PRAYAS

JEE 2025

Lecture - 01 **Physics**

Modern Physics - 01

Radiation pressure & photon theory.

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Todays Goal

- Photon theory
- Radiation pressure

Photon theory

- Light has two characteristics wave as well as particle
- Light is an electromagnetic wave having dual nature, it shows wave nature by exhibiting phenomenon like interference & diffraction and it shows particle nature by exerting force, impulse, pressure & carry momentum

- photon can Visualise as packet of energy (Energy particle of light
- photon is an elementary particle. It is a quantum of light.
- A photon remains unaffected by electric & magnetic field
  it is electrically neutral
- Photon always travel with speed of light.

- momentum of a photon $= \dfrac{h}{\lambda}$ ($\lambda \rightarrow$ wavelength)
- Energy of a photon $= E = \dfrac{hc}{\lambda} = h\nu$

$\nu \rightarrow$ frequency

$E = h\nu$

$c = \nu\lambda = f\lambda$

- Energy of one photon in eV $= \dfrac{12400}{\lambda}$ eV $= \dfrac{1240}{\lambda}$ eV

$\lambda \rightarrow$ A° में रखना है

$\lambda \rightarrow$ (nm)

* Dir^n of momentum of a photon is along in the dir^n of velocity of light.

Q what is energy of one photon of wavelength

① $\lambda = 310\,A^0$

$$E = \frac{12400}{\lambda} = \frac{12400}{310} = 40\ eV$$

② $\lambda = 620\ nm$

$$E = \frac{1240}{620} = 2\ eV$$

$$1eV = 1.6\times10^{-19} J$$

$$1J = \frac{1\,eV}{1.6\times10^{-19}}$$

$$E = \frac{6.6\times10^{-34} \cdot 3\times10^{-8}}{\lambda} \text{ Joule} = \frac{6.6\times10^{-34}\times 3\times10^{-8}}{\lambda\times1.6\times10^{-19}}\ eV$$

$$\lambda \rightarrow (\text{meter})$$

$$\simeq \frac{12400}{\lambda} = \frac{1240}{\lambda}$$

$$\lambda \rightarrow (\text{put in } \mathring{A})$$

$$\lambda \rightarrow (nm)$$

Q find energy & momentum of a photon having wavelength 310 A°

Sol^n

$$p = \frac{h}{\lambda} = \frac{6.6\times10^{-34}}{310\times10^{-10}}$$

$$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{310\times10^{-10}}$$

Energy of one photon in eV $= \frac{12400}{310} = 40$ eV

$h \rightarrow$ planck const $= 6{\cdot}63 \times 10^{-34}$ Js

$$E = h\nu$$

$$h = \frac{E}{\nu} \Rightarrow \frac{ML^2T^{-2}}{T^{-1}} \Rightarrow [ML^2T^{-1}]$$

$$E = \frac{hc}{\lambda} = h\nu$$

$\nu \rightarrow$ freq.

Q

$\lambda_R > \lambda_{Blue}$

$$\boxed{\lambda \uparrow \Rightarrow P \downarrow \Rightarrow E \downarrow}$$

$P = \frac{h}{\lambda}$, $E = \frac{hc}{\lambda}$

$P_{Red} < P_{Blue}$

$E_{Red} < E_{blue}$.

Power of Source of monochromatic light

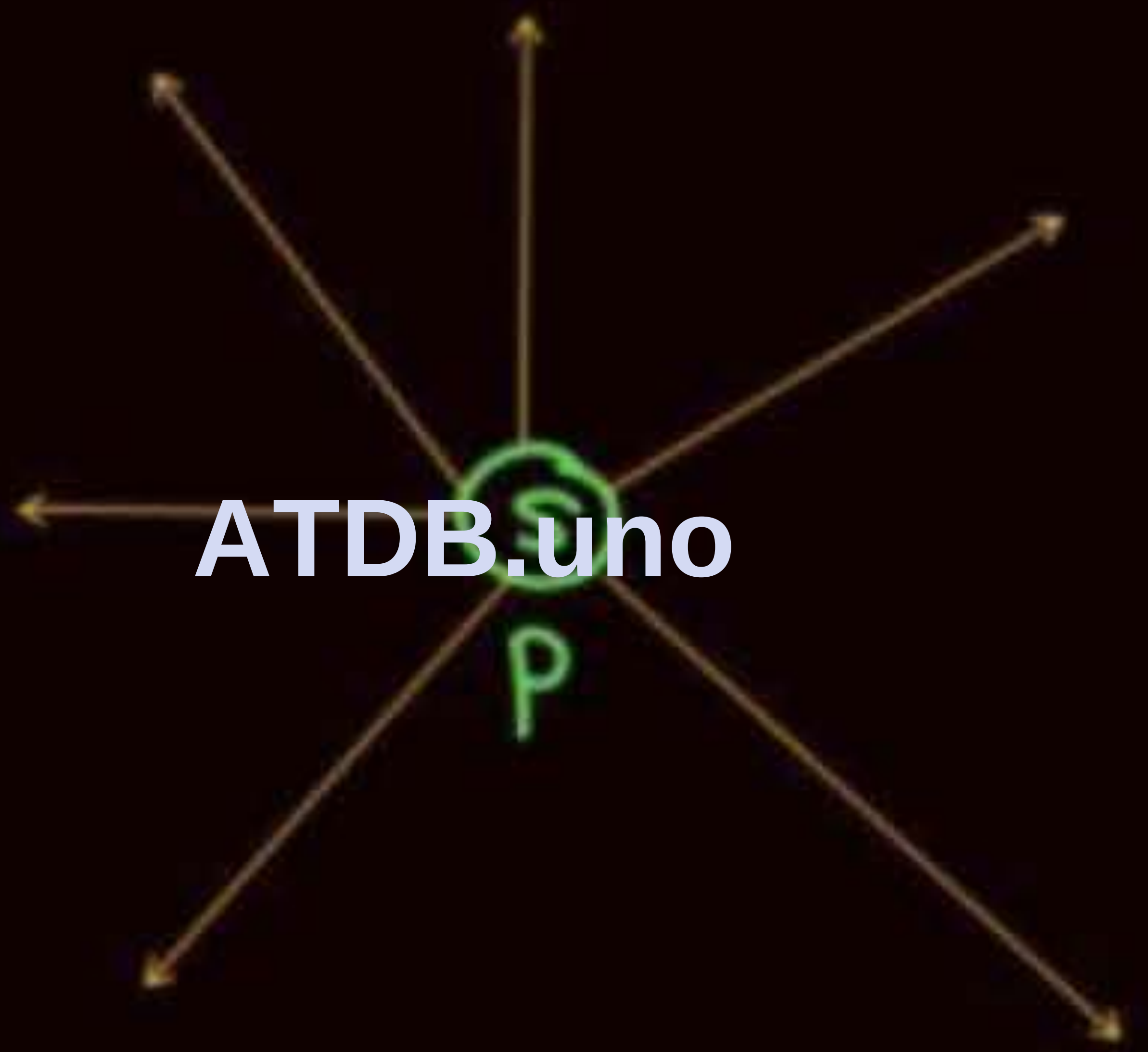
monochromatic → λ

p → power of source

power = Energy per Unit time

n → no. of photon per sec emitted.

$$n = \frac{P}{\frac{hc}{\lambda}}$$



$$P = \underbrace{n}_{\text{no. of photon per sec}} \overbrace{\frac{hc}{\lambda}}^{\text{energy of One photon}}$$

$$n = \frac{P}{\frac{hc}{\lambda}}$$

① point source

power of source = P

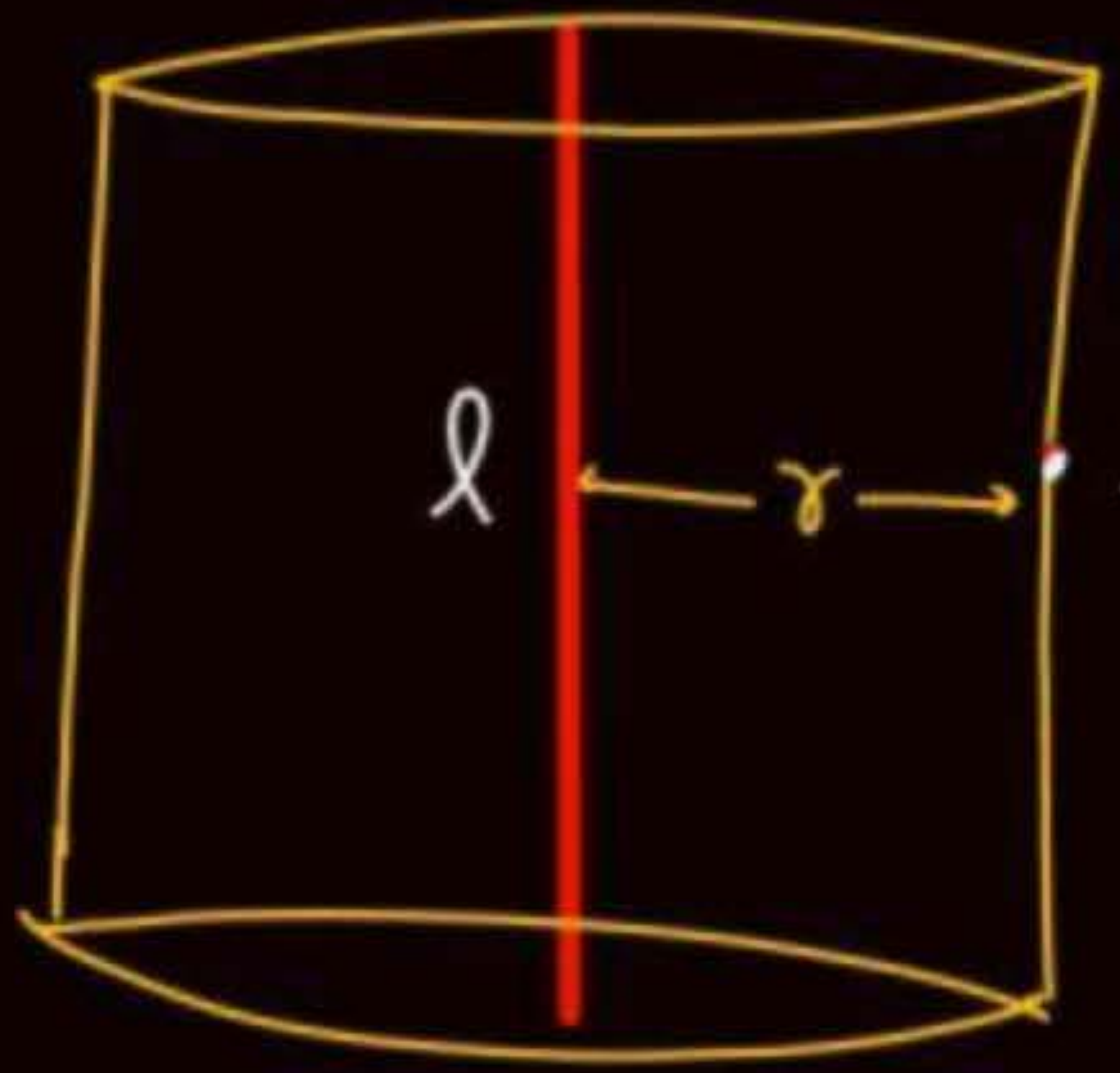
Power Recieved by S_1 = P

$$\text{Intensity} = \frac{P}{4\pi r^2}$$

$$I \propto \frac{1}{r^2}$$

$$r\uparrow \Rightarrow I\downarrow$$

② Linear Source



$$I = \frac{P}{2\pi r h}$$

$$I \propto \frac{1}{r}$$

③ parallel Beam

$I \propto r^0$

$I \longrightarrow$ const.

Power Recieved by Disc $= I\pi R^2$

Energy . . . in time 't' $= I\pi R^2 t$

$I = \frac{E}{At} = \frac{P}{A}$

$c = f\lambda$

(*) Q Consider a point monochromatic source of power 100 watt (100 J/sec) which emit photon of wavelength 310 A°. Find

① Frequency of photon $= \nu = \frac{c}{\lambda} = \frac{3\times10^{8}}{310\times10^{-10}}$

② Momentum of one photon $= \frac{h}{\lambda} = \frac{6.6\times10^{-34}}{310\times10^{-10}}$

③ Energy of one photon in eV $= \frac{12400}{310} = 40$ eV

④ No. of photon emitted per sec $= \frac{P}{\frac{hc}{\lambda}} = \frac{100\times310\times10^{-10}}{6.6\times10^{-34}\times3\times10^{8}} =$ ✓

⑤ Intensity as function of 'x'

r → Distance of point from source

$I = \frac{P}{4\pi r^2}$

⑥ Consider a small detector of area $\cdot 3\ mm^2$ placed at a distance of 2m from the source. find no. of photon recieved by detector in 10sec. also energy recieved by detector in 10sec.

