BONUS SESSION

ELECTROMAGNETIC WAVES

L-2

GRADE 11 PHYSICS

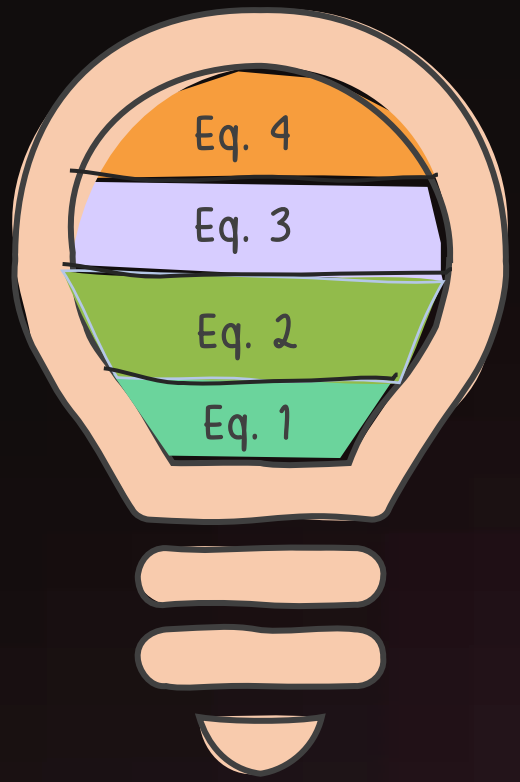
MRINAL SIR

https://t.me/neetaakashdigital

CONTENTS

RECAP

- Maxwell's equations



01

$$\oint \vec{E}.d\vec{A} = \frac{q}{\varepsilon_o}$$

02

$$\oint \vec{B}.d\vec{A} = 0$$

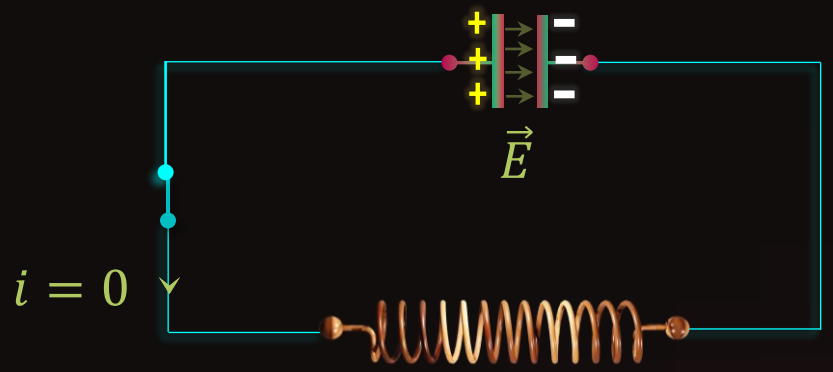
03

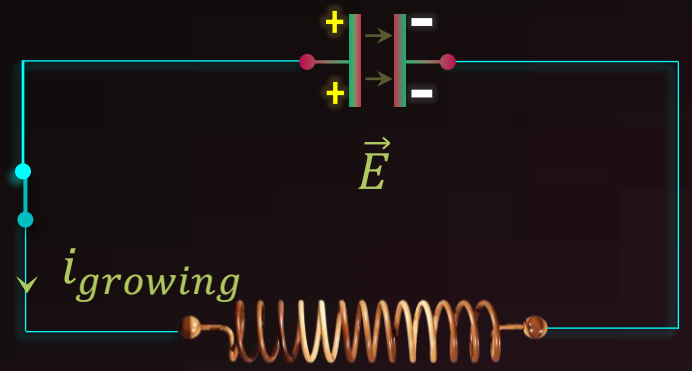
$$\oint \vec{E}.d\vec{l} = -\frac{d\phi_B}{dt}$$

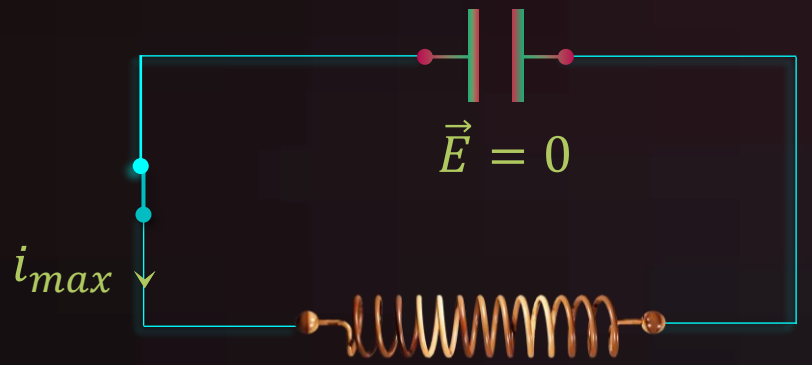
04

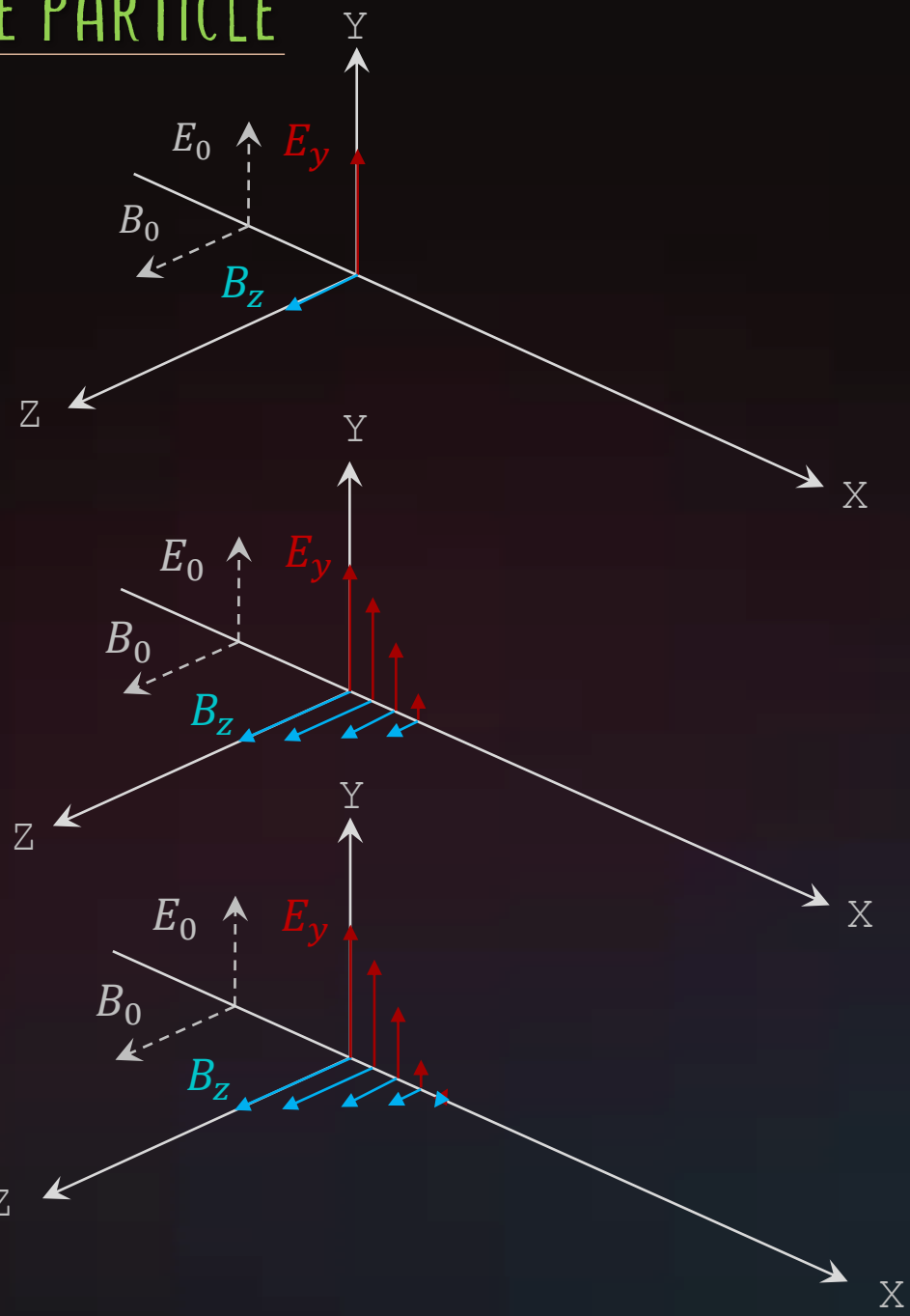
$$\oint \vec{B}.d\vec{l} = \mu_o\left(i_c + \varepsilon_o \frac{d\phi_E}{dt}\right)$$

