

TAI sur la propa électrique

Exo 1

1°) propagat° selon Ox car $\vec{E}(x,t)$

donc $\vec{k} = \begin{pmatrix} k_x \\ 0 \\ 0 \end{pmatrix}$

d'après équation $k_x = \frac{\pi}{3} \cdot 10^7 \text{ rad} \cdot \text{m}^{-1}$

• $\lambda = \frac{2\pi}{\|\vec{k}\|} = \frac{2\pi}{k_x}$

AN: $\lambda = \frac{2\pi}{\frac{\pi}{3} \cdot 10^7} = 2 \times \frac{3}{10^7} = 6 \cdot 10^{-7} \text{ m} = \boxed{600 \text{ nm}}$

• $\lambda = cT$ donc $T = \frac{\lambda}{c}$

AN: $T = \frac{6 \cdot 10^{-7}}{3 \cdot 10^8} = \boxed{2 \cdot 10^{-15} \text{ s}}$

• $f = \frac{1}{T}$

AN: $f = \frac{1}{2 \cdot 10^{-15}} = \boxed{5 \cdot 10^{14} \text{ Hz}}$

2°) d'après la 3^e équation de Maxwell $\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$

$\vec{\nabla} \wedge \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ (3)

notation complexe: $\vec{\nabla} = i\vec{k}$ et $\frac{\partial}{\partial t} = -i\omega$

$\vec{k} \wedge \vec{E} = \omega \vec{B}$ (3)

donc $\vec{B} = \frac{1}{\omega} \vec{k} \wedge \vec{E} = \frac{1}{\omega} \begin{pmatrix} k_x \\ 0 \\ 0 \end{pmatrix} \wedge \begin{pmatrix} 0 \\ E_y \\ 0 \end{pmatrix} = \frac{1}{\omega} \begin{pmatrix} 0 \\ 0 \\ k_x E_y \end{pmatrix} = \begin{pmatrix} B_x = 0 \\ B_y = 0 \\ B_z = \frac{k_x E_y}{\omega} \end{pmatrix}$

prop OPPS: $E_0 = c B_0$

$B_0 = \frac{E_0}{c}$

AN: $B_0 = \frac{2 \cdot 10^4}{3 \cdot 10^8} = \boxed{6,7 \cdot 10^{-5} \text{ Tesla}}$

3°) $\vec{S} = \frac{\vec{E} \wedge \vec{B}}{\mu_0} = \frac{1}{\mu_0} \begin{pmatrix} 0 \\ E_y \\ 0 \end{pmatrix} \wedge \begin{pmatrix} 0 \\ 0 \\ B_z \end{pmatrix} = \frac{1}{\mu_0} \begin{pmatrix} E_y B_z \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} \frac{E_y B_z}{\mu_0} \\ 0 \\ 0 \end{pmatrix}$

OPPS $S_0 = \frac{E_0 B_0}{\mu_0}$ AN: $S_0 = \frac{2 \cdot 10^4 \cdot 6,7 \cdot 10^{-5}}{4\pi \cdot 10^{-7}} = \boxed{1,0 \cdot 10^6 \text{ W} \cdot \text{m}^{-2}}$

2

2

1°) selon Oy car $\vec{B}(y,t)$

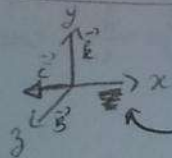
$$\bullet \boxed{k = \frac{2\pi}{\lambda}} \quad k = 2\pi \frac{1}{1.10^{-7}} = \boxed{2\pi \cdot 10^7 \text{ rad}\cdot\text{m}^{-1}}$$

$$\bullet \boxed{\omega = kc} \quad \omega = 2\pi \cdot 10^7 \times 3 \cdot 10^8 = \boxed{6\pi \cdot 10^{15} \text{ rad}\cdot\text{s}^{-1}}$$

