b3}.

So, here we have series parallel combination

$$q_1 = \frac{E_{b_1} - E_{b_2}}{R_1 + \frac{(R_{12})(R_{13}+R_{23})}{R_{12}+R_{13}+R_{23}} + R_2}$$

(we know E_{b_1}, E_{b_2} & all resistances)

So, we get q_1 & from picture $q_1 = q_2$.

Given $q_3 = 0$ (reradiating)

$$q_{12} = q_1 \left[\frac{R_{13} + R_{23}}{R_{12} + R_{13} + R_{23}} \right]$$ (current divider theorem from circuit theory)

$$q_{23} = q_1 \left[\frac{R_{12}}{R_{12} + R_{13} + R_{23}} \right] = q_{32}$$

So, we have q_1 q_2 q_{13} . q_{23} q_{12}.
We can also find T_3 if not given.

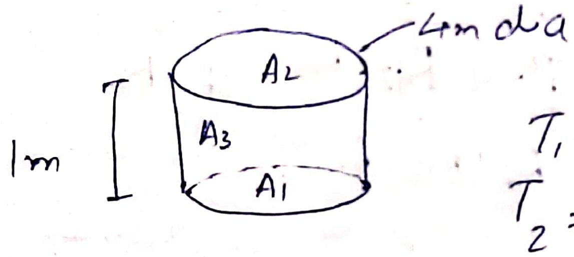
$$q_1 = \frac{E_{b_1} - J_1}{R_1}$$

we get J_1.

$$q_{13} = \frac{J_1 - J_3}{R_{13}}$$

we get J_3.
But $J_3 = E_{b_3} = \sigma T_3^4$ (As no resistance b/w them)
we get T_3.

(IV) Non-black surfaces, all T's & ε given.



$T_1 = 1000K$
$T_2 = 325K$
$T_3 = 468K$

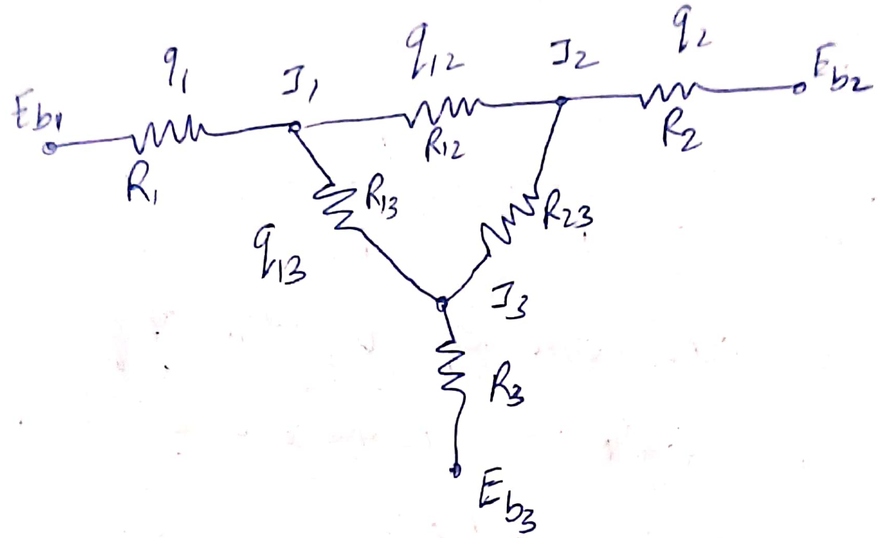
$\varepsilon_1 = \varepsilon_2 = 0.5$, $\varepsilon_3 = 0.25$

$R_1 = R_2 = 0.0796$ $R_3 = 0.239$
(Surface resistances)

$R_{12} = 0.0994$ $R_{13} = 0.3978$ $R_{23} = 0.3978$
(Space resistances)

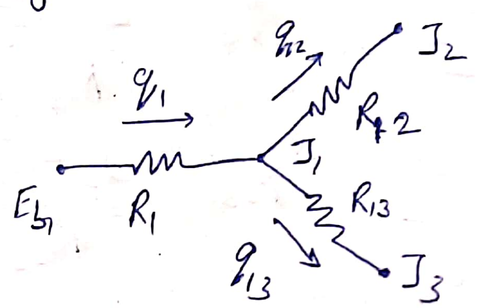
$E_{b_1} = 56,700$ $E_{b_2} = 633$ $E_{b_3} = 2284$

We need to find all q's.