ACCELERATED MOTION OF A CHARGE PARTICLE

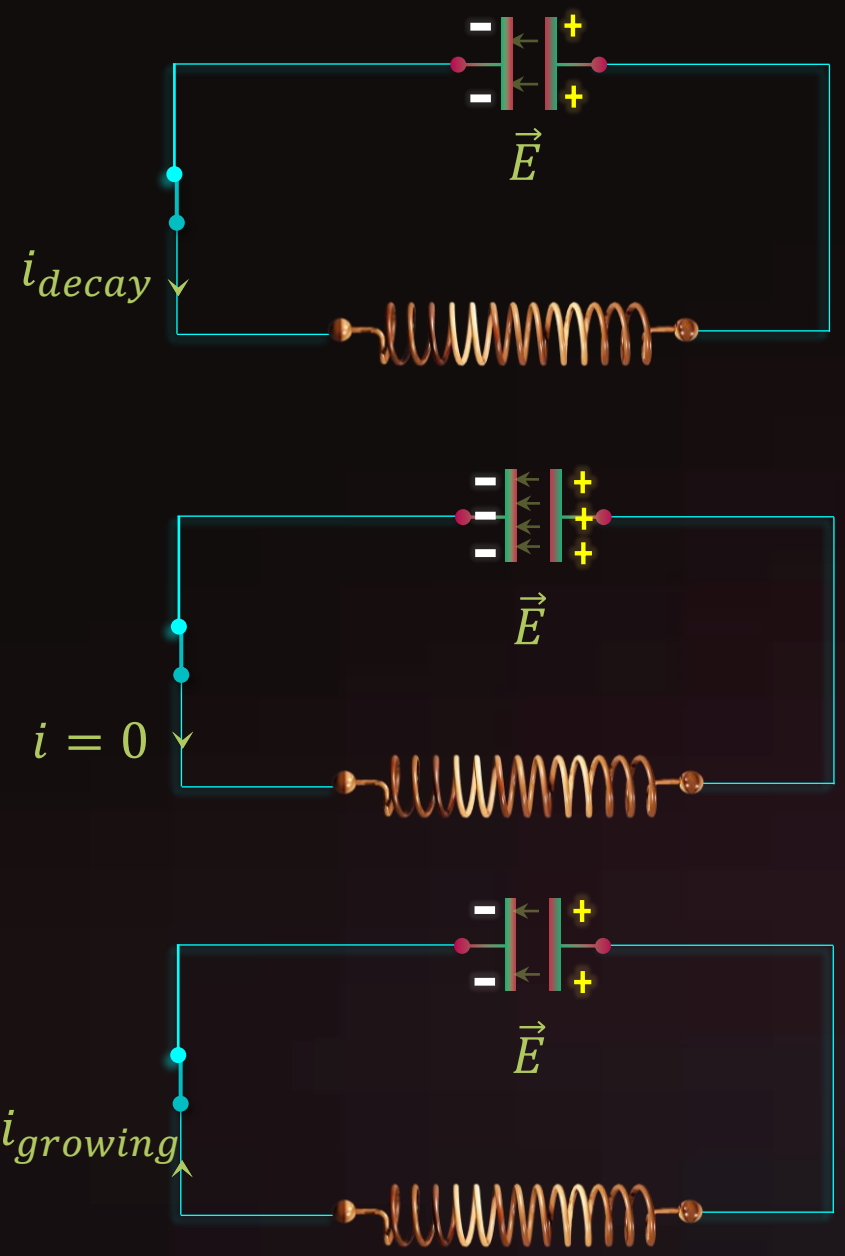


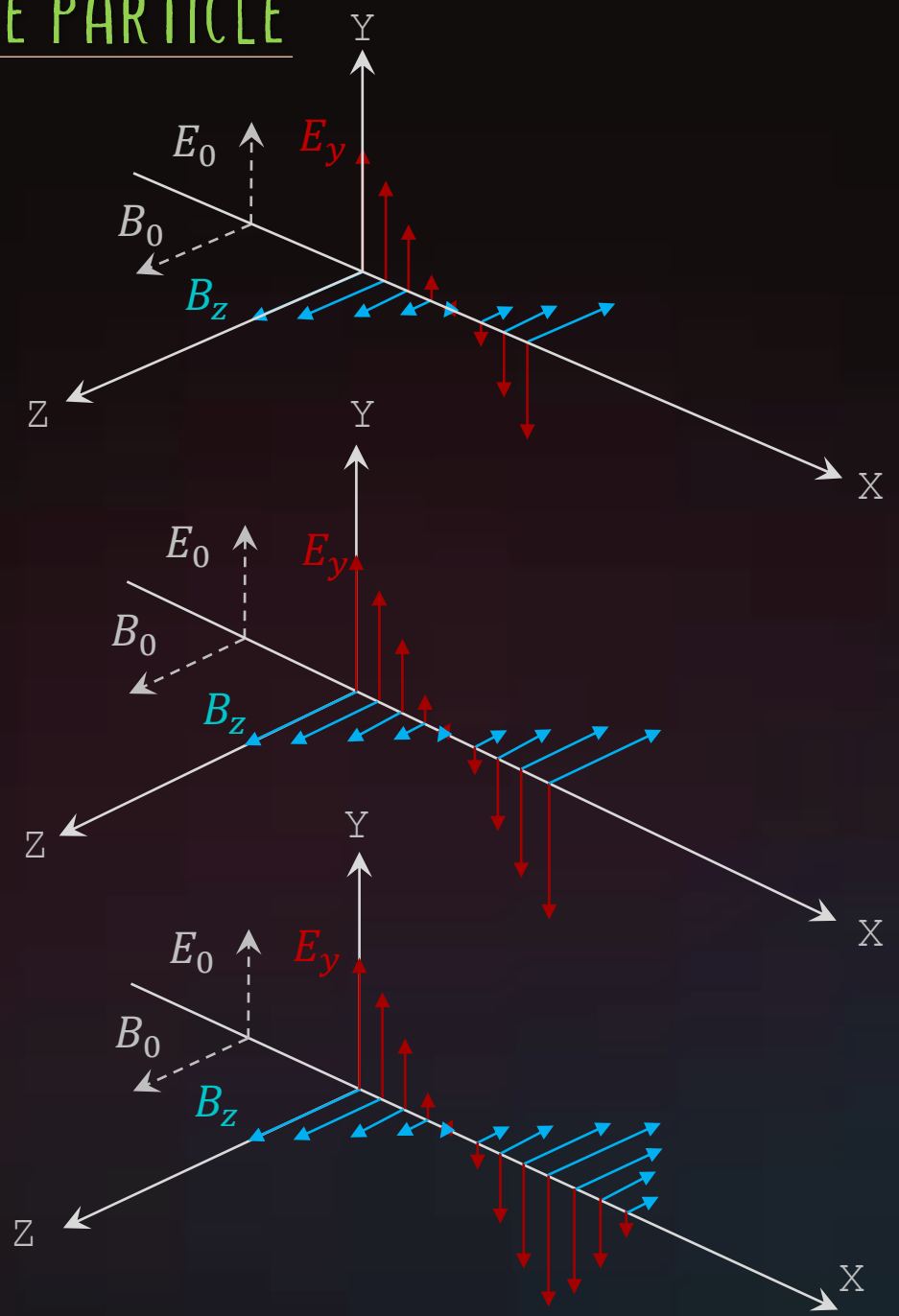




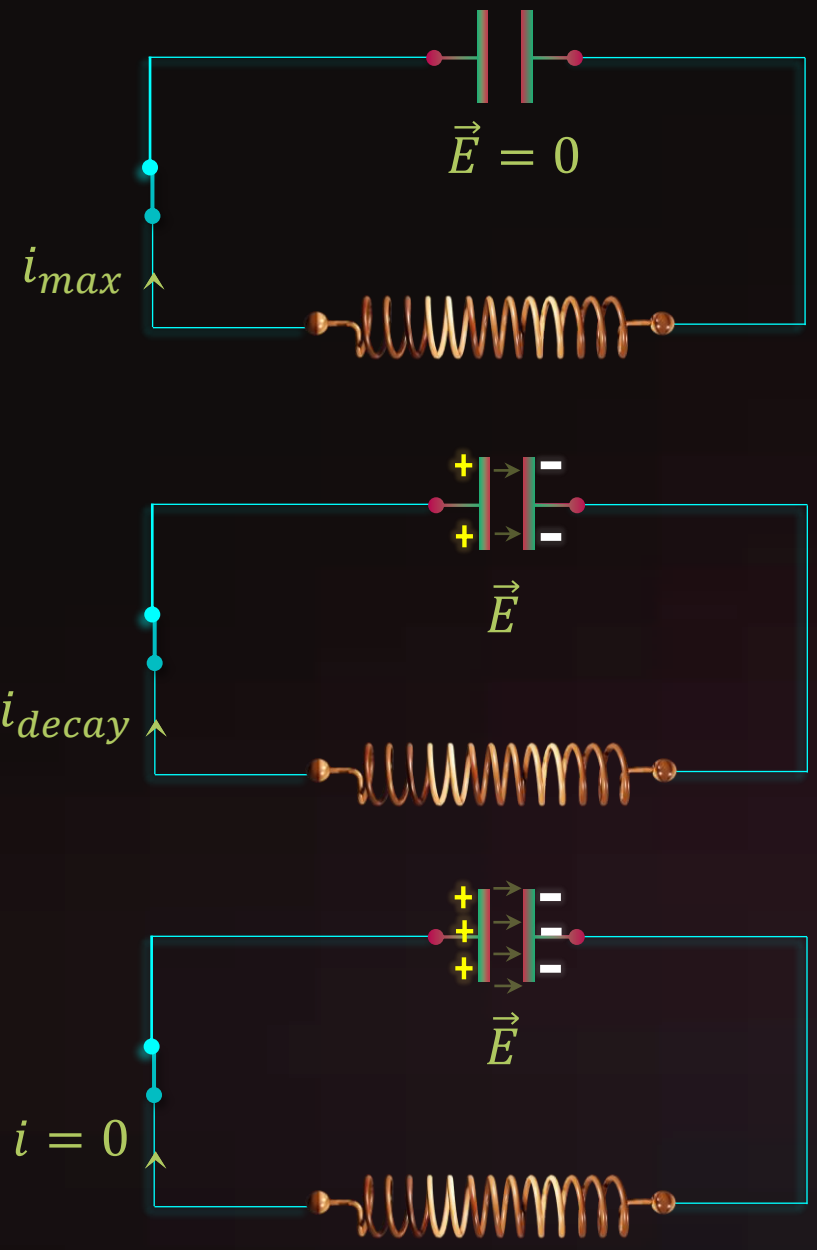


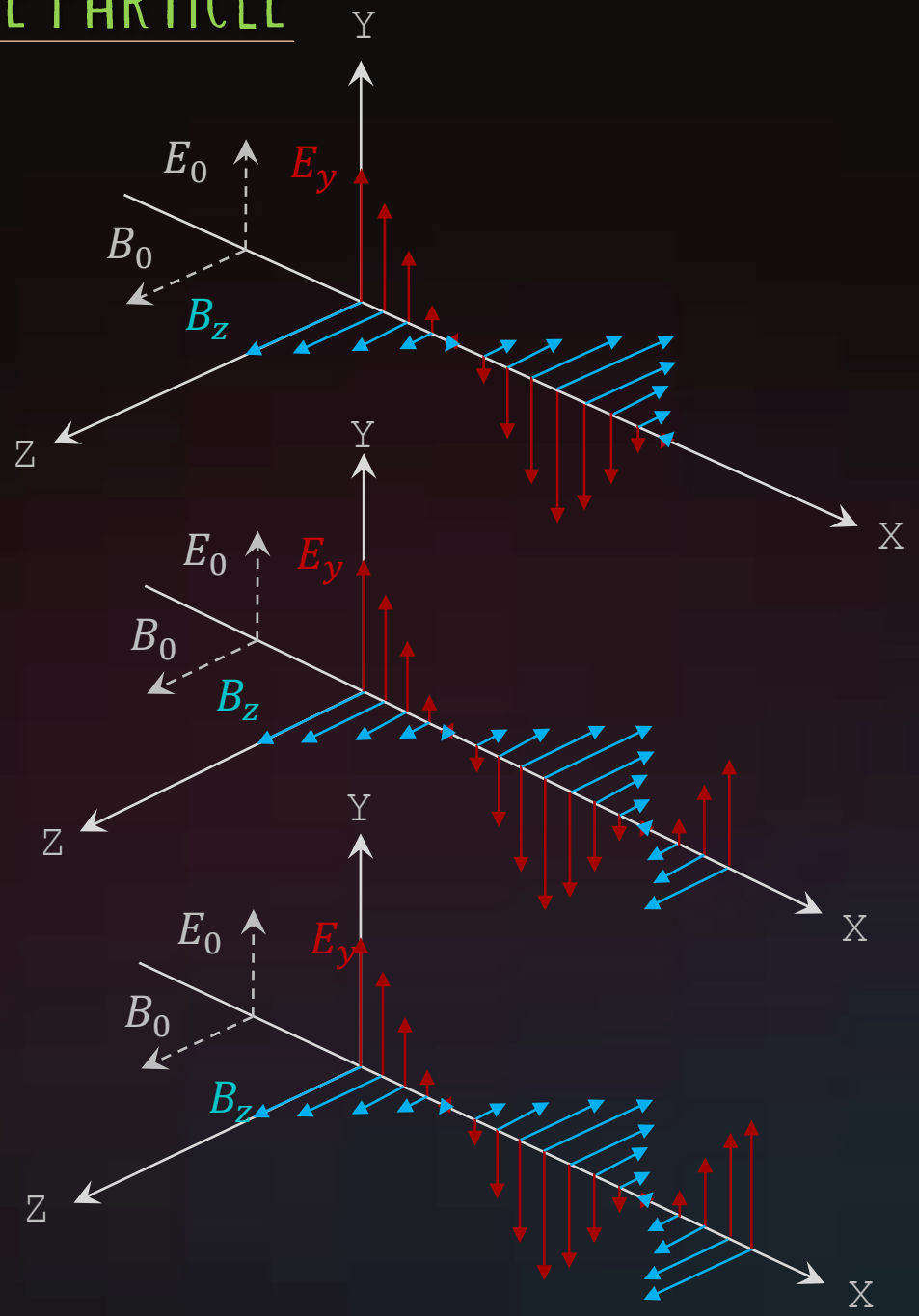
ACCELERATED MOTION OF A CHARGE PARTICLE



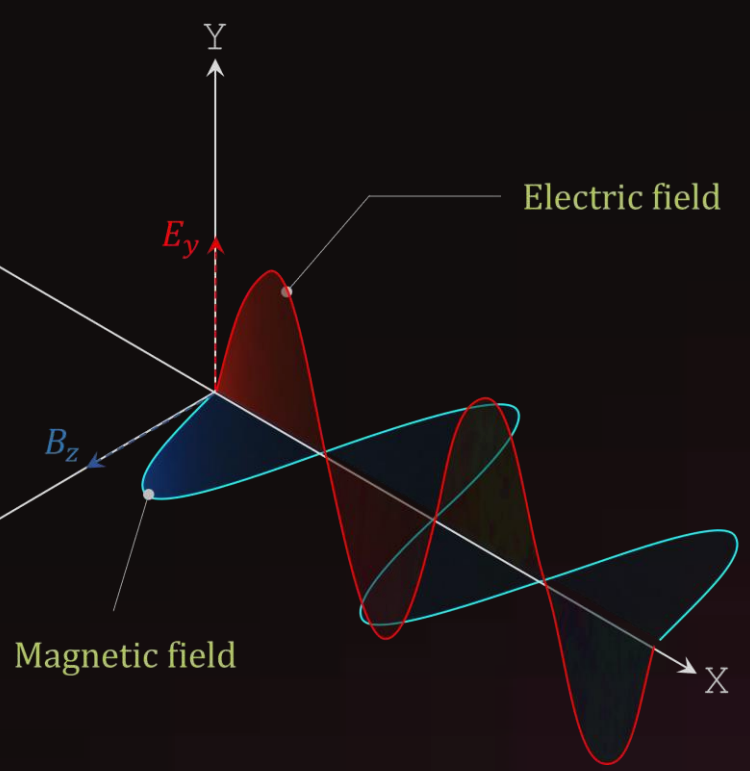


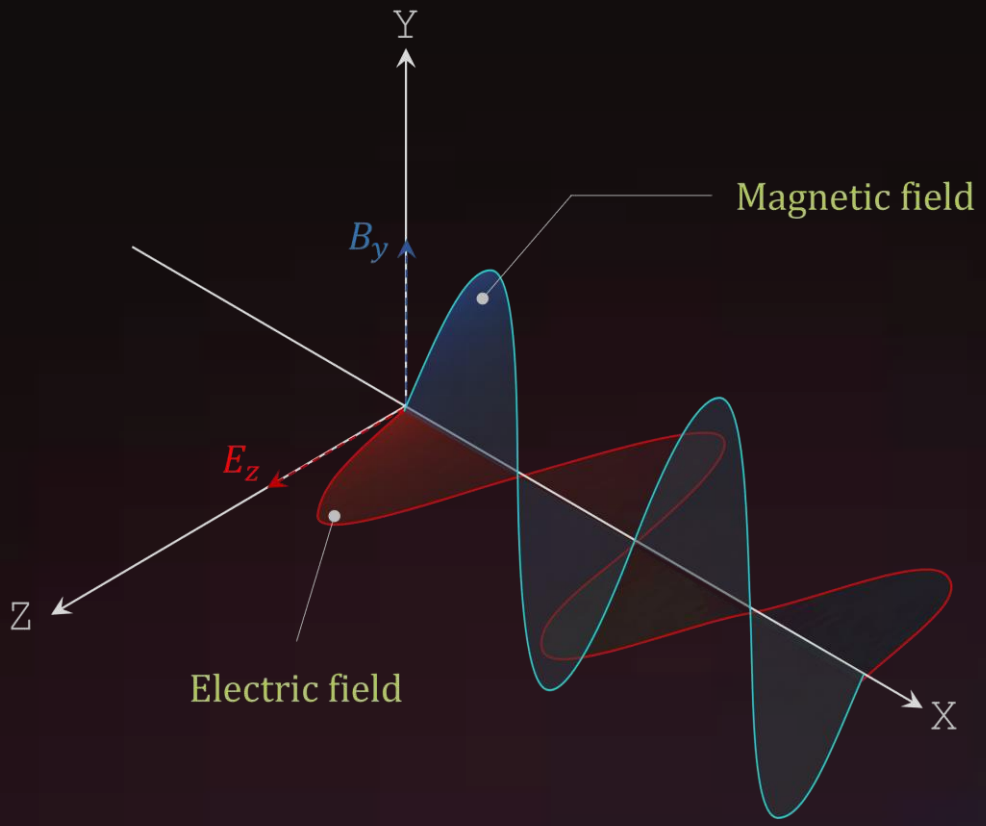
ACCELERATED MOTION OF A CHARGE PARTICLE





TRANSVERSE NATURE OF ELECTROMAGNETIC WAVE





- In an electromagnetic wave, electric and magnetic field vectors are perpendicular to each other and at the same time are perpendicular to the direction of propagation of the wave. This nature of electromagnetic wave is known as Transverse nature.


>>> 3.14 3.14
>>> 314\. # Trailing zero(s) not required. 314.0
>>> 3.14 3.14 Retrying...
>>> 3.14 3.14 Retrying...
>>> 3.14 3.14 Retrying...
>>> 314\. # Trailing zero(s) not required. 314.0
>>> .314 # Leading zero(s) not required. 0.314