2°) 1^{re} équation de Maxwell $\text{rot } \vec{B} = \frac{1}{c^2} \frac{\partial \vec{E}}{\partial t}$

avec notation complexe $\boxed{\vec{k} \wedge \vec{B} = \frac{-i\omega}{c^2} \vec{E}}$

donc $\vec{E} = \frac{-c^2}{\omega} \vec{k} \wedge \vec{B} = \frac{-c^2}{\omega} \begin{pmatrix} 0 \\ k \\ 0 \end{pmatrix} \wedge \begin{pmatrix} 0 \\ 0 \\ B_z \end{pmatrix} = \frac{-c^2}{\omega} \begin{pmatrix} kB_z \\ 0 \\ 0 \end{pmatrix} = \left(\frac{-c^2}{\omega} k B_z \right) \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$



$$\vec{E} = \begin{pmatrix} E_x \\ 0 \\ 0 \end{pmatrix}$$

$$\vec{E} = E_0 \cos(ky - \omega t) \vec{e}_x$$

prop OPPS: $\boxed{E_0 = c B_0}$

$$E_0 = 3 \cdot 10^8 \times 10^{-3} = \boxed{3 \cdot 10^5 \text{ V}\cdot\text{m}^{-1}}$$

3°) $\boxed{\vec{S} = \frac{\vec{E} \wedge \vec{B}}{\mu_0}}$ $\vec{S} = \frac{1}{\mu_0} \begin{pmatrix} E_x \\ 0 \\ 0 \end{pmatrix} \wedge \begin{pmatrix} 0 \\ 0 \\ B_z \end{pmatrix} = \frac{1}{\mu_0} \begin{pmatrix} 0 \\ -E_x B_z \\ 0 \end{pmatrix}$

OPPS: $\boxed{S_0 = \frac{E_0 B_0}{\mu_0}} = \frac{3 \cdot 10^5 \times 10^{-3}}{4\pi \cdot 10^{-7}} = \boxed{2,38 \cdot 10^8 \text{ W}\cdot\text{m}^{-2}}$

Exo 3

1°) $\Delta \vec{E} = \begin{pmatrix} \Delta E_x \\ \Delta E_y \\ \Delta E_z \end{pmatrix} = \begin{pmatrix} 0 \\ \Delta E_y \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ -E_0 k^2 \cos(kx - \omega t) \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ -k^2 E_y \\ 0 \end{pmatrix} = -k^2 \begin{pmatrix} 0 \\ E_y \\ 0 \end{pmatrix} = -k^2 \vec{E}$

$$\Delta E_y = \frac{\partial^2 E_0 \cos(kx - \omega t)}{\partial x^2} + \frac{\partial^2 E_0 \cos(kx - \omega t)}{\partial y^2} + \frac{\partial^2 E_0 \cos(kx - \omega t)}{\partial z^2}$$

$$= E_0 \frac{\partial^2 \cos(kx - \omega t)}{\partial x^2} = -E_0 k^2 \frac{\partial \sin(kx - \omega t)}{\partial x} = -E_0 k^2 \cos(kx - \omega t) = -k^2 E_y$$

$\boxed{\Delta \vec{E} = -k^2 \vec{E}}$



$$\frac{\partial^2 \vec{E}}{\partial t^2} = \frac{\partial^2 \vec{E}_0 \cos(kx - \omega t)}{\partial t^2} = \vec{E}_0 \frac{\partial^2 \cos(kx - \omega t)}{\partial t^2}$$

(3)

~~$$\frac{\partial^2 \cos(kx - \omega t)}{\partial t^2} = -\omega^2 \cos(kx - \omega t)$$~~

$$= -\vec{E}_0 \omega^2 \cos(kx - \omega t)$$

$$\boxed{\frac{\partial^2 \vec{E}}{\partial t^2} = -\omega^2 \vec{E}}$$

$$\frac{\partial^2}{\partial t^2} = (-i\omega)^2 = -\omega^2$$

$$3^\circ) \left[\Delta \vec{E} - \frac{1}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} = \vec{0} \right] \text{ équation de D'Alembert}$$

$$-k^2 \vec{E} + \mu_0 \epsilon_0 \omega^2 \vec{E} = \vec{0}$$

$$\mu_0 \epsilon_0 \omega^2 - k^2 = 0 \quad \text{car } \vec{E} \neq \vec{0}$$

$$\mu_0 \epsilon_0 \omega^2 = k^2$$

$$\mu_0 \epsilon_0 = \frac{k^2}{\omega^2}$$

$$\frac{k}{\omega} = \sqrt{\mu_0 \epsilon_0} \Leftrightarrow \frac{k}{\omega} = \frac{1}{c} \Leftrightarrow \boxed{k = \omega/c}$$