$$4\pi r^2 \longrightarrow P$$

$$1 \longrightarrow \frac{P}{4\pi r^2}$$

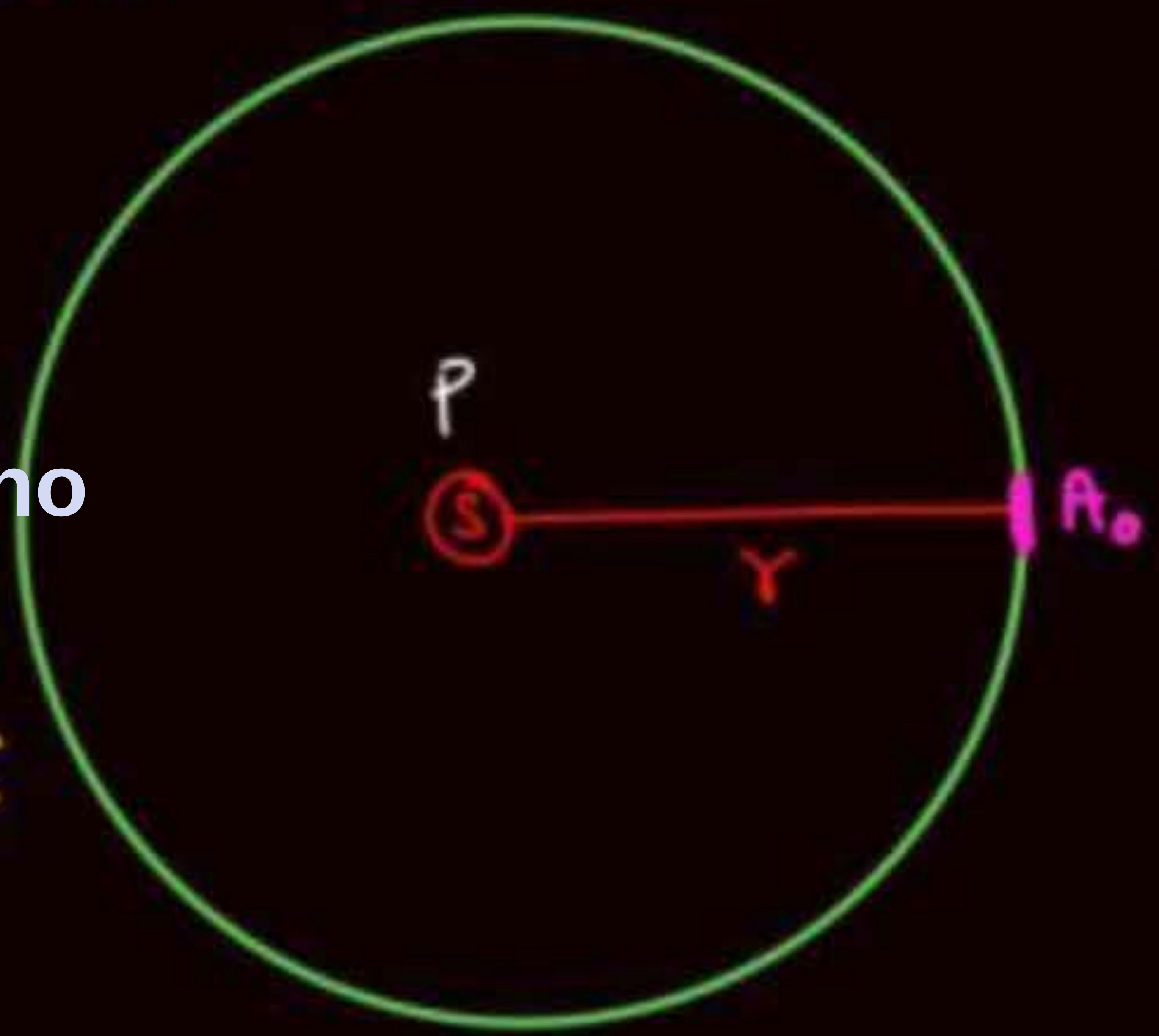
$$A_0 \longrightarrow \frac{P}{4\pi r^2}A_0$$

Sol^n

Energy recieved by detector in 1sec $= \dfrac{P}{4\pi r^2}A_0$

10sec में Energy Recieved $= \dfrac{P}{4\pi r^2}A_0 t$

(t = 10sec)

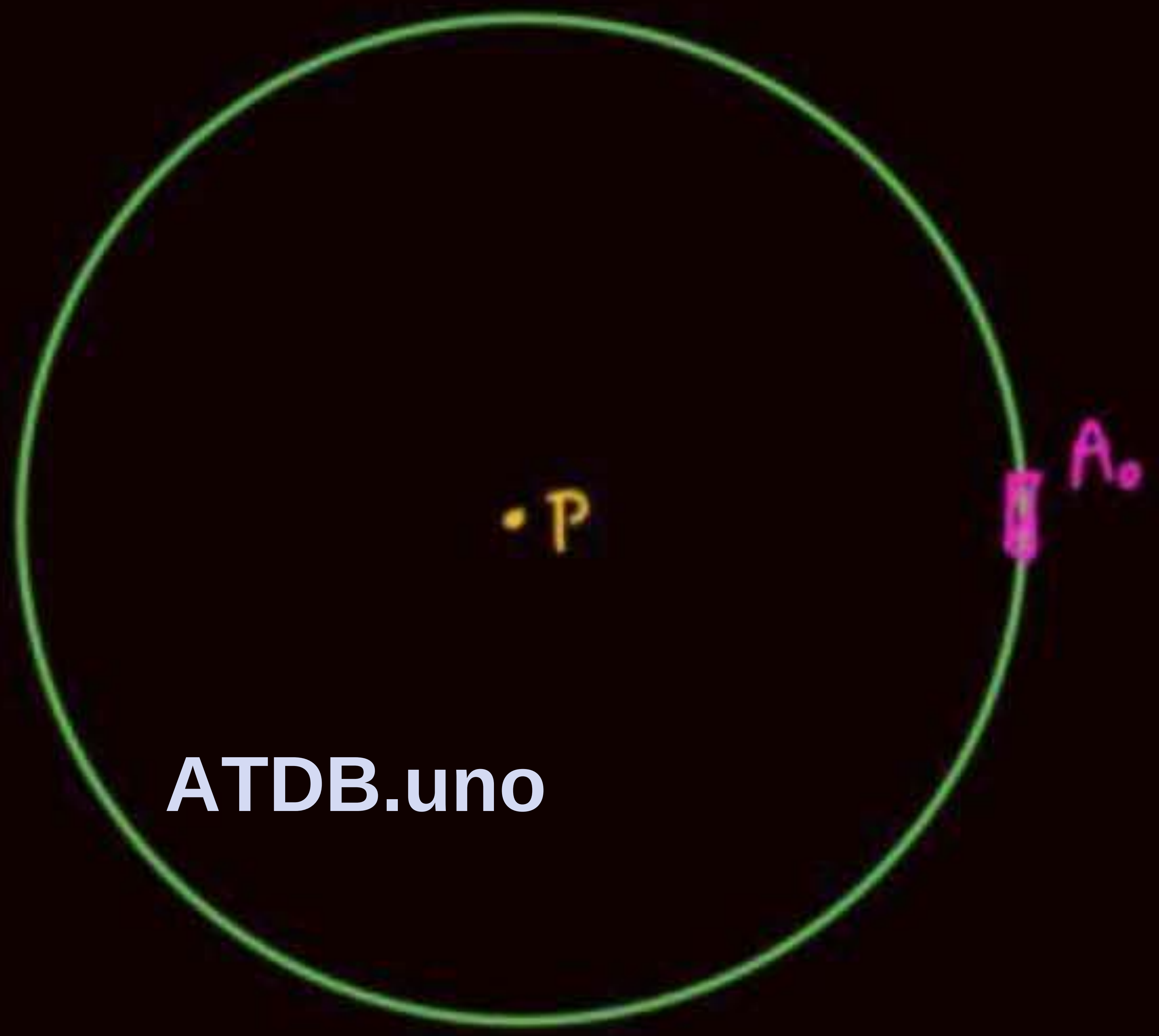


$$I = \frac{P}{4\pi r^2}$$

No of photon detected in 10sec $= \dfrac{\frac{P}{4\pi r^2}\cdot A_0 t}{\frac{hc}{\lambda}}$