>>> 3e0 3.0 >>> 3E0 # 'e' or 'E' can be used. 3.0 _3e1 # Positive value after e moves the decimal to the right. 30.0
>>> 3e-1 # Negative value after e moves the decimal to the left. 0.3
>>> 3.14e+2 # '+' not required but can be used for exponent part. 314.0
>>> 3.14 3.14
>>> 314\. # Trailing zero(s) not required. 314.0
>>> 3.14 3.14 Retrying...
>>> 314\. # Trailing zero(s) not required. 314.0
>>> .314 # Leading zero(s) not required. 0.314
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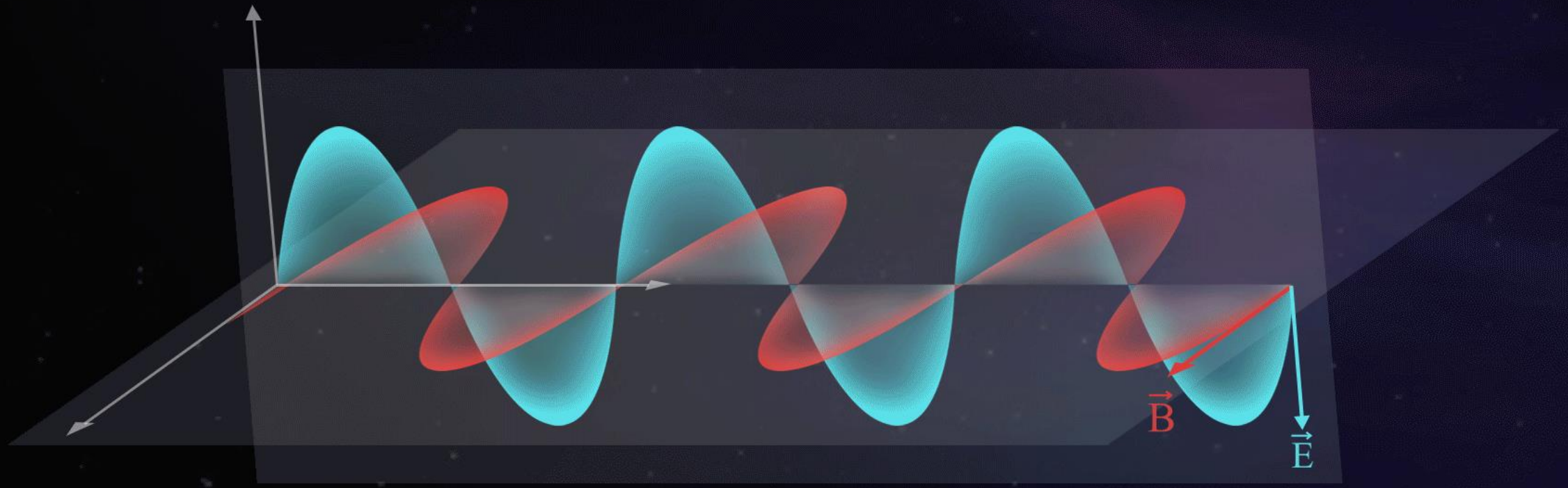
TRANSVERSE NATURE OF ELECTROMAGNETIC WAVE



CLASSIFICATION OF WAVES

BASED ON THE DIRECTION OF PARTICLE MOTION

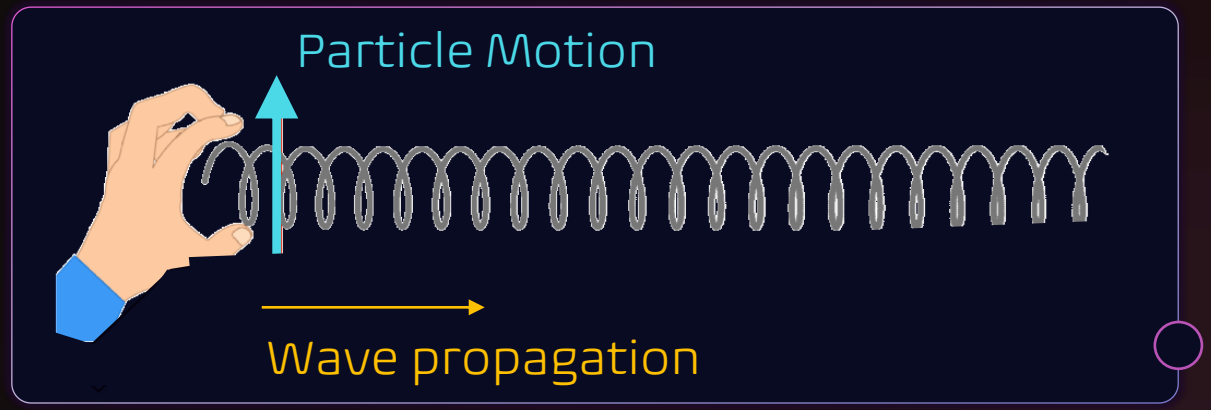
- Transverse waves
- Longitudinal waves

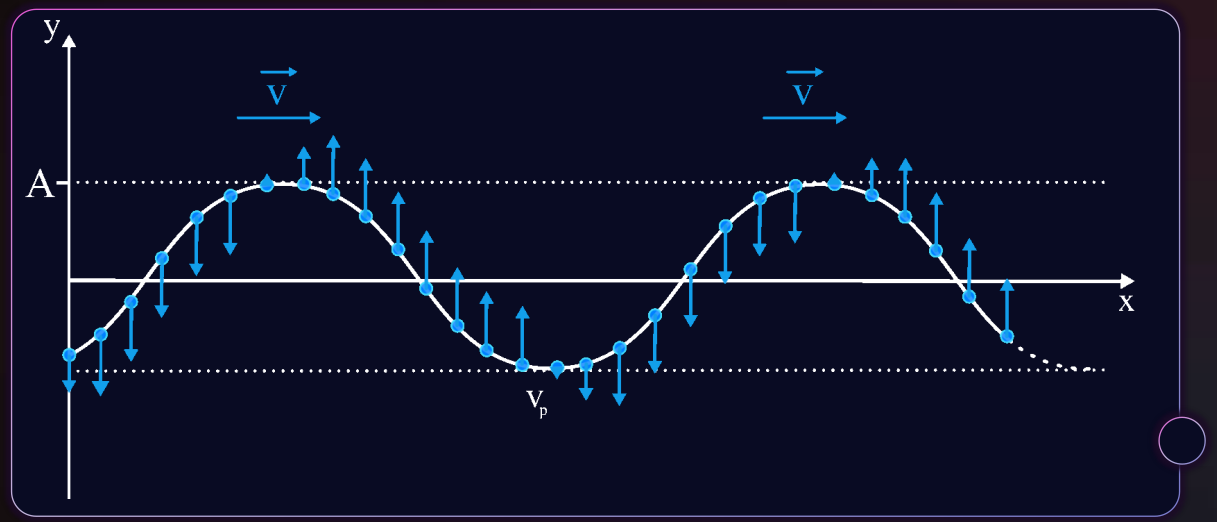
CLASSIFICATION OF WAVES

TRANSVERSE WAVES

Particles of the medium vibrate in a direction perpendicular to the direction of propagation of wave.

