

# PRAYAS

## JEE 2025



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Lecture - 01

Physics

Modern Physics - 01

Radiation pressure & photon theory

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# Today's Goal

- Photon theory
- Radiation pressure

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## 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

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- 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.

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- ⊗ momentum of a photon =  $\frac{h}{\lambda}$  ( $\lambda \rightarrow$  wavelength) frequency
- ⊕ Energy of a photon =  $E = \frac{hc}{\lambda} = h\nu$   $E = h\nu$   
 $c = \nu\lambda = f\lambda$

⊕ Energy of one photon in eV =  $\frac{12400}{\lambda}$  eV =  $\frac{1240}{\lambda}$  eV

$\lambda$   $\rightarrow$  (nm)

$\lambda$   $\rightarrow$  A° में रखना है

\* Dir<sup>n</sup> of momentum of a photon is along in the dir<sup>n</sup> of velocity of light.



Q What is energy of one photon of wavelength

①  $\lambda = 310 \text{ \AA}$

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

②  $\lambda = 620 \text{ nm}$

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

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$$E = \frac{6.6 \times 10^{-34} \cdot 3 \times 10^8}{\lambda} \text{ Joule}$$

$\lambda$   
↳ (meter)

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$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$1 \text{ J} = \frac{1 \text{ eV}}{1.6 \times 10^{-19}}$$

$$\text{Joule} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{\lambda \times 1.6 \times 10^{-19}} \text{ eV}$$

$$\approx \frac{12400}{\lambda} = \frac{1240}{\lambda} \text{ (nm)}$$

$\lambda$  → (put in  $\text{\AA}$ )



Q find energy & momentum of a photon having wavelength  $310 \text{ \AA}$

Sol<sup>n</sup>

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

$$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{310 \times 10^{-10}}$$

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



$$E = h\nu \rightarrow \text{planck const} = 6.63 \times 10^{-34} \text{ Js}$$
$$h = \frac{E}{\nu} \Rightarrow \frac{\text{ML}^2\text{T}^{-2}}{\text{T}^{-1}} \Rightarrow [\text{ML}^2\text{T}^{-1}]$$

$$E = \frac{hc}{\lambda} = h\nu \rightarrow \text{freq.}$$

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Q

$$\lambda_R > \lambda_{\text{Blue}}$$

$$p = \frac{h}{\lambda}, \quad E = \frac{hc}{\lambda}$$

$$\lambda \uparrow \Rightarrow p \downarrow \Rightarrow E \downarrow$$

$$p_{\text{Red}} < p_{\text{Blue}}$$

$$E_{\text{Red}} < E_{\text{blue}}$$

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# Power of Source of monochromatic light

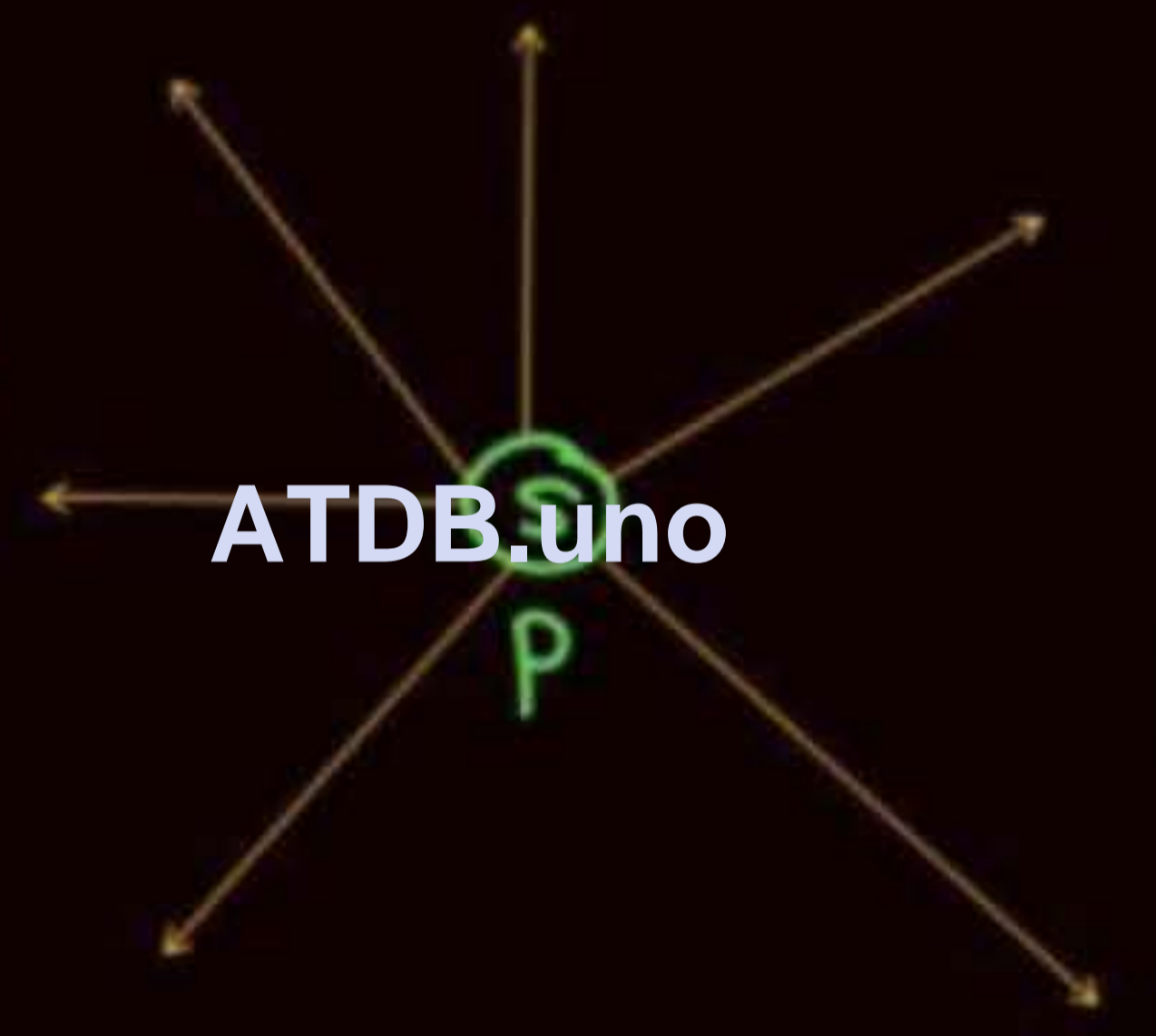


p → power of source

power = Energy per Unit time

n → no. of photon per sec emitted.

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



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

energy of one photon

no. of photon per sec

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



## ① point source

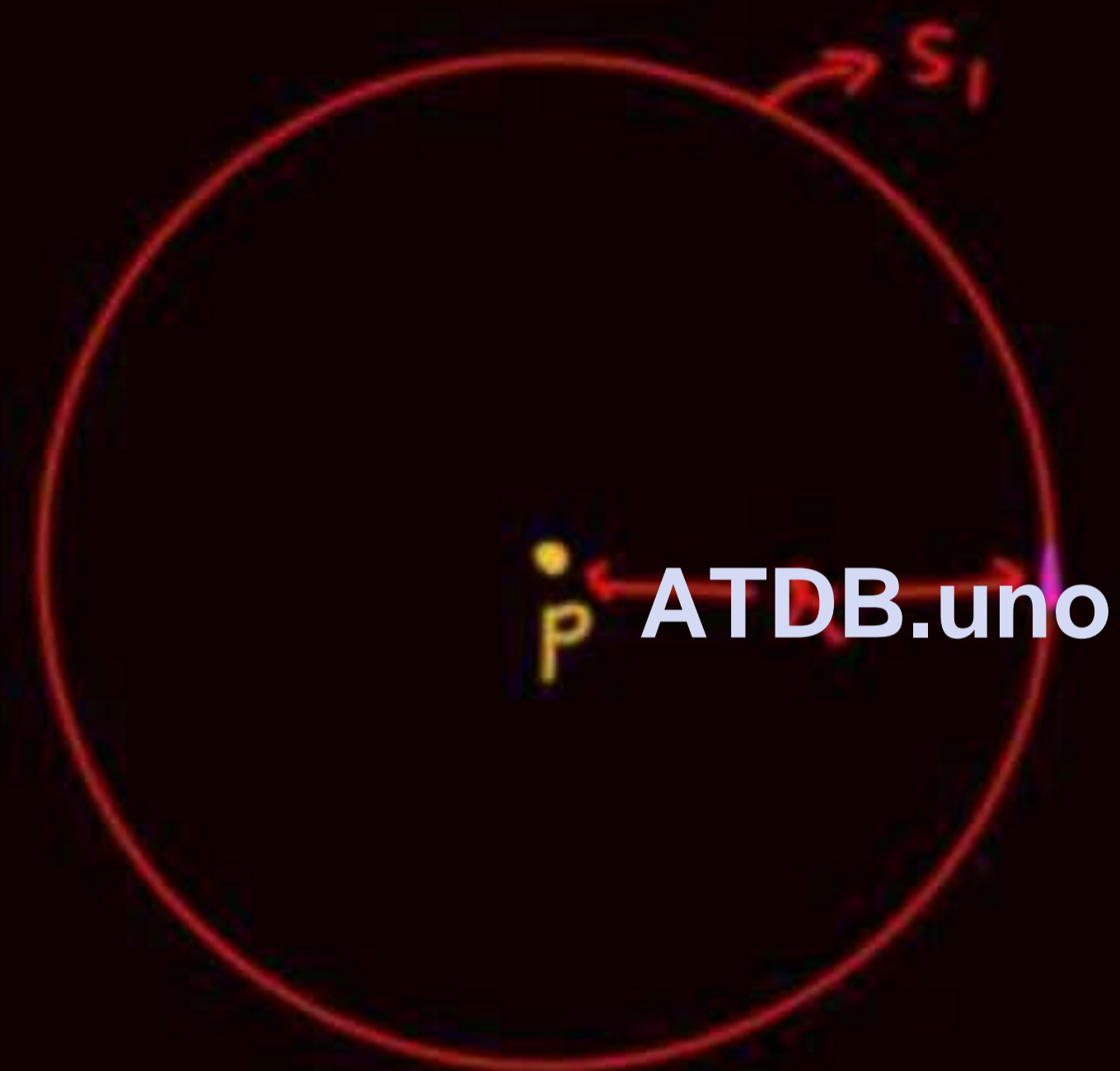
power of source =  $P$

Power Received by  $S_1 = P$

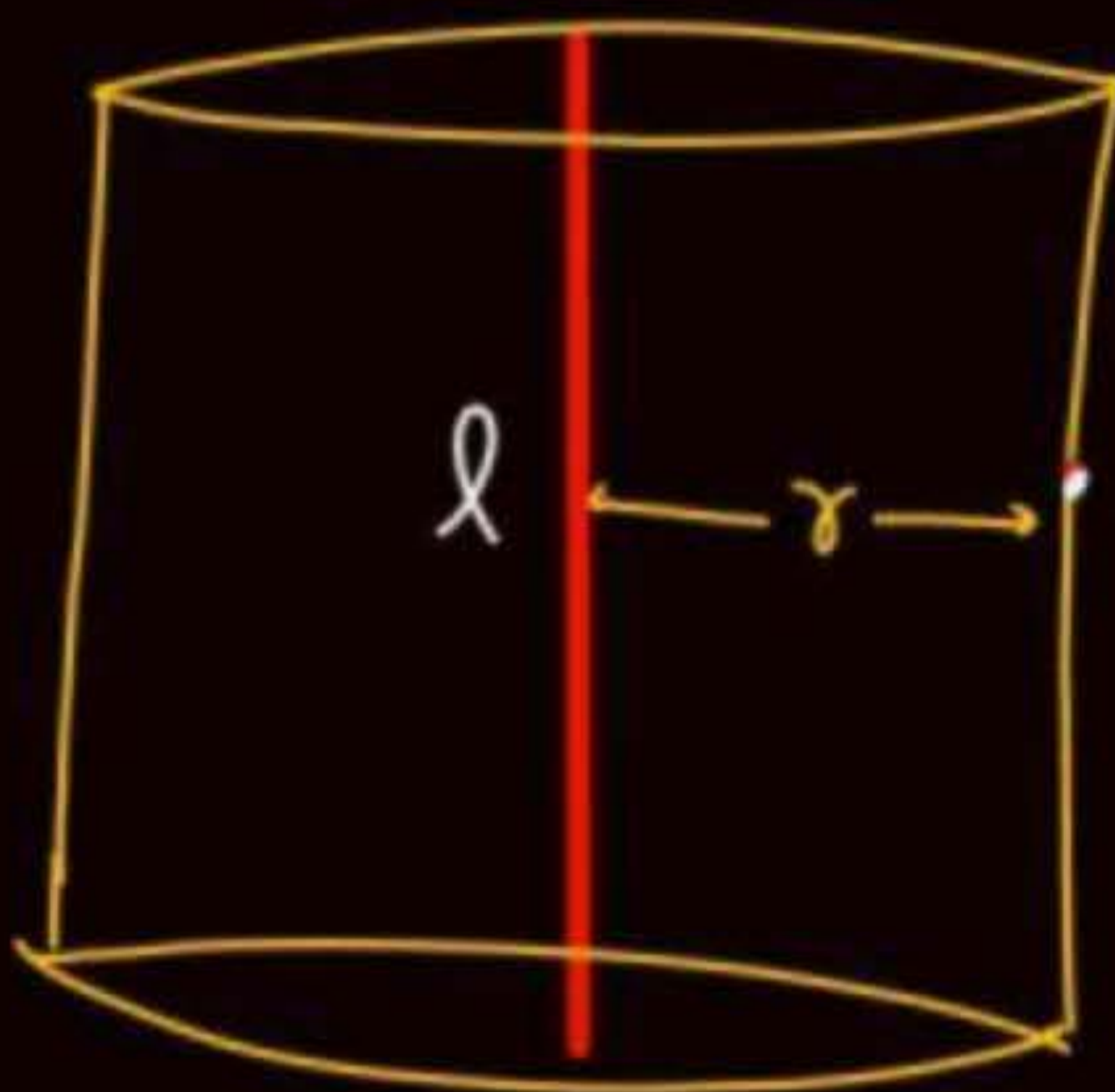
$$\text{Intensity} = \frac{P}{4\pi r^2}$$