For each surface in the enclosure

For surface A_1

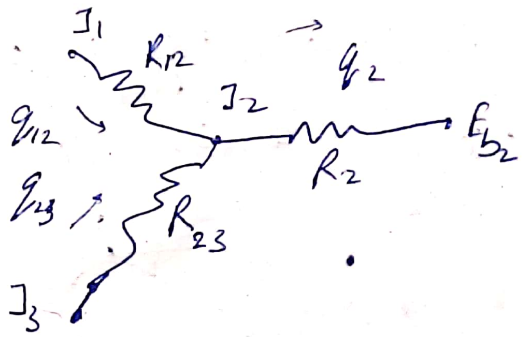


($R_{13} = R_{31}$, $R_{32} = R_{23}$)

$$q_1 = q_{12} + q_{13}$$

$$\frac{E_{b_1} - J_1}{R_1} = \frac{J_1 - J_2}{R_{12}} + \frac{J_1 - J_3}{R_{13}}$$

For surface A_2.



$$q_2 = q_{12} + q_{23}$$

$$\frac{E_{b_2} - J_2}{R_2} = \frac{J_2 - J_1}{R_{12}} + \frac{J_2 - J_3}{R_{23}}$$

Similarly for surface A_3

$$\frac{E_{b_3} - J_3}{R_3} = \frac{J_3 - J_1}{R_{13}} + \frac{J_3 - J_2}{R_{23}}$$

The math takes care of direction of q.

We have 3 eq^{n}s & 3 unknowns J_1, J_2 & J_3.

Then we calculate all q's

$$q_1 = \frac{E_{b_1} - J_1}{R_1} \qquad q_{12} = \frac{J_1 - J_2}{R_{12}}$$

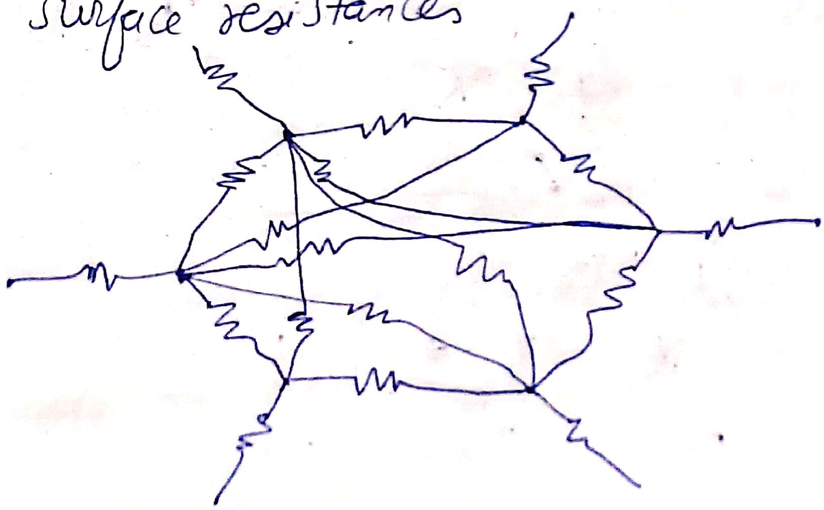
$$q_2 = \frac{E_{b_2} - J_2}{R_2} \qquad q_{13} = \frac{J_1 - J_3}{R_{13}}$$

$$q_3 = \frac{E_{b_3} - J_3}{R_3} \qquad q_{23} = \frac{J_2 - J_3}{R_{23}}$$

If we have negative sign then it flows in other direction.

We hav q_1 q_2 q_3 q_{12} q_{13} q_{23}.

We can have many surfaces & many surface resistances



If we have more than 3 surfaces don't attempt to draw the radiation circuit, it wont help. (137)

We use- for every surface

$$q_1 = q_{12} + q_{13} + q_{14} + \dots$$

We solve for J by substituting $\frac{E_{b_1} - J_1}{R_1} \dots$

and so on.