$$\vec{v}_p \perp \vec{v}_w, \qquad \vec{v}_p . \vec{v}_w = 0$$

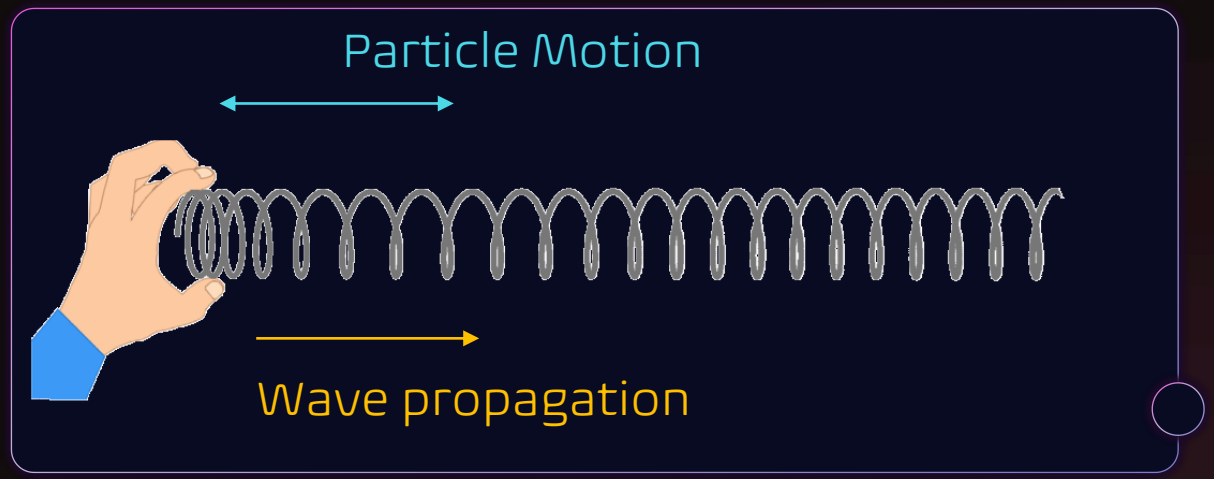




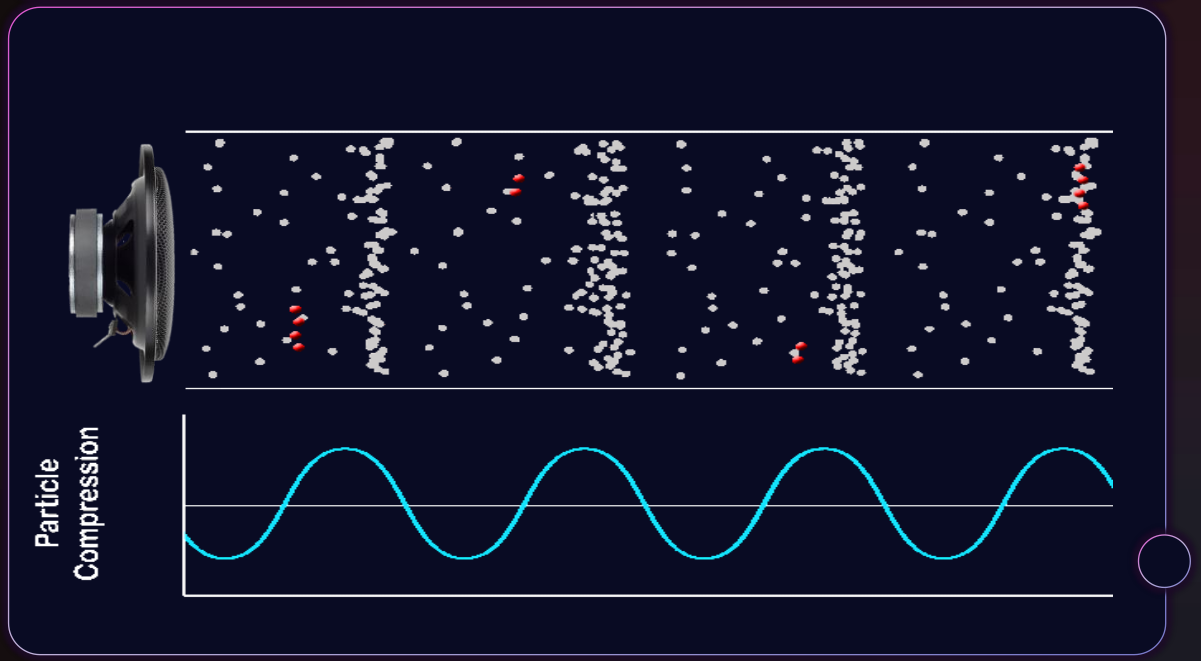
CLASSIFICATION OF WAVES

LONGITUDINAL WAVES

Particles of a medium vibrate in the direction of propagation of wave.



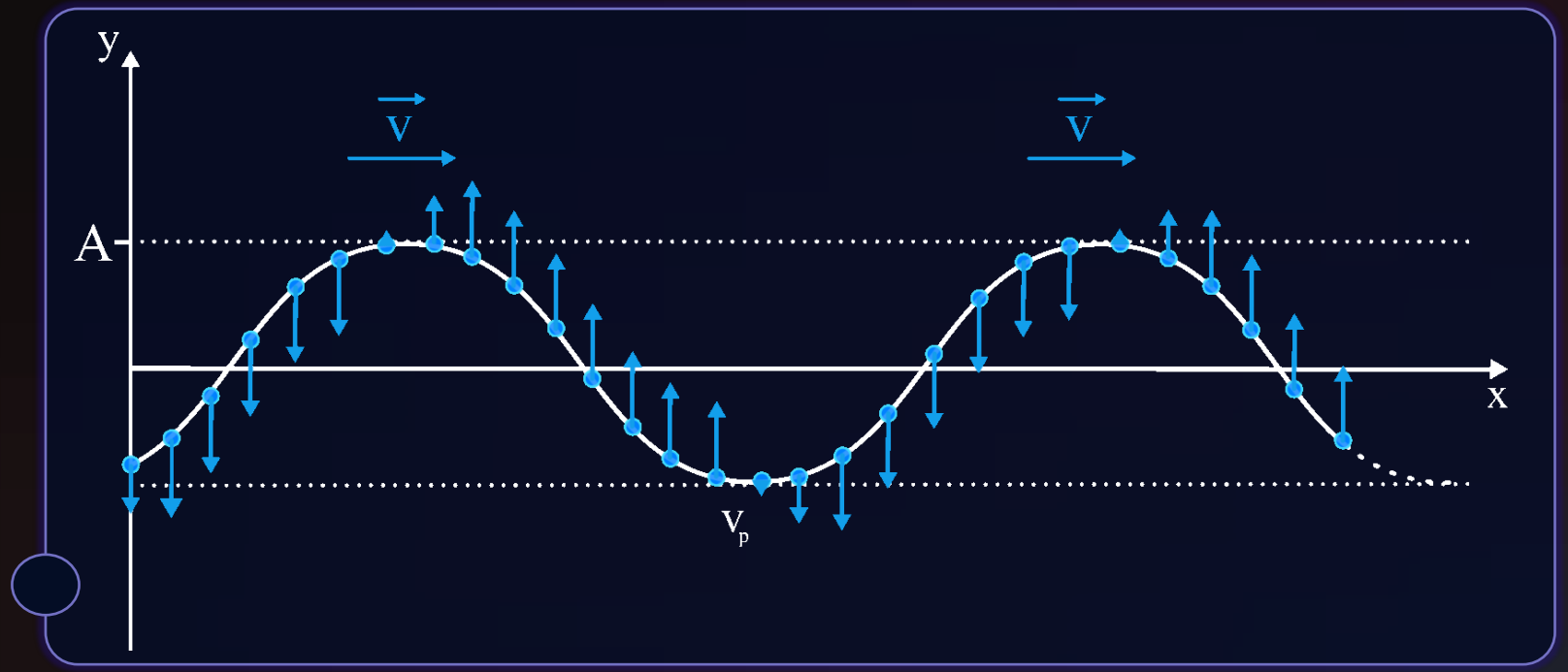
$$\vec{v}_p \parallel \vec{v}_w, \qquad \vec{v}_p \times \vec{v}_w = 0$$