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

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



## ② Linear Source

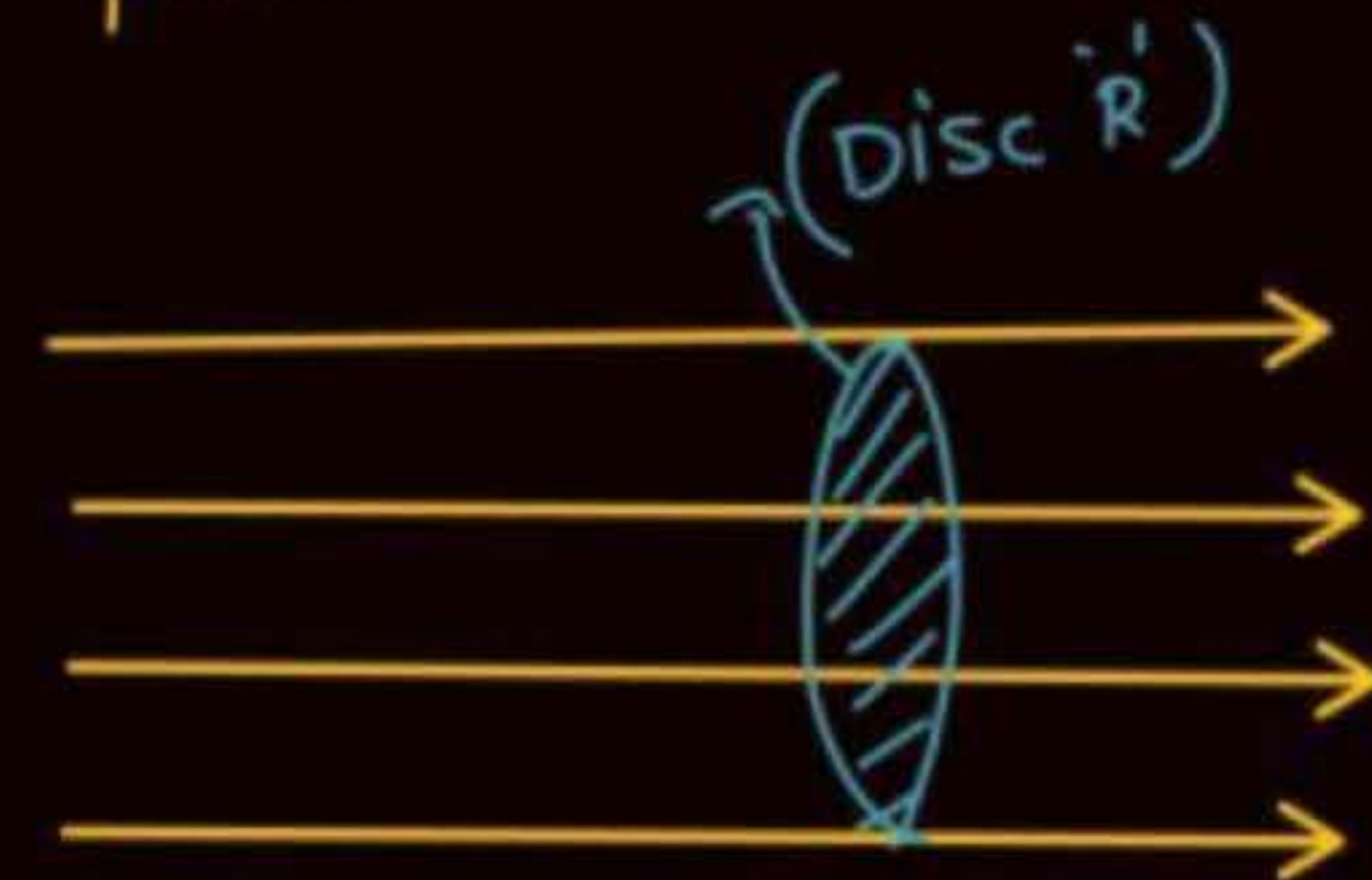


$$I = \frac{P}{2\pi r h}$$

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



③ parallel Beam



$$I \propto r^0$$

$$I \rightarrow \text{const.}$$

$$\text{Power received by Disc} = I \pi R^2$$

$$\text{Energy in time } t = I \pi R^2 t$$

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

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$$c = f\lambda$$

\*  
Q

Consider a point monochromatic source of power 100 watt which emit photon of wavelength  $310 \text{ \AA}$ . Find (100 J/sec)

- ① Frequency of photon  $= \nu = \frac{c}{\lambda} = \frac{3 \times 10^8}{310 \times 10^{-10}}$
- ② Momentum of one photon  $= \frac{h}{\lambda} = \frac{6.6 \times 10^{-34}}{310 \times 10^{-10}}$
- ③ Energy of one photon in eV  $= \frac{12400}{310} = 40 \text{ eV}$
- ④ No. of photon emitted per sec  $= \frac{P}{\frac{hc}{\lambda}} = \frac{100 \times 310 \times 10^{-10}}{6.6 \times 10^{-34} \times 3 \times 10^8} = \checkmark$

⑤ Intensity as function of 'r'  
r  $\rightarrow$  Distance of point from source

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



- ⊛  
 ⑥ Consider a small detector of area  $3 \text{ mm}^2$  placed at a distance of  $2 \text{ m}$  from the source. find no. of photon received by detector in  $10 \text{ sec}$ . also energy received by detector in  $10 \text{ sec}$ .

Sol<sup>n</sup>

$$\text{Energy received by detector in 1 sec} = \frac{P}{4\pi r^2} A_0$$

$$10 \text{ sec में Energy Received} = \frac{P}{4\pi r^2} A_0 t$$

( $t = 10 \text{ sec}$ )

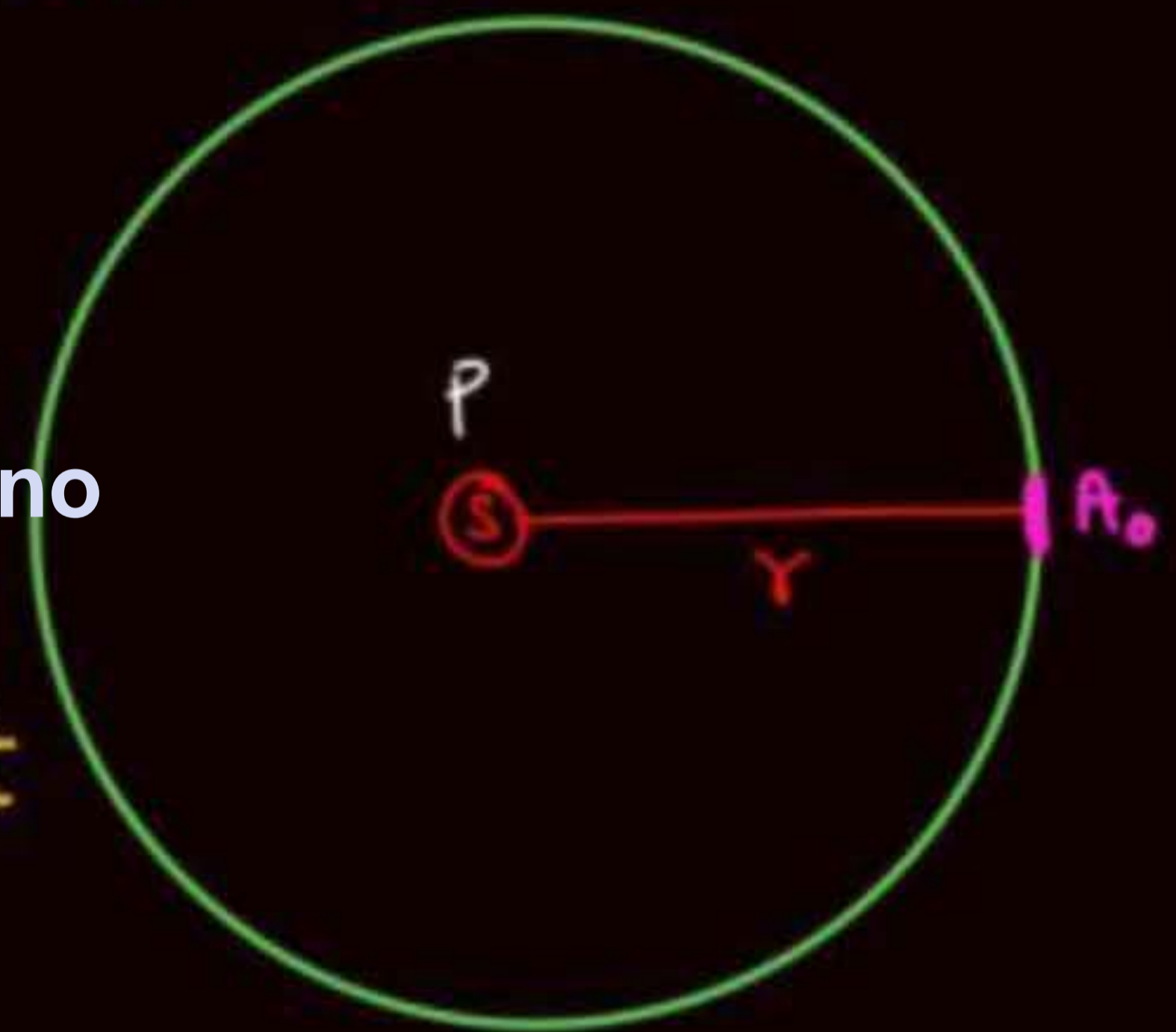
$$\text{No of photon detected in 10 sec} = \frac{\frac{P}{4\pi r^2} A_0 t}{\frac{hc}{\lambda}}$$

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

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

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

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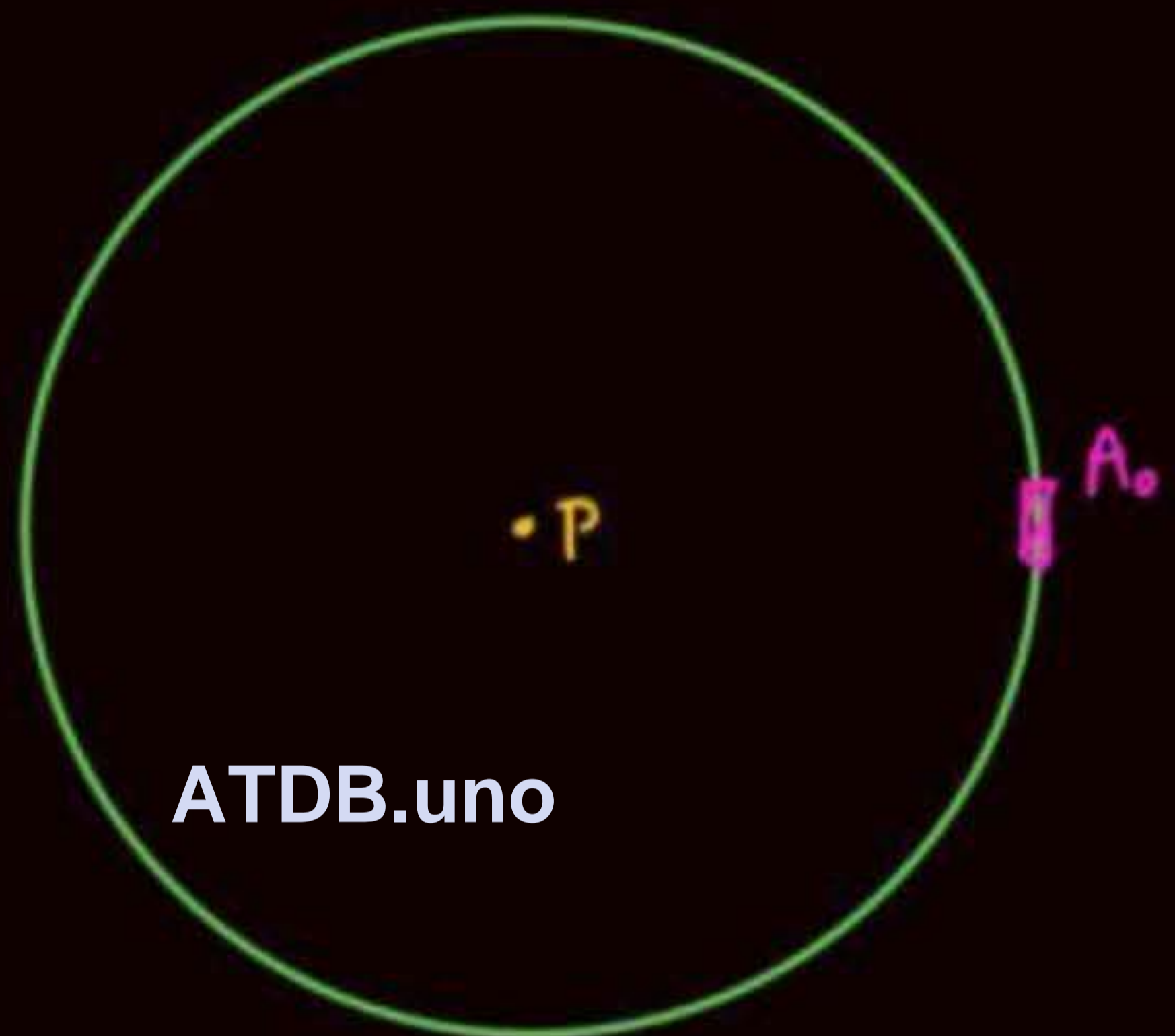


