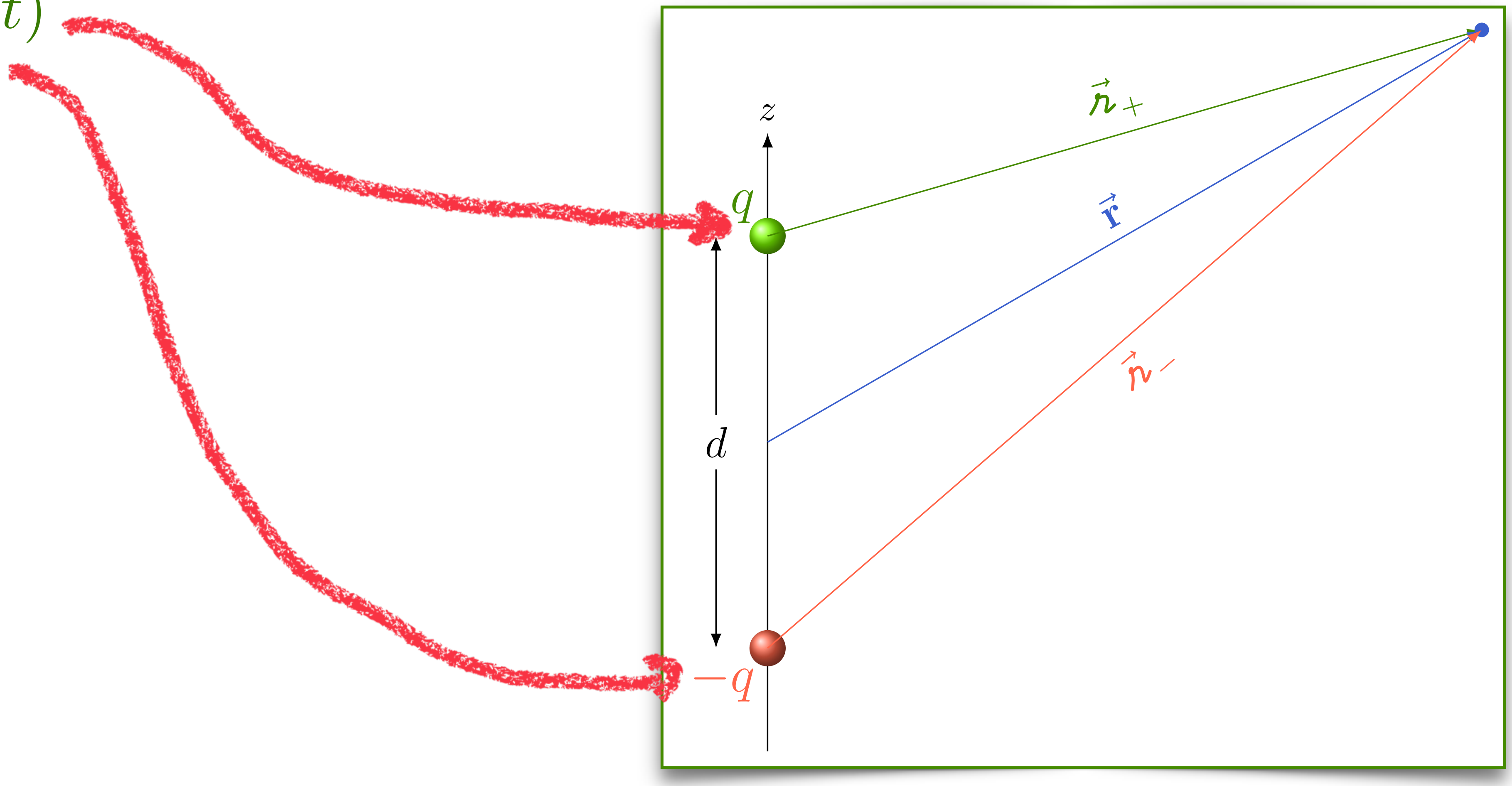
Eletromagnetismo Avançado

3º ciclo
Aula de 17 de novembro

Radiação de dipolo

$$q(t) = q_0 \cos(\omega t)$$

$$r \gg \lambda \gg d$$



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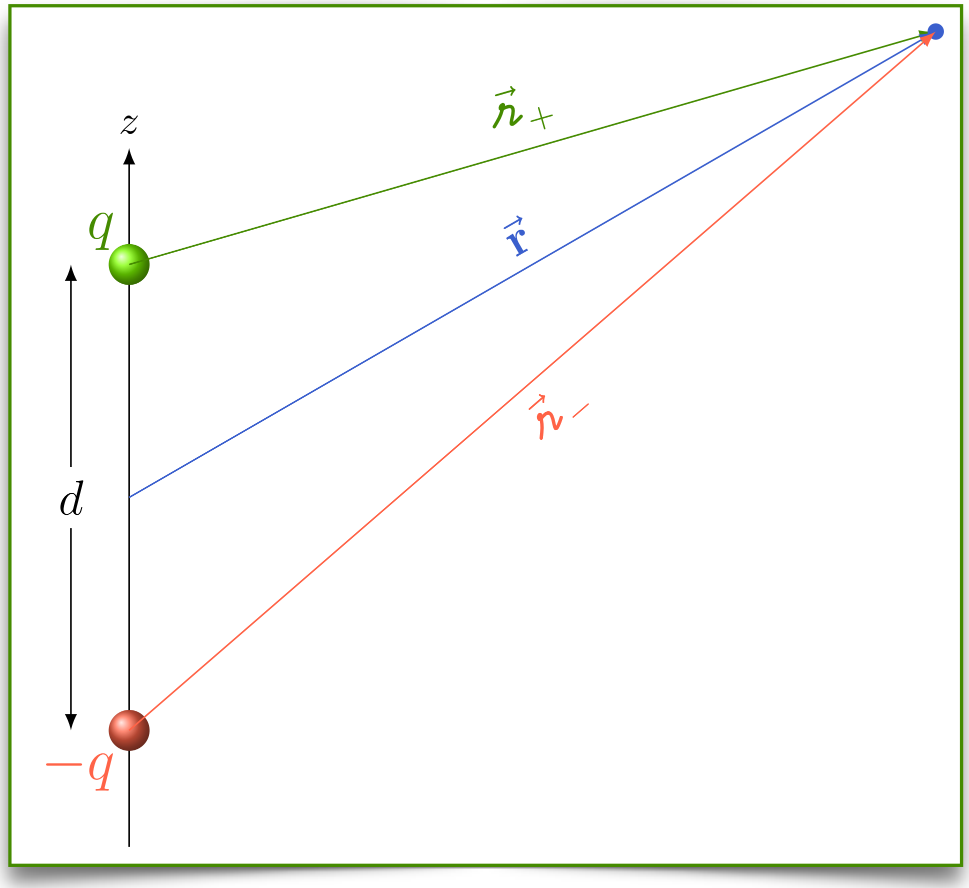