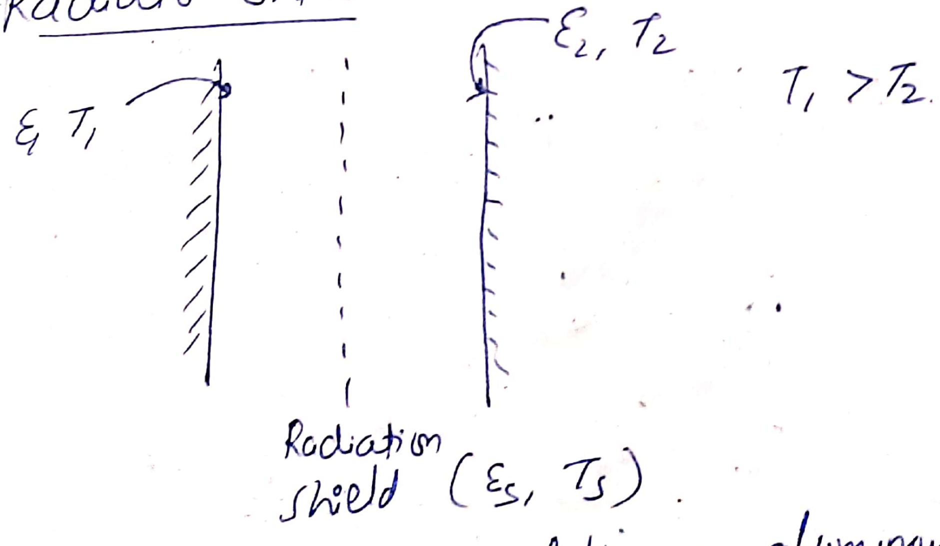
First we solve for J, then for q's.

If a surface is reradiating $q_i = 0$.

If we are given q we can directly put q instead of $\frac{E_{b_i} - J_i}{R_i}$.

Lec-22 (Radiation heat shield (examples))

Radiation Shields



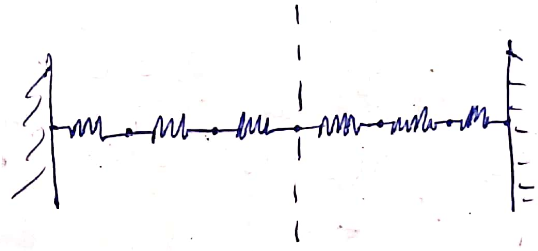
Radiation shield is like an aluminum foil. It is a very thin sheet. It cuts down heat transfer from hot surface to cold surface.

Let $\varepsilon_1 = \varepsilon_2 = \varepsilon_s$

We need to find heat flux from hot surface to cold surface.

$$q'' = \frac{E_{b_1} - E_{b_2}}{\frac{1-\varepsilon_1}{\varepsilon_1 \cancel{A_1}} + \frac{1}{\cancel{A_1} F_{1s}} + \frac{1-\varepsilon_s}{\varepsilon_s \cancel{A}} + \frac{1-\varepsilon_s}{\varepsilon_s \cancel{A}} + \frac{1}{\cancel{A_2} F_{2s}} + \frac{1-\varepsilon_2}{\varepsilon_2 \cancel{A}}}$$

We have 6 resistances.

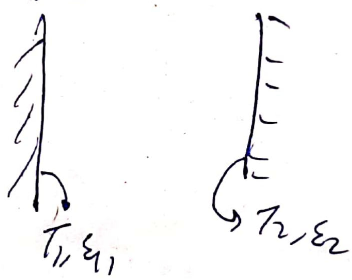


If $\varepsilon_s = 0.07$ for bright aluminium foil.