$$I = \frac{P}{4\pi r^2}$$



$t$  sec में कितने photon निकले

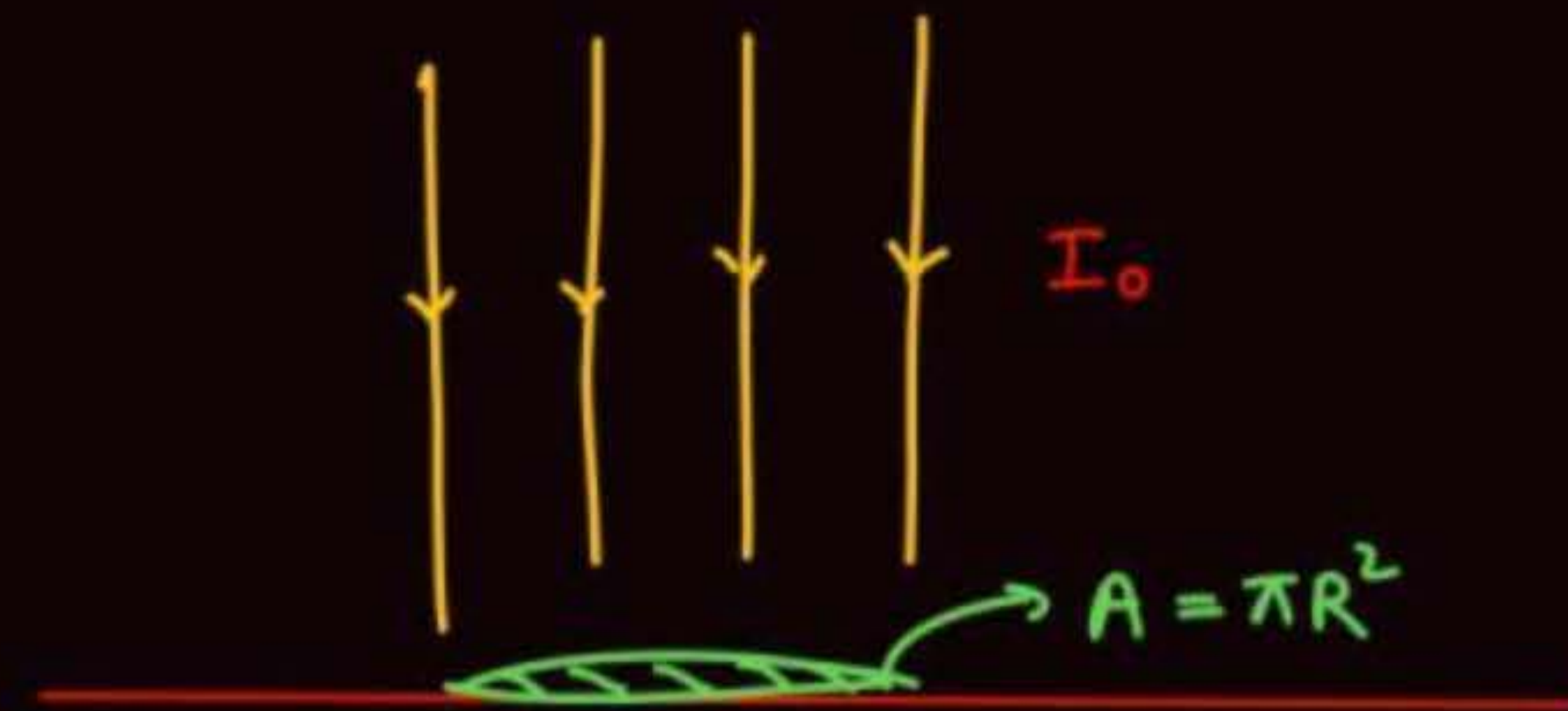
$$= \frac{P}{\frac{hc}{\lambda}} t$$



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



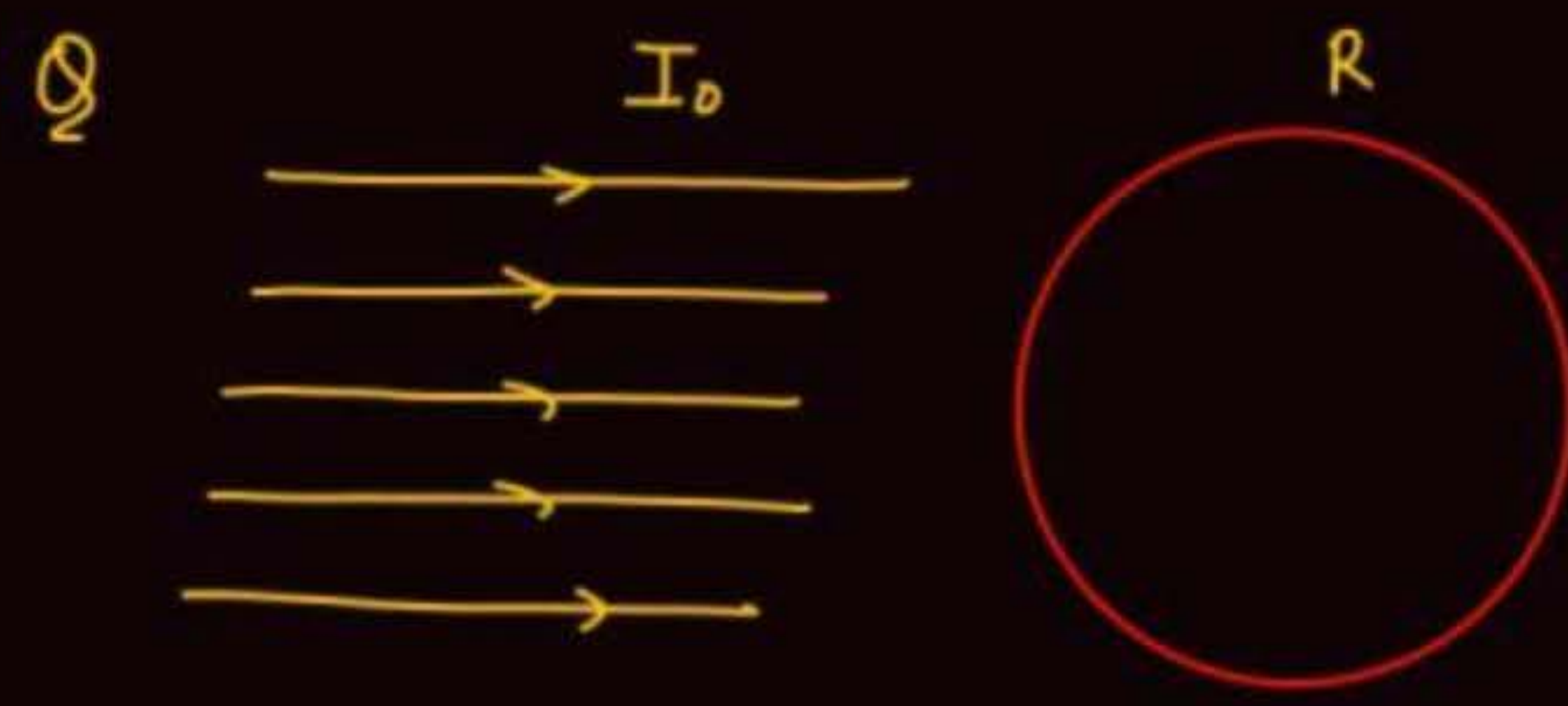
Q



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

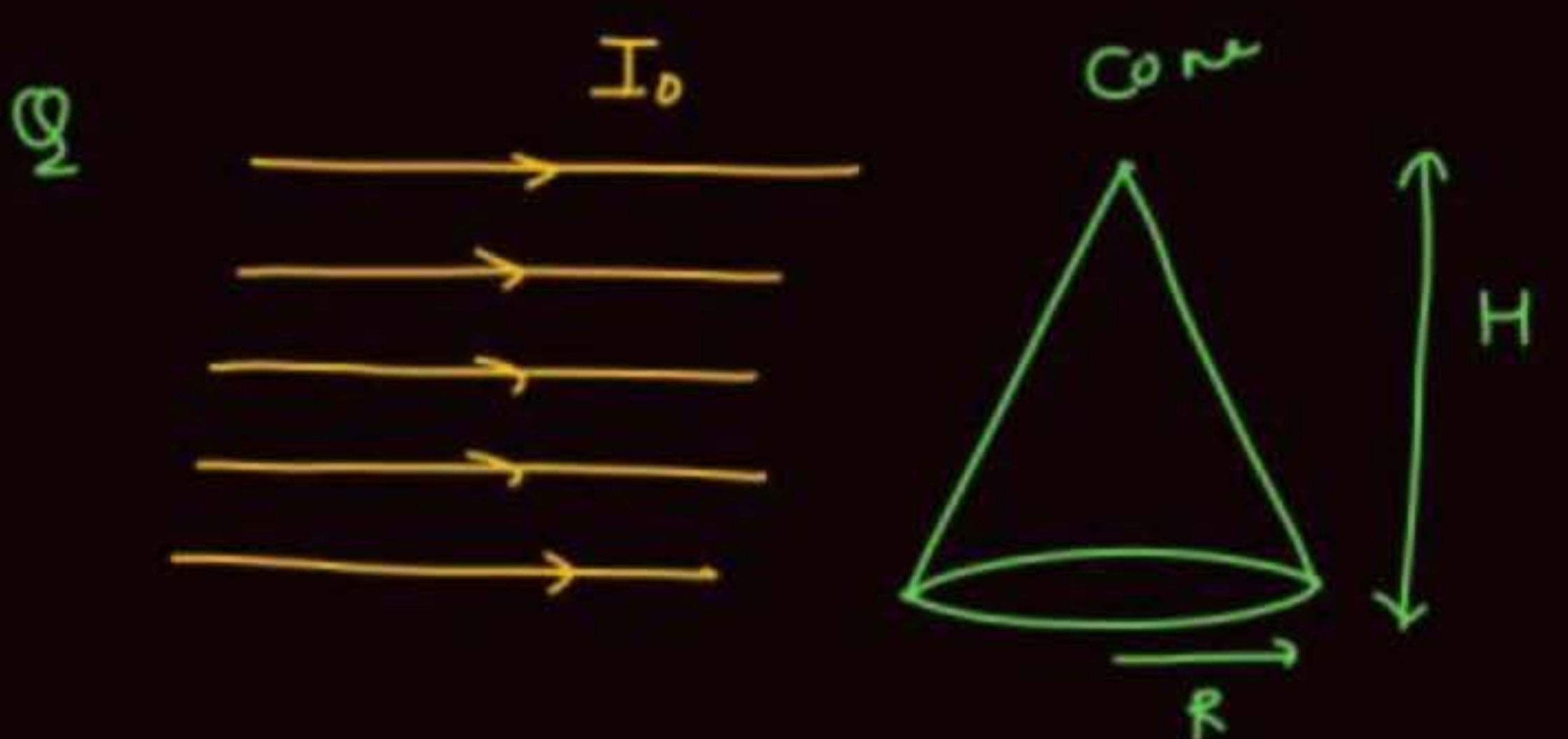
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" " fall on plate in time  $t_0 = \frac{I_0 \pi R^2 t_0}{\frac{hc}{\lambda}}$

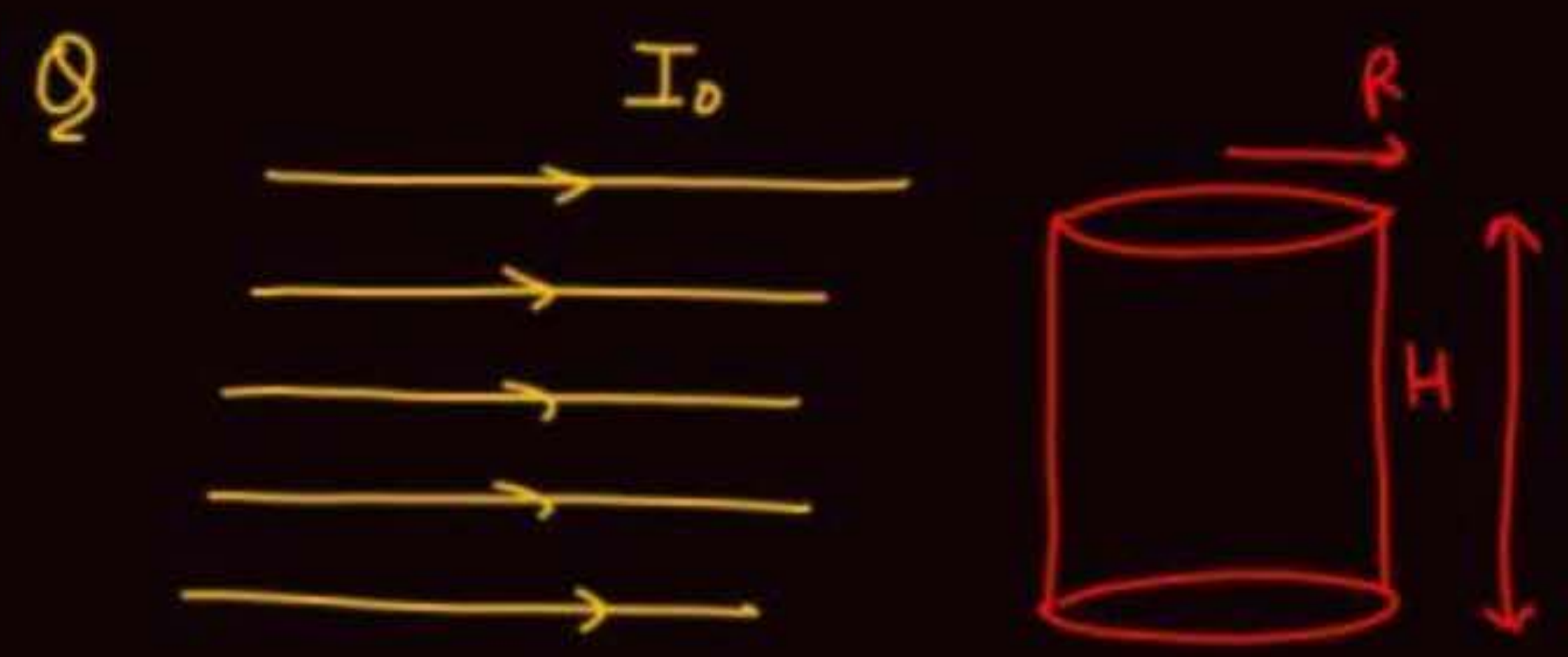


no. of photon per sec falling  
on sphere =  $\frac{I_0 \pi R^2}{\frac{hc}{\lambda}}$

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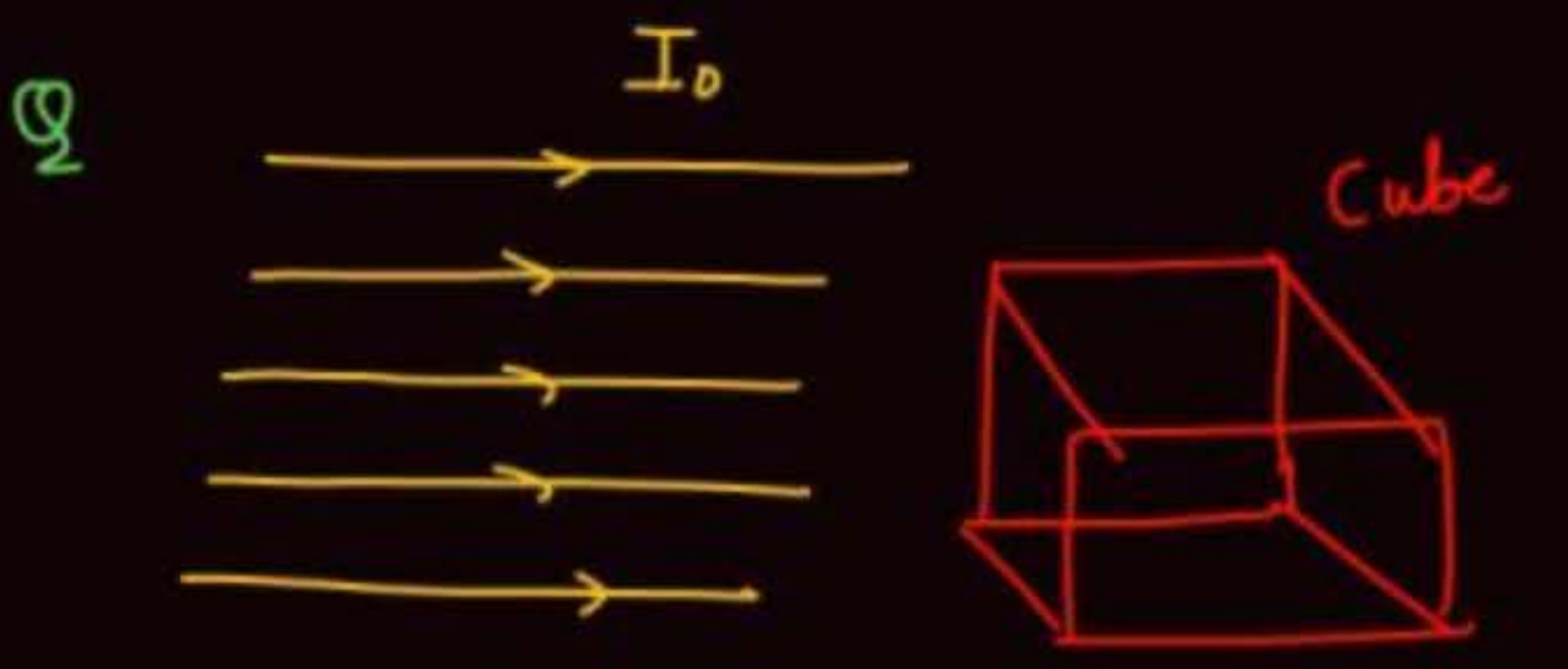


of photon per sec falling  
on cone =  $\frac{I_0 \cdot \frac{1}{2} \times 2R \times H}{\frac{hc}{\lambda}}$



no. of photon per sec falling  
 on cylinder =  $\frac{I_0 H 2R}{\frac{hc}{\lambda}}$

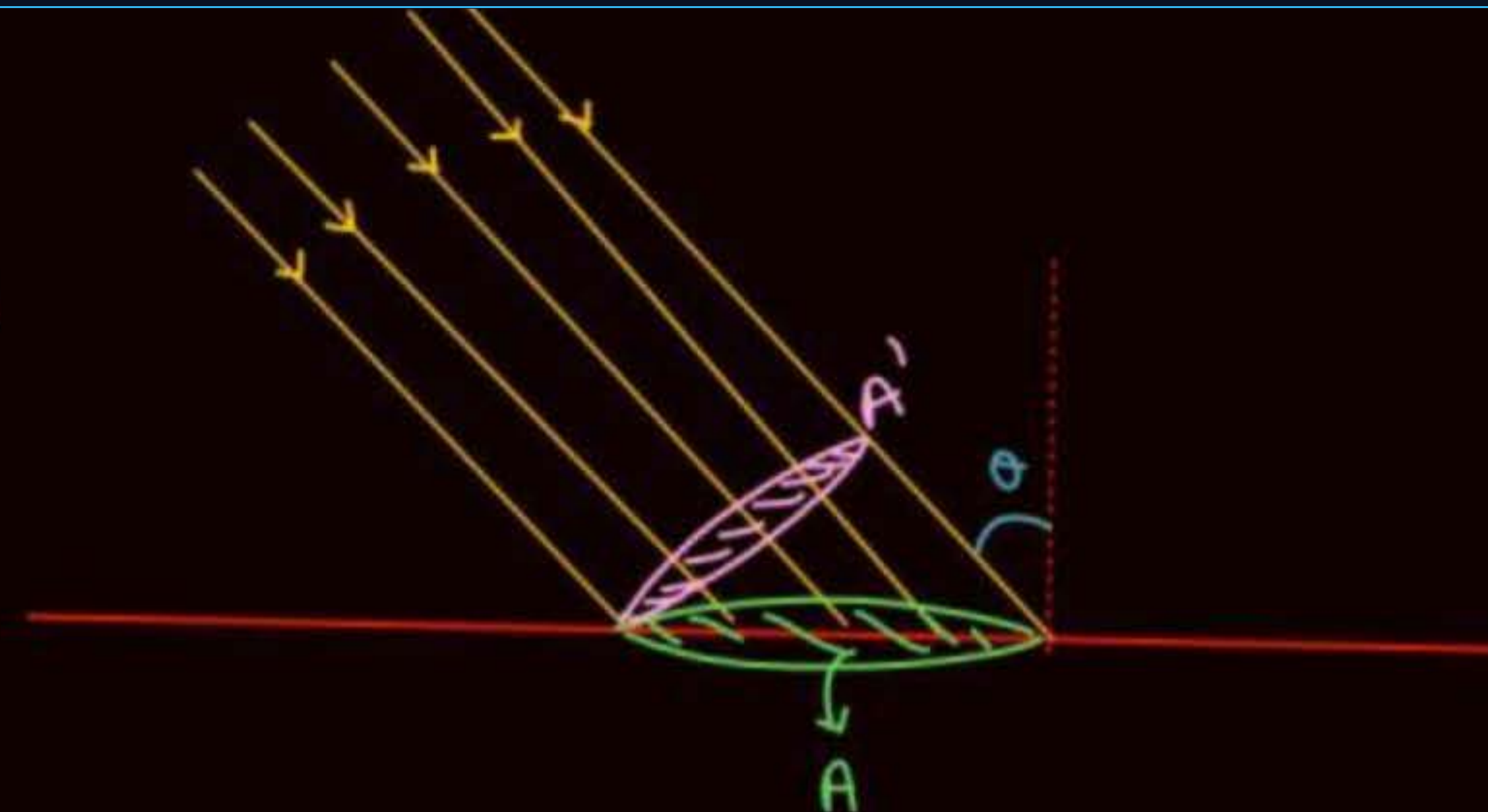
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of photon per sec falling  
 on cube =  $\frac{I_0 L^2}{\frac{hc}{\lambda}}$



$\theta$



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

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## Result

$$* \quad E = \frac{hc}{\lambda} = \frac{1240}{\lambda} = \frac{12400}{\lambda} = \text{Energy of one photon}$$

$\lambda \rightarrow (\text{nm})$                        $\lambda \rightarrow \text{\AA}$

$$* \quad p = \text{momentum of one photon} = \frac{h}{\lambda}$$

$$* \quad v = f \lambda$$

$$* \quad c = f \lambda$$

frequency

$$* \quad p = n \frac{hc}{\lambda} \Rightarrow * \quad n = \frac{p}{\frac{hc}{\lambda}}$$

$p$  → power of source  
 $n$  → no of photon emitted per second

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# PHOTON THEORY OF LIGHT



- A photon is a particle of light moving with speed  $299792458 \text{ m/s}$  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.

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# PHOTON THEORY OF LIGHT



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

$$E \propto \nu$$

or

$$E = h\nu$$

$$E = \frac{hc}{\lambda} \text{ joule } (\because c = \nu\lambda)$$

or

$$E = \frac{hc}{\lambda e} = \frac{12400}{\lambda} \text{ eV} - \text{\AA}$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$\left[ \because \frac{hc}{e} = 12400 (\text{\AA} - \text{eV}) \right]$$

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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,  $\nu$  = frequency of photon,  $\lambda$  = wavelength of photon

# PHOTON THEORY OF LIGHT

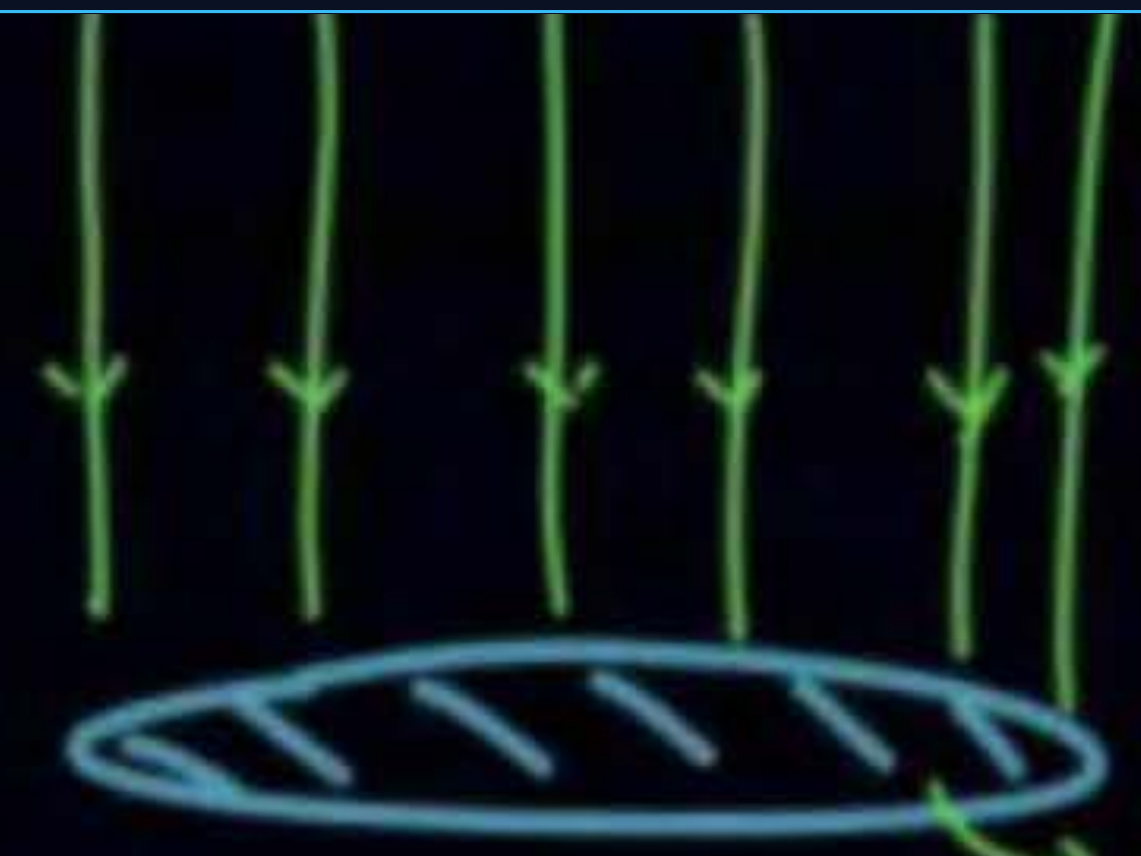


- Linear momentum of photon  $p = \frac{E}{c} = \frac{hv}{c} = \frac{h}{\lambda}$
- Energy of light passing through per unit area per unit time is known as intensity of light.
- Intensity of light  $I = \frac{E}{At} = \frac{P}{A}$
- When photons fall on a surface, they exert a force and pressure on the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

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Q

find no. of photons  
falling in 5 sec.  
 $= n = ?$



$$I = 1000 \text{ watt/m}^2$$

$$\lambda = 1240 \text{ \AA}$$

$$A_0 = 10 \text{ m}^2$$

~~$$\frac{hc}{\lambda} = \frac{12400}{1240} = 10$$~~

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

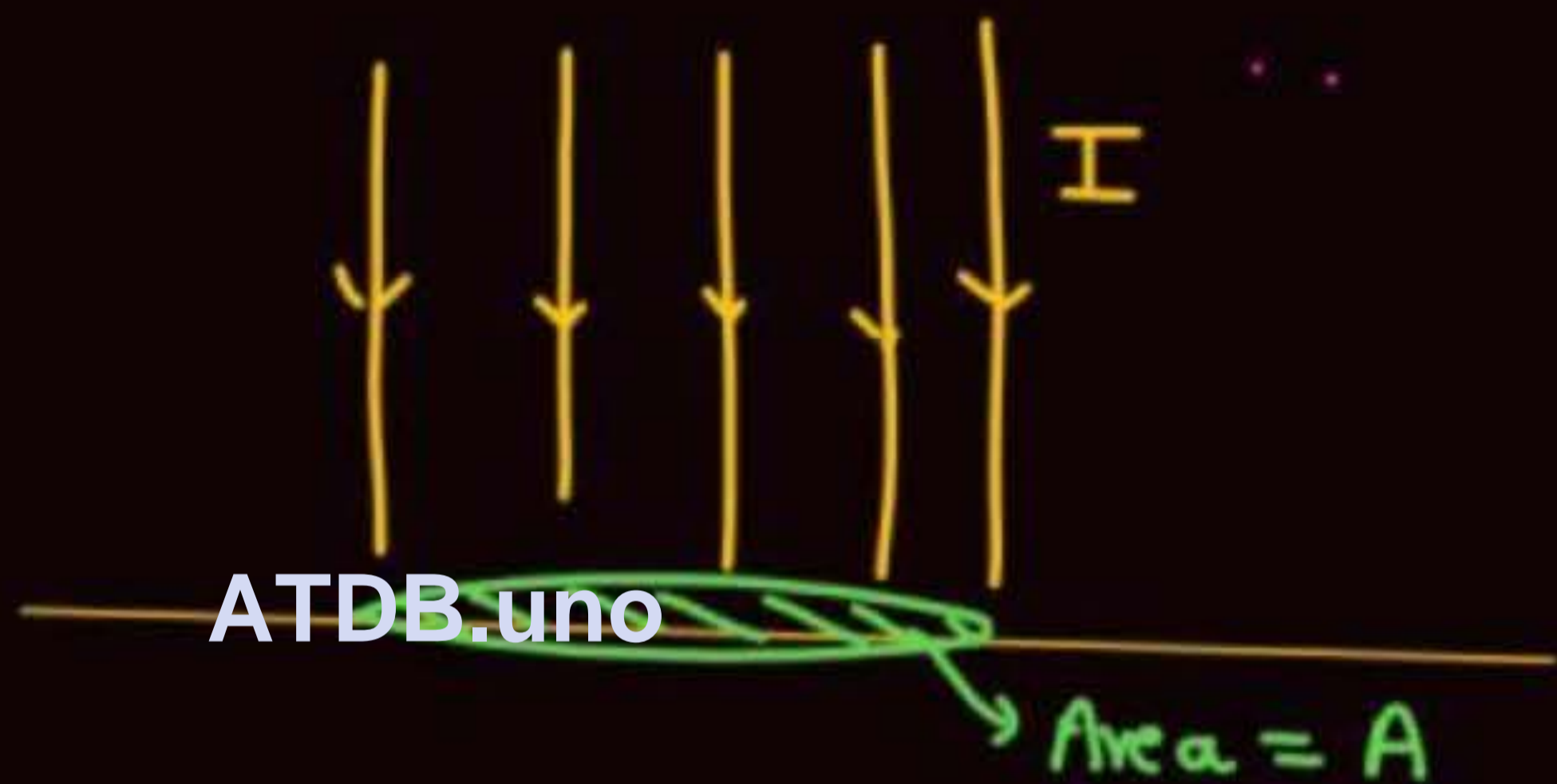
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Radiation falling on surface normally & perfectly reflected by surface

$$a=0, r=1$$

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



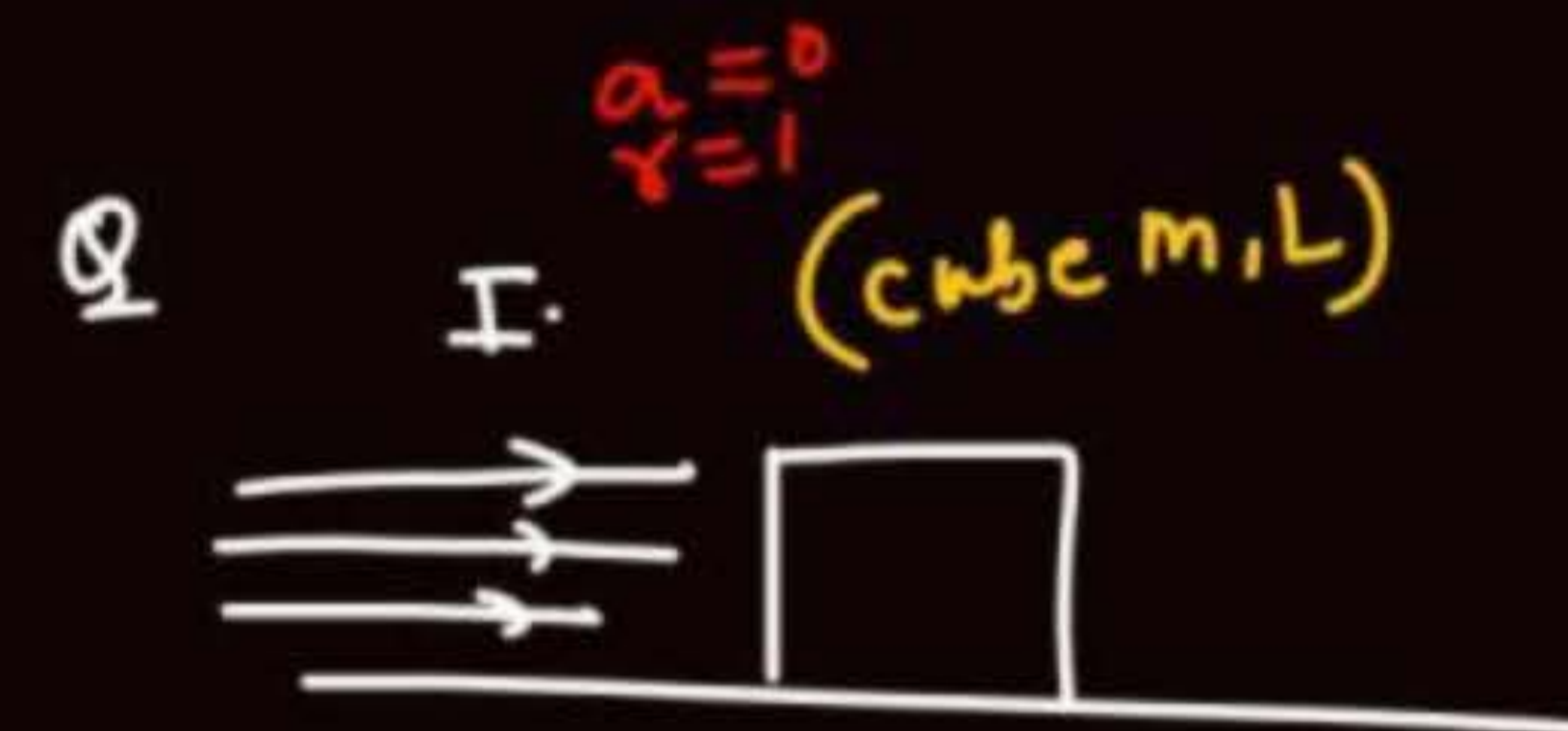
$a \rightarrow$  absorption coeff.  
 $r \rightarrow$  reflection coeff.

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

no. of photon falling per sec

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

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



Find  $I_{min}$  so that block start moving

Sol<sup>n</sup>

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

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Radiation falling on surface normally & absorbed completely by surface

$$a = 1, r = 0$$

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

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

$$F = \frac{IA}{c}$$

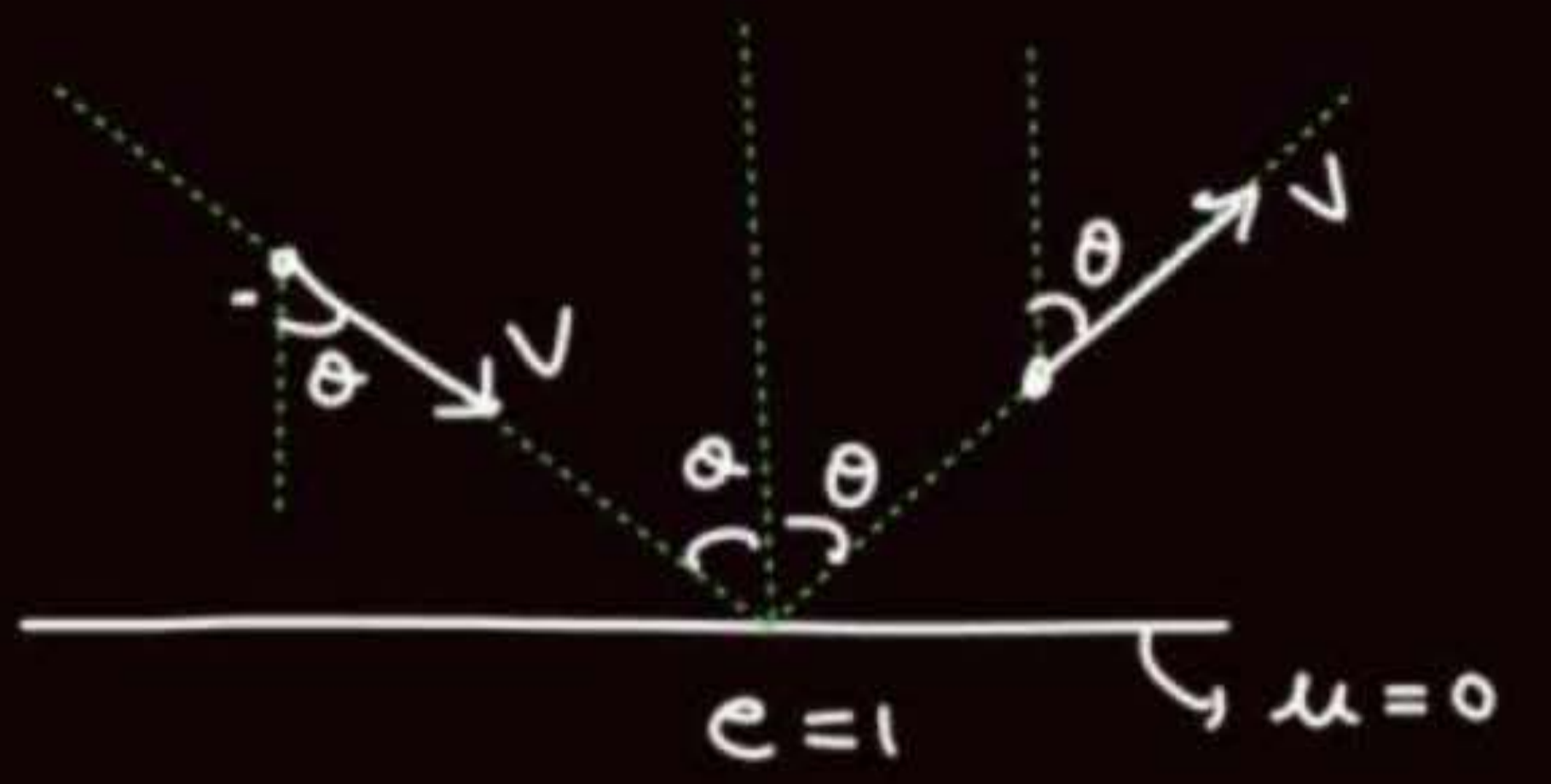
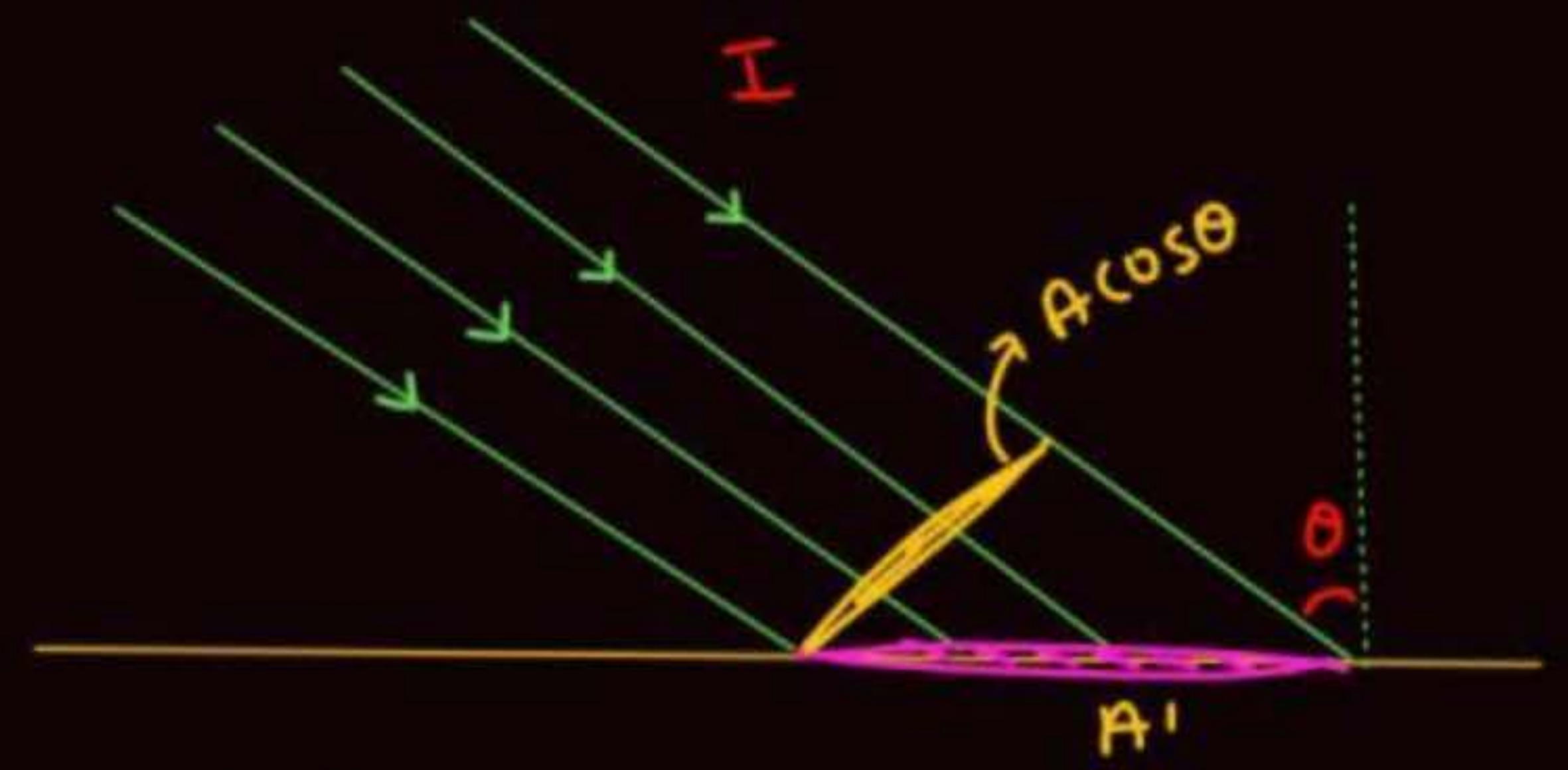
 $\Rightarrow$ 

$$P = \frac{F}{A} = \frac{I}{c}$$





#  
 $\gamma = 1$   
 $a = 0$



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

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

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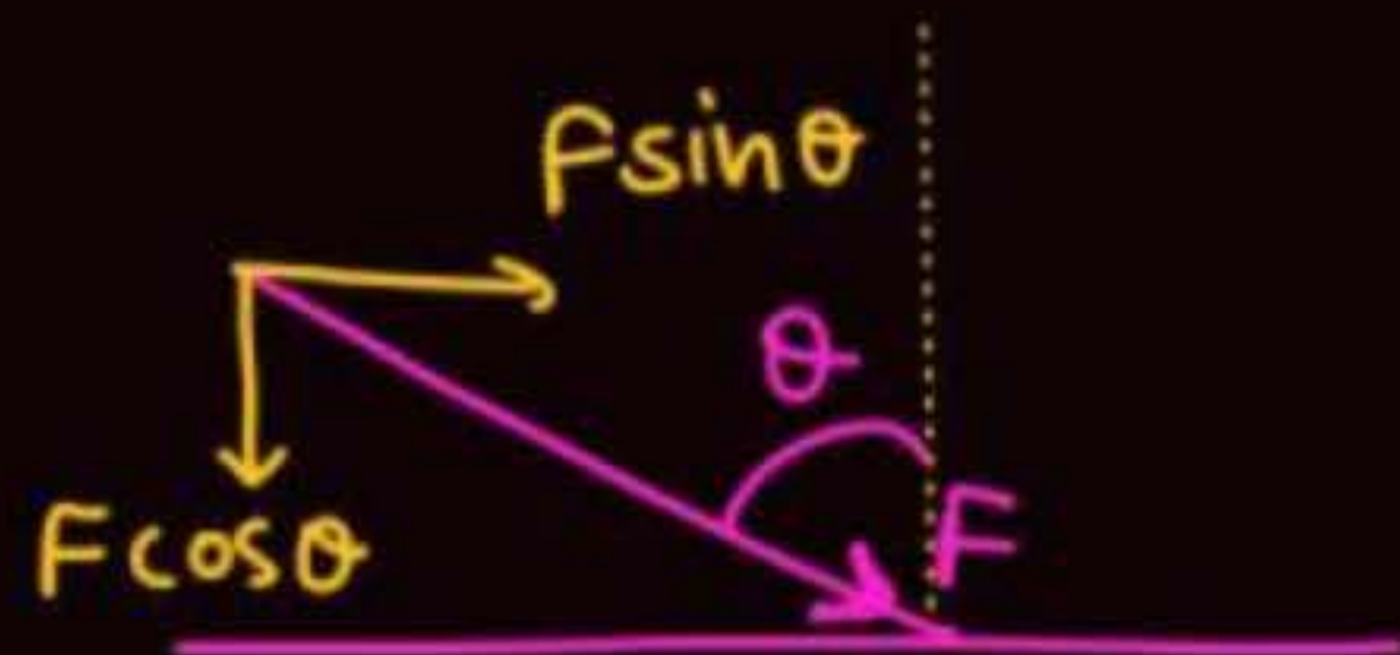
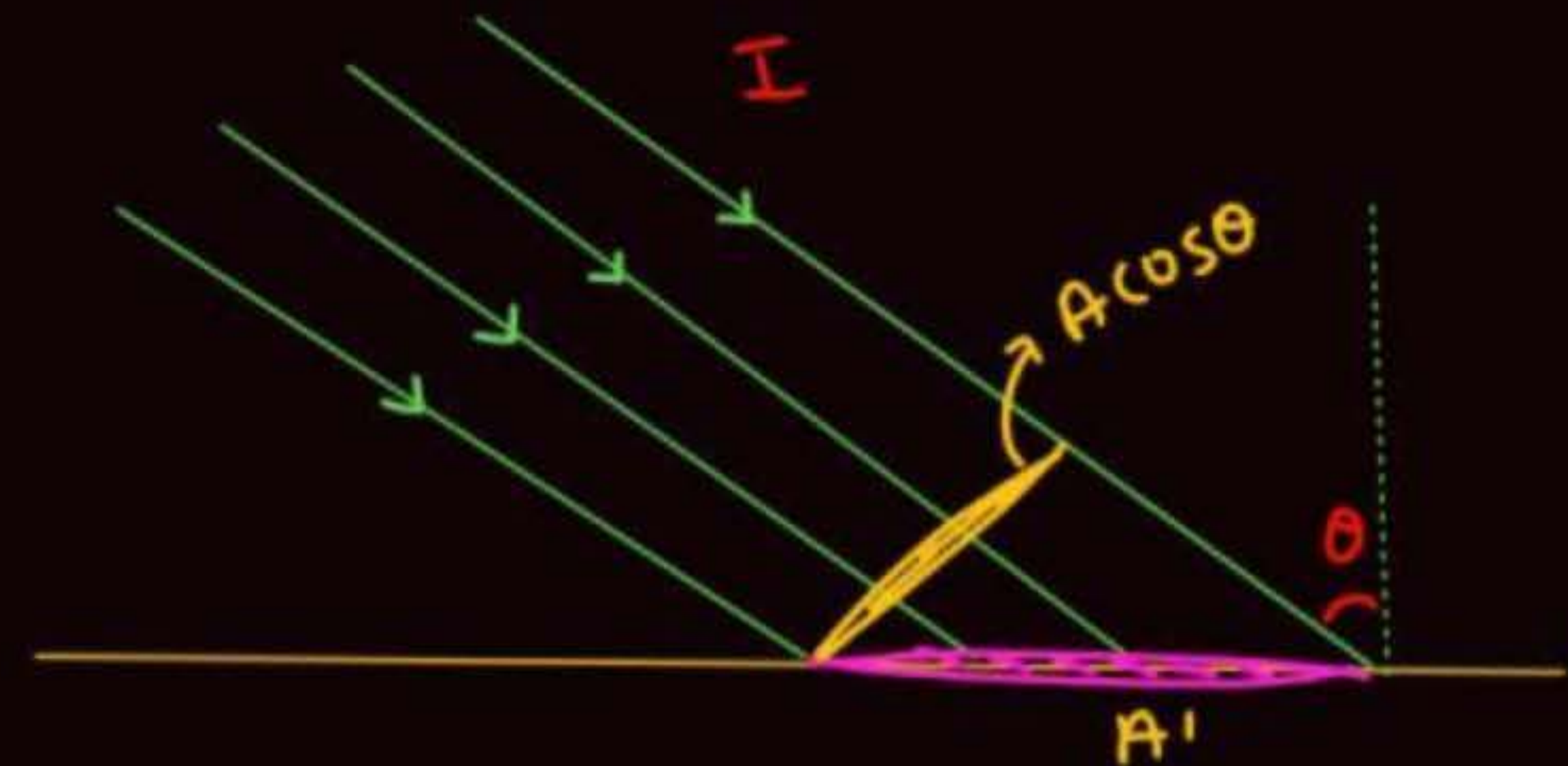
$$F = n \frac{2h}{\lambda} \cos \theta = \frac{I A \cos \theta}{\frac{hc}{\lambda}} \cdot \frac{2h}{\lambda} \cos \theta = \frac{2IA}{c} \cos^2 \theta$$



