VISUAL PHYSICS

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SHORT NOTES

CHAPTER

Heat Transfer

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Rate of heat flow $= \frac{dQ}{dt}$ = Heat current

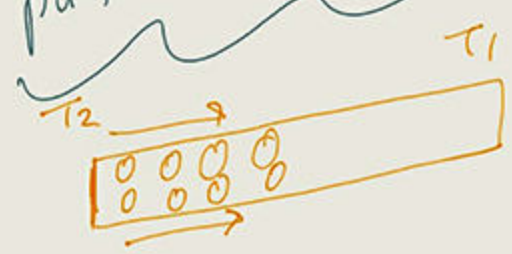
Heat transfer

transfer of energy due to the presence of temperature difference

models

Conduction

Heat transfer through the medium via energy transfer from particle to particle



$T_2 > T_1$

Convection

heat transfer from one part to other by motion of medium itself

Radiation

heat transfer using E-M waves
It do not need medium for energy transfer.

Variable state: When the variables (density, temperature etc) at a perticular point change with time

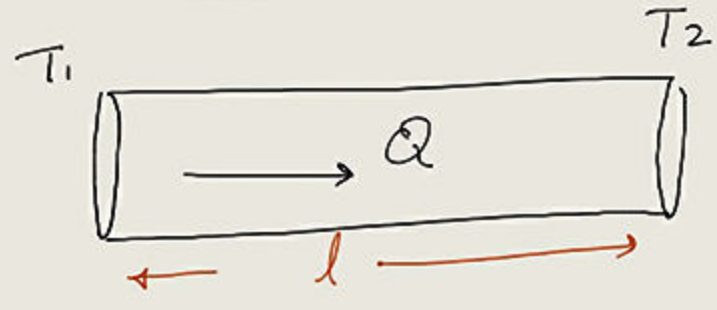
steady state: When the variables associated with a perticular point do not change with time.

i.e.

$\left(\frac{\partial T}{\partial x}\right)_t \neq 0$, $\left(\frac{\partial T}{\partial t}\right)_t \neq 0$ → variable state

$\left(\frac{\partial T}{\partial x}\right)_t = 0$, $\left(\frac{\partial T}{\partial t}\right)_t = 0$ → steady state

Conduction:



$T_1 > T_2$

$\frac{dQ}{dt} = \dot{Q}$

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$\dot{Q} \propto A$ → Area of cross-section

$\dot{Q} \propto (T_1 - T_2)$ or ΔT → Temperature difference

$\dot{Q} \propto \frac{1}{l}$ → length

→ $\dot{Q} \propto \frac{A \Delta T}{l}$ → $\dot{Q} = K \frac{A \Delta T}{l}$

K → Thermal conductivity

Ability to conduct heat

different for different material.

represent!

$\dot{Q}$ → SI unit → $\frac{W}{m \cdot C}$

$\dot{Q} = H$ → Heat current

Analogy :-

Heat

$\dot{Q} = H$ = heat current

ΔT = Temperature difference

$H = \left(\frac{KA}{l}\right) \Delta T$

Electricity

$\frac{dq}{dt} = I$ = Current

ΔV = potential difference

$I = \frac{\Delta V}{R}$

So we can say

$R_{TH} = \frac{l}{KA}$

Thermal resistance

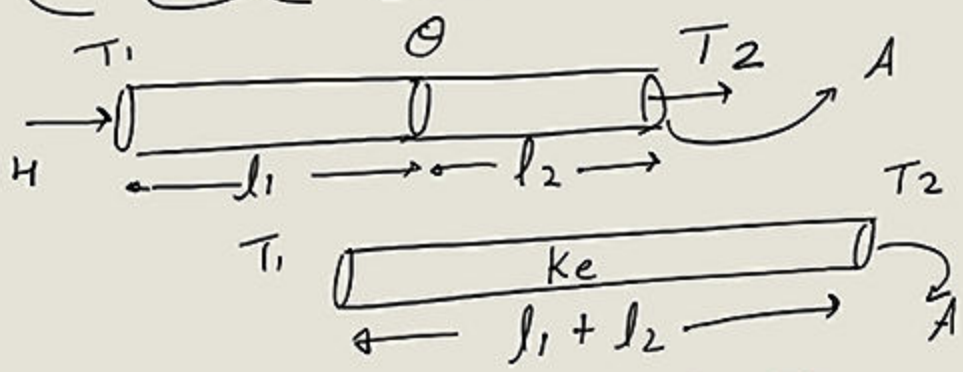
$\Delta V \rightarrow \Delta T$

$I \rightarrow H$

$R \rightarrow \frac{l}{KA} = R_{Th}$

Combination of conductors :