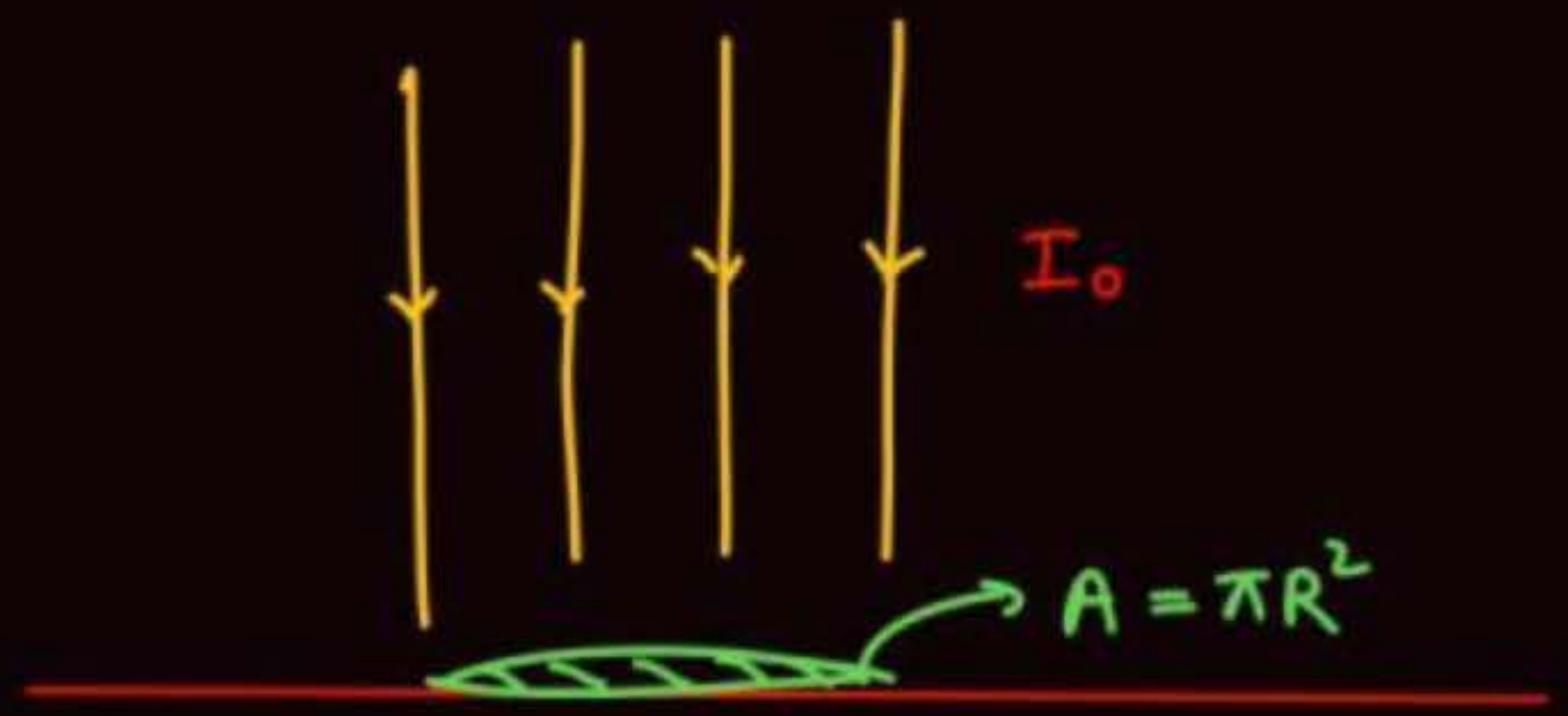
t sec में कितने photon निकले

$$= \frac{P}{\frac{hc}{\lambda}} t$$



$$\frac{\frac{P}{\frac{hc}{\lambda}} t}{4\pi r^2} \times A_0$$

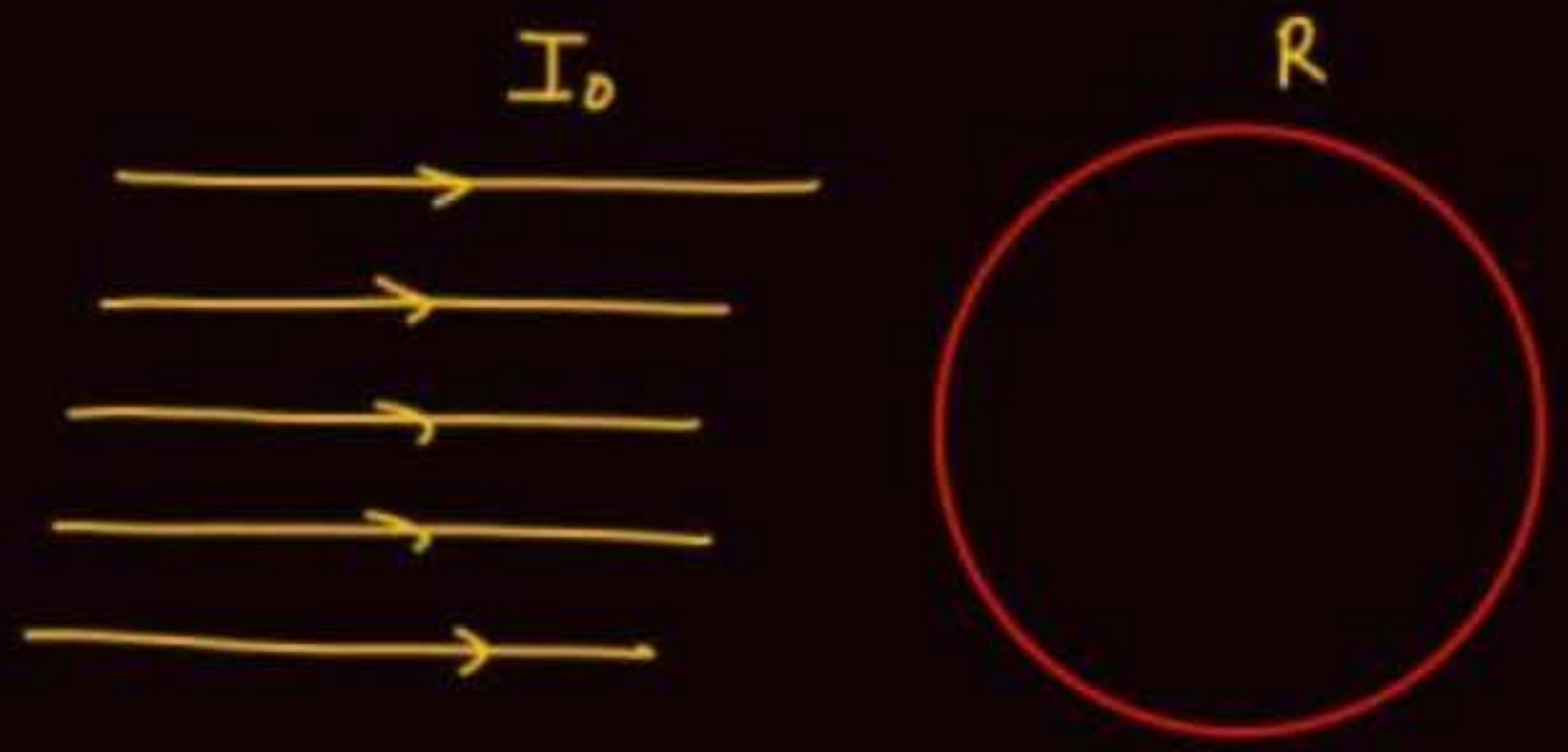
Q



no of photon falling per sec on Area = $\frac{I_0 \pi R^2}{hc/\lambda}$

" " fall on plate in time t_0 = $\frac{I_0 \pi R^2 t_0}{\frac{hc}{\lambda}}$

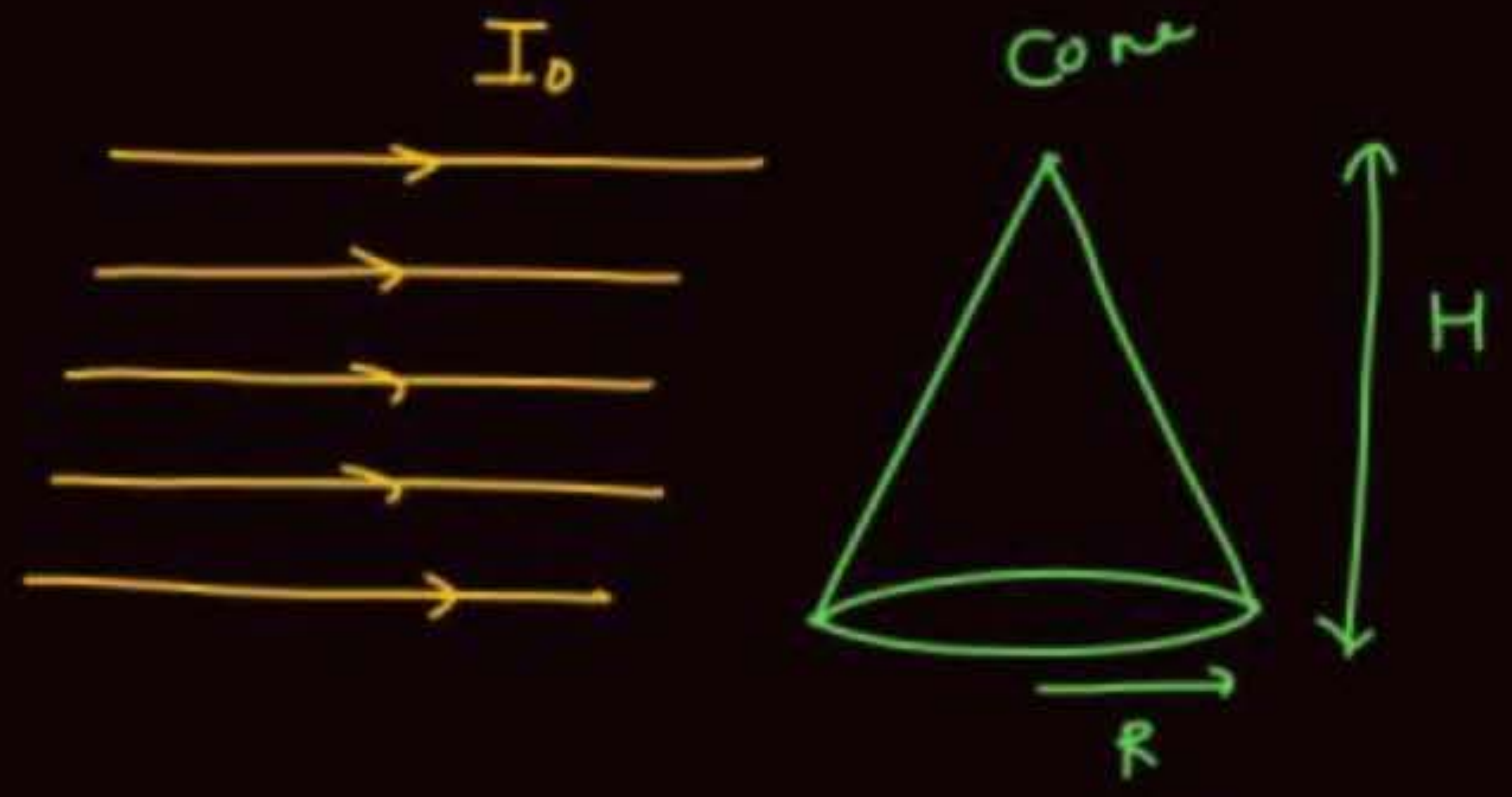
Q



no. of photon per sec falling

On sphere = $\dfrac{I_0 \pi R^2}{\dfrac{hc}{\lambda}}$

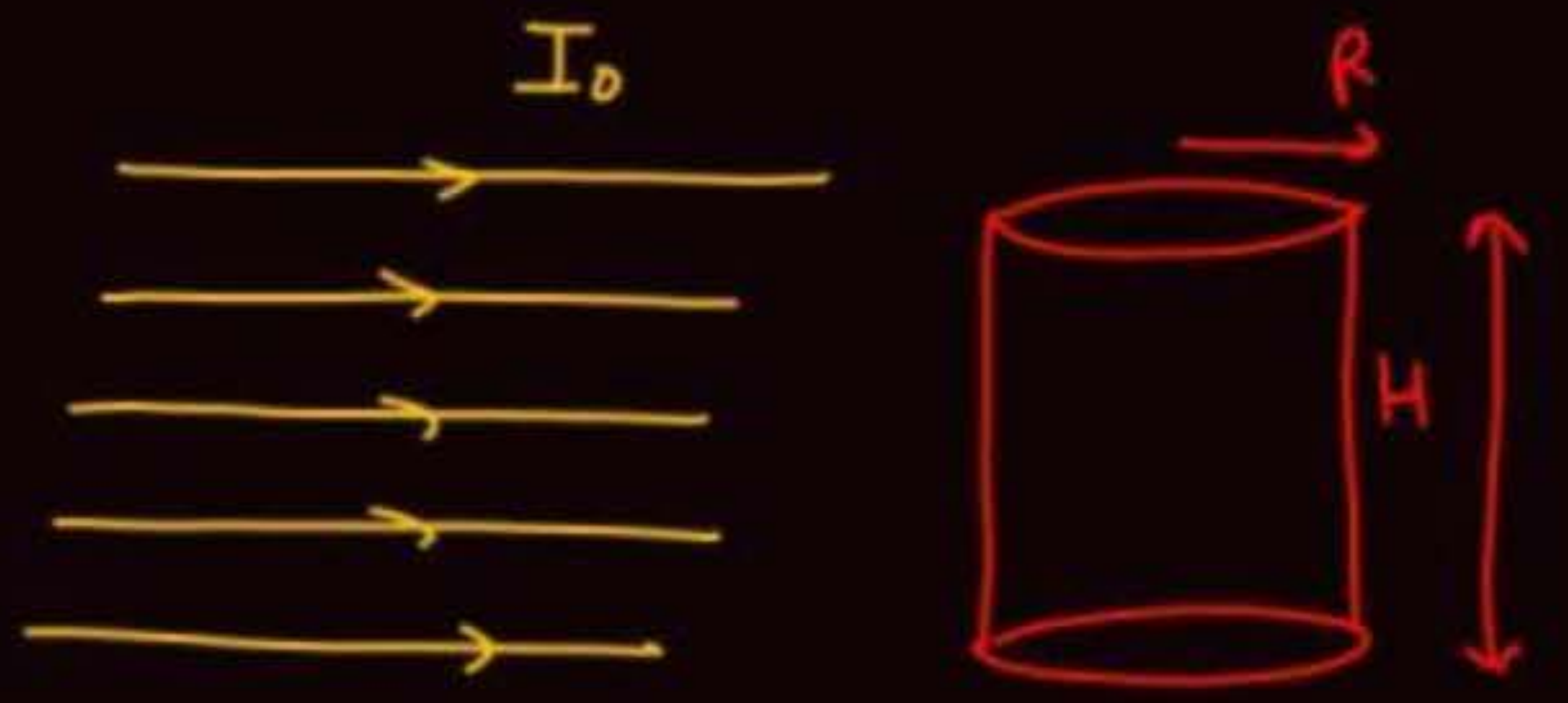
Q



of photon per sec falling

On Cone = $\dfrac{I_0 \cdot \frac{1}{2} \times 2R \times H}{\dfrac{hc}{\lambda}}$