$$V(\vec{\mathbf{r}}, t) = \frac{1}{4\pi\epsilon_0}\left(\frac{q_0 \cos(\omega t_r)}{\mathscr{r}_+} - \frac{q_0 \cos(\omega t_r)}{\mathscr{r}_-}\right)$$

$$t_r = t - \frac{\mathscr{r}}{c}$$



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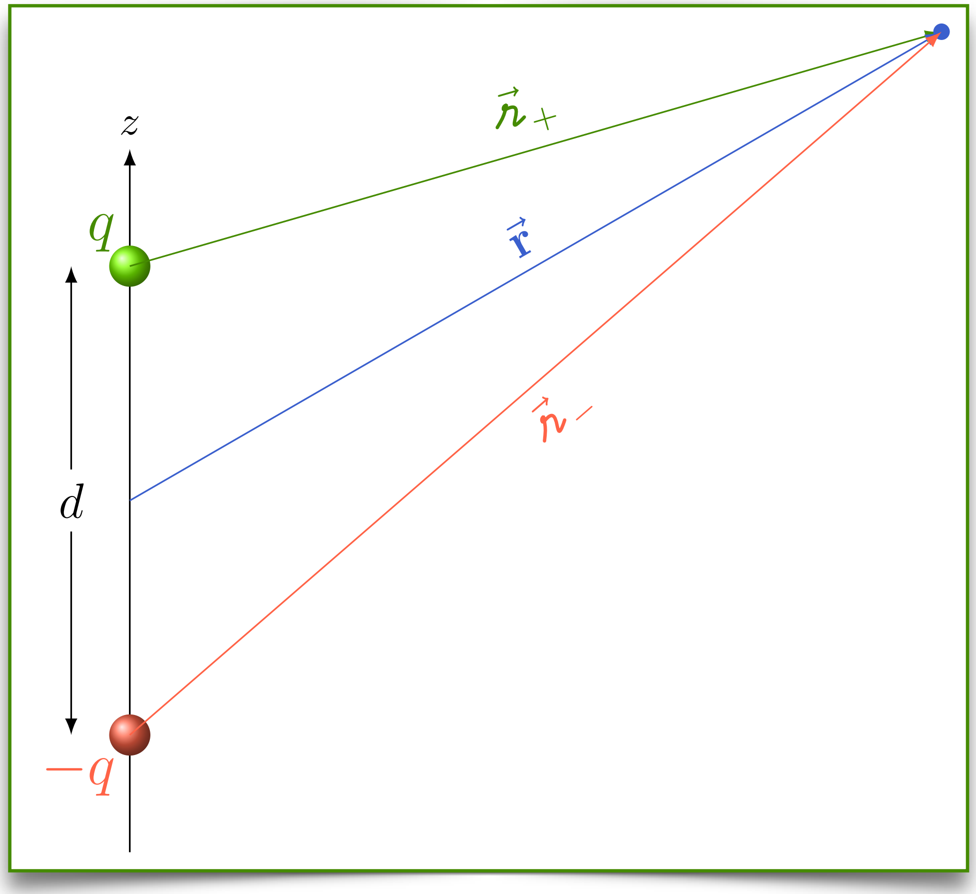
$$\mathscