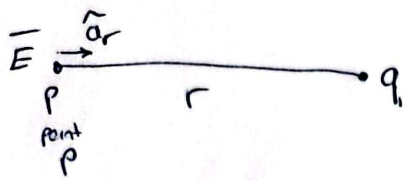
Coulumb's Law: stationary charge:



$$\bar{E} = -\frac{q}{4\pi\epsilon_0}\frac{\hat{a}_r}{r^2}$$

so actualy

In 1880's; Maxwell came up with modifications:

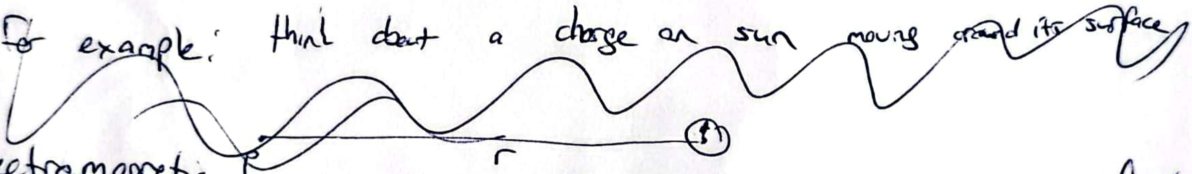
moving charge results in time dependence

$$\bar{E}(t) = \frac{-q}{4\pi\epsilon_0}\left[\frac{\hat{a}_r'}{r'^2} + \frac{r'}{c}\frac{d}{dt}\left(\frac{\hat{a}_r}{r'^2}\right) + \frac{1}{c^2}\frac{d}{dt^2}a_r'\right]$$

You have to look at the position of the charge at some earlier time to calculate the electric field at position 'P'. Since field takes time to reach Point 'P'. Remember it moves with light of speed 'c'. So $\bar{E}$ should depend on the position at an earlier time. This is called reterded position and time.

time takes to reach 'P' $= \frac{r}{c}$ so reterded time: $t - \frac{r}{c}$

For example: think about a charge on sun moving around its surface

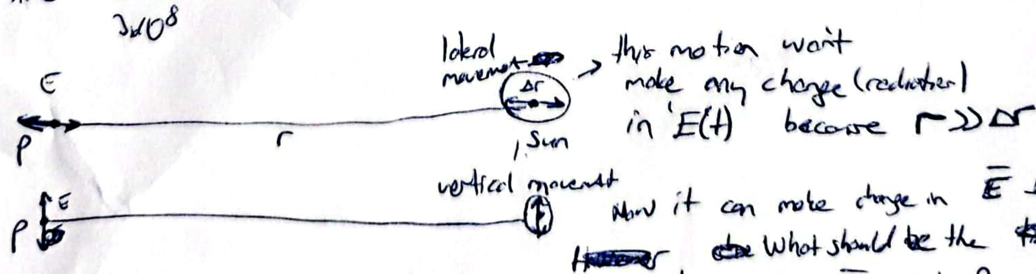


Electromagnetic Radiation: refers to the waves of the electromagnetic field, propagating (radiating) through space carrying electromagnetic radiant energy

Now check $E(t)$; which term can generate radiation?

Assume Sun; it is 1.5×10^{11} m far from us and speed of light is 3×10^8 m/s

means that time $= \frac{1\times10^{11}}{3\times10^8} = 500$ sec. $\Rightarrow$ reterded time: $t - 500s$



this motion won't make any change (radiation) in $E(t)$ because $r \gg \Delta r$

Now it can make change in $\bar{E}$ far away. What should be the $r(t)$ to enable $\bar{E}$ radiation?

$$\left(\frac{\hat{a}_r'}{r'^2} + \frac{r'}{c}\frac{d}{dt}\frac{(\hat{a}_r)}{r'^2} + \frac{1}{c^2}\frac{d}{dt^2}\hat{a}_r'\right)$$

$\frac{1}{r^2}$ $\leftrightarrow$ $\frac{1}{r^2}$!

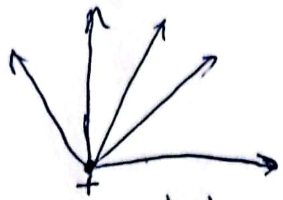
same $\rightarrow$ stationary!

can have radiation

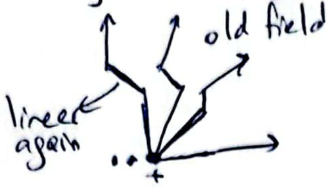
$\rightarrow$ turns out that it can radiate at only $1/r$ dependence.

$\rightarrow$ need acceleration!

~~Watch youtube video 'Understanding Electromagnetic Radiation'~~



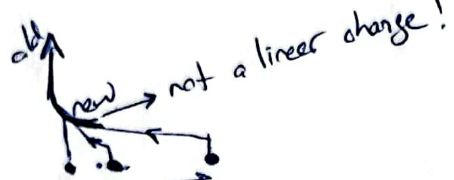
constant charge



moving linear speed

$\Rightarrow$ similar to each other
no change with linear movement
still linear field profile!

we need acceleration;



accelerating charge

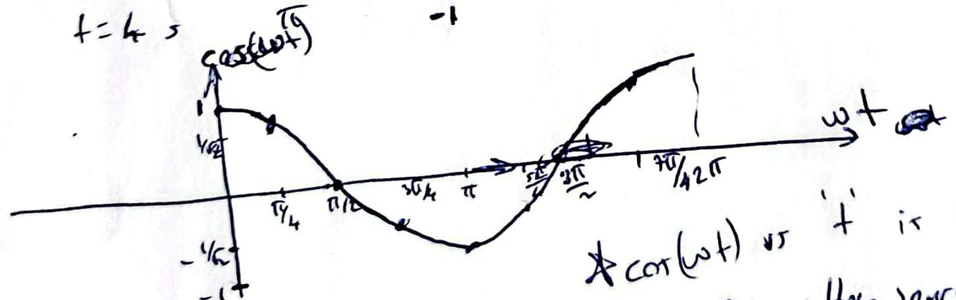
now we understand that we need 2'nd derivative w.r.t 't' should be non zero
and we know that e^{wt} has infinite non-zero derivative ability and $\cos wt$, or $\sin wt$

$w \rightarrow$ açısal hız radyan/s.
radial velocity

draw $\cos(wt)$ versus wt and $\cos(wt)$ versus 't' for $0 < wt < 2\pi$

assume $w = \frac{\pi}{4}$ radian/s then

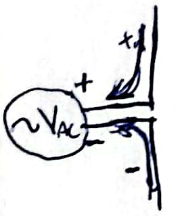
	wt	(1) $\cos wt$		wt	$\cos wt$
at $t=0$					
$t=1$ sec	$\frac{\pi}{4}$	$\frac{1}{\sqrt{2}}$	$t=5$ sec	$5\frac{\pi}{4}$	$-\frac{1}{\sqrt{2}}$
$t=2$ s.	$\frac{\pi}{2}$	0	$t=6$	$\frac{3\pi}{2}$	0
$t=3$ s	$\frac{3\pi}{4}$	$-\frac{1}{\sqrt{2}}$	$t=7$	$7\pi/4$	$1/\sqrt{2}$
$t=4$ s		-1	$t=8$	2π	1



for $w = \frac{\pi}{4}$

* $\cos(wt)$ vs 't' is similar just put 't' in x-axis.

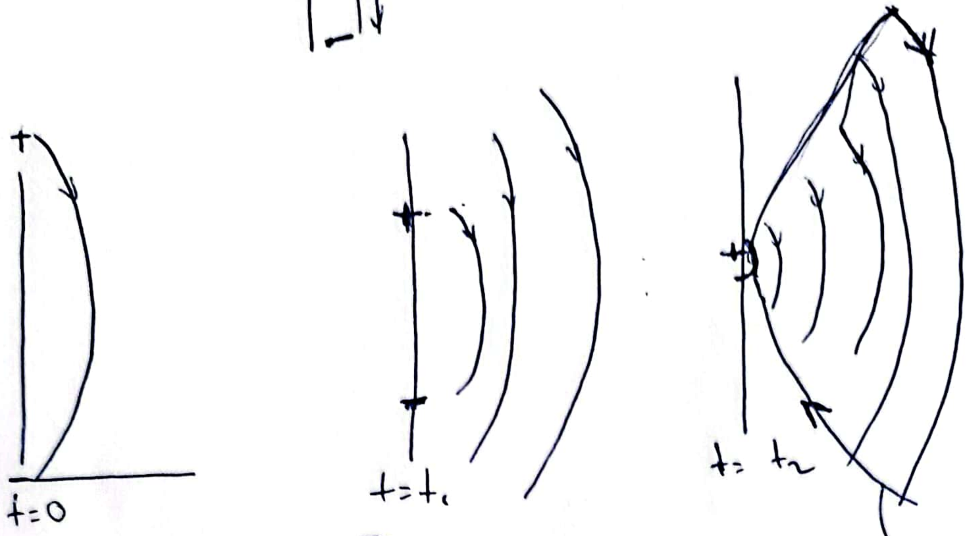
Now if we have 2 wires and a AC voltage source in the following schematic.



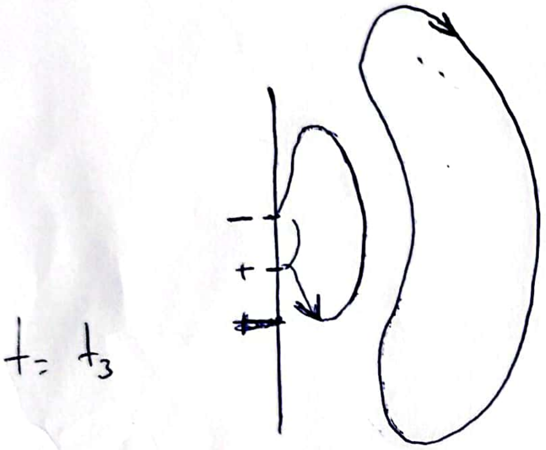
for $V_{AC} = A\cos wt$; a decreasing + charge for wire on top
$0 > wt > \frac{\pi}{2}$ charge with time!
     - charge for wire on bottom

for $V_{AC} = A\cos wt$; increasing '-' charge on top wire
$\frac{\pi}{2} > wt > \pi$ '+' charge on bottom wire

this is similar to:  '+' and '−' charges ~~assert~~ oscillating along a line which produces radiating electric field.



→ ~~merge~~ draw the disterbance (radiation)



frequency of radiation (electric field) is same as input voltage (V_{ac})

watch youtube understanding electro magnetic radiation time 0−5:40

watch: Lect 13 Electromagnetic Waves, solutions to Maxwell's 59:00−1:03

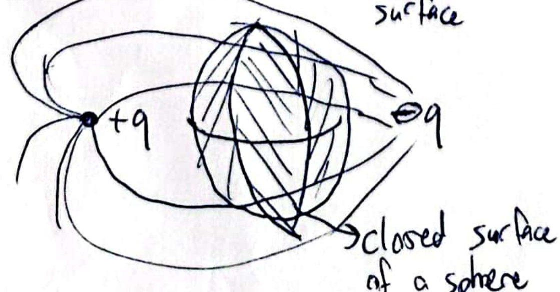
Maxwell's equations ⟶ ① Explain how magnetic field is generated

$\nabla \cdot D = \rho_v$ → divergence of electric flux density (D) is equal to volume charge density (ρ_v)

② Then simply draw E, H field diagram on page 5.

remember $D = \epsilon E$ ↳ dielectric constant

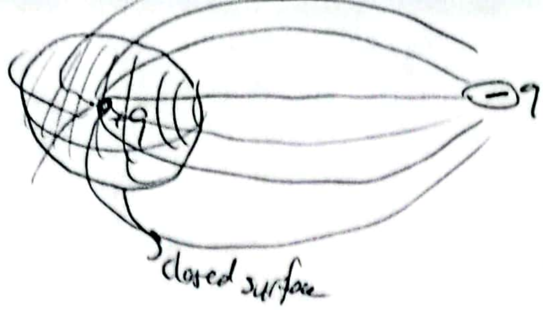
so it means that $\oint_{surface} D \cdot da = \int \rho \, dv$



$\bar{D}$ field going in and out is equal to each

$\nabla \bar{D} = 0$ since no charge is present inside the sphere.

~~$\nabla \cdot B = 0$~~

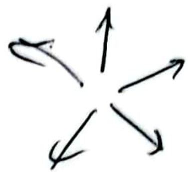


$$\oint_S D \cdot da = \int \rho \, dV = +q$$

$\boxed{\nabla \cdot B = 0}$ Divergence of magnetic flux density (B) is zero since there is no net magnetic charge. They always have N-S polarity independent of size. So net is always zero.

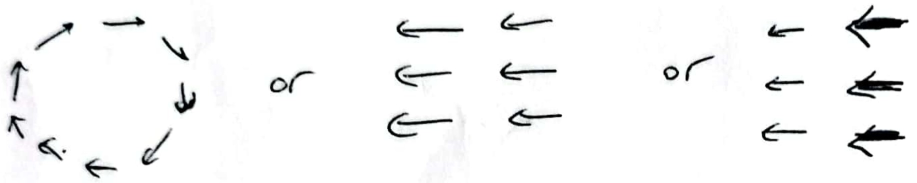
$B = \mu H$ → permeability

so manetic field lines can't not be looking

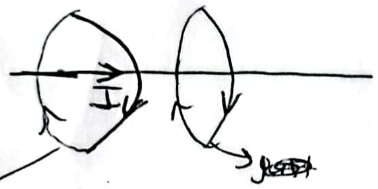


→ requires net + magnetic charge which doesn't exist.

magnetic field lines can look;



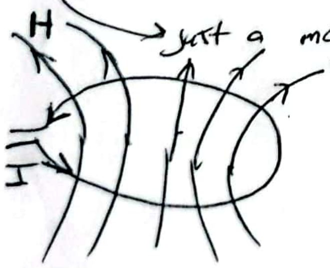
for example



a current carrying wire has rotating magnetic fied and magnetic flux density.

right hand rule
thumb shows current direction rest fingers show magnetic field direction

just a magnetic flux, no electrical flux if I is constant current



a circular loop current path generating H field lines

$\boxed{\nabla \times E = -\frac{\partial B}{\partial t}}$ The curl of a Electric field is equal to − time derivative of magnetic flux density.

Curl: infinity small circulation of a vector field

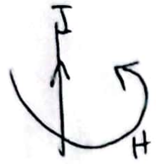
assume $E = E_x \hat{x} + E_y \hat{y} + E_z \hat{z}$

$$\nabla \times E = \underbrace{\left(\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z}\right)\hat{x} + \left(\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x}\right)\hat{y} + \left(\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y}\right)\hat{z}}$$

↳ equals to $-\frac{\partial B}{\partial t}$

E and B (thus H) are coupled
(beraber, ilişkili)

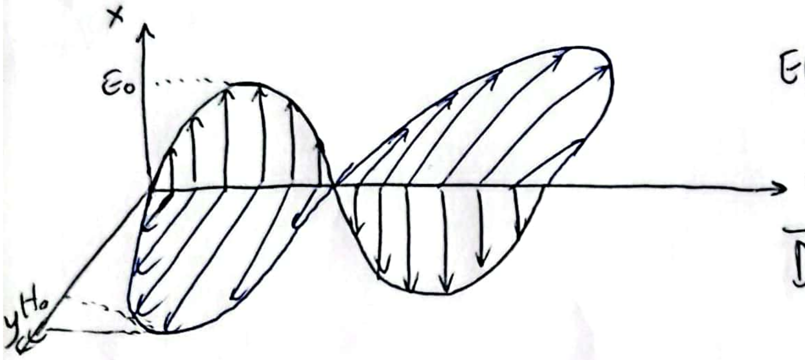
$\nabla \times H = \frac{\partial D}{\partial t} + J$ infinitely small circulation of H is equal to current density if $\frac{\partial D}{\partial t} = 0$



current and H are coupled.

if $\frac{\partial D}{\partial t}$ is not zero then 'H' and 'D' are coupled.

Overall it turns out that if $E(t)$ has non zero second time derivative, it is coupled with $H(t)$ meaning that they propogate together.



$$E(z,t) = E_0 \sin\left(2\pi\left(ft + \frac{z}{\lambda}\right)\right)$$

$$H(z,t) = H_0 \sin\left(2\pi\left(ft + \frac{z}{\lambda}\right)\right)$$

$\overline{D} = \underbrace{\epsilon_0}_{\text{permittivity}} \overline{E}$ $\qquad B = \underbrace{\mu_0}_{\text{permability}} \overline{H}$

Assume we have linearly polarized E and H field as depicted.

E field is a function of (z and t and is along $\hat{x}$

$$\nabla \times E = -\frac{\partial E_x}{\partial z}\hat{y} = \frac{2\pi}{\lambda} E_0 \cos\left(2\pi\left(ft + \frac{z}{\lambda}\right)\right)$$

$$-\frac{\partial B}{\partial t} = -\frac{\partial}{\partial t}\left(B \sin\left(2\pi\left(ft + \frac{z}{\lambda}\right)\right)\right) = -2\pi f B_0 \cdot \cos\left(2\pi\left(ft + \frac{z}{\lambda}\right)\right)$$

$$\Rightarrow \frac{2\pi E_0}{\lambda} = 2\pi f B_0 \Rightarrow \frac{E_0}{B_0} = \lambda f = \text{speed} = c$$

$$\frac{E_0}{B_0} = \sqrt{\frac{1}{\mu_0 \epsilon_0}} \Rightarrow E_0 \cdot \sqrt{\epsilon_0} = \sqrt{\mu_0}\, H_0$$

Movement of charges in a material induces thermal radiation which is also a kind of electromagnetic radiation.

Power density of EMW $= S = E \times H = \frac{1}{2} E_0 . H_0 = \frac{1}{2} E_0^2 \sqrt{\frac{\epsilon_0}{\mu_0}}$

↳ comes due to nature of alternating signal if it was constant then this would be '1'.

Photons; are elementary charges with zero rest mass and moving with 'c'. Energy of photon is linked to its frequency ν;

$E = h\nu$ where h is ~~plank~~ planck's constant $(6.62 \times 10^{-34}\,Js)$

$E = h\frac{c}{\lambda} = h\nu \qquad c = \lambda\nu$

converting wavelength to energy of a photon;

$E = \frac{1240 \cdot eV/nm}{\lambda(nm)} \qquad : \qquad 6.62 \times 10^{-34}$

Ex/ what is the energy of a blue (420nm) photon?

$E = \frac{1241}{420} \approx 3\ eV$