WAVE EQUATION

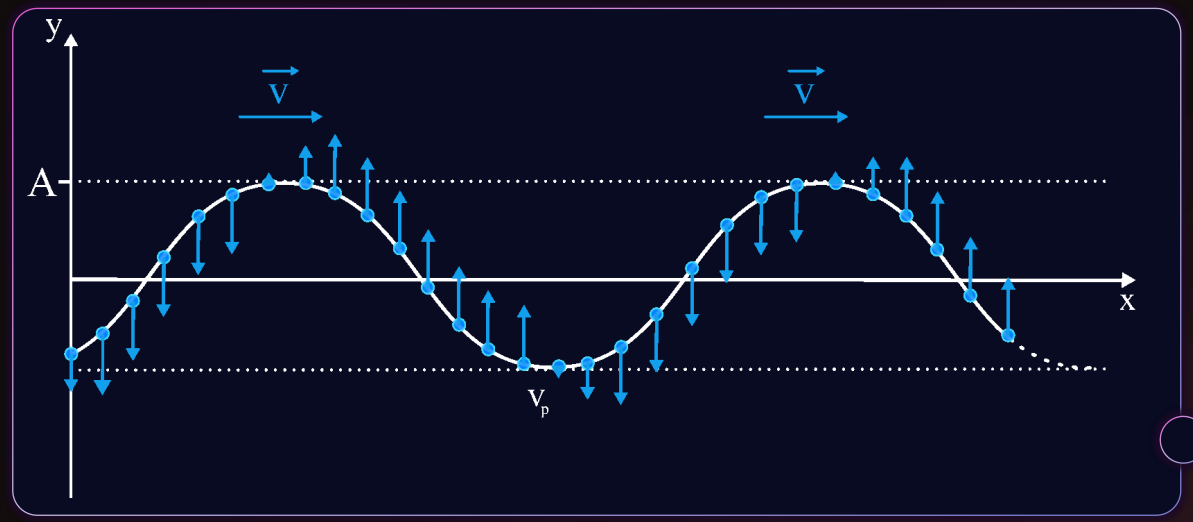
EQUATION OF A PLANE PROGRESSIVE WAVE

$$f(x,t) = y(x \pm \omega t + \phi)$$



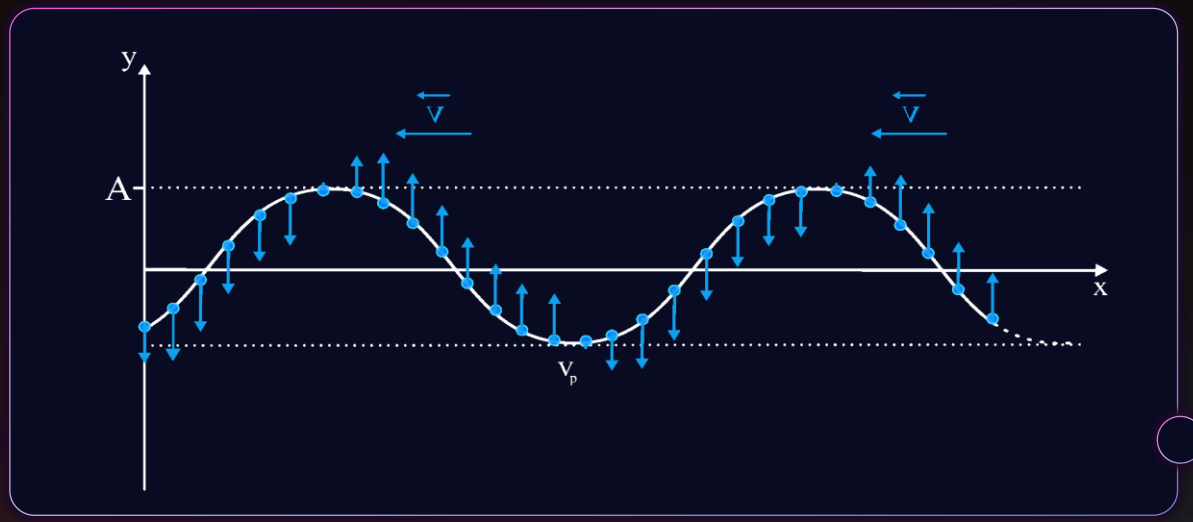
WAVE EQUATION

TRAVELLING ALONG $+x$



$$f(x,t) = y(x - \omega t + \phi)$$

TRAVELLING ALONG $-x$

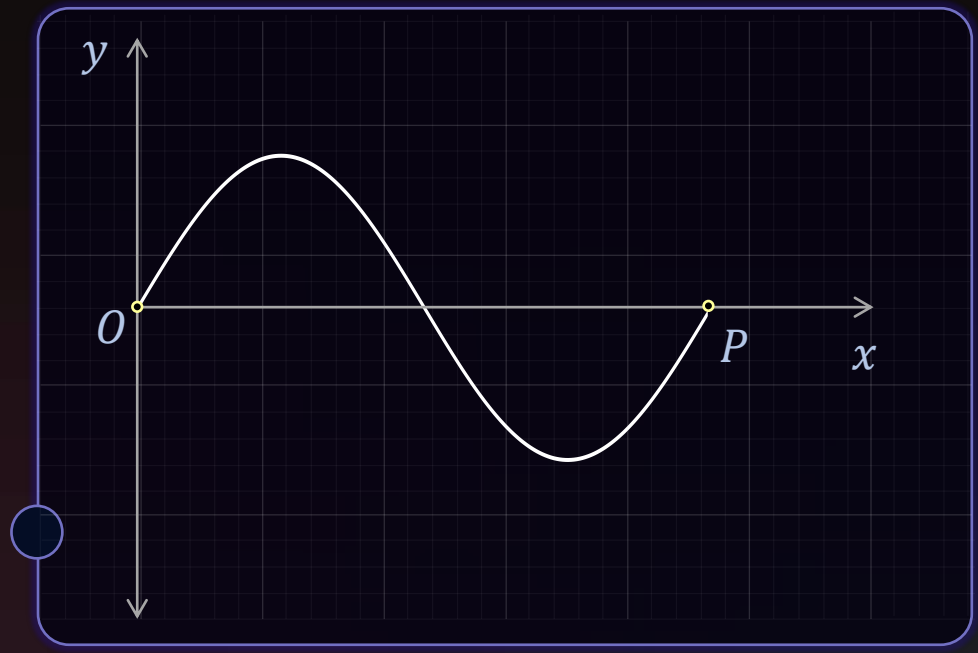


$$f(x,t) = y(x + \omega t + \phi)$$

WAVE PARAMETERS

$$E = E_0 \sin(Kx - \omega t)$$

$$y = A \sin((Kx \pm \omega t + \phi)$$



AMPLITUDE (A)

Maximum displacement of each particle from its undisturbed position

WAVELENGTH (λ)

The distance between two consecutive crests or troughs.

WAVE NUMBER (K)

The number of the complete cycle of a wave over its wavelength

$$K = \frac{2\pi}{\lambda}$$

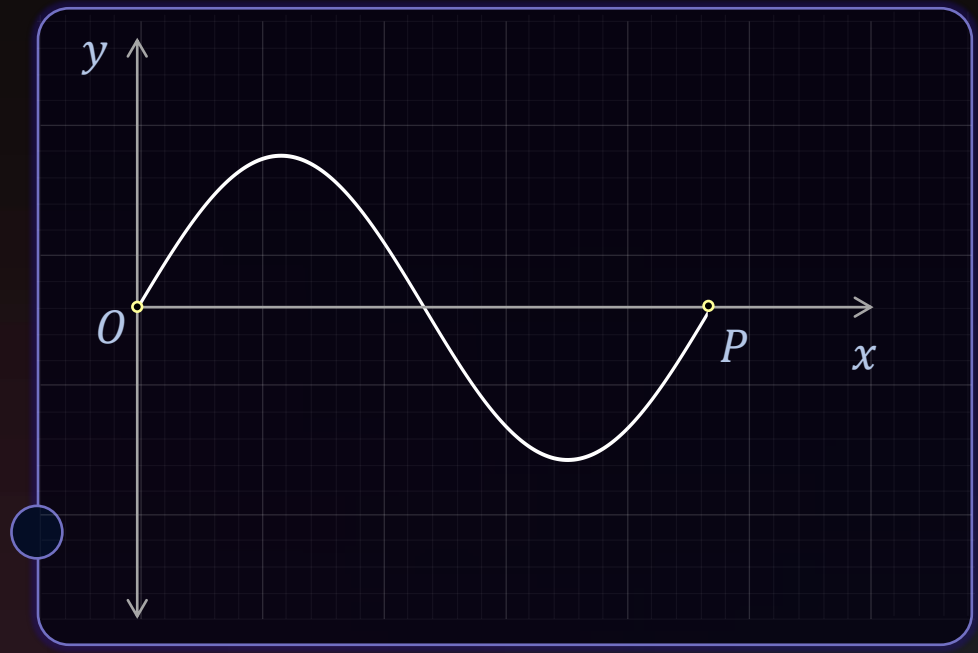
TIME PERIOD (T)

It is the time taken for one complete oscillation.

WAVE PARAMETERS

$$E = E_0 \sin(Kx - \omega t)$$

$$y = A \sin((Kx \pm \omega t + \phi)$$



FREQUENCY (f)

It is the number of oscillations per unit time.

$$f = \frac{1}{T}$$

ANGULAR FREQUENCY (ω)

$$\omega = \frac{2\pi}{T} = 2\pi f$$

SPEED OF WAVE (v)

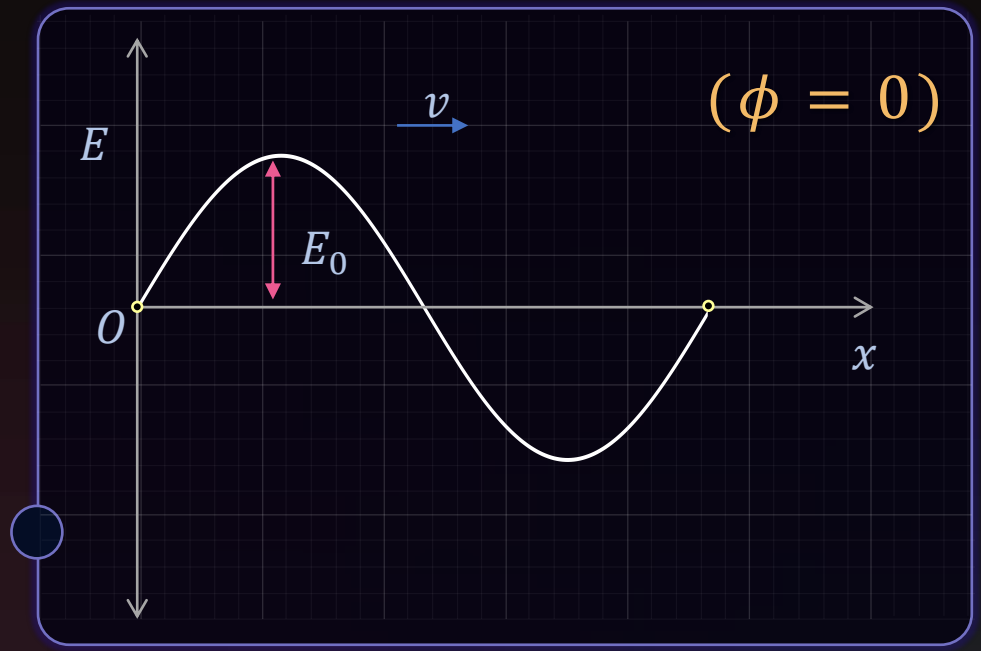
$$v = \frac{\omega}{k} = f\lambda$$

PHASE CONSTANT (ϕ)

Describes how displaced is the wave from equilibrium position.

EQUATION OF AN ELECTROMAGNETIC WAVE

ELECTRIC FIELD $(\vec{E})$



EQUATION OF AN ELECTROMAGNETIC WAVE

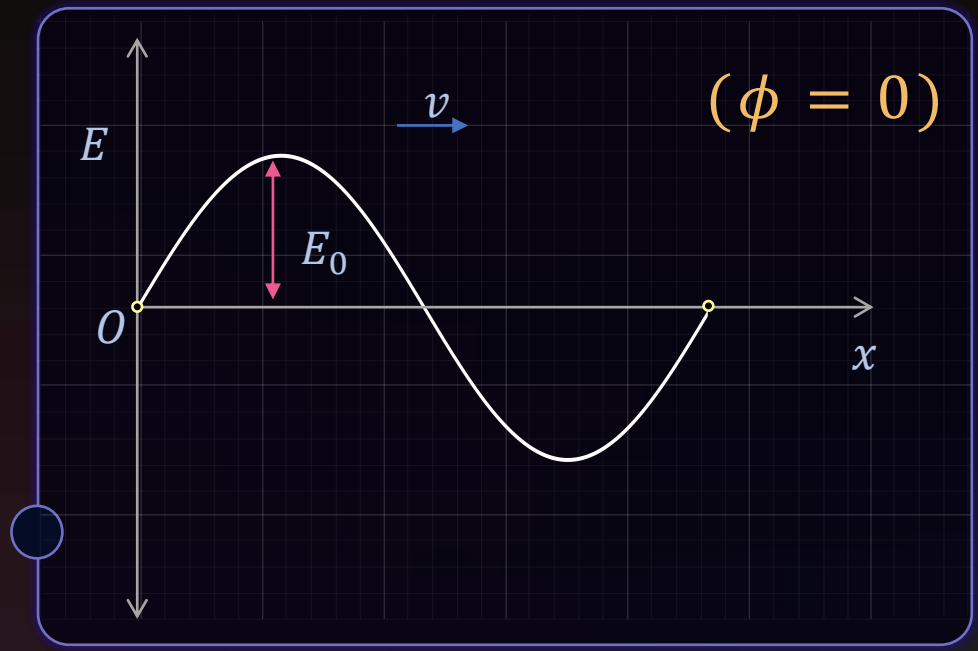
ELECTRIC FIELD ($\vec{E}$)

$$E = E_0 \sin(Kx - \omega t) \quad | \quad K = \frac{2\pi}{\lambda},\ \omega = \frac{2\pi}{T}$$

$$E = E_0 \sin\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right)$$

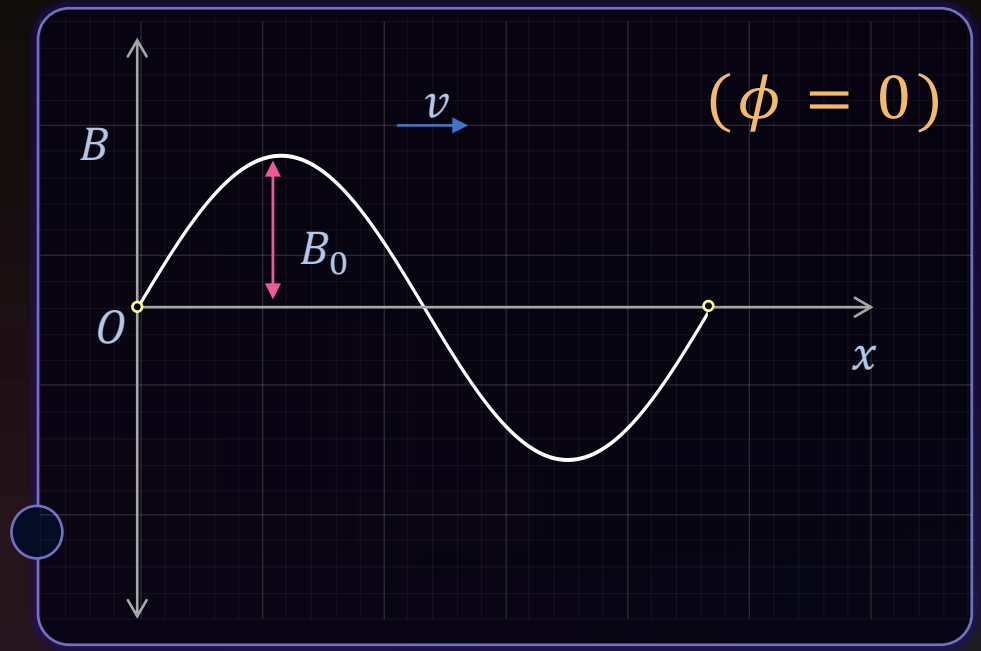
$$E = E_0 \sin\left(2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right) \quad | \quad \frac{1}{T} = f$$

$$E = E_0 \sin\left(2\pi\left(\frac{x}{\lambda} - ft\right)\right)$$



EQUATION OF AN ELECTROMAGNETIC WAVE

MAGNETIC FIELD ($\vec{B}$)