$\varepsilon_s = \varepsilon_1 = \varepsilon_2$; $F_{1s} = 1$, $F_{2s} = 1$.

$$q'' = \frac{E_{b_1} - E_{b_2}}{\cancel{27.6}\ 55.2}$$

If no shield



$$q'' = \frac{E_{b_1} - E_{b_2}}{\frac{1-\varepsilon_1}{\varepsilon_1} + \frac{1}{F_{12}} + \frac{1-\varepsilon_2}{\varepsilon_2}} = \frac{E_{b_1} - E_{b_2}}{27.6}$$

It is a 2:1. We cut heat transfer by a half.

$$q''_{\text{one shield}} = \frac{1}{2} q''_{\text{no shields}}$$

In general

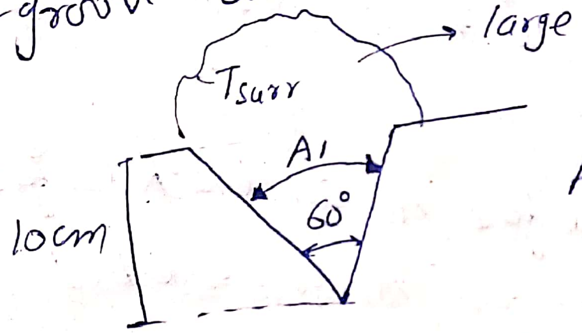
$$\boxed{q''_{N\,\text{shields}} = \frac{1}{N+1} q''_{\text{no shields}}}$$

(only valid if emissivities be equal)

(MLI sheets are example of radiation sheets)

Example

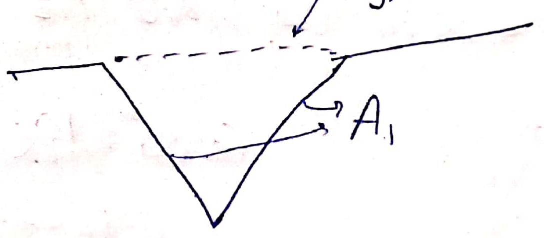
V-groove cut into a plate



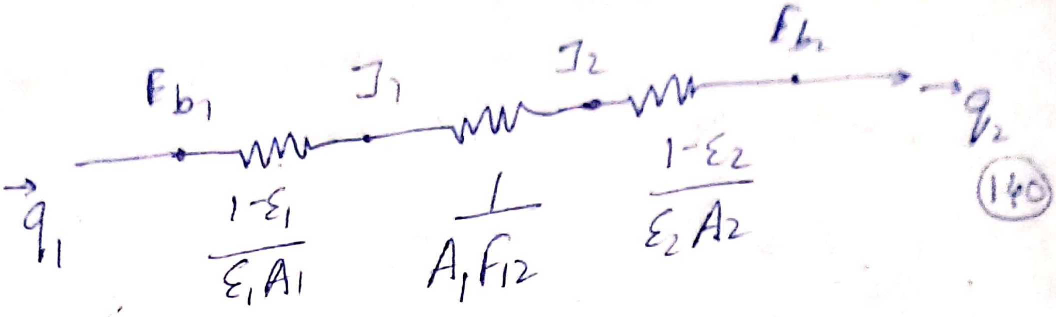
At V we have T_1 & ε_1.

we need to find how much heat goes from Vgroove to surroundings.

we first construct an enclosure. so we make a hypothetical surface across the groove.



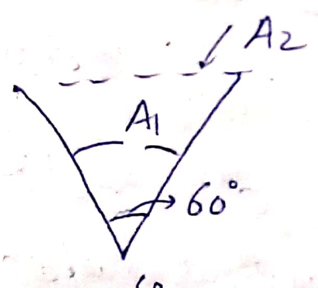
Assume T_1 is heat



$$q_1 = q_2 = \frac{E_{b_1} - E_{b_2}}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1 F_{12}} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2}}$$

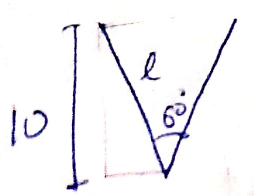
~~We assume~~ $\frac{1-\varepsilon_2}{\varepsilon_2 A_2}$ is 0, as we know that radiation coming in from large surrounding to a small surface inside ~~is~~ a black body radiation.

we model surface A_2 as black surface. So, all radiation from A_1 is absorbed by A_2.