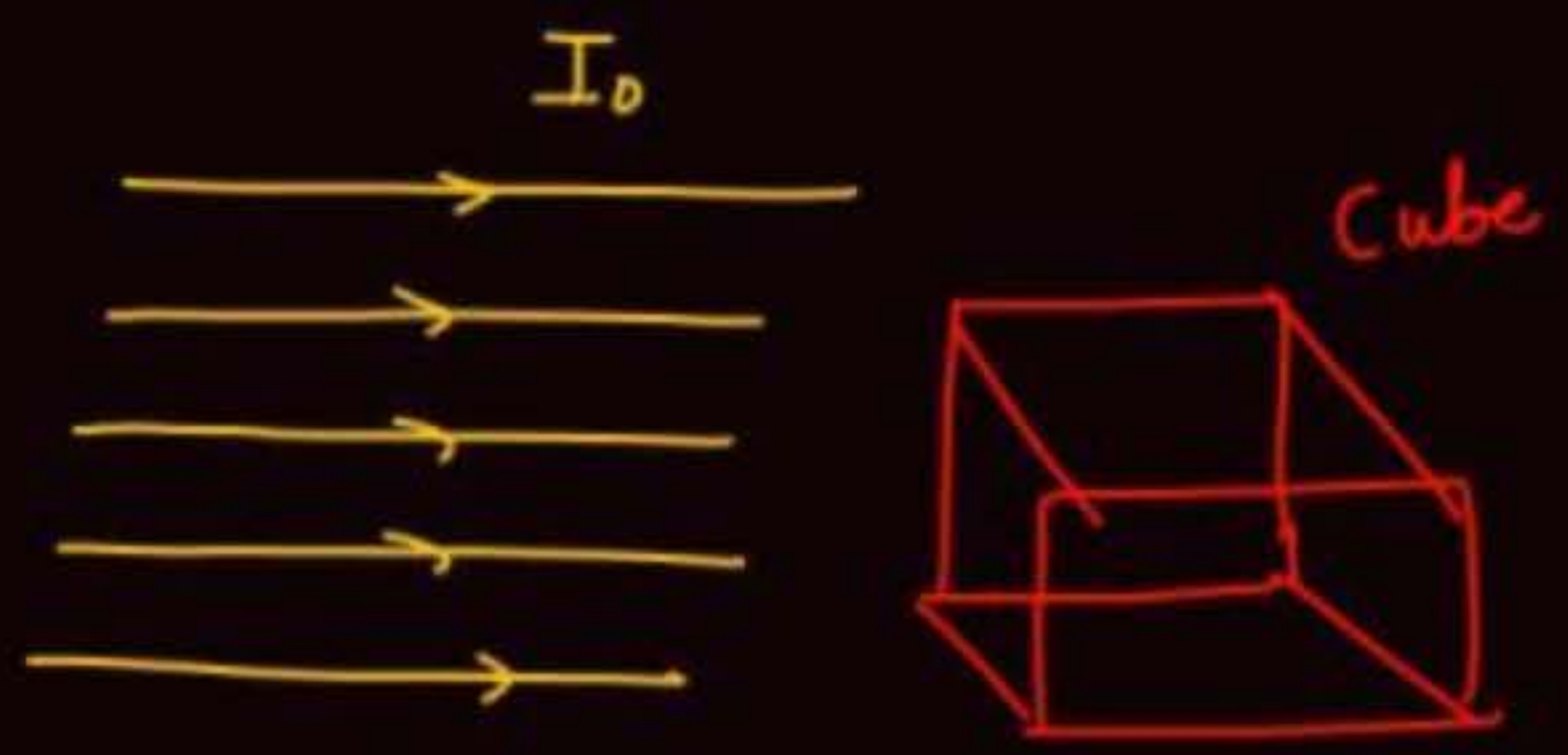
Q



no. of photon per sec falling

On cylinder $= \dfrac{I_0 H 2R}{\frac{hc}{\lambda}}$

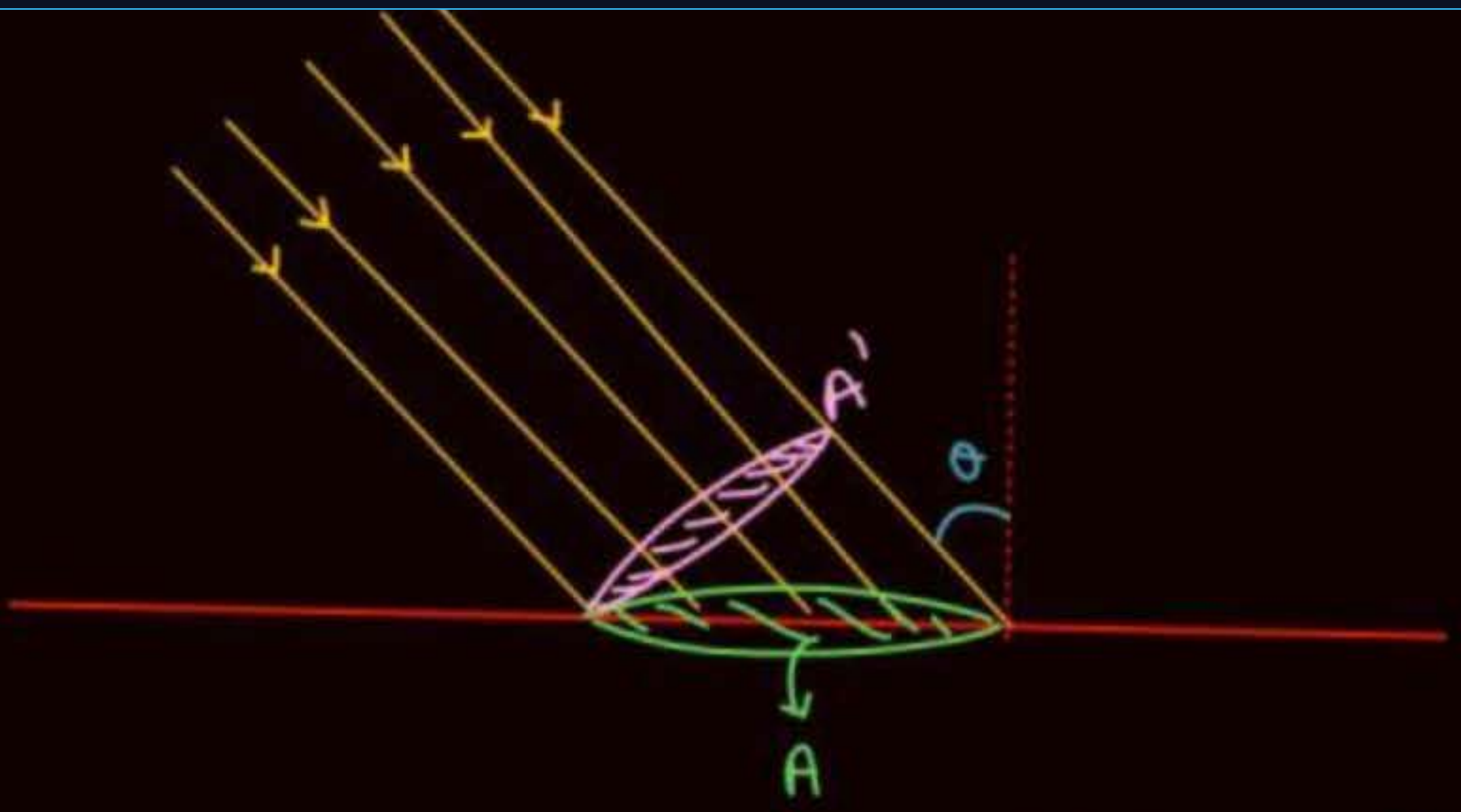
Q

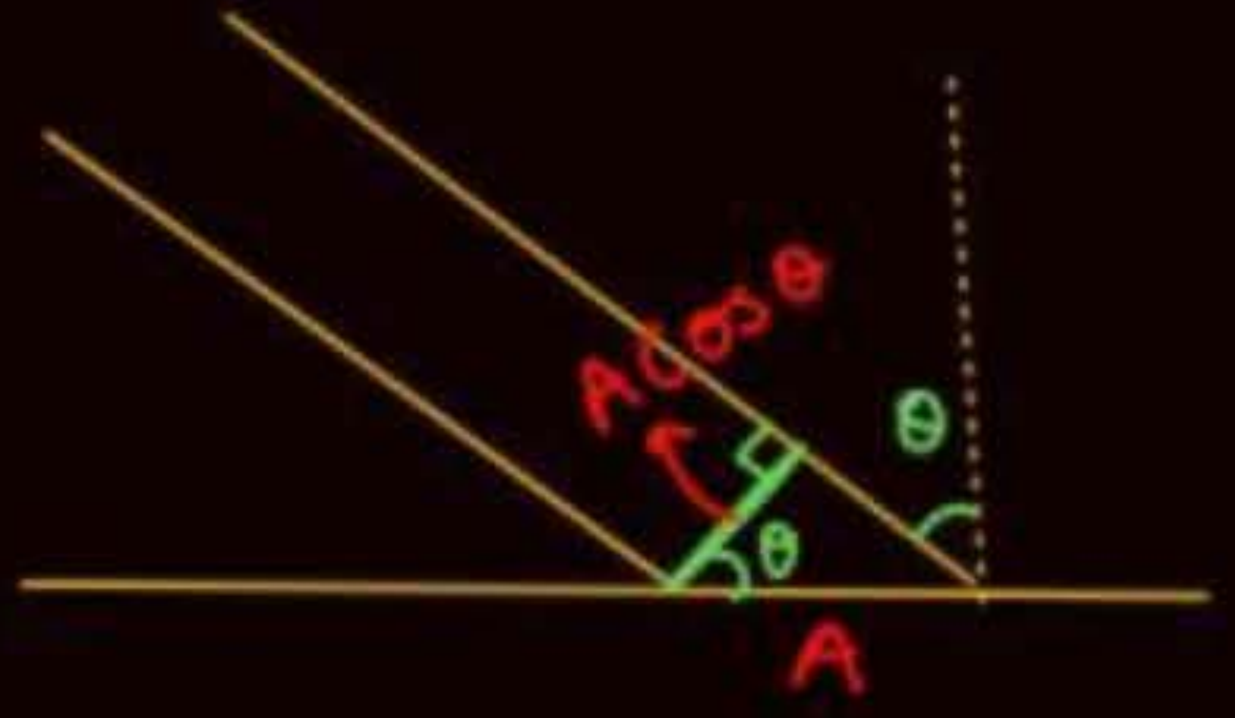


of photon per sec falling

On Cube $= \dfrac{I_0 \cdot L^2}{\frac{hc}{\lambda}}$

Q





no. of photon per sec falling on plate of area A $= \dfrac{IA'}{\dfrac{hc}{\lambda}} = \dfrac{IA\cos\theta}{\dfrac{hc}{\lambda}}$

Result

- * $E = \frac{hc}{\lambda} = \frac{1240}{\underset{\hookrightarrow (nm)}{\lambda}} = \frac{12400}{\underset{\searrow A^{\circ}}{\lambda}}$ = Energy of one photon

- * P = momentum of one photon $= \frac{h}{\lambda}$

- * $P = n \frac{hc}{\lambda} \implies * \; n = \frac{P}{\frac{hc}{\lambda}}$

P → power of source

n → no of photon emitted per second

- * $v = f\lambda$ (f → frequency)
- * $c = f\lambda$

PHOTON THEORY OF LIGHT

- A photon is a particle of light moving with speed 299792458 m/s in vacuum.
- The speed of a photon is independent of frame of reference. This is the basic postulate of theory of relativity.
- The rest mass of a photon is zero. i.e. photons do not exist at rest.

[redacted]

PHOTON THEORY OF LIGHT

- According to Planck the energy of a photon is directly proportional to the frequency of the radiation.

$E \propto v$ or $E = hv$

$E = \frac{hc}{\lambda} joule (\because c = v\lambda)$ or $E = \frac{hc}{\lambda e} = \frac{12400}{\lambda} eV - \mathring{A}$

$1\,eV = 1{\cdot}6 \times 10^{-19}\,J$

$\left[\because \frac{hc}{e} = 12400 (\mathring{A} - ev)\right]$

Here E = energy of photon, c = speed of light, h = Planck's constant, e = charge of electron, $h = 6.62 \times 10^{-34}$ J–s, v = frequency of photon, λ = wavelength of photon

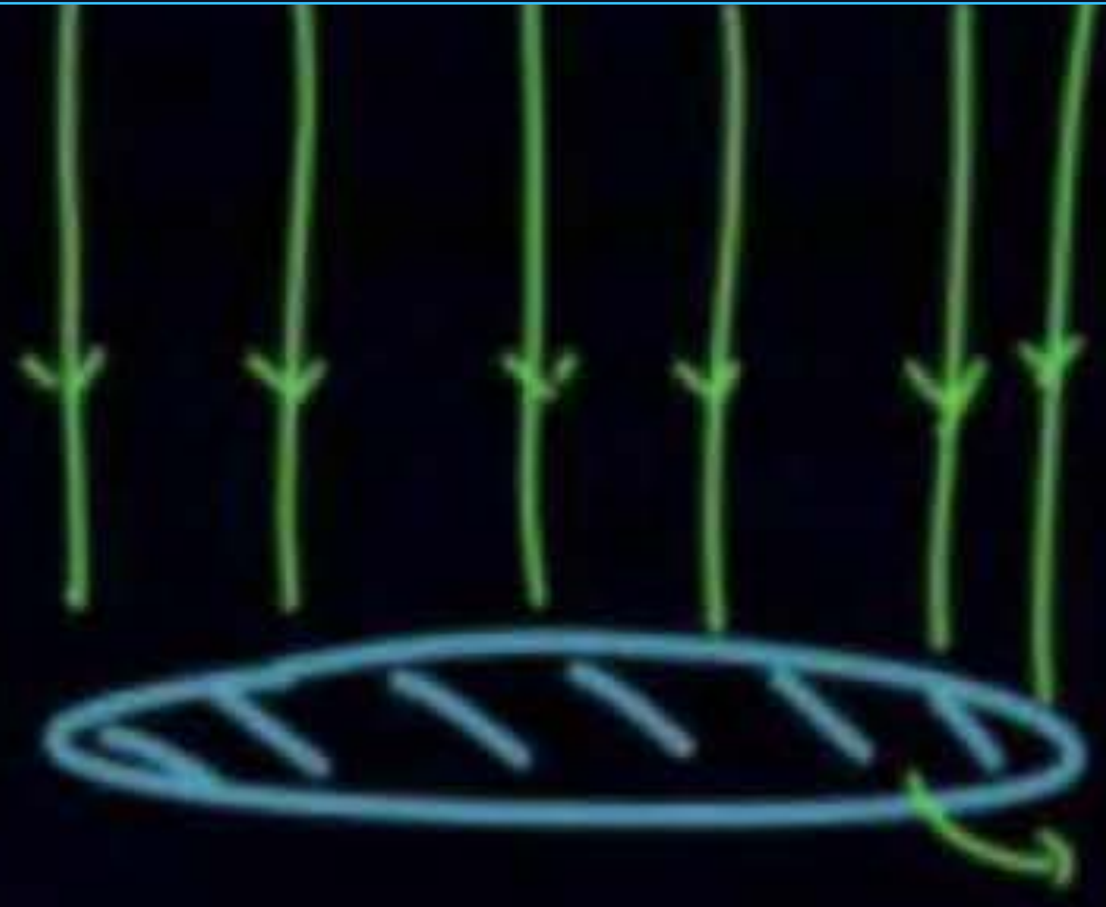
PHOTON THEORY OF LIGHT

- Linear momentum of photon $p = \frac{E}{c} = \frac{hv}{c} = \frac{h}{\lambda}$
- Energy of light passing through per unit area per unit time is known as intensity of light.
- Intensity of light $I = \frac{E}{At} = \frac{P}{A}$
- When photons fall on a surface, they exert a force and pressure on the surface. This pressure is called radiation pressure.

Q

find no of photons falling in 5 sec.

= n = ?



I = 1000 watt/m^2

$\lambda = 1240\ \text{Å}$

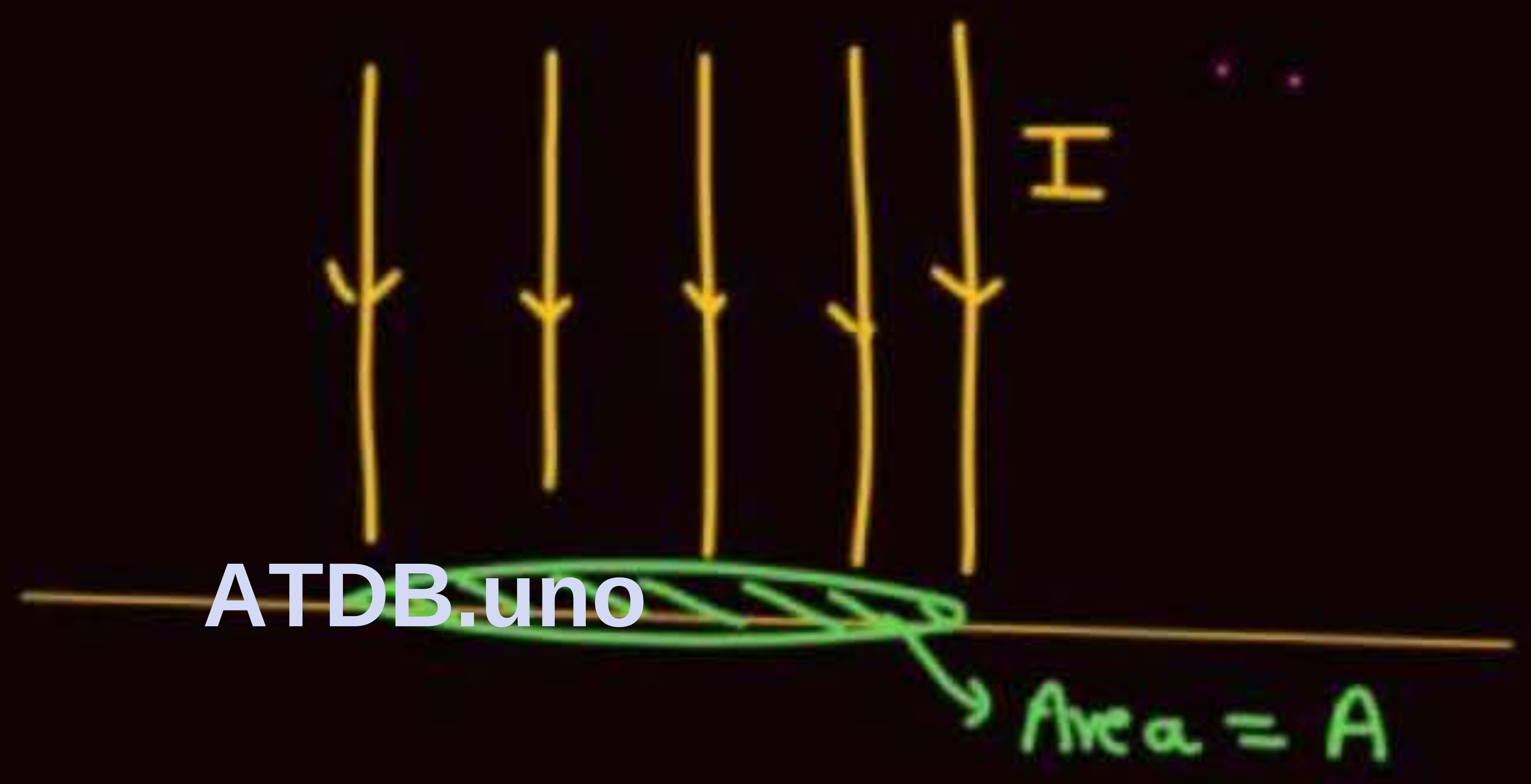
$A_0 = 10\,m^2$

$$\cancel{\frac{hc}{\lambda} = \frac{12400}{1240} =}$$

$$\frac{IAt}{\frac{hc}{\lambda}} = \frac{1000 \times 10 \times 5}{\frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{1240 \times 10^{-10}}}$$

Radiation falling on surface normally & perfectly reflected by surface

$a = 0, \; r = 1$



$a \rightarrow$ absorption coff.

$r \rightarrow$ reflection coff.

Change in momentum of one photon $= \frac{2h}{\lambda}$

$$F = n \cdot \frac{2h}{\lambda}$$

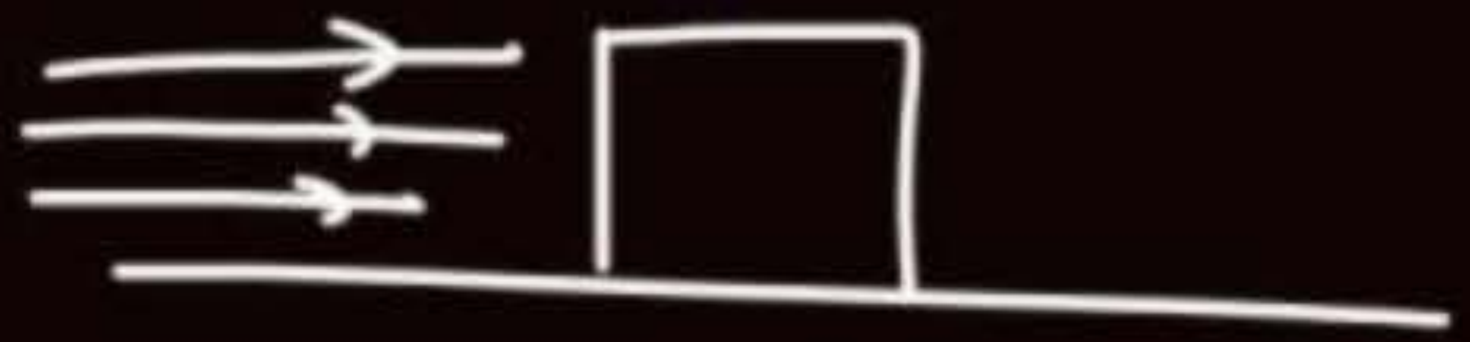
$n \rightarrow$ no. of photon falling per sec

$$F = \frac{IA}{\frac{hc}{\lambda}} \cdot \frac{2h}{\lambda}$$

$$\boxed{\frac{F}{A} = \frac{2I}{c} = \text{Pressure}}$$

$a = 0$
$r = 1$

Q I. (cube m, L)



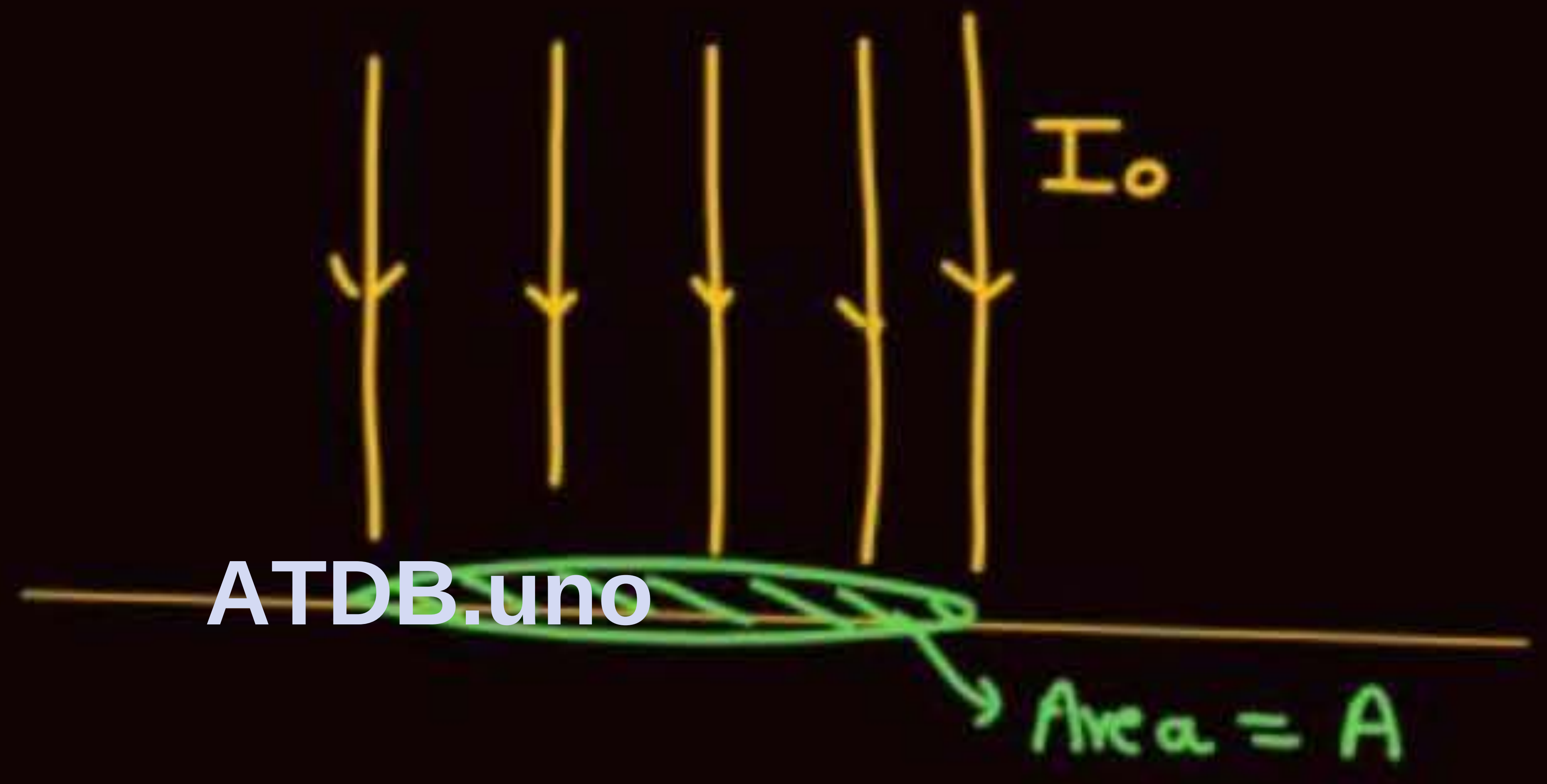
Find Imin so that block start moving

Soln

$$\frac{2I}{c}L^2 = \mu_s mg$$

Radiation falling on surface normally & absorbed completely by surface

$a = 1,\ r = 0$



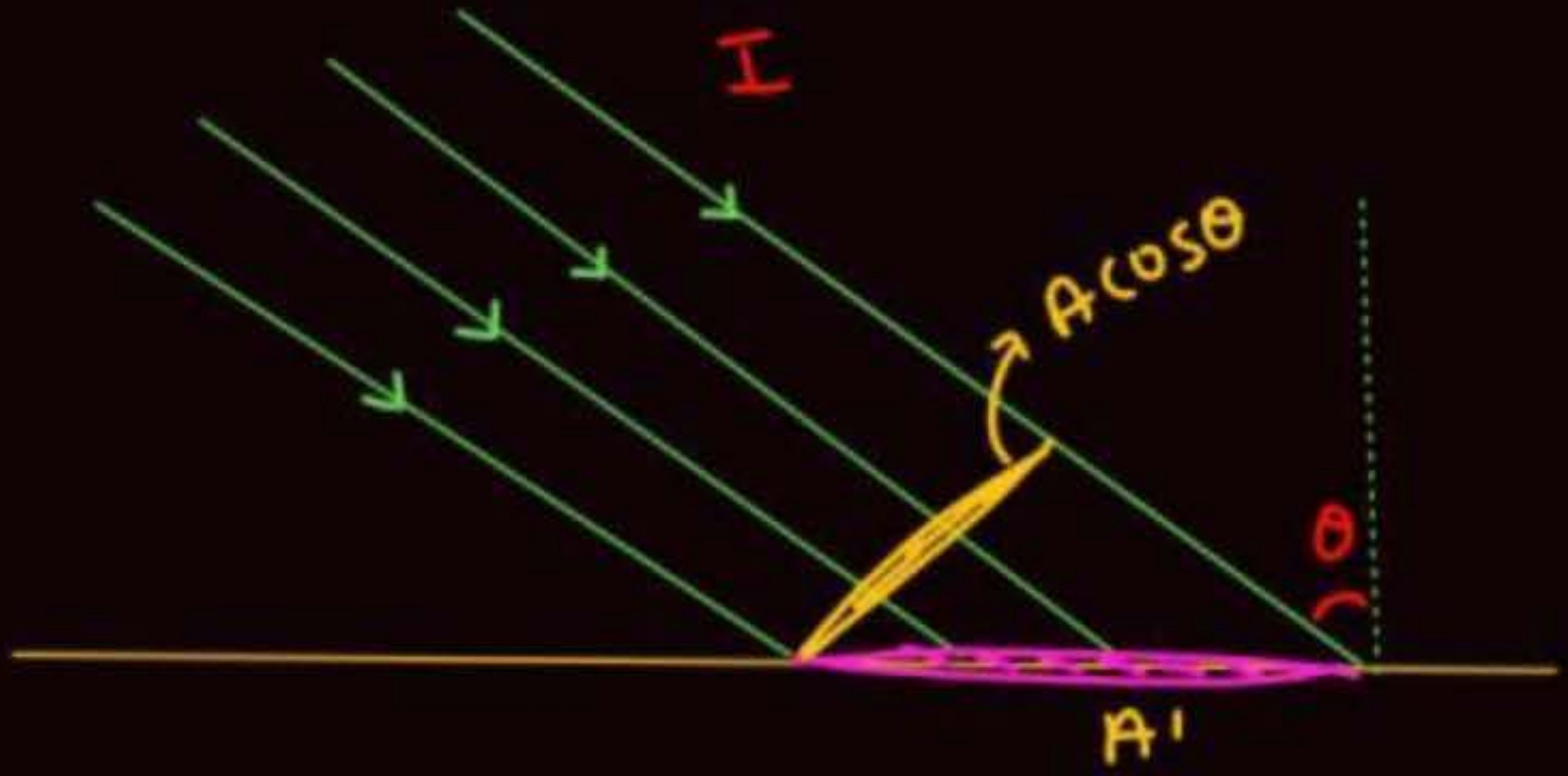
$$(\Delta P)_{\text{one photon}} = \frac{h}{\lambda}$$

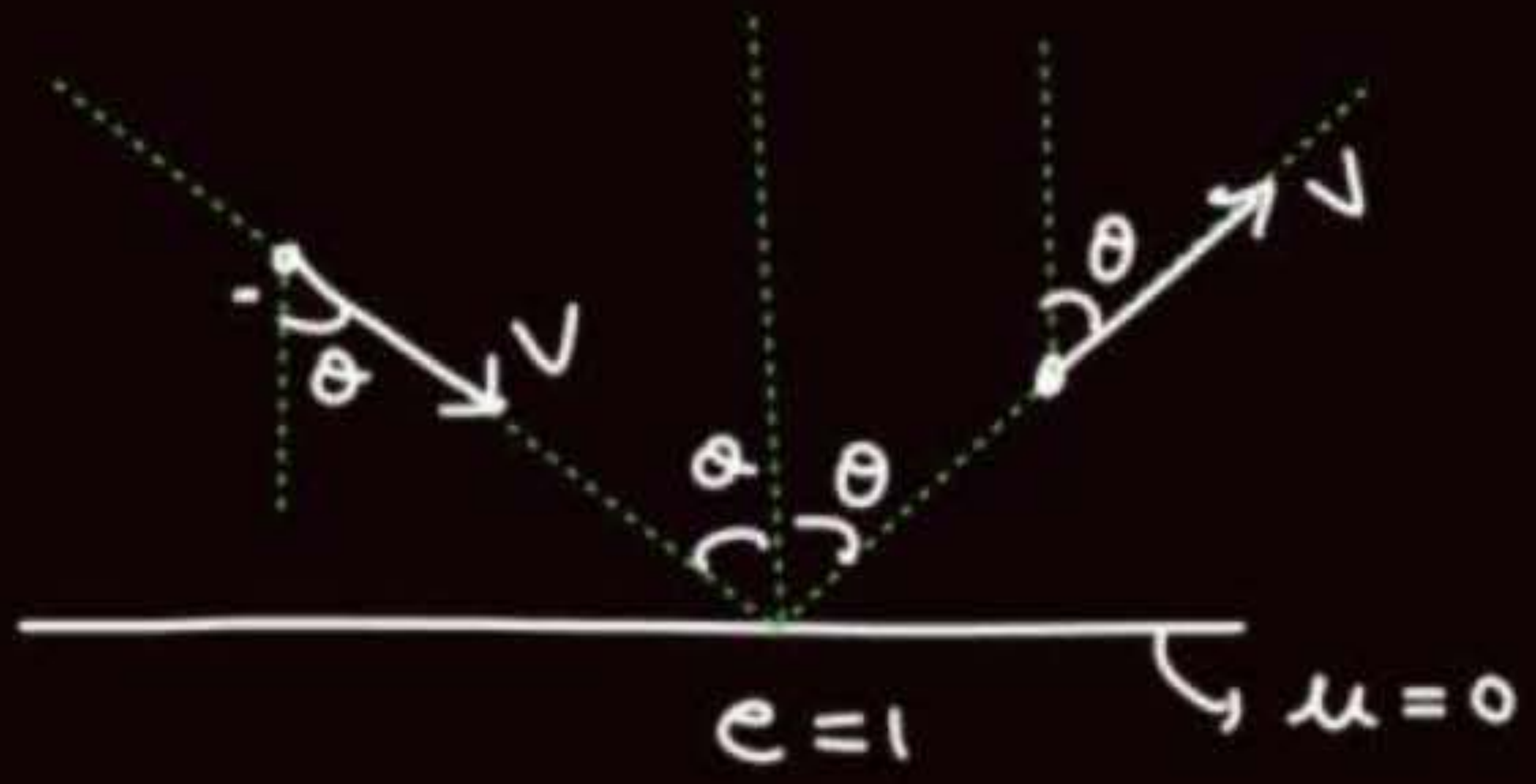
$$F = n\frac{h}{\lambda} = \frac{IA}{\frac{hc}{\lambda}} \cdot \frac{h}{\lambda}$$

$$F = \frac{IA}{c} \Rightarrow \boxed{P = \frac{F}{A} = \frac{I}{c}}$$

#

$r = 1$
$a = 0$





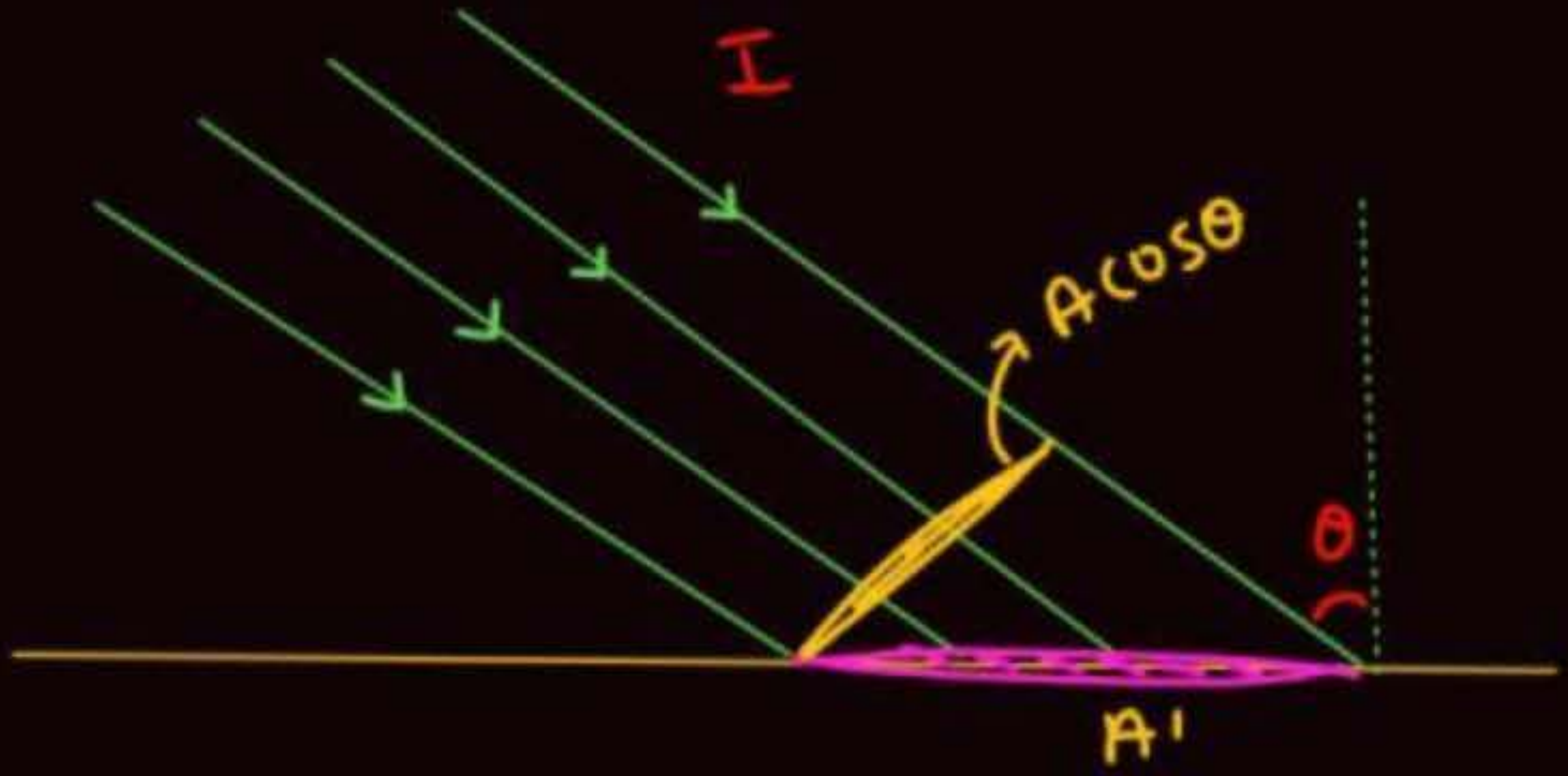
$$(\Delta P)_{\text{one photon}} = \frac{2h}{\lambda}\cos\theta$$