Series combination



$H = \frac{T_1 - \theta}{R_1}$, $H = \frac{\theta - T_2}{R_2}$

$T_1 - \theta = HR_1$, $\theta - T_2 = HR_2$

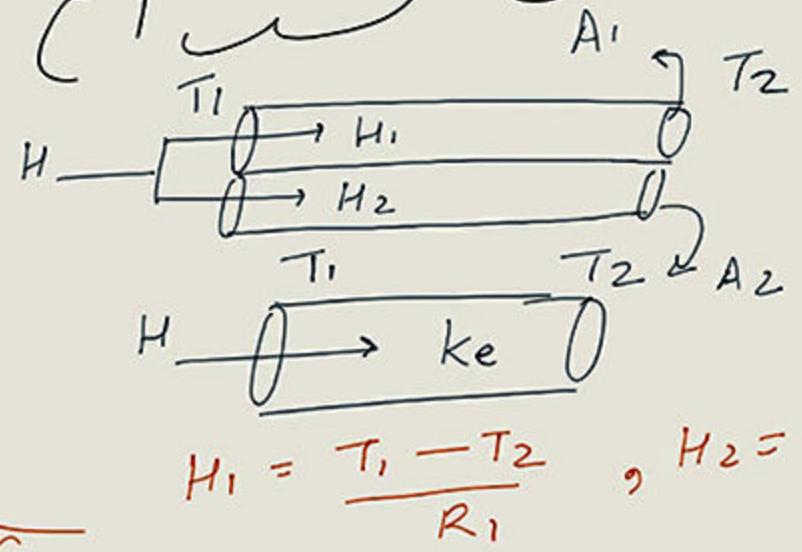
$T_1 - T_2 = H\,R_{eq}$

$R_{eq} = R_1 + R_2$

$\frac{l_1 + l_2}{K_e} = \frac{l_1}{k_1} + \frac{l_1}{k_2}$

$K_e = \frac{l_1 + l_2}{\frac{l_1}{k_1} + \frac{l_2}{k_2}}$

Parallel combination



$H_1 = \frac{T_1 - T_2}{R_1}$, $H_2 = \frac{T_1 - T_2}{R_2}$

$H = H_1 + H_2 = \frac{T_1 - T_2}{R_{eq}}$

$\frac{T_1 - T_2}{R_{eq}} = \frac{T_1 - T_2}{R_1} + \frac{T_1 - T_2}{R_2}$

$\Rightarrow \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$

$\frac{K_e (A_1 + A_2)}{l} = \frac{k_1 A_1}{l} + \frac{k_2 A_2}{l}$

$K_e = \frac{k_1 A_1 + k_2 A_2}{A_1 + A_2}$

Radiation

Prevost's theory

All body emits radiation at all temperature

All body absorbs radiation at all temperature