So, $E_{b_2} = \sigma T_{surr}^4$, $\frac{1-\varepsilon_2}{\varepsilon_2 A_2} = 0$

We know ε_1, A_1 we need F_{12}.



$\cos 30° = 10/l$

$l = 11.55$ cm

$A_2' = 11.55$

(its a long groove so we use Area/length)
(Answer will be in watts per meter)

$A_1' = 11.55 + 11.55 = 23.1$

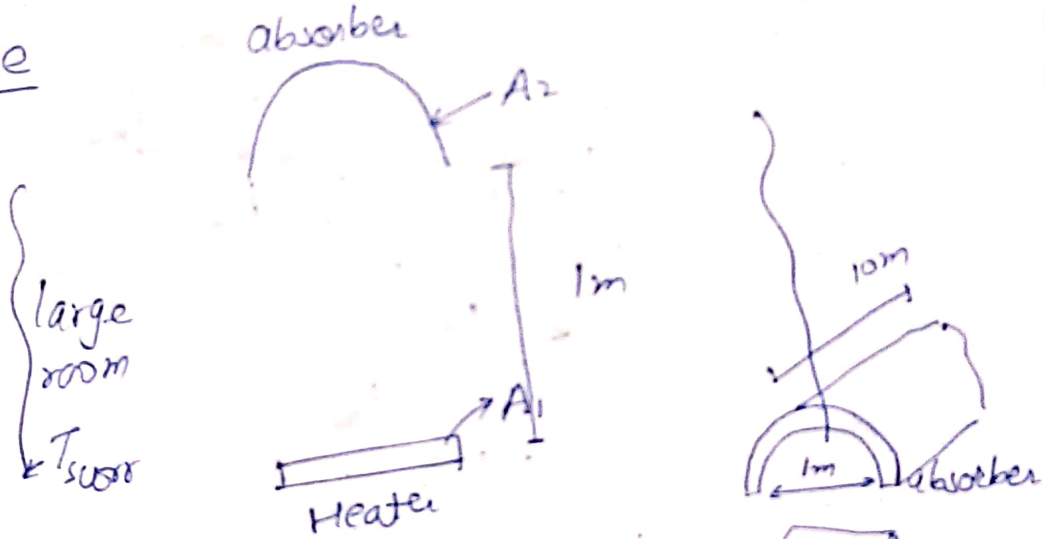
F_{12} $A_1 F_{12} = A_2 F_{21}$

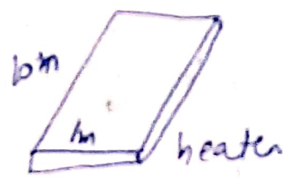
$F_{21} = 1$

$$F_{12} = \frac{A_2}{A_1} = \frac{11.55}{23.1} = 0.50$$

$$q_1' = \frac{E_{b_1} - \sigma T_{surr}^4}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1'} + \frac{1}{A_1' \times F_{12}}}$$

Example





$A_1 = 10 \times 1 = 10 m^2$

$A_2 = 15 m^2$ (given)