#

$$\mu = 0$$

$$a = 1$$

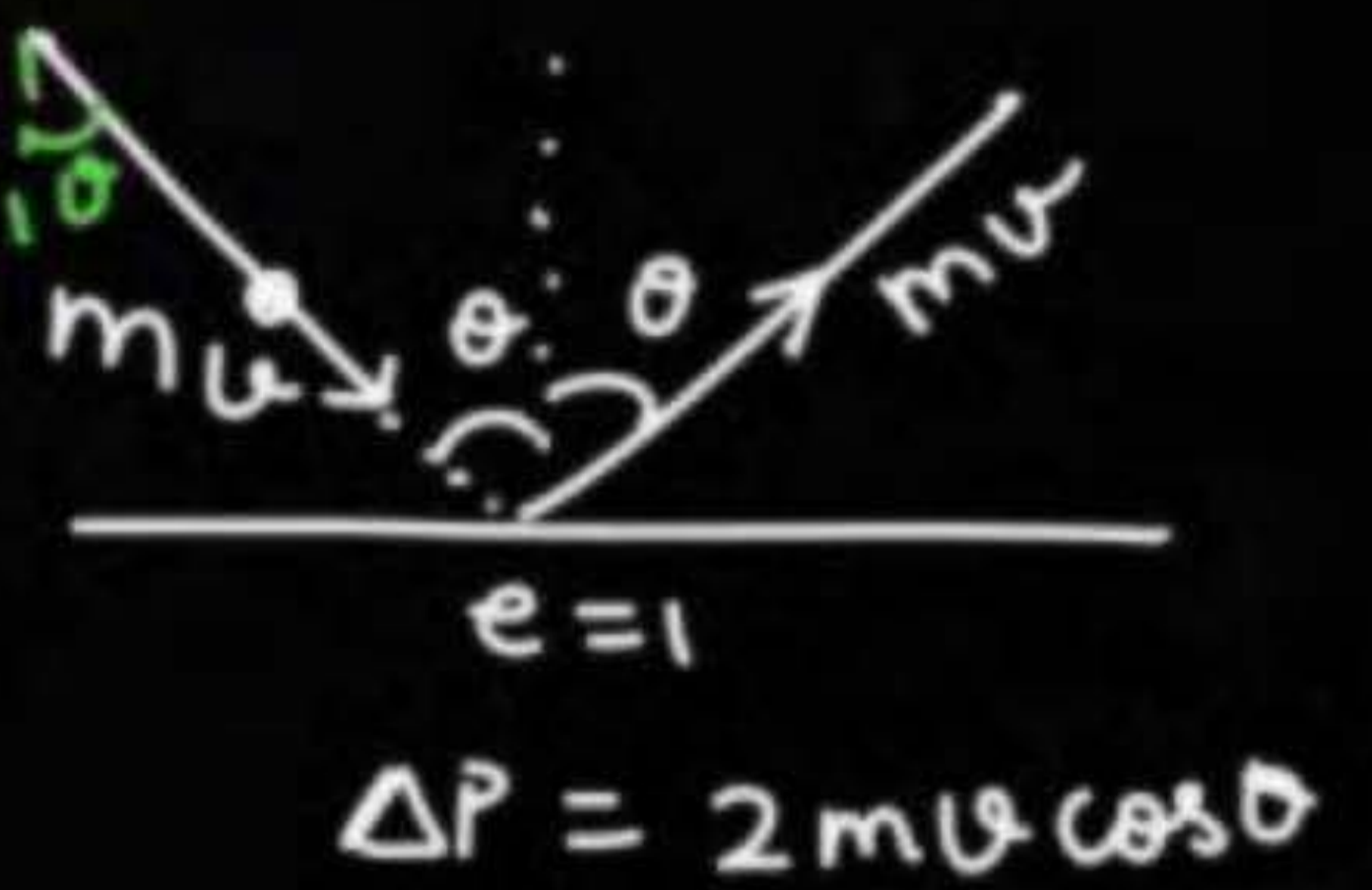
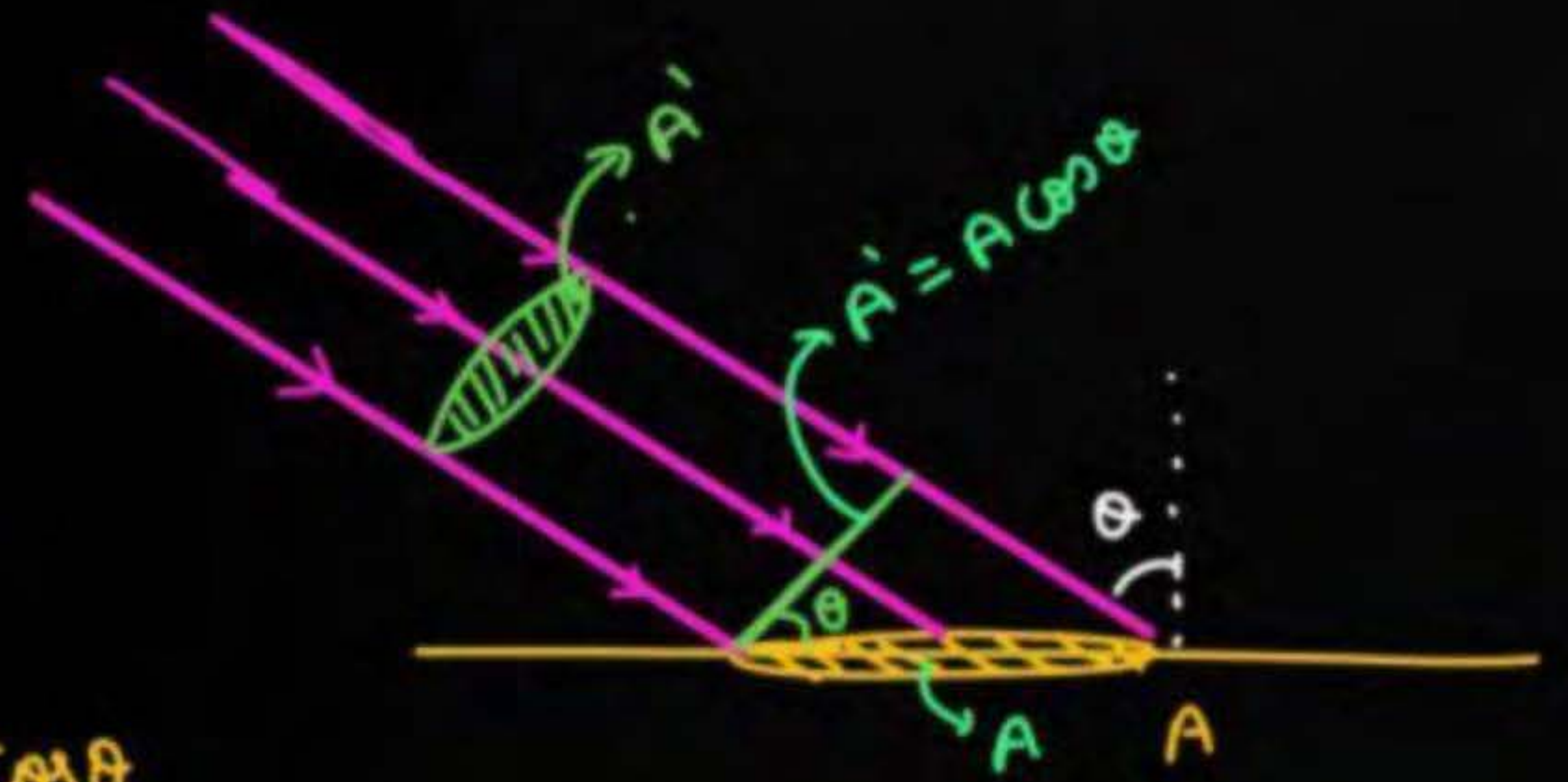


$$(\Delta p)_{\text{one photon}} = \frac{h}{\lambda}$$

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

$$p = \frac{F \cos \theta}{A} = \frac{n \frac{h}{\lambda} \cos \theta}{A} = \frac{I A \cos \theta}{\frac{hc}{\lambda}} \cdot \frac{h}{\lambda} \frac{\cos \theta}{A}$$

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



no. of photon per sec.

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

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

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

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



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

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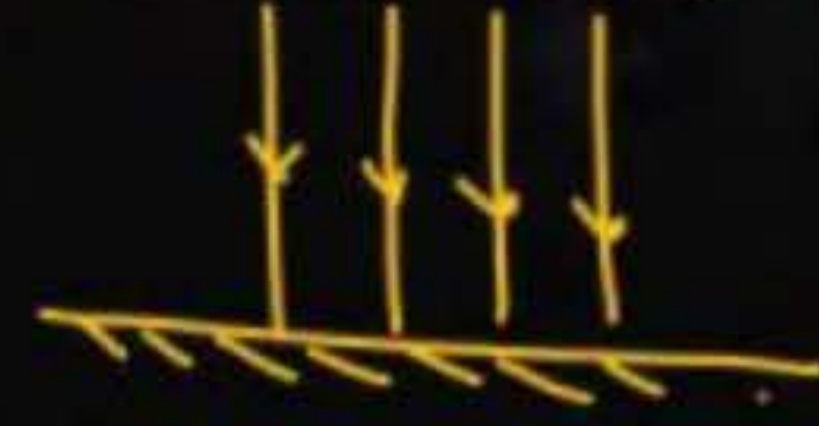




$P = \frac{I \cos^2 \theta}{c} (1 + \mu)$

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①  $\theta = 0,$



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

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

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

$\mu = 0.3, a = 0.7$

$$P = \frac{I}{c} (1 + 0.3)$$



$\mu = 0.7, a = 0.3$

$$P = \frac{I}{c} \cos^2 30 \cdot (1 + 0.7)$$



$$- p = \frac{h}{\lambda}$$

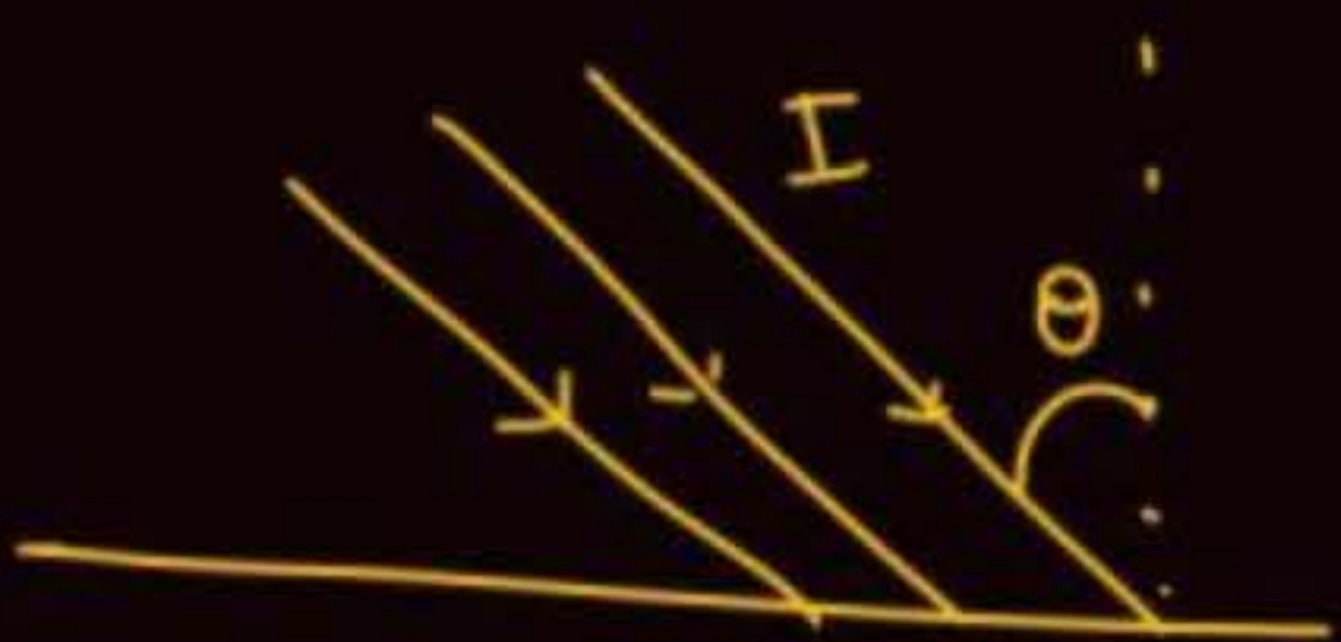
$$- E = \frac{hc}{\lambda} = \frac{12400}{\lambda \text{ (Å)}} = \frac{1240}{\lambda \text{ (nm)}}$$

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

no. of photon per sec

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

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



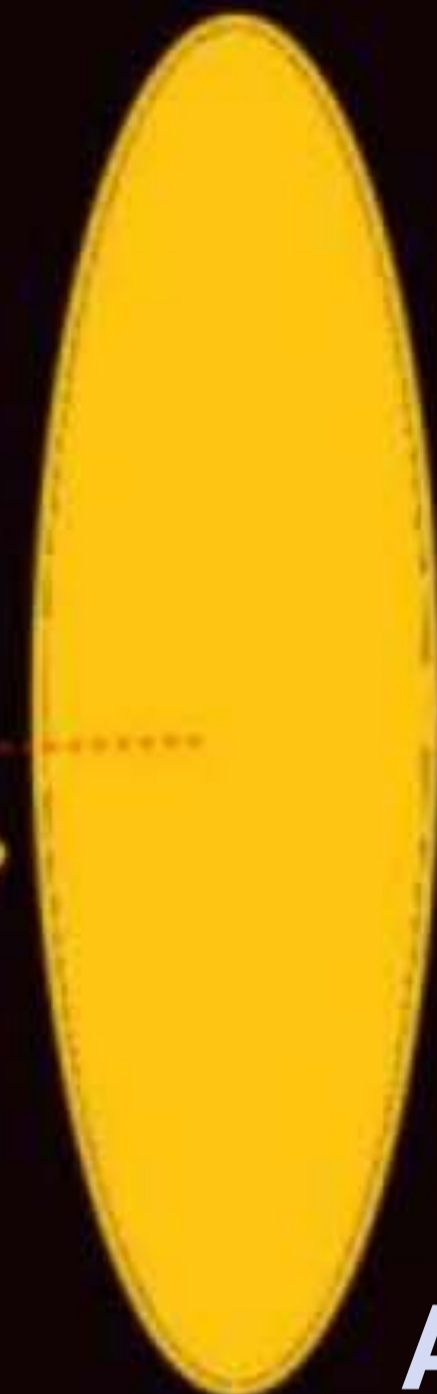
$$P = \frac{I}{c} \cos^2 \theta (1 + \rho)$$