EQUATION OF AN ELECTROMAGNETIC WAVE

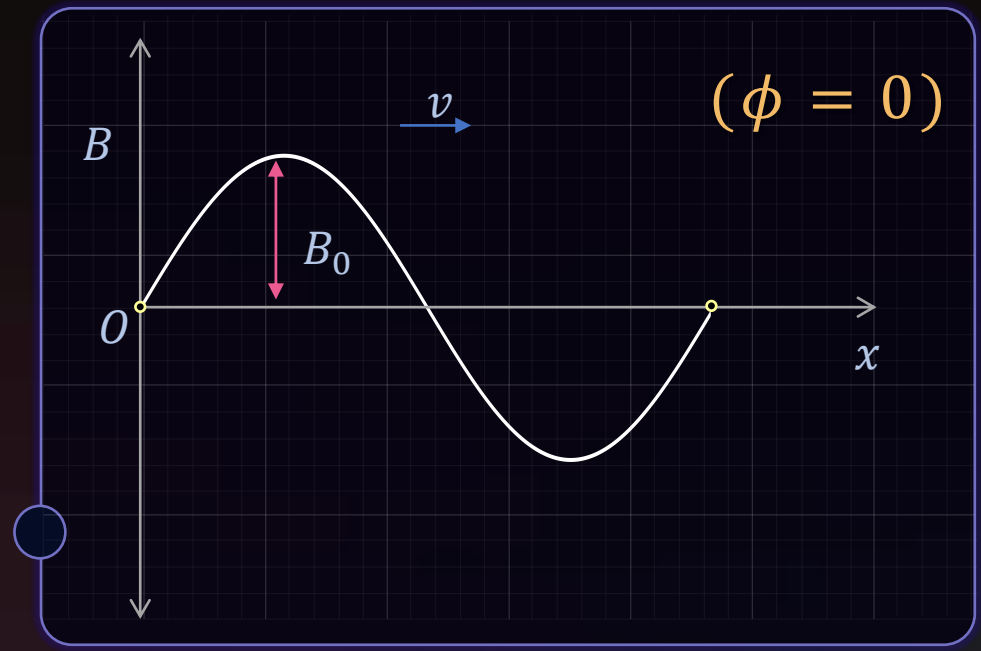
MAGNETIC FIELD ($\vec{B}$)

$$B = B_0 \sin(Kx - \omega t) \quad | \quad K = \frac{2\pi}{\lambda},\ \omega = \frac{2\pi}{T}$$

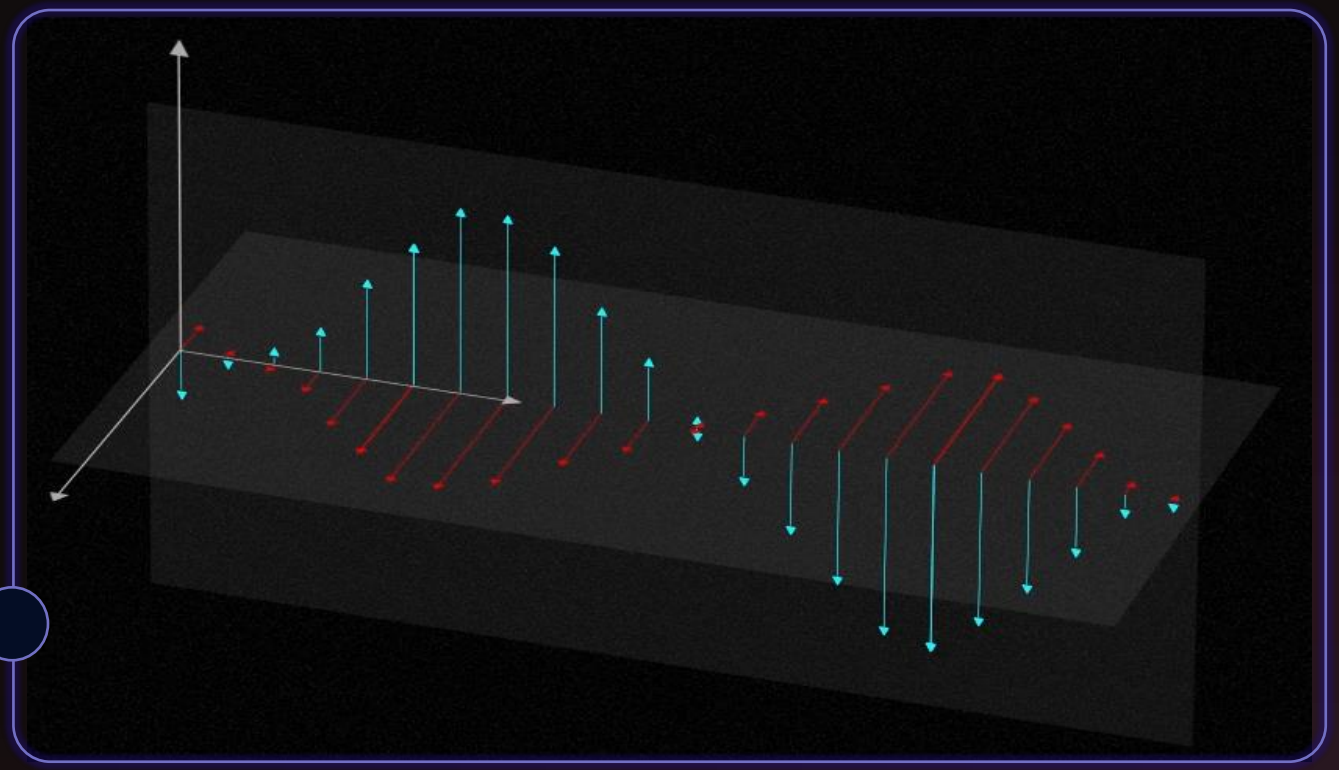
$$B = B_0 \sin\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right)$$

$$B = B_0 \sin\left(2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right) \quad | \quad \frac{1}{T} = f$$

$$B = B_0 \sin\left(2\pi\left(\frac{x}{\lambda} - ft\right)\right)$$



EQUATION OF AN ELECTROMAGNETIC WAVE



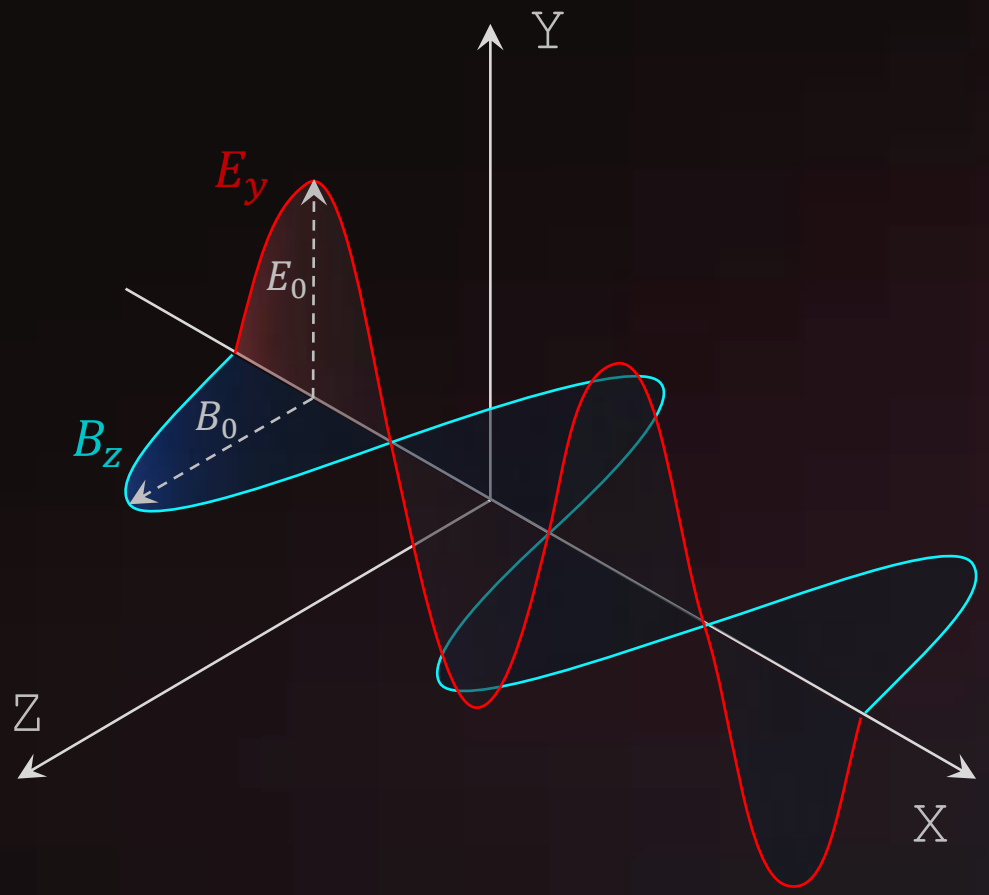
$$\vec{E} = E_0 \sin\left(2\pi\left(\frac{x}{\lambda} - ft\right)\right)\hat{j}$$

$$\vec{B} = B_0 \sin\left(2\pi\left(\frac{x}{\lambda} - ft\right)\right)\hat{k}$$

- Phase constant of electric field and magnetic field will always remain same

EQUATION OF AN ELECTROMAGNETIC WAVE

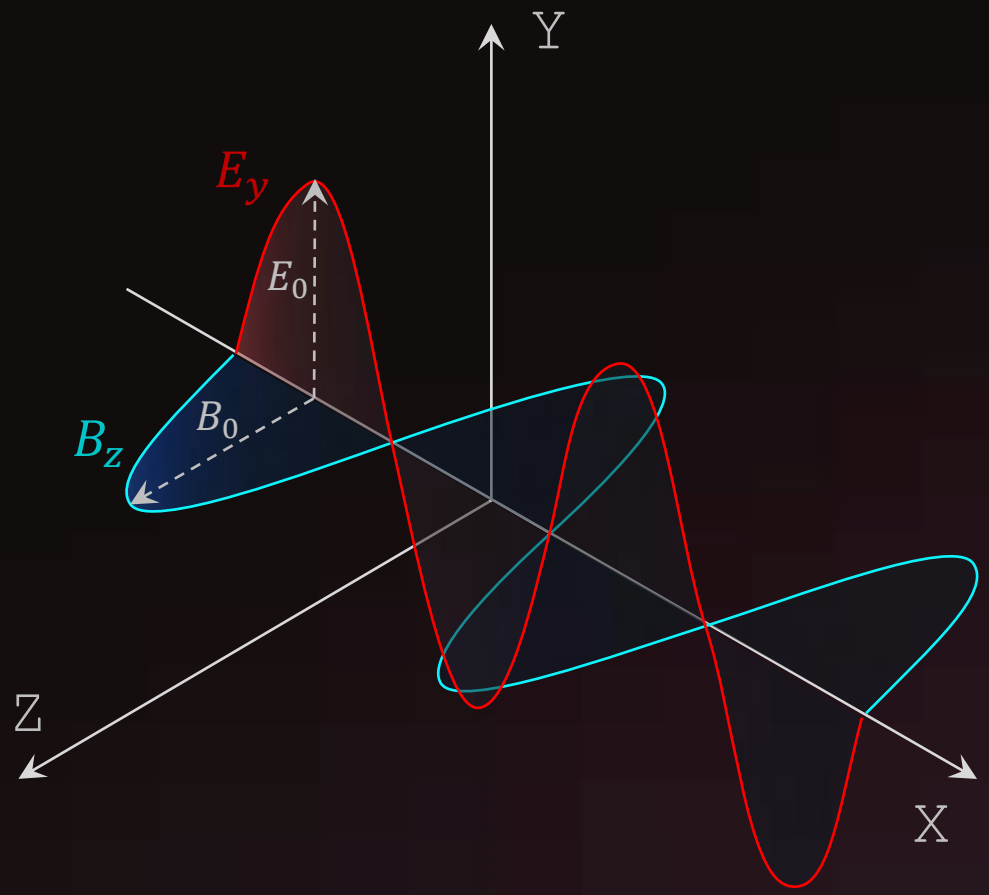
- Electromagnetic wave propagates in space through oscillations of electric and magnetic field, perpendicular to each other and also perpendicular to the direction of wave propagation.