Exo 4

$$1^\circ) \operatorname{div} \vec{E} = \vec{\nabla} \cdot \vec{E} = \frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z} = \frac{\partial E_0 \cos(kx - \omega t)}{\partial x} = 0$$

$$\boxed{\operatorname{div} \vec{E} = 0}$$

c 1^{re} équation de Maxwell du vide

$$2^\circ) \begin{array}{c} y \\ \uparrow \vec{E} \\ \vec{B} \text{ sur } O_3 \\ \swarrow \vec{B} \\ z \end{array} \quad \text{de } \vec{B} \text{ sur } O_3 \quad \vec{B} = \begin{pmatrix} 0 \\ 0 \\ B_z \end{pmatrix} \quad \vec{B} = B_0 \cos(kx - \omega t) \vec{e}_z$$

$$3^\circ) \text{ d'après 3^e équation Maxwell } \boxed{\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \wedge \vec{E}}$$

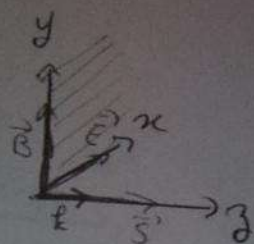
notation complexe : $\vec{\nabla} = i\vec{k}$ et $\frac{\partial}{\partial t} = -i\omega$

$$\boxed{\vec{k} \wedge \vec{E} = \omega \vec{B}}$$

$$\text{donc } \vec{B} = \frac{1}{\omega} \begin{pmatrix} k \\ 0 \\ 0 \end{pmatrix} \wedge \begin{pmatrix} 0 \\ E_0 \cos(kx - \omega t) \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ \frac{k}{\omega} E_0 \cos(kx - \omega t) \end{pmatrix}$$

Exo 5

10)



$(\vec{E}, \vec{B})$ ds plan (yOx)
propriété onde $(\vec{u}, \vec{E}, \vec{B})$ triède direct

20) par def $\vec{S}' = \frac{\vec{E} \wedge \vec{B}}{\mu}$

$\rightarrow$ OPPS ds aire ou vide $\mu = \mu_0$
 $\rightarrow \vec{E} \perp \vec{B} \quad \vec{E} \wedge \vec{B} = E \cdot B \cdot \vec{u} \quad \left. \vphantom{\vec{E} \perp \vec{B}} \right\} \text{OPPS}$

$\vec{S}' = \frac{E \cdot B}{\mu_0} \vec{u} =$

30) $P = \oiint_{\Sigma} \vec{S}' \cdot d\vec{\Sigma} = \Phi(\vec{S}')$

$= \vec{S}' \iint_{\Sigma} d\vec{\Sigma}$

$= S \cdot \Sigma$

$= S \cdot \pi R^2$

$= \frac{E \cdot B}{\mu_0} \cdot \pi R^2$

or $E = cB \rightarrow B = \frac{E}{c}$

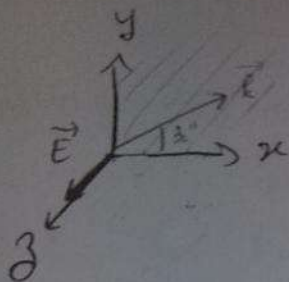
$\frac{EB}{\mu_0} = \frac{E^2}{c\mu_0} = \frac{E_0^2 \cos^2(kz - \omega t)}{c\mu_0}$

$P_{moy} = \langle P \rangle = \left\langle \frac{E_0^2 \cos^2(kz - \omega t)}{c\mu_0} \pi R^2 \right\rangle_t$
 $= \frac{E_0^2}{c\mu_0} \langle \cos^2(kz - \omega t) \rangle_t \pi R^2$

$P_{moy} = \frac{E_0^2}{2c\mu_0} \pi R^2$

AN: $P_{moy} = \frac{(10^7)^2}{2 \times 3 \cdot 10^8 \times 4\pi \cdot 10^{-7}} \pi (4 \cdot 10^{-3})^2 = \frac{1}{6} \cdot 10^7 = 1,7 \cdot 10^6 \text{ W}$
 $= 1,7 \text{ MW}$

10)



$$2^{\circ}) \vec{E}(x, y, t) = E_0 (k_x x + k_y y - \omega t) \vec{e}_z$$

$$3^{\circ}) \vec{k} = \begin{pmatrix} k \cos 30^\circ \\ k \sin 30^\circ \\ 0 \end{pmatrix} = \begin{pmatrix} \frac{k\sqrt{3}}{2} \\ \frac{k}{2} \\ 0 \end{pmatrix}$$

d'après 3^e équation Maxwell $\boxed{\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \wedge \vec{E}}$
 notation complexe : $\vec{\nabla} = i\vec{k}$ et $\frac{\partial}{\partial t} = -i\omega$

$$\boxed{\vec{k} \wedge \vec{E} = \omega \vec{B}}$$

$$\text{donc } \vec{B} = \frac{1}{\omega} \vec{k} \wedge \vec{E} = \begin{pmatrix} \frac{k\sqrt{3}}{2} \\ \frac{k}{2} \\ 0 \end{pmatrix} \wedge \begin{pmatrix} 0 \\ 0 \\ E_0 \cos\left(\frac{k\sqrt{3}}{2}x + \frac{k}{2}y - \omega t\right) \end{pmatrix} \frac{1}{\omega}$$

$$= \frac{1}{\omega} \begin{pmatrix} \frac{k}{2} E_0 \cos\left(\frac{k\sqrt{3}}{2}x + \frac{k}{2}y - \omega t\right) \\ -\frac{k\sqrt{3}}{2} E_0 \cos\left(\frac{k\sqrt{3}}{2}x + \frac{k}{2}y - \omega t\right) \\ 0 \end{pmatrix}$$

$$\vec{B}(x, y, t) = B_0 (k_x x + k_y y - \omega t)$$

$$\boxed{E_0 = c B_0} \text{ prop OPPS}$$

$$\boxed{B_0 = \frac{E_0}{c} = \frac{\omega E_0}{k}}$$

$$\text{comme } \boxed{\frac{\omega}{k} = c}$$

10) $k^2 = \frac{\omega^2}{c^2} \left(1 + \frac{i\gamma}{\omega\epsilon_0} \right)$ or $\gamma = \frac{im_e e^2}{m \cdot \omega}$

donc $\frac{i\gamma}{\omega\epsilon_0} = \frac{i}{\omega\epsilon_0} \cdot \frac{im_e e^2}{m \cdot \omega} = - \frac{1}{\omega^2} \times \frac{m_e e^2}{\epsilon_0 \cdot m} = - \frac{\omega_p^2}{\omega^2}$ avec $\omega_p^2 = \frac{ne}{m\epsilon_0}$

donc $k^2 = \frac{\omega^2}{c^2} \left(1 - \frac{\omega_p^2}{\omega^2} \right)$

2°) a) coupure quand $k^2 = 0$
 or si $\omega = \omega_p$, on a $k^2 = \frac{\omega^2}{c^2} (1-1) = 0$

donc $f_c = f_p = \frac{\omega_p}{2\pi}$

$f_c = f_p = \frac{1}{2\pi} \sqrt{\frac{ne^2}{m\epsilon_0}} = \frac{1}{2\pi} \times \frac{e}{\sqrt{m\epsilon_0}} \times \sqrt{ne} = \frac{1}{2\pi} \times 62,8 \times \sqrt{10^{12}} = 9,99 \cdot 10^6 \text{ Hz} = 9,99 \text{ MHz}$

b) pour $f > f_c$ l'onde se propage

donc pour $f \geq 10 \text{ MHz}$

donc une onde de 5 MHz sera réfléchi

3°)

	10 MHz	
k^2	-	+
k	Imaginaire pur	réel
Onde	atténuée	progressive

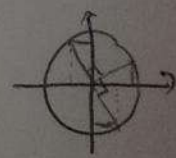
$\omega_p = 62,8 \sqrt{10^{12}} = 62,8 \cdot 10^6 \text{ rad} \cdot \text{s}^{-1}$

Exo 8

1°) a) pas de déphasage $\cos/\cos$
 polarisation à α $\frac{E_{01} \sin \alpha}{E_{01} \cos \alpha} = \tan \alpha$ } rectiligne

b) déphasés de $+\pi/2$ $\cos/\sin$ } circulaire (droite)
 $E_{02} \neq E_{01} = E_0$

c) déphasés de $+\pi/2$ $\cos/-\sin$ } circulaire (gauche)
 $E_{02} \neq E_{01} = E_0$



$$\vec{E} = \vec{E}_2 + \vec{E}_3 = \begin{pmatrix} (E_{02} + E_{03}) \cos(kz - \omega t) \\ (E_{02} - E_{03}) \sin(kz - \omega t) \end{pmatrix} \quad (7)$$

• déphasage de $\frac{\pi}{2}$ cos/sin } elliptique (droit)
 $E_{02} + E_{03} \neq E_{02} - E_{03}$

• si $E_{02} = E_{03} = E_0$

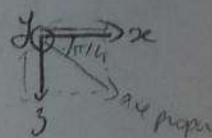
$\vec{E} \begin{pmatrix} 2E_0 \cos(kz - \omega t) \\ 0 \end{pmatrix}$ } l'onde devient polarisée selon Oz .

Exo 9

1°) $\vec{E}_1 = \begin{pmatrix} 0 \\ E_{01} \cos(\frac{\pi}{4}) \cos(kx - \omega t) \\ E_{01} \sin(\frac{\pi}{4}) \cos(kx - \omega t) \end{pmatrix}$ ← axe propagation donc pas de composante $\pi/4$ de Oy ⊕ rectiligne

2°) $\vec{E}_2 = \begin{pmatrix} E_{02} \cos(ky - \omega t) \\ 0 \\ 3E_{02} \cos(ky - \omega t + \frac{\pi}{2}) \end{pmatrix}$ ← déphasage de $\frac{\pi}{2}$
 ← axe propa
 gd axe sur z 3x et gd que petit axe

3°) $\vec{E}_3 = \begin{pmatrix} 0 \\ E_{03} \cos(\frac{k\sqrt{2}}{2}x + \frac{k\sqrt{2}}{2}y - \omega t) \\ 0 \end{pmatrix}$ ← plan propa



Exo 10

1°) ... } elliptique droite

② déphase cos/sin ($\Rightarrow \frac{\pi}{2}$)

③ comme $E_{0x} > E_{0y} \Rightarrow E_{0x}$ est gd axe, E_{0y} est petit axe

④ équation : $\frac{E_x^2}{E_{0x}^2} + \frac{E_y^2}{E_{0y}^2} = \frac{E_{0x}^2 \cos^2(kz - \omega t)}{E_{0x}^2} + \frac{E_{0y}^2 \sin^2(kz - \omega t)}{E_{0y}^2} = 1$

2°) $\frac{E_x^2}{E_0^2} + \frac{E_y^2}{E_0^2} = \frac{E_0^2 \cos^2(kz - \omega t)}{E_0^2} + \frac{E_0^2 \sin^2(kz - \omega t)}{E_0^2} = 1$

$\Leftrightarrow E_x^2 + E_y^2 = E_0^2$ } circulaire droite
 cos/sin ($\Rightarrow \frac{\pi}{2}$)

donc ... de d'axe Ox et Oy .

1°) $\vec{E} = \begin{pmatrix} 0 \\ 0 \\ E_0 \cos(kx - \omega t) \end{pmatrix} = E_0 \cos(kx - \omega t) \vec{e}_z$

(b)

$$f = \frac{\omega}{2\pi} = \frac{2\pi \cdot 10^{14}}{2\pi} = 10^{14} \text{ Hz}$$

2°) 3° equation de Maxwell $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \wedge \vec{E}$
 en notation complexe $\vec{\nabla} = i\vec{k}$ et $\frac{\partial}{\partial t} = -i\omega$

$$\vec{k} \wedge \vec{E} = \omega \vec{B}$$

$$\vec{B} = \frac{1}{\omega} \begin{pmatrix} k \\ 0 \\ 0 \end{pmatrix} \wedge \begin{pmatrix} 0 \\ 0 \\ E_0 \cos(kx - \omega t) \end{pmatrix} = \frac{1}{\omega} \begin{pmatrix} 0 \\ -kE_0 \cos(kx - \omega t) \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ -\frac{k}{\omega} E_0 \cos(kx - \omega t) \\ 0 \end{pmatrix}$$

prop OPPS $E_0 = c B_0$

$$B_0 = \frac{E_0}{c} = \frac{10^6}{3 \cdot 10^8} = \frac{1}{3} \cdot 10^{-2} = 3,33 \cdot 10^{-3} \text{ Tesla}$$

3°) $\vec{S} = \frac{\vec{E} \wedge \vec{B}}{\mu_0} = \frac{1}{\mu_0} \begin{pmatrix} 0 \\ 0 \\ E_0 \cos(kx - \omega t) \end{pmatrix} \wedge \begin{pmatrix} 0 \\ B_0 \cos(kx - \omega t) \\ 0 \end{pmatrix} = \begin{pmatrix} \frac{E_0 B_0}{\mu_0} \cos^2(kx - \omega t) \\ 0 \\ 0 \end{pmatrix}$

OPPS

$$S_0 = \frac{E_0 B_0}{\mu_0} = \frac{10^6 \times 3,33 \cdot 10^{-3}}{4\pi \cdot 10^{-7}} = 2,65 \cdot 10^9 \text{ W, m}^{-2}$$

10 12

$$1^o) \vec{E} = \begin{pmatrix} 0 \\ E_0 \cos(kz - \omega t) \\ 0 \end{pmatrix} = E_0 \cos(kz - \omega t) \vec{e}_y$$

d'après la 3^e équation de Maxwell $\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ (vide)

en complexe avec $\vec{\nabla} = i\vec{k}$, $\frac{\partial}{\partial t} = -i\omega$

donc $\vec{E} \wedge \vec{k} = \omega \vec{B}$

$$\vec{B} = \frac{1}{\omega} \vec{E} \wedge \vec{k} = \frac{1}{\omega} \begin{pmatrix} 0 \\ E_0 \cos(kz - \omega t) \\ 0 \end{pmatrix} \wedge \begin{pmatrix} 0 \\ 0 \\ k \end{pmatrix} = \begin{pmatrix} \frac{k E_0}{\omega} \cos(kz - \omega t) \\ 0 \\ 0 \end{pmatrix}$$

$\vec{B} = B_0 \cos(kz - \omega t) \vec{e}_x$

$$2^o) \vec{S} = \frac{\vec{E} \wedge \vec{B}}{\mu_0} = \frac{1}{\mu_0} \begin{pmatrix} 0 \\ E_0 \cos(kz - \omega t) \\ 0 \end{pmatrix} \wedge \begin{pmatrix} B_0 \cos(kz - \omega t) \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ \frac{E_0 B_0}{\mu_0} \cos(kz - \omega t) \end{pmatrix}$$

$$3^o) P_{moy} = \Phi(\vec{S}) = \oint_{\Sigma} \vec{S} \cdot d\vec{\Sigma} = \iint S \cdot d\Sigma = S \cdot \Sigma$$

or $\vec{S} = \frac{\vec{E} \wedge \vec{B}}{\mu_0}$ comme $\vec{E} \perp \vec{B}$: $S = \frac{E \cdot B}{\mu_0}$

or $E = cB$: $S = \frac{E^2}{c \cdot \mu_0} = \frac{E_0^2 \cos^2(kz - \omega t)}{c \mu_0}$

or $\Sigma = a^2$

$$\Rightarrow P_{moy} = \left\langle \frac{E_0^2 \cos^2(kz - \omega t)}{c \cdot \mu_0} a^2 \right\rangle = \frac{E_0^2 a^2}{c \cdot \mu_0} \langle \cos^2(kz - \omega t) \rangle$$

$$P_{moy} = \frac{E_0^2 a^2}{2 \cdot c \cdot \mu_0}$$

$$1^{\circ}) \vec{E}(R) = \begin{pmatrix} 0 \\ E_0 \cos(kR - \omega t) \\ 0 \end{pmatrix}$$

$\downarrow$
 $z = R$

$$2^{\circ}) \boxed{\vec{S} = \frac{\vec{E} \wedge \vec{B}}{\mu_0}}$$

comme $\vec{E} \perp \vec{B}$

$$S = \frac{E \cdot B}{\mu_0}$$

comme $E = cB$

$$S = \frac{E^2}{c\mu_0} = \boxed{\frac{E_0^2 \cos^2(kR - \omega t)}{c\mu_0}}$$

$$3^{\circ}) \boxed{P_{\text{moy}} = \Phi(\vec{S}) = \oiint_{\Sigma} \vec{S} \cdot d\vec{\Sigma} = \iiint_{\Sigma} S \cdot d\Sigma = S \cdot \Sigma}$$

$$\text{or } \Sigma = 4\pi R^2$$

$$P_{\text{moy}} = \left\langle \frac{E_0^2 \cos^2(kR - \omega t)}{c\mu_0} 4\pi R^2 \right\rangle = \frac{E_0^2 4\pi R^2}{c\mu_0} \langle \cos^2(kR - \omega t) \rangle$$

$$= \boxed{\frac{E_0^2 4\pi R^2}{c\mu_0} \cdot \frac{1}{2}}$$