Amount of emission / absorbtion depends on temperature and material

$T_{surrounding} > T_{body}$

Absorbtion > Emission

$\Rightarrow$ Body temperature ↓

$T_{surrounding} < T_{body}$

Absorbtion < Emission

body temperature ↑

Body temperature constant

$T_{surrounding} = T_{body}$

Emission = Absorbtion

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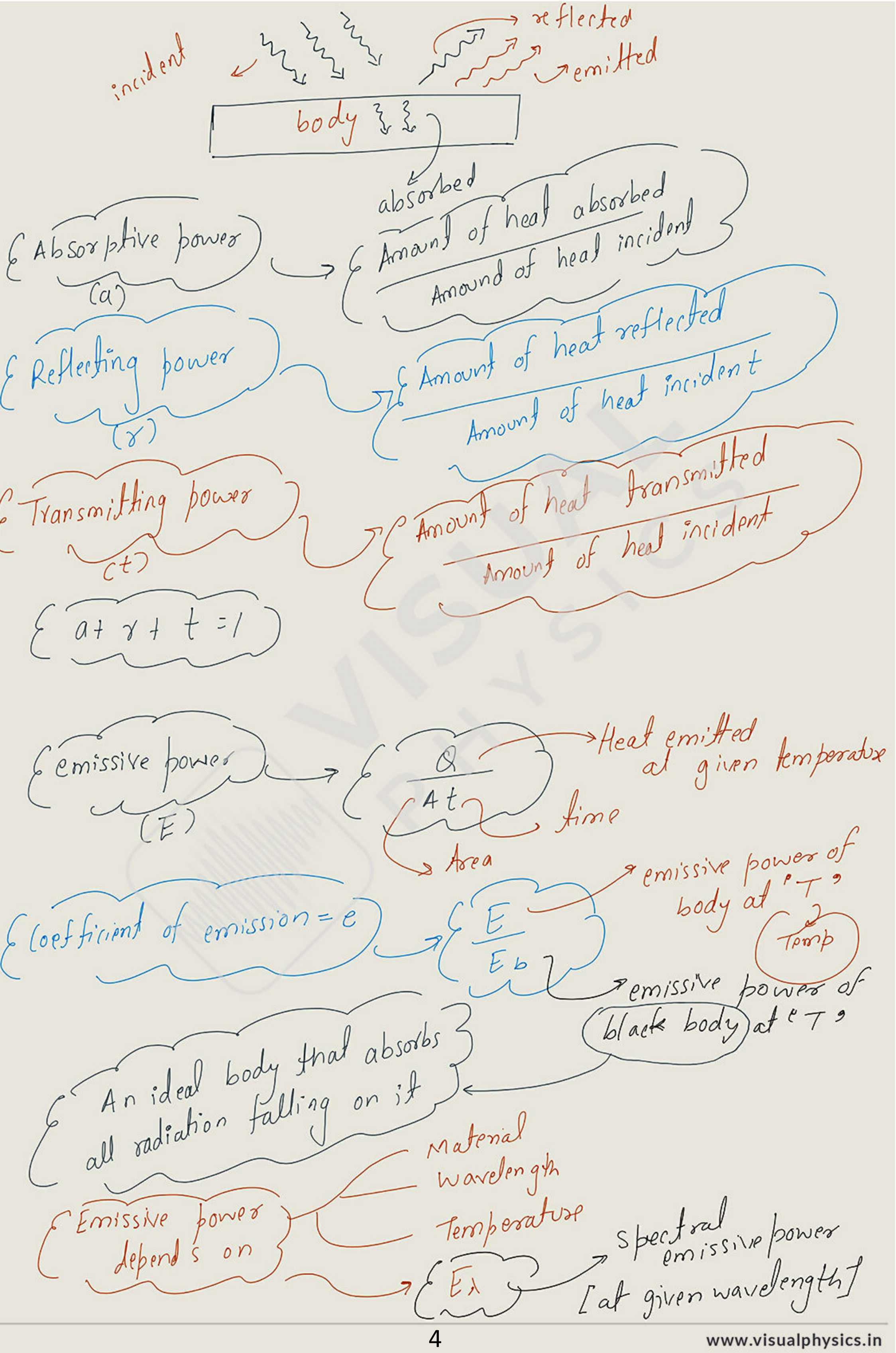

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similarly → a_λ → spectral absorbtive powers [at particular wavelength of radiation]

for black body

→ $a_\lambda = 1$, $e_\lambda = 1$

* for a given condition, black body radiates / absorbs maximum amount of radiation.

{practical black body

Lamp black (1% reflection)

Graphite (3% reflection)

platinum

Isothermal enclosure

{Kirchoff's law → $\frac{E}{a} = E_b$ [for any substance]