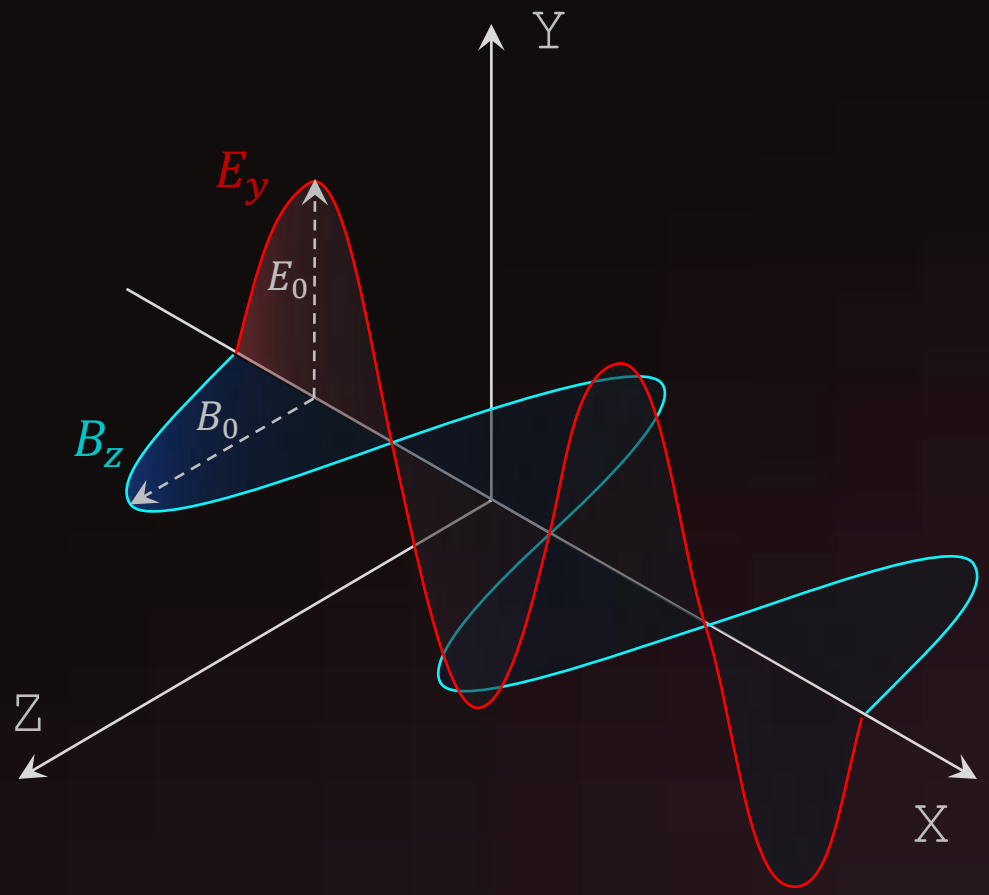
- Direction of propagation

$$\vec{v} = \vec{E} \times \vec{B}$$

RELATION BETWEEN E_0 AND B_0



RELATION BETWEEN E_0 AND B_0



- Relation between peak value of $\vec{E}$ and $\vec{B}$

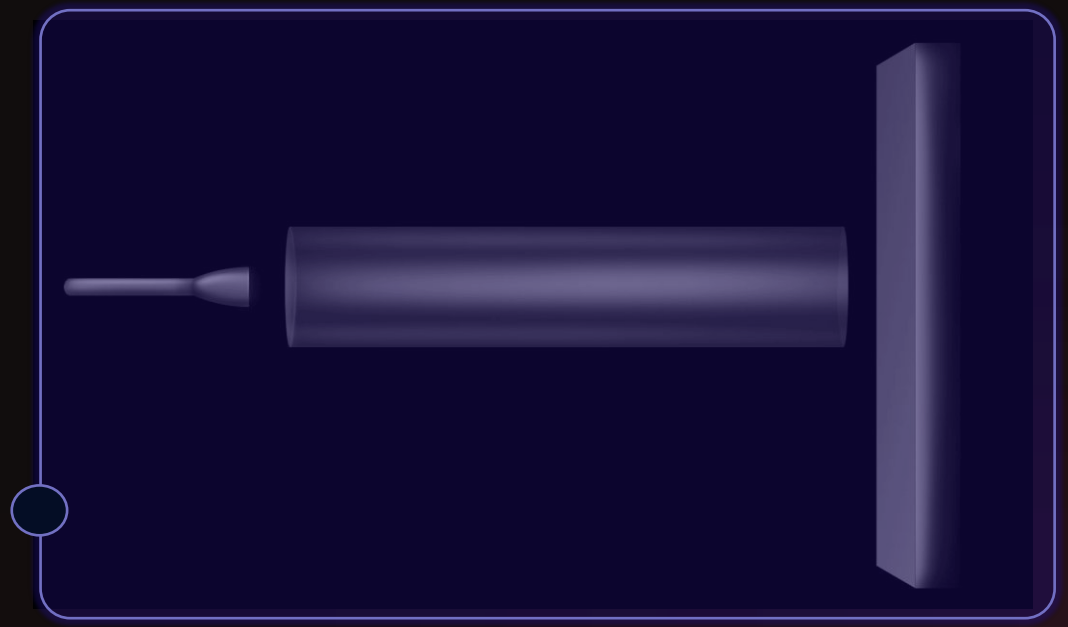
$$\frac{E_0}{B_0} = c \qquad (c: \text{Speed of light})$$

PERMEABILITY AND PERMITTIVITY OF MEDIUM

⊙ In air/vacuum/free space

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$ (c: Speed of light)

PERMEABILITY AND PERMITTIVITY OF MEDIUM



- In any other medium

$$v = \frac{1}{\sqrt{\mu_m \epsilon_m}}$$

$$\mu_r = \frac{\mu_m}{\mu_0}$$

$$\epsilon_r = \frac{\epsilon_m}{\epsilon_0}$$

ϵ_r dielectric constant

PERMEABILITY AND PERMITTIVITY OF MEDIUM

- Speed of light in air/vacuum/free space

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

- Speed of light in other medium

$$v = \frac{1}{\sqrt{\mu_m \epsilon_m}}$$

- Refractive index of medium (n)

$$n = \frac{c}{v} = \frac{\sqrt{\mu_m \epsilon_m}}{\sqrt{\mu_0 \epsilon_0}} = \sqrt{\mu_r \epsilon_r}$$

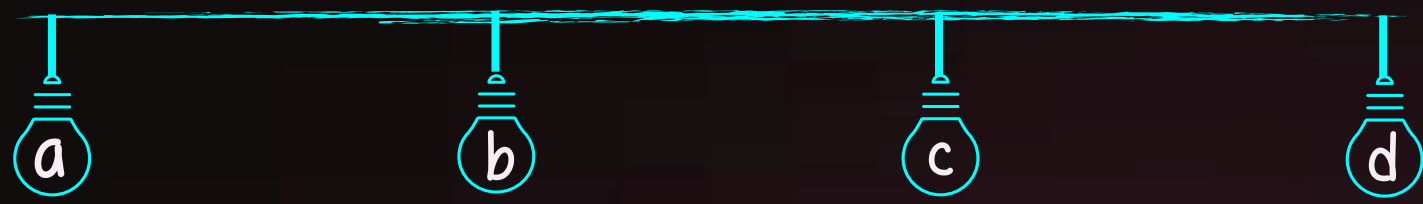
$$\mu_r = \frac{\mu_m}{\mu_0}$$

$$\epsilon_r = \frac{\epsilon_m}{\epsilon_0}$$

ϵ_r dielectric constant

QUESTION

When light propagates through a material medium of relative permittivity ε_r and relative permeability μ_r , the velocity of light, n is given by :
(c-velocity of light in vacuum)



a) $v = c$

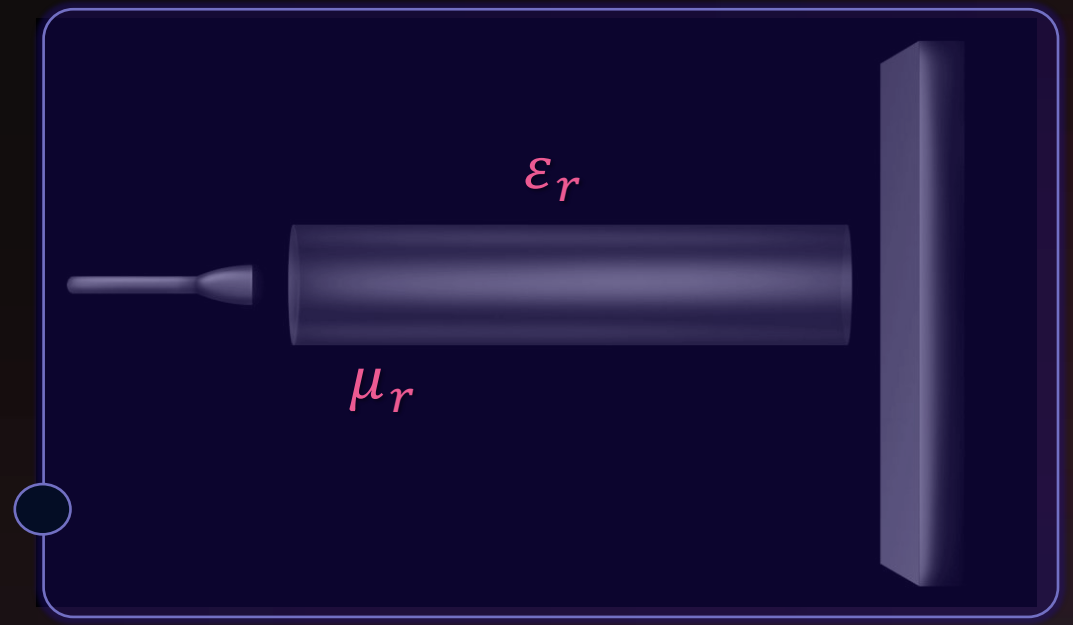
b) $v = \sqrt{\frac{\mu_r}{\varepsilon_r}}$

c) $v = \sqrt{\frac{\varepsilon_r}{\mu_r}}$

d) $v = \frac{c}{\sqrt{\varepsilon_r \mu_r}}$

DISCUSSION

When light propagates through a material medium of relative permittivity ε_r and relative permeability μ_r , the velocity of light, n is given by :
(c-velocity of light in vacuum)



ANSWER

B

When light propagates through a material medium of relative permittivity ε_r and relative permeability μ_r , the velocity of light, n is given by :
(c-velocity of light in vacuum)