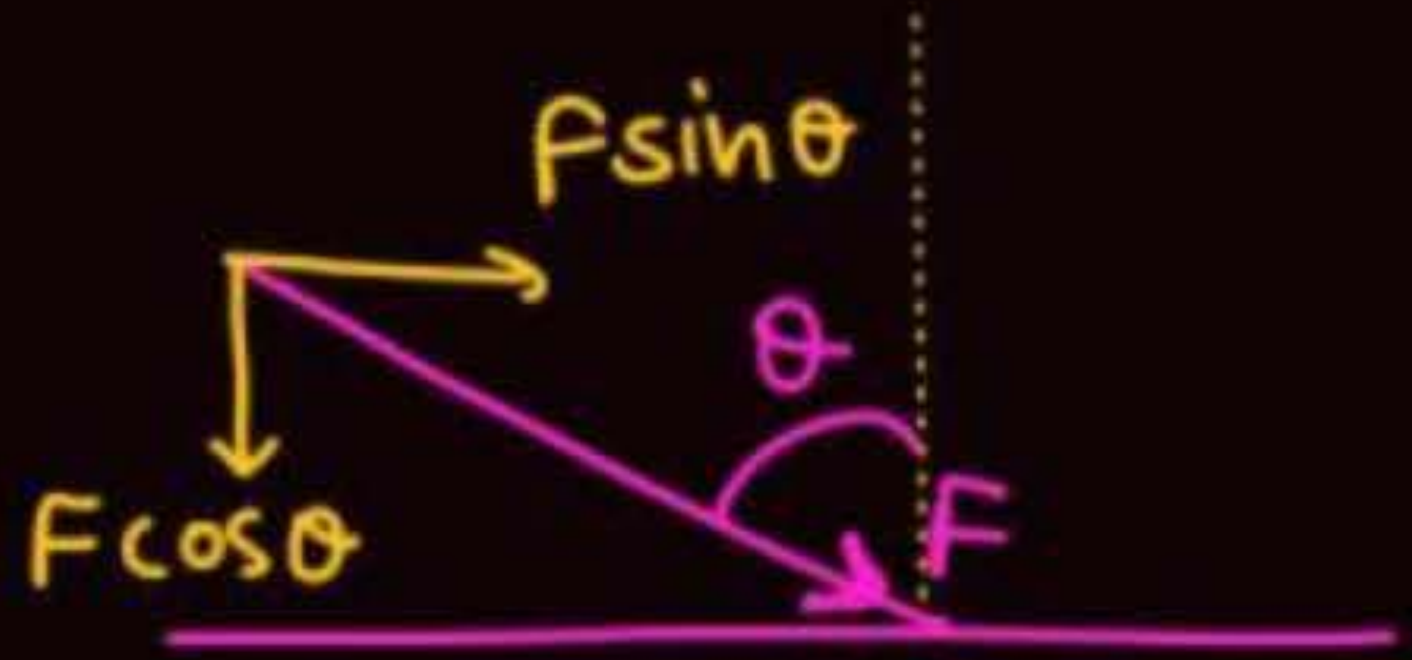
$$\Delta P = 2mV\cos\theta$$

$$F = n\frac{2h}{\lambda}\cos\theta = \frac{IA\cos\theta}{\frac{hc}{\lambda}}\cdot\frac{2h}{\lambda}\cos\theta = \frac{2IA}{c}\cos^2\theta$$

#

$r = 0$
$a = 1$



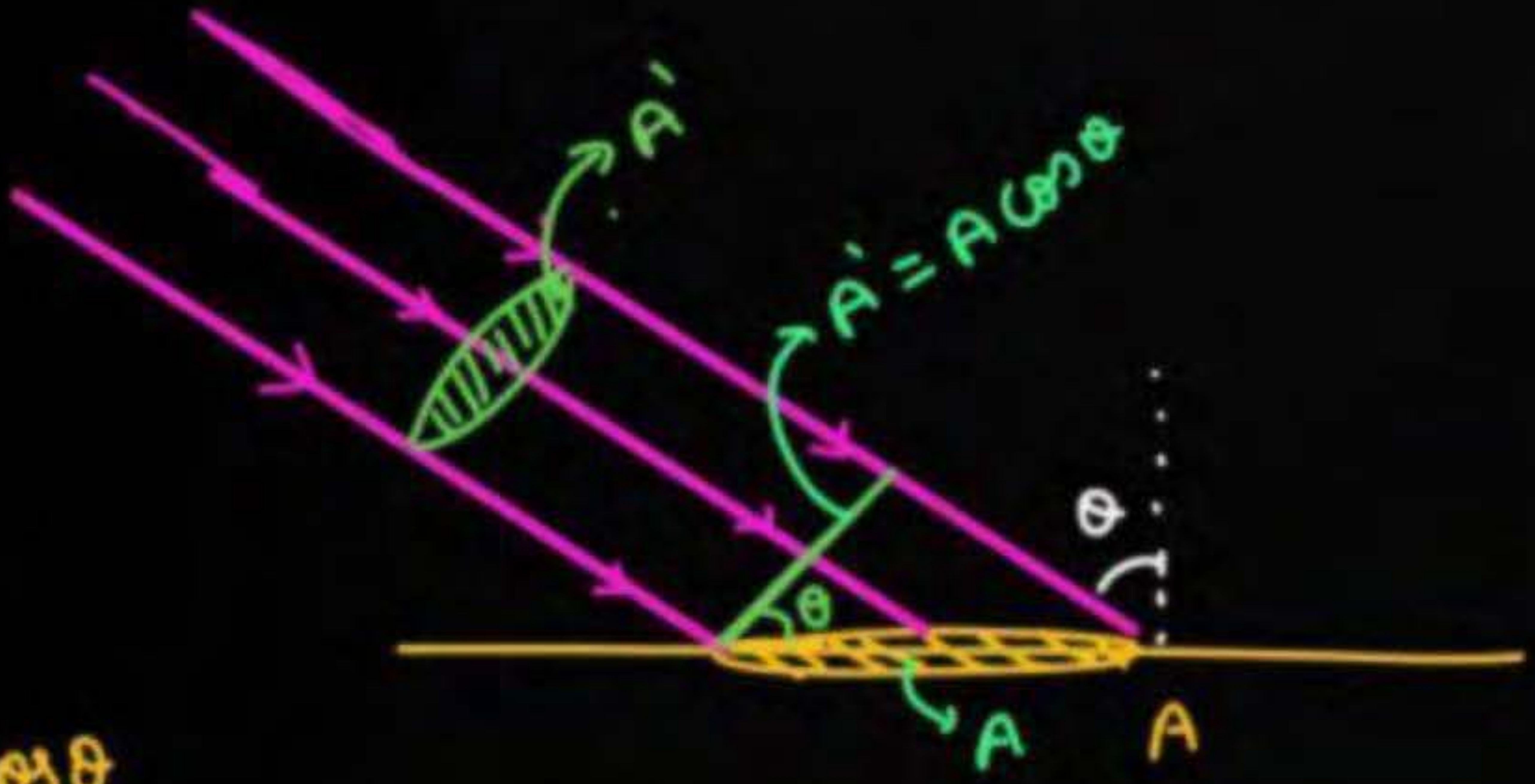


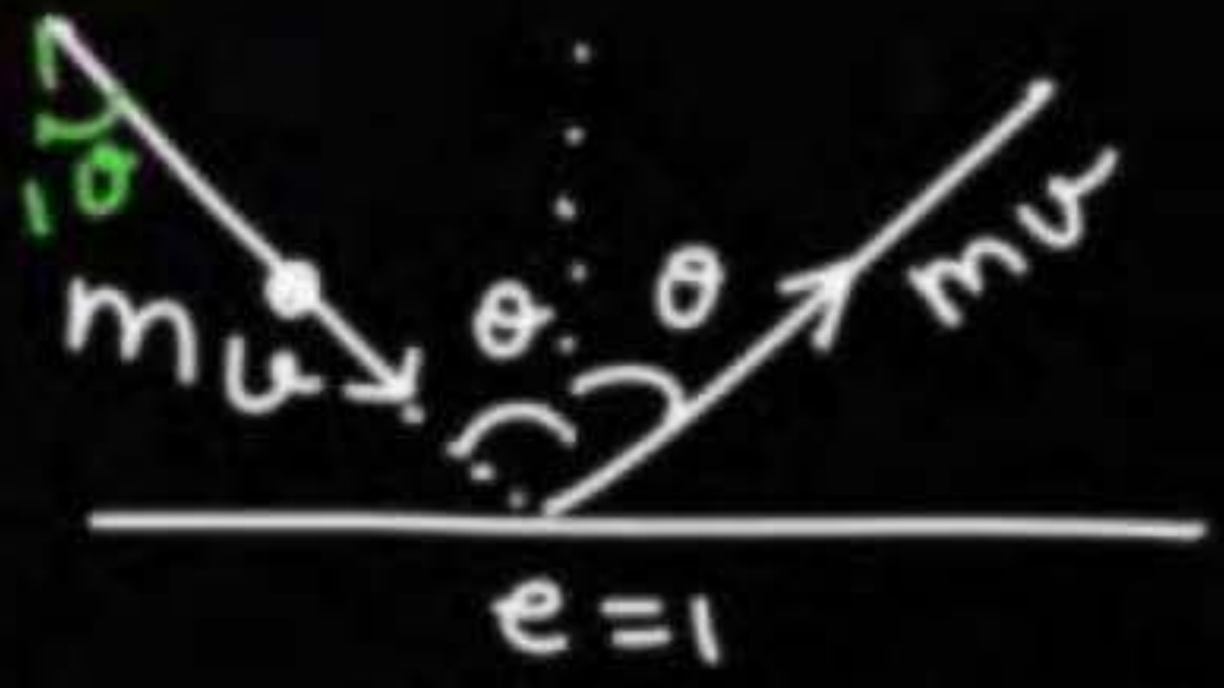
$$(\Delta P)_{one\ photon} = \frac{h}{\lambda}$$

$$F = n\frac{h}{\lambda}$$

$$P = \frac{F\cos\theta}{A} = \frac{n\frac{h}{\lambda}\cdot\cos\theta}{A} = \frac{IA\cos\theta}{\frac{hc}{\lambda}}\cdot\frac{h}{\lambda}\,\frac{\cos\theta}{A}$$

$$= \frac{I}{c}\cos^2\theta$$





$\Delta P = 2mv\cos\theta$

no. of photon per sec.

$$F = \overset{\uparrow}{n}\; 2\frac{h}{\lambda}\cos\theta$$

$$F = \frac{IA'}{\frac{hc}{\lambda}}\left(2\frac{h}{\lambda}\cos\theta\right)$$

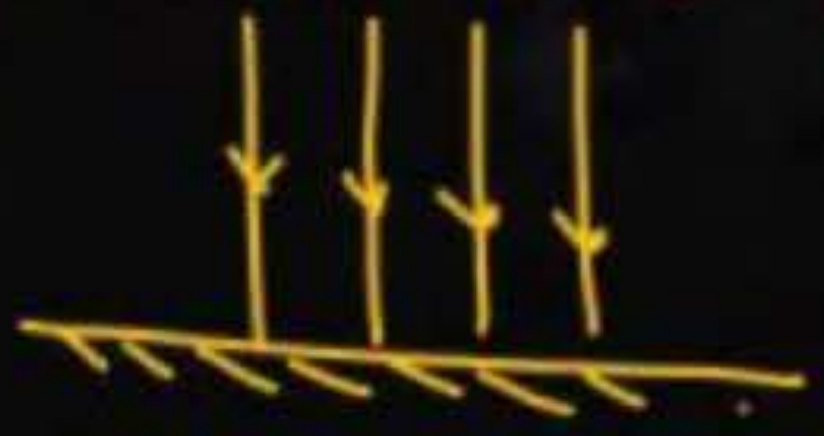
$$\boxed{P = \frac{2I_0\cos^2\theta}{c}}$$

$$F = \frac{IA\cos\theta}{\frac{hc}{\lambda}}\;\frac{2h}{\lambda}\cos\theta \Rightarrow$$

$$P = \frac{I\cos^2\theta}{c}(1+r)$$

$$\boxed{P = \frac{I\cos^2\theta}{c}(1+r)}$$

① $\theta = 0$,



$P = \frac{I}{c}(1+r)$

$r = 1 \Rightarrow P = 2\frac{I}{c}$

$r = 0 \Rightarrow P = \frac{I}{c}$

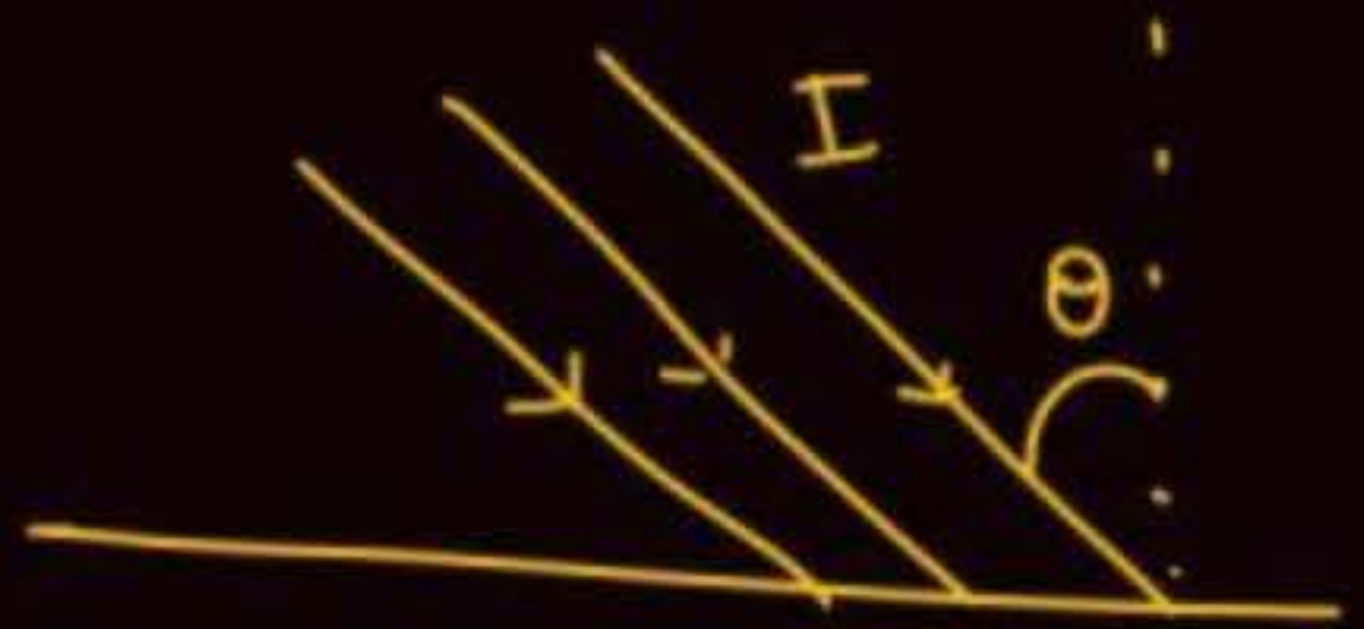
$r = \cdot 3, \; a = \cdot 7$

$P = \frac{I}{c}(1+\cdot 3)$

Q

$r = \cdot 7, \; a = \cdot 3$

$P = \frac{I}{c}\cos^2 30 \cdot (1+\cdot 7)$



$$P = \frac{I}{c}\cos^2\theta\,(1+r)$$

- $p = \frac{h}{\lambda}$
- $E = \frac{hc}{\lambda} = \frac{12400}{\lambda_{(A^0)}} = \frac{1240}{\lambda} \rightarrow (nm)$
- $n = \frac{P}{\frac{hc}{\lambda}}$

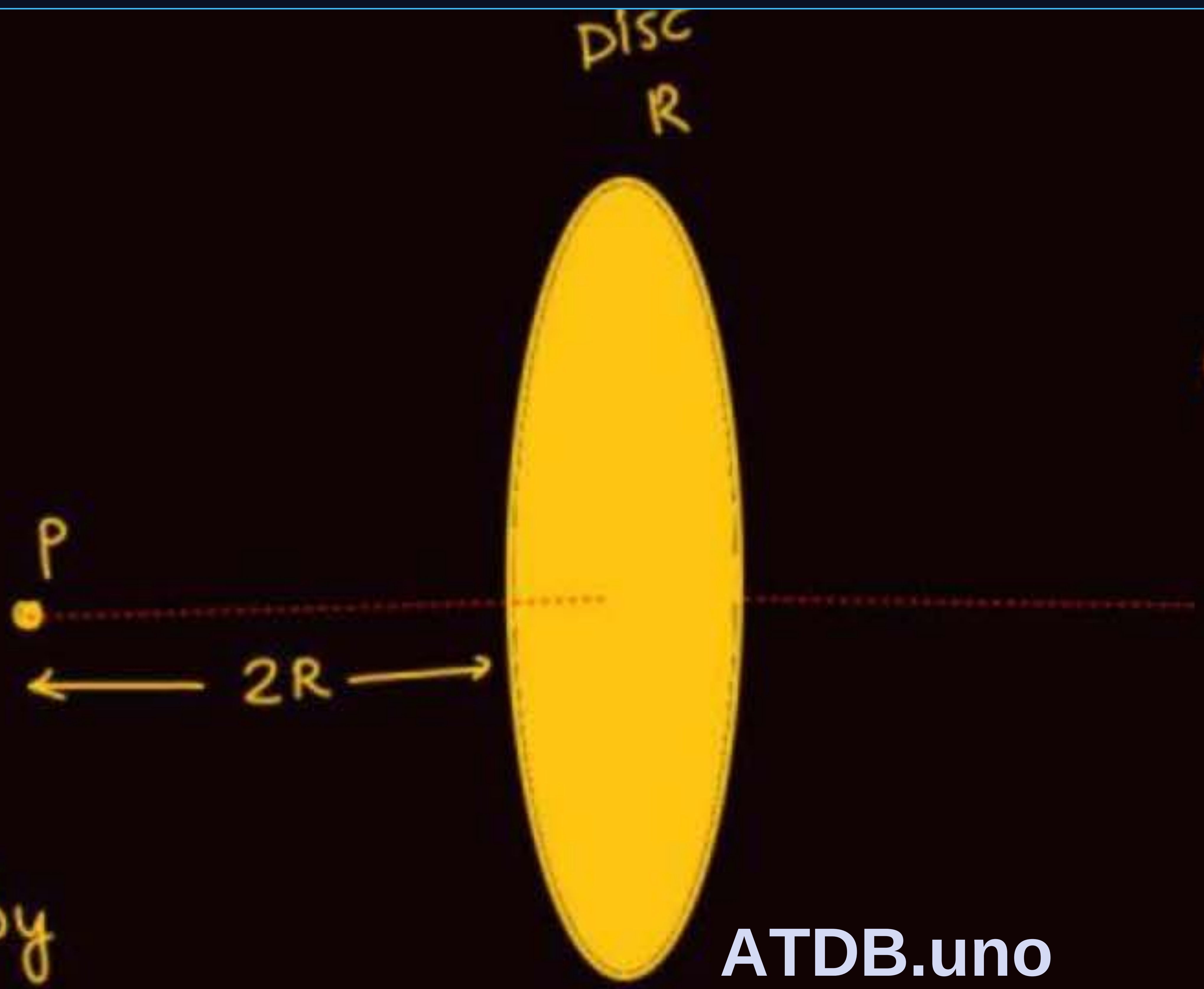
no. of photon per sec

$I = \frac{\text{Energy}}{\text{Area}} = \frac{\text{Power}}{\text{Area}}$

point source $I = \frac{P}{4\pi r^2}$

(JA)

Q



mirror plate ≡ $r=1$

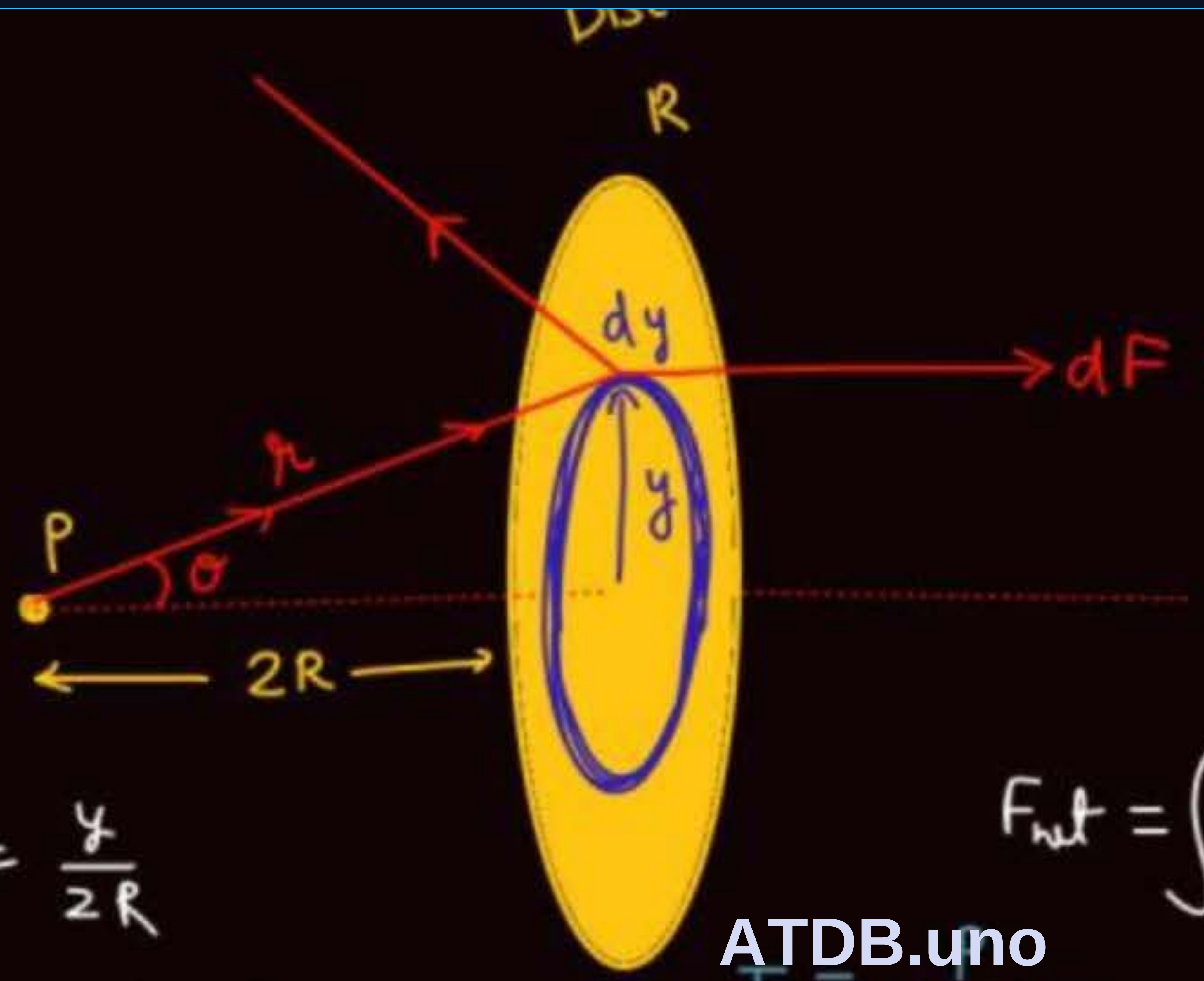
surface

point source 'P'.

find force applied by light on plate.

(assume perfectly reflecting $r=1$)

(Jn) Sol^n



$$dF = PdA = \frac{I}{c}(1+r)\cos^2\theta \cdot 2\pi y\,dy$$

$$dF = \frac{2I}{c}\cos^2\theta \cdot 2\pi y\,dy$$

$$\tan\theta = \frac{y}{2R}$$

$$y = 2R\tan\theta$$

$$dy = 2R\sec^2\theta\,d\theta$$

$$r = 2R\sec\theta$$

$$I = \frac{P}{4\pi r^2}$$

$$F_{net} = \int dF = \int_0^{\theta_0} \frac{2I}{c}\cdot\cos^2\theta \cdot 2\pi \cdot 2R\tan\theta\ 2R\sec^2\theta\,d\theta$$

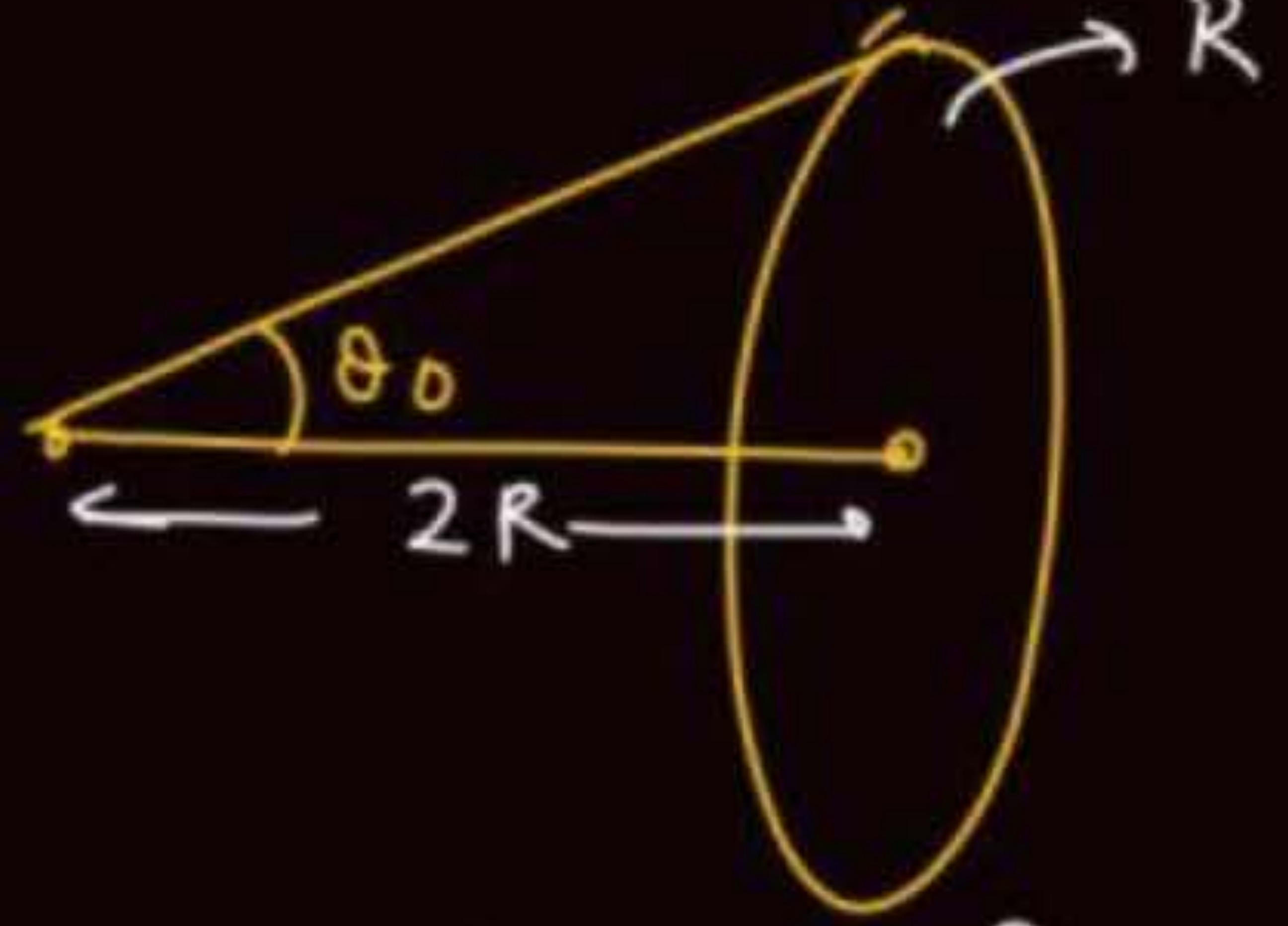
$$= \int \frac{2}{c}\cdot\frac{P}{4\pi r^2}\cos^2\theta \cdot 2\pi\cdot 2R\tan\theta\ 2R\sec^2\theta\,d\theta$$

$$= \frac{4PR^2}{c}\int \frac{\cos^2\theta\cdot\tan\theta\sec^2\theta\,d\theta}{4R^2\sec^2\theta} = \frac{P}{c}\int_0^{\theta_0}\sin\theta\cos\theta\,d\theta$$

$$\frac{P}{C}\int_{0}^{\theta_0} \sin\theta \cos\theta \, d\theta$$

$$\sin\theta = t$$

$$\cos d\theta = dt$$



$$\sin\theta_0 = \frac{R}{R\sqrt{5}}$$

$$\frac{P}{C}\int t\,dt = \frac{P}{C}\cdot\frac{\sin^2\theta}{2}\Big|_{0}^{\theta_0} = \frac{P}{2C}\left(\sin^2\theta_0\right)$$

$$= \frac{P}{2C}\left(\frac{1}{\sqrt{5}}\right)^2 = \frac{P}{10C}$$

Q Find force on hemisphere due to light falling on it if power of point source is P ($r = 1$)