→ {true for any wavelength

OR

$a = \frac{E}{E_b} = e$

$\frac{E_\lambda}{a_\lambda} = E_{\lambda b} = \text{Constant}$

Wein's displacement law: (Can be used to measure star's temp

$T_3 > T_2 > T_1$ → $\lambda_3 < \lambda_2 < \lambda_1$

λ_m = wavelength of maximum Radiation

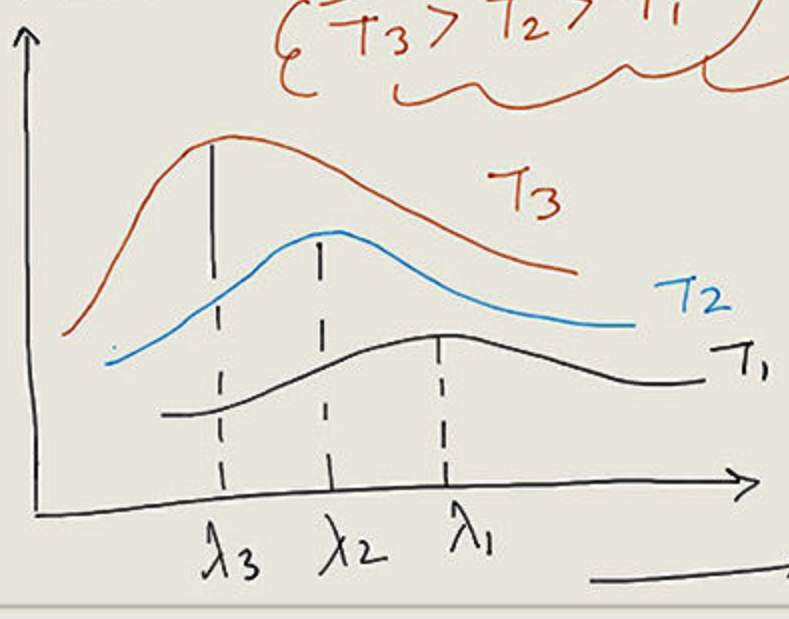
$\lambda_m T = \text{Constant} = b$

↓ Wein's displacement law

for black body

$b = 2.898 \times 10^{-3}$ m-k

$E = \frac{Q}{At}$



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* $T_3 > T_2 > T_1$ → $I_3 > I_2 > I_1$ → $\lambda_3 < \lambda_2 < \lambda_1$

Intensity of radiation

stefan's boltzman law:

for perctly black body

$I \propto T^4$

$\dot{Q} = \sigma A T^4$

- $\dot{Q}$: power radiated / rate of heat / radiation emission
- T : absolute Temperature (k)
- A : Area
- σ : stefan's boltzman constan = universal constant $= 5.67 \times 10^{-8}\ W/m^2k^4$

for other material

$\dot{Q} = e\sigma A T^4$

$0 \le e \le 1$

power emitted → $e\sigma A T^4$

when surrounding is at T_0

$\dot{Q}$ = net heat emitted $= e\sigma A (T^4 - T_0^4)$

power absorbed → $a\sigma A T_0^4 = e\sigma A T_0^4$ → $\because e = a$

Newton's law of cooling

if temperature difference between body and surrounding is less

$T - T_0 = \Delta T$ (small)

T = body's temperature

T_0 = surrounding temperature

Rate of cooling $\propto \Delta T$

rate of change of body temperat $\propto \Delta T$

$\frac{dT}{dt} \propto \Delta T$

$\frac{dT}{dt} \propto (T - T_0)$

or $\frac{dT}{dt} = k(T - T_0)$

k → proportionality Constant (depends on material & surrounding condition)

derivation of Newton's cooling

$\frac{mc\,dT}{dt}$

$\dot{Q} = e\sigma A(T^4 - T_0^4)$

$\frac{mc\,dT}{dt} = e\sigma A(T^4 - T_0^4)$

$\frac{dT}{dt} = \left(\frac{e\sigma A}{mc}\right)(T^4 - T_0^4)$

$T = T_0 + \Delta T$

$\Rightarrow \frac{dT}{dt} = \left(\frac{e\sigma A}{mc}\right)\left[(T_0 + \Delta T)^4 - T_0^4\right] = \left(\frac{e\sigma A\, T_0^4}{mc}\right)\left[\left(1 + \frac{\Delta T}{T_0}\right)^4 - 1\right]$

$\frac{dT}{dt} = \left(\frac{e\sigma A\, T_0^4}{mc}\right)\left[\left(1 + 4\frac{\Delta T}{T_0}\right) - 1\right]$ if $\left(\frac{\Delta T}{T_0} \ll 1\right)$

$\frac{dT}{dt} = \left(\frac{4e\sigma A\, T_0^4}{mc}\right)(\Delta T) = K[T - T_0]$

$K = \frac{4e\sigma A\, T_0^4}{mc}$

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