(JA)

 $Q$ DISC  
R

P

 $2R$ 

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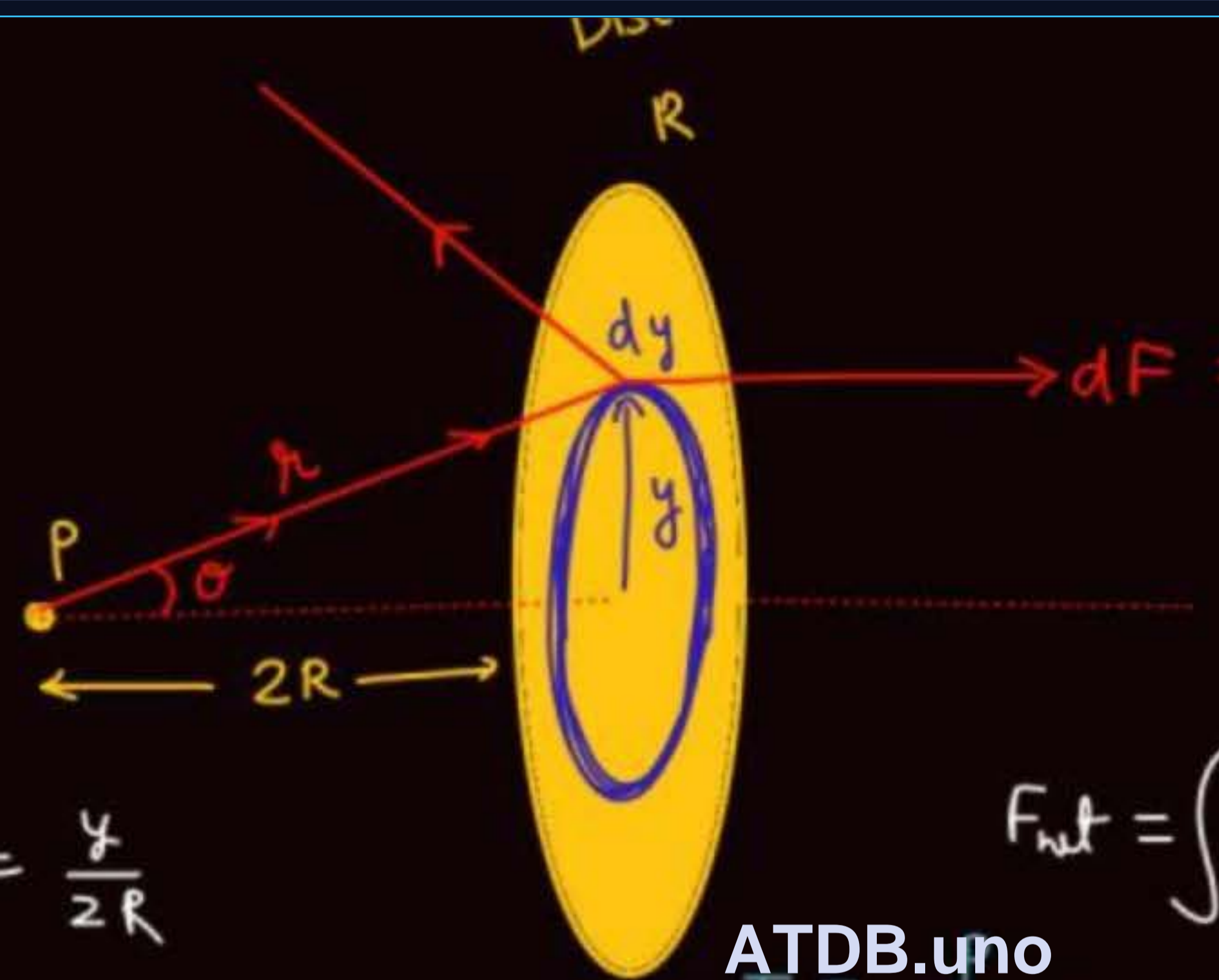
mirror plate  $\equiv \sigma = 1$ 

surface

point source  $\vec{P}$ .find force applied by  
light on plate.(assume perfectly reflecting)  
 $\sigma = 1$



(JA) Sol<sup>n</sup>



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

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

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

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

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

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

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$$I = \frac{1}{4\pi R^2}$$

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

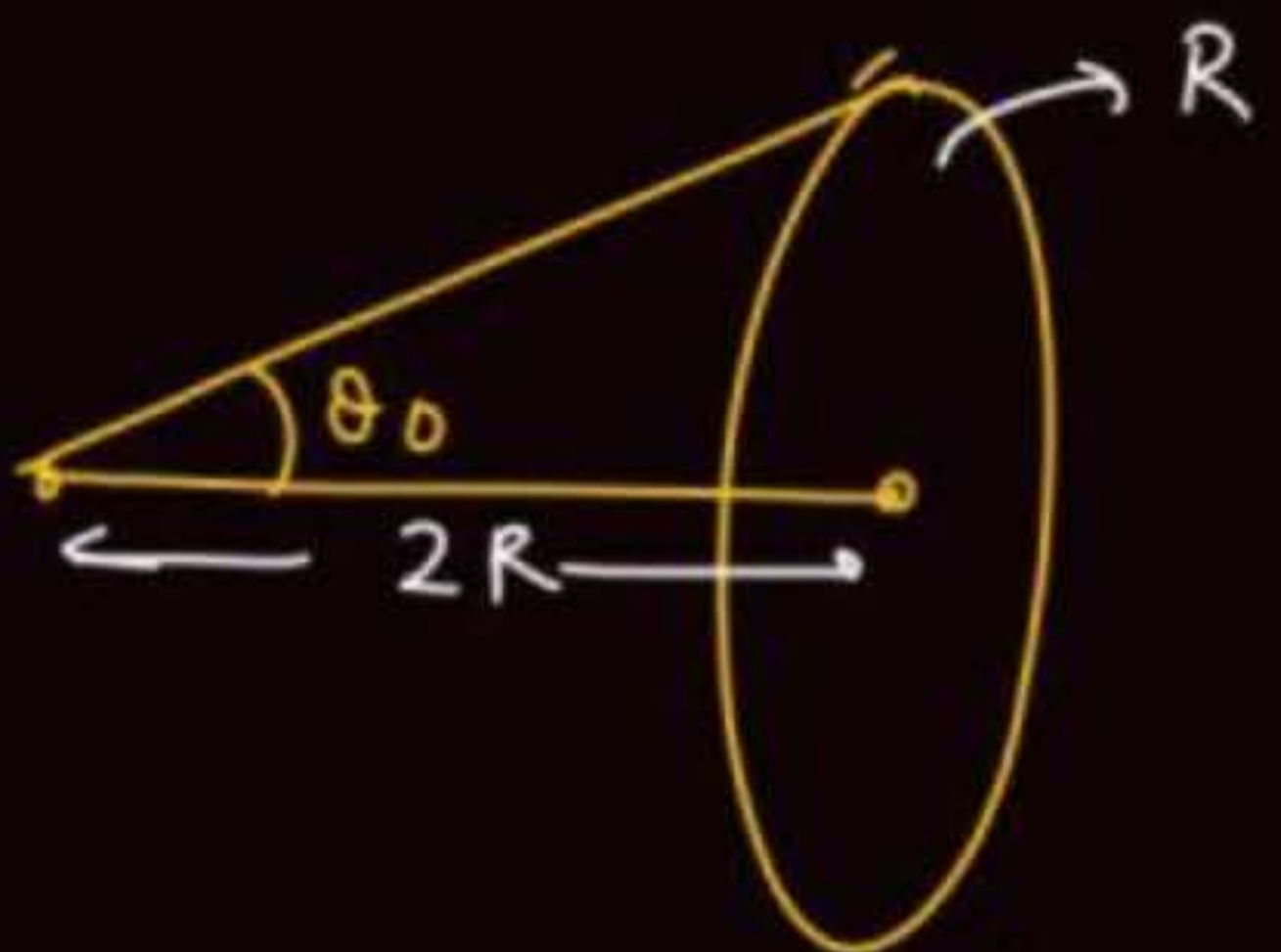
$$= \int \frac{2}{C} \cdot \frac{P}{4\pi R^2} \cos^2 \theta \cdot 2\pi \cdot 2R \tan \theta \cdot 2R \sec^2 \theta d\theta$$

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



$$\frac{P}{c} \int_0^{\theta_0} \sin \theta \cos \theta d\theta$$

$$\begin{aligned} \sin \theta &= t \\ \cos \theta d\theta &= dt \end{aligned}$$



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

$$\frac{P}{c} \int t dt = \frac{P}{c} \cdot \frac{\sin^2 \theta}{2} \Big|_0^{\theta_0} = \frac{P}{2c} (\sin^2 \theta_0)$$

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



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

Ans

$$\frac{P}{2C}$$



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

Sol<sup>n</sup>

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

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

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

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



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

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

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

## 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]

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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 \_\_\_\_\_  $\times 10^{-8}$  N. **[30 January 2023 - Shift 1]**

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

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Ans. (4)

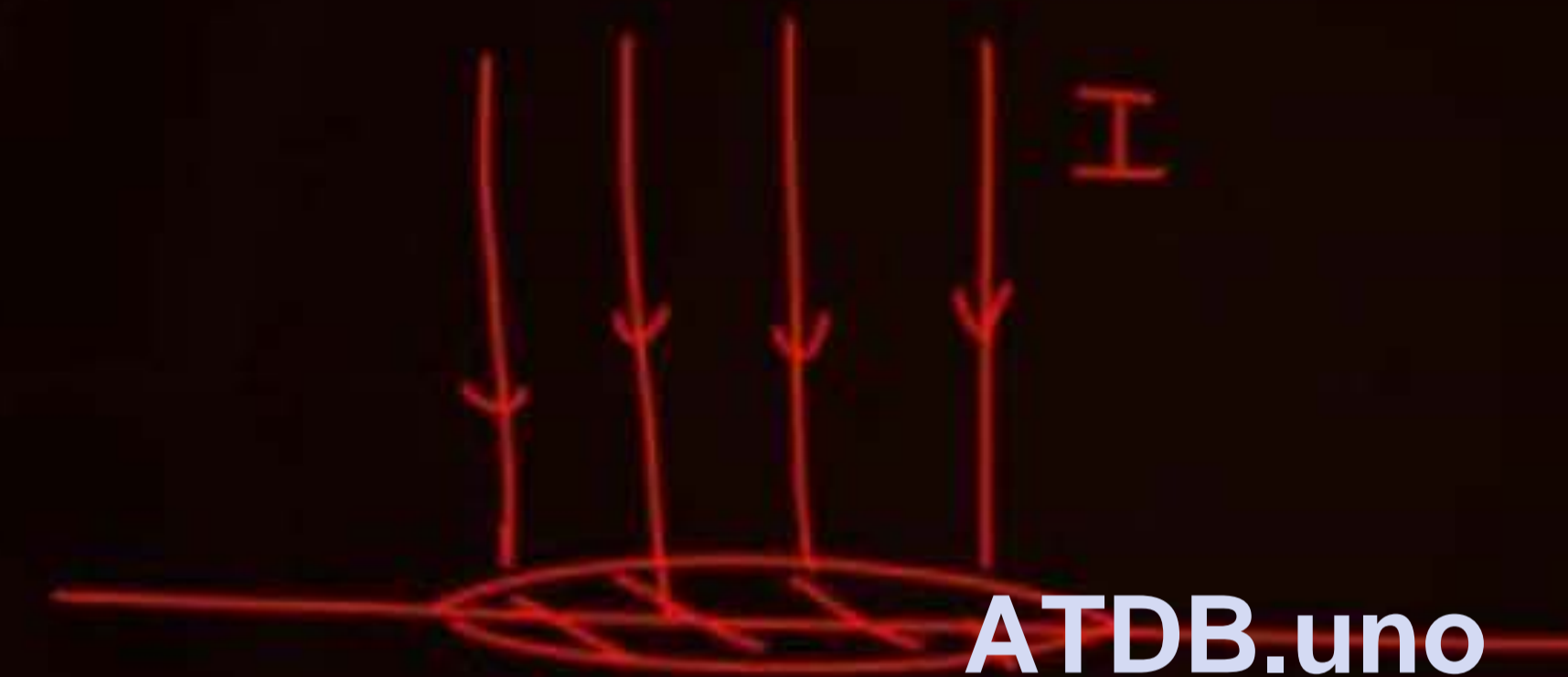
## QUESTION



Average force exerted on a non-reflecting surface at normal incidence is  $2.4 \times 10^{-4} \text{ N}$ .  
If  $360 \text{ W/cm}^2$  is the light energy flux during span of 1 hour 30 minutes, Then the area  
of the surface is: [08 Apr. 2024 - Shift 1]

$a = 1$

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



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

Ans : (4)

## QUESTION



Average force exerted on a non-reflecting surface at normal incidence is  $2.4 \times 10^{-4}$  N. If  $360 \text{ W/cm}^2$  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  $0.02 \text{ m}^2$

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

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

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

Ans : (4)



# THANK YOU

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