Ans $\boxed{\dfrac{P}{2C}}$

Q Find force on hemisphere due to light falling on it if power of point source is P

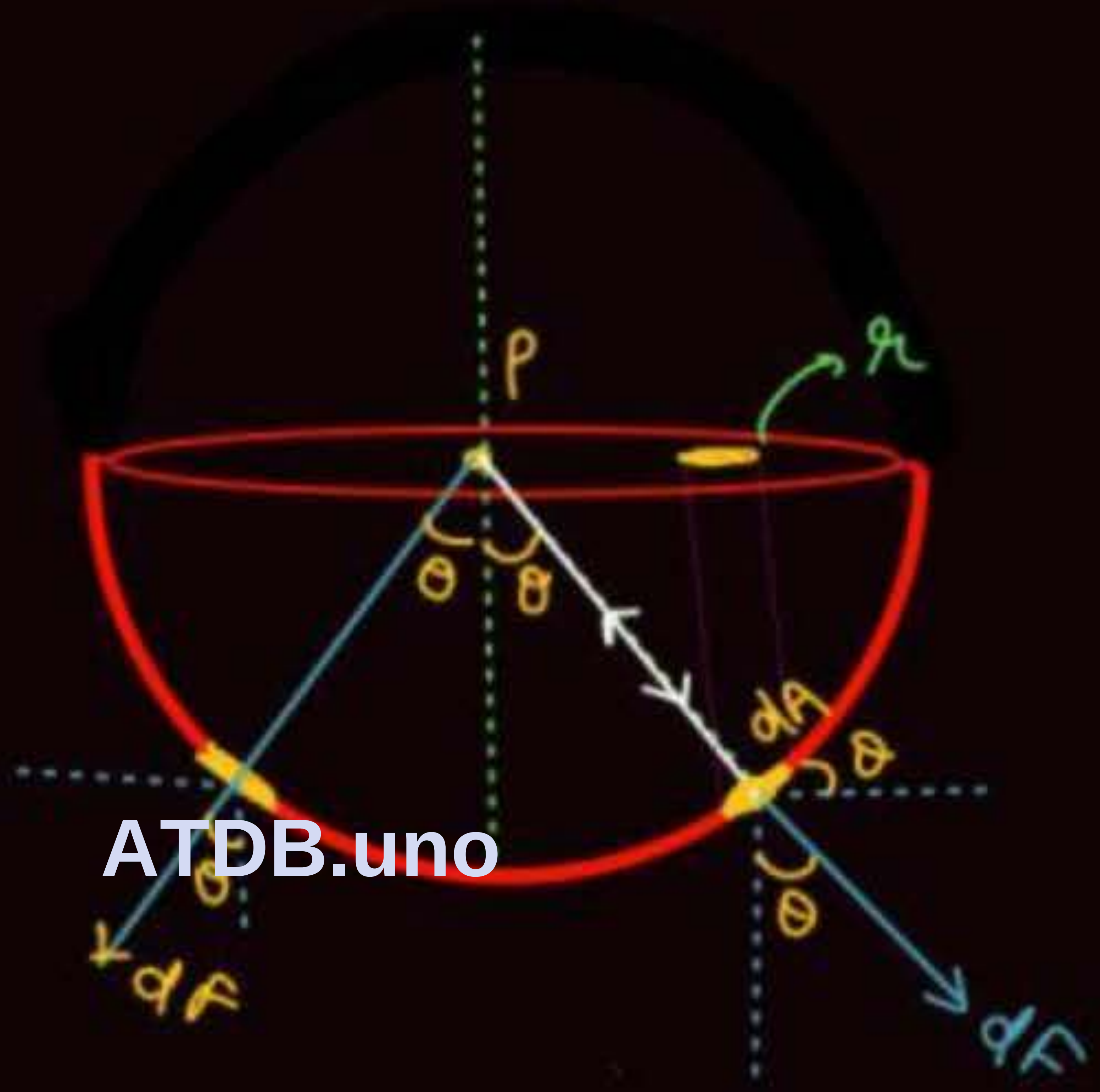
Sol^n

$$F_{net} = \int dF\cos\theta$$

$$= \int 2\frac{P}{4\pi r^2}\cdot\frac{1}{c}\,dA\cos\theta$$

$$= \frac{2P}{4\pi r^2 c}\int dA\cos\theta$$

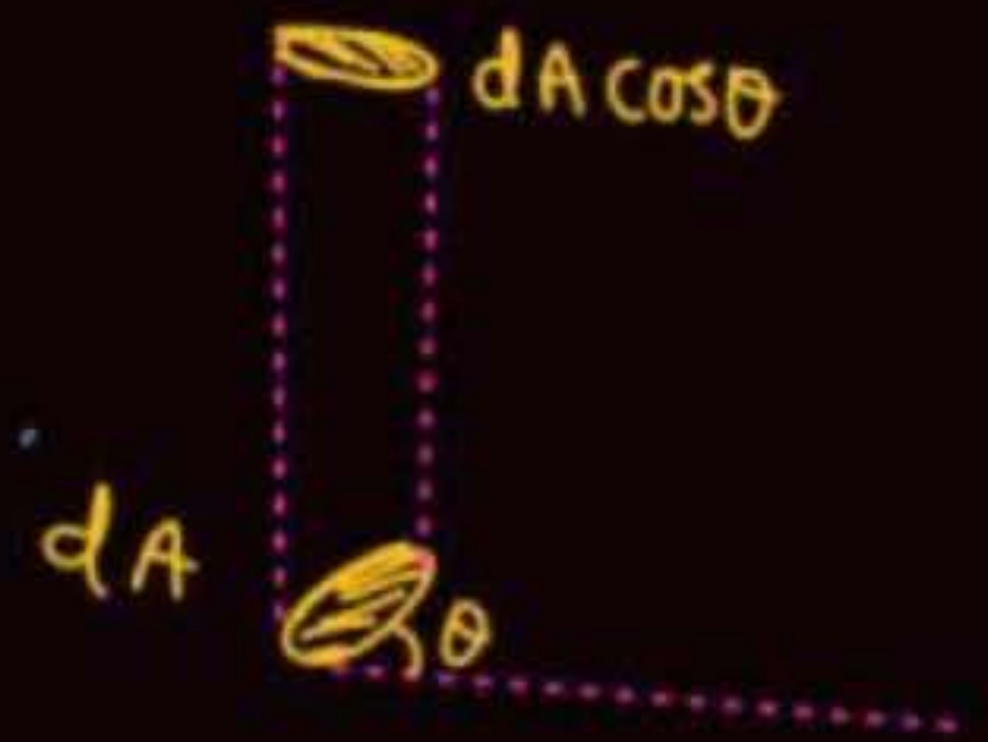
$$= \frac{2P}{4\pi r^2 c}\cdot\pi r^2 = \boxed{\frac{P}{2c}}$$



$$dF = (\text{Pressure})\,dA$$

$$dF = \frac{2I}{c}\cdot dA$$

$$= 2\cdot\frac{P}{4\pi r^2}\cdot\frac{1}{c}\cdot dA$$



QUESTION

A point source of light is placed at the centre of curvature of a hemispherical surface. The source emits a power of 24 W The radius of curvature of hemisphere is 10 cm and the inner surface is completely reflecting. The force on the hemisphere due to the light falling on it is ______ $\times 10^{-8}$ N.

$\gamma = 1$

[30 January 2023 - Shift 1]

Ans. (4)

QUESTION

A point source of light is placed at the centre of curvature of a hemispherical surface. The source emits a power of 24 W The radius of curvature of hemisphere is 10 cm and the inner surface is completely reflecting. The force on the hemisphere due to the light falling on it is ______ × 10^{-8} N. [30 January 2023 - Shift 1]

$$F = \frac{P}{2c} = \frac{24}{2 \times 3 \times 10^{8}} = \underline{\underline{4 \times 10^{-8}}}$$

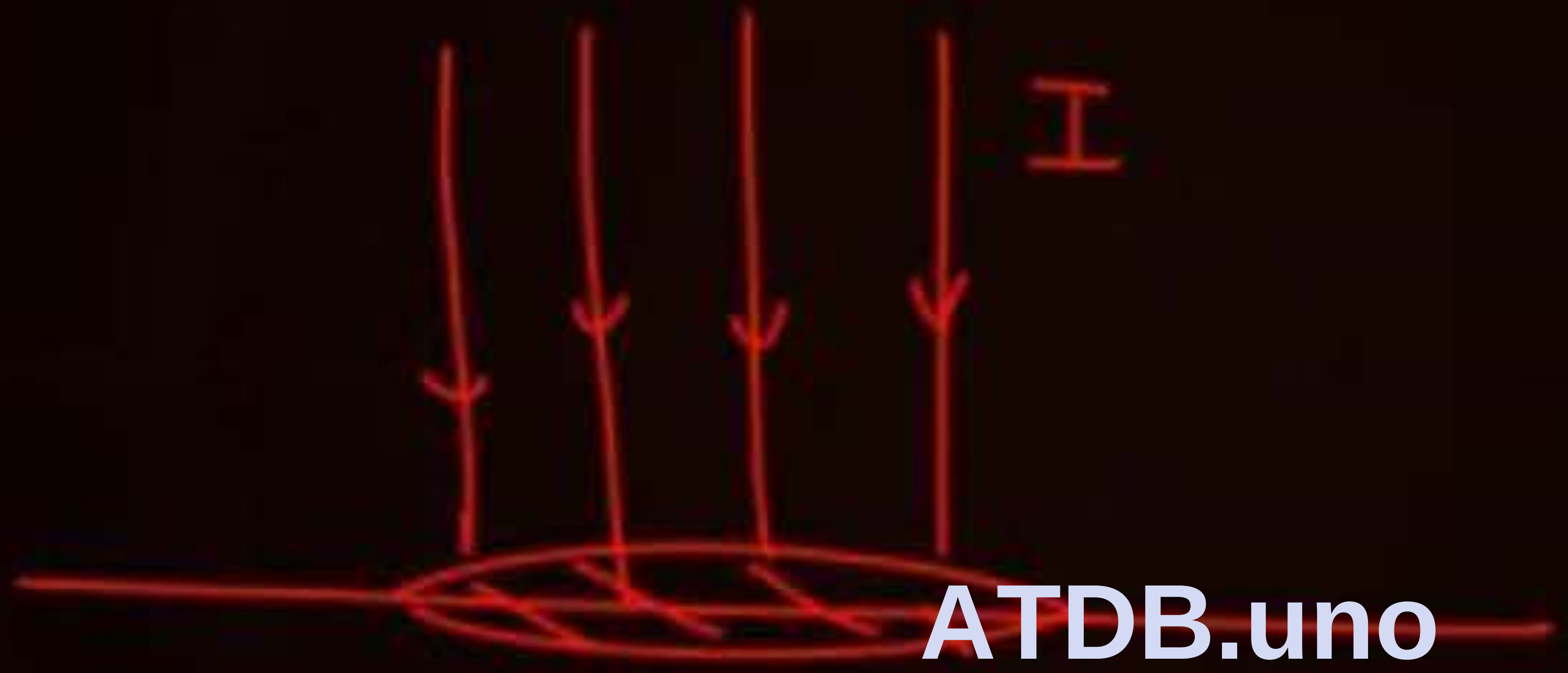
Ans. (4)

QUESTION

$a = 1$

Average force exerted on a non-reflecting surface at normal incidence is 2.4×10^{-4} N. If 360 W/cm^2 is the light energy flux during span of 1 hour 30 minutes, Then the area of the surface is:

[08 Apr. 2024 - Shift 1]



$$F = \frac{I}{c} \times (\text{Area})$$

1. $0.2\ \text{m}^2$
2. $20\ \text{m}^2$
3. $0.1\ \text{m}^2$
4. $0.02\ \text{m}^2$

Ans : (4)

QUESTION

Average force exerted on a non-reflecting surface at normal incidence is 2.4×10^{-4} N. If 360 W/cm^2 is the light energy flux during span of 1 hour 30 minutes, Then the area of the surface is:

[08 Apr. 2024 - Shift 1]

1. $0.2\ \text{m}^2$
2. $20\ \text{m}^2$
3. $0.1\ \text{m}^2$
4. $0.02\ \text{m}^2$

$$F = \frac{I}{c}\,\text{Area} = \frac{360}{10^{-4} \times 3\times10^{8}} \times A$$

$$2.4\times10^{-4} = \frac{360 \times 10^{-4}}{3}\,(\text{Area})$$

$$\text{Area} = \frac{7.2}{360} = \frac{2}{100}\ \text{m}^2$$

Ans : (4)


THANK
YOU