$A_3 =$ side walls

$T_1 = 1000K$

$T_2 = 600K$

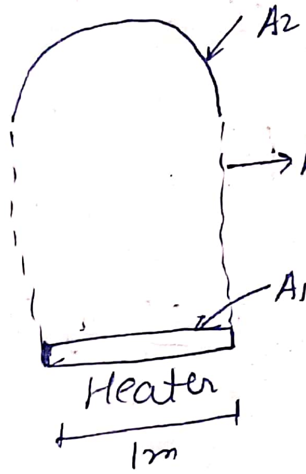
$T_{surr} = 300K$

$\varepsilon_1 = 0.9$

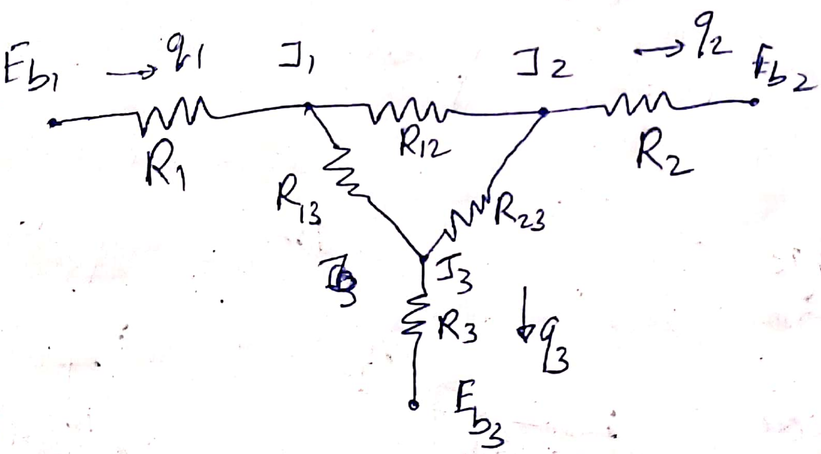
$\varepsilon_2 = 0.5$

Find q_2 (Heat into absorber)

It is ~~an~~ not an encolsure, so we make it an enclosure just like we did in V-groove. by making hypothetical surface.

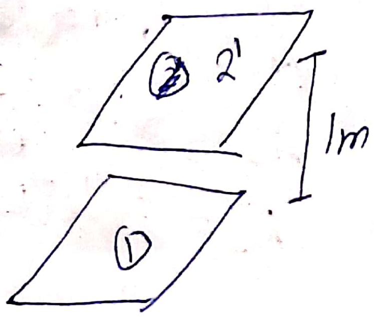


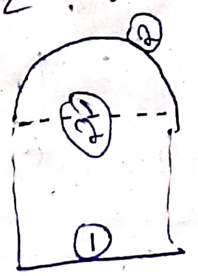
~~Hypothe~~ We are assuming that hypothetical surface is a black surface at $T = 300K$ & $\varepsilon = 1$. ($\varepsilon_3 = 1$)



we first find view factors

to find F_{12}. we use fig





we can find F from 1 to dashed line.

All radiation goes from ① to dashed line ends up in surface ②. So, we have a hypothetical surface A_2'. (143)

$$F_{12} = F_{12'}$$

~~For~~ For finding in graph/figure we need

$$\frac{X}{L} = \frac{1}{1}$$

and $\frac{Y}{L} = \frac{10}{1} = 10$

We get $F_{12} = 0.39$

~~R_1~~ $F_{11} + F_{12} + F_{13} = 1$

$F_{11} = 0$ $\quad F_{13} = 1 - F_{12}$

$$F_{13} = 0.61$$

For R_{23}, we need F_{23}.

$$A_2 F_{23} = A_{2'} F_{2'3}$$

Radiation leaving 2' surface is same as it is receiving from 2.

Radiation leaving from ~~2 to 3 is same as leaving from 2' to 3.~~

So, from symmetry ~~$A_{13} = F_{2'3}$~~ $F_{13} = F_{2'3}$

$\Rightarrow F_{2'3} = 0.61$

Now, ~~R_{23}~~ $A_2 F_{23} = A_{2'} F_{2'3}$

$$F_{23} = \frac{A_2'}{A_2} F_{23}$$

$$F_{23} = \frac{10 \times 1}{15} \times F_{2'3} = \frac{10}{15} \times 0.61$$

Scanned with OKEN Scanner

$F_{23} = 0.41$

So, we get $R_1, R_2, R_3,$
R_{12}, R_{13}, R_{23}

$R_3 = 0$ (surface behaves as black surface)

$\Rightarrow J_3 = E_{b_3} = \sigma T_{surr}^4$

We know $E_{b_1}, E_{b_2}, J_3,$
We need J_1 & J_2

for node 1

$$\frac{E_{b_1} - J_1}{R_1} = \frac{J_1 - \overset{E_{b_3}}{J_3}}{R_{13}} + \frac{J_1 - J_2}{R_{13}}$$

for node 2

$$\frac{E_{b_2} - J_2}{R_2} = \frac{J_2 - J_1}{R_{12}} + \frac{J_2 - E_{b_3}}{R_{23}}$$

we can find J_1 & J_2 from the above two equations.
Then we find q's.