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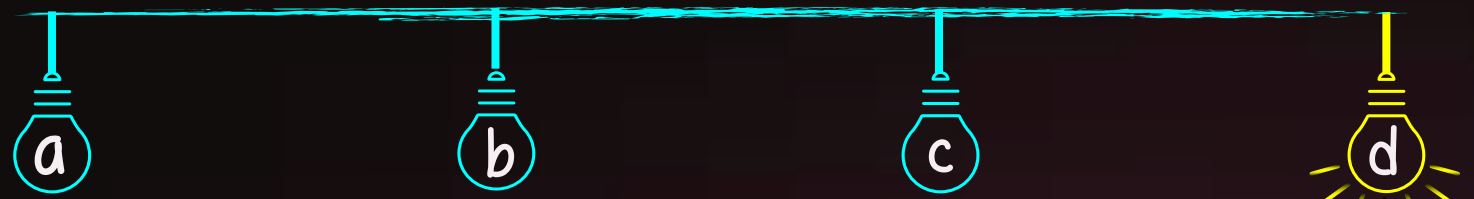


a) $v = c$

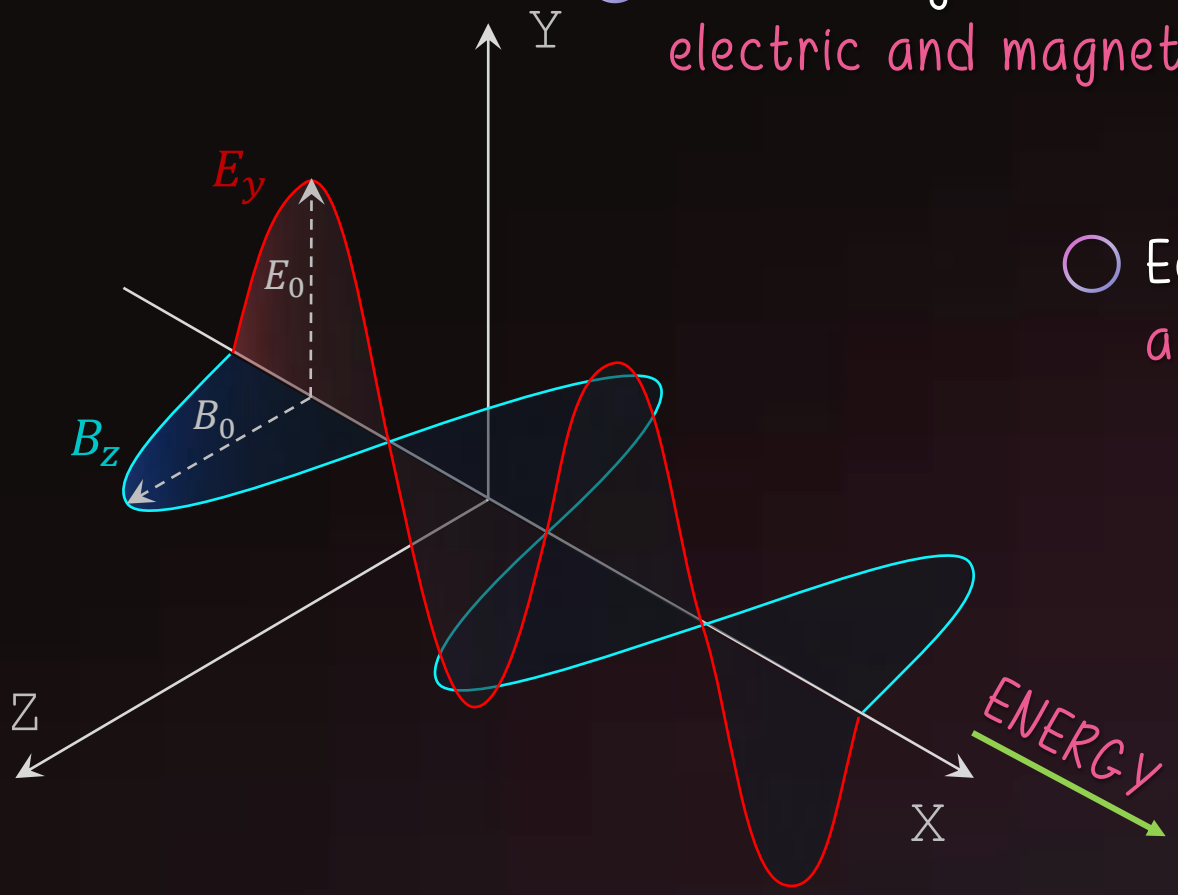
b) $v = \sqrt{\dfrac{\mu_r}{\varepsilon_r}}$

c) $v = \sqrt{\dfrac{\varepsilon_r}{\mu_r}}$

d) $v = \dfrac{c}{\sqrt{\varepsilon_r \mu_r}}$

ENERGY DENSITY OF ELECTROMAGNETIC WAVES

- Electromagnetic waves carry energy in oscillating electric and magnetic field.



- Equal amount of energy is contributed by electric and magnetic field.

ENEGRY DENSITY OF ELECTRIC FIELD

ENEGRY DENSITY OF ELECTRIC FIELD

$$U = \frac{1}{2} C V^2$$

$$V = \vec{E} . \vec{d} = Ed \cos 0° = Ed$$

$$U = \frac{1}{2} \frac{\epsilon_0 A}{d} (Ed)^2$$

$$U = \frac{1}{2} \epsilon_0 E^2 A d$$

$$U = \frac{1}{2} \epsilon_0 E^2 (Vol.)$$

$$\frac{U}{Vol.} = \frac{1}{2} \epsilon_0 E^2$$

$$\mu_E = \frac{1}{2} \epsilon_0 E^2$$

AVERAGE VALUE OF ENEGRY DENSITY OF ELECTRIC FIELD

$$\mu_E = \frac{1}{2}\epsilon_0 E^2$$

$$E = E_0 \sin(Kx - \omega t)$$

AVERAGE VALUE OF ENEGRY DENSITY OF ELECTRIC FIELD

$$\mu_E = \frac{1}{2}\epsilon_0 E^2 \qquad E = E_0 \sin(Kx - \omega t)$$

$$\mu_E = \frac{1}{2}\epsilon_0 E_0^2 \sin^2(Kx - \omega t)$$

$$\overline{\mu_E} = \frac{1}{2}\epsilon_0 E_0^2 \overline{\sin^2(Kx - \omega t)}$$

$$\overline{\mu_E} = \frac{1}{2}\epsilon_0 E_0^2 \times \frac{1}{2}$$

$$(\mu_E)_{avg} = \frac{1}{4}\epsilon_0 E_0^2$$

ENEGRY DENSITY OF ELECTRIC FIELD

ENEGRY DENSITY OF ELECTRIC FIELD

$$U = \frac{1}{2} L i^2$$

$$L = \mu_0 n^2 A l \quad \text{and} \quad i = \frac{B}{\mu_0 n}$$

n = no. of turns per unit length

$$B = \mu_0 n i$$

$$U = \frac{1}{2} \mu_0 n^2 A l \times \frac{B^2}{\mu_0^2 n^2}$$

$$U = \frac{1}{2} \frac{B^2}{\mu_0} A l$$

$$\frac{U}{Vol.} = \frac{1}{2} \frac{B^2}{\mu_0}$$

$$\mu_B = \frac{1}{2} \frac{B^2}{\mu_0}$$

AVERAGE VALUE OF ENEGRY DENSITY OF MAGNETIC FIELD

$$\mu_B = \frac{1}{2}\frac{B^2}{\mu_0}$$

$$B = B_0 \sin(Kx - \omega t)$$

AVERAGE VALUE OF ENEGRY DENSITY OF MAGNETIC FIELD

$$\mu_B = \frac{1}{2}\frac{B^2}{\mu_0}$$

$$B = B_0 \sin(Kx - \omega t)$$

$$\mu_B = \frac{1}{2}\frac{B_0^2}{\mu_0}\sin^2(Kx - \omega t)$$

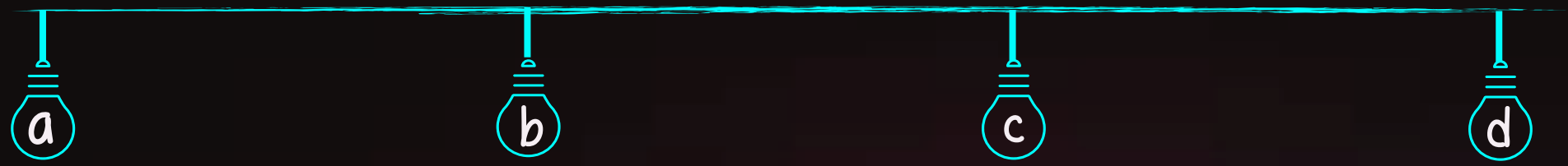
$$\overline{\mu_B} = \frac{1}{2}\frac{B_0^2}{\mu_0}\overline{\sin^2(Kx - \omega t)}$$

$$\overline{\mu_B} = \frac{1}{2}\frac{B_0^2}{\mu_0} \times \frac{1}{2}$$

$$(\mu_B)_{avg} = \frac{1}{4}\frac{B_0^2}{\mu_0}$$

QUESTION

Which of the following is true



$(\mu_E)_{Avg} = (\mu_B)_{Avg}$

$(\mu_E)_{Avg} = 2(\mu_B)_{Avg}$

$2(\mu_E)_{Avg} = (\mu_B)_{Avg}$

$(\mu_E)_{Avg} = 4(\mu_B)_{Avg}$

DISCUSSION

$$(\mu_E)_{Avg} = \frac{1}{4}\epsilon_0 E_0^2 \qquad (\mu_B)_{Avg} = \frac{1}{4\mu_0} B_0^2$$

SUMMARY

$$(\mu_E)_{Avg} = \frac{1}{4}\epsilon_0 E_0^2 \qquad (\mu_B)_{Avg} = \frac{1}{4\mu_0} B_0^2$$

$$(\mu_E)_{Avg} = \frac{1}{4}\epsilon_0 (B_0 c)^2$$

$$\frac{E_0}{B_0} = c \qquad c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

$$(\mu_E)_{Avg} = \frac{1}{4}\epsilon_0 {B_0}^2 \frac{1}{\mu_0 \epsilon_0}$$

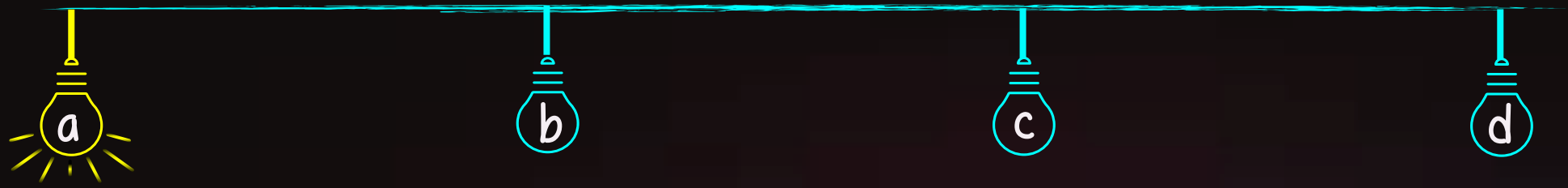
$$(\mu_E)_{Avg} = \frac{1}{4}{B_0}^2 \frac{1}{\mu_0}$$

$$(\mu_E)_{Avg} = \frac{1}{4\mu_0} B_0^2 = (\mu_B)_{Avg}$$

$$(\mu_E)_{Avg} = (\mu_B)_{Avg}$$

ANSWER

Which of the following is true



a. $(\mu_E)_{Avg} = (\mu_B)_{Avg}$

b. $(\mu_E)_{Avg} = 2(\mu_B)_{Avg}$

c. $2(\mu_E)_{Avg} = (\mu_B)_{Avg}$

d. $(\mu_E)_{Avg} = 4(\mu_B)_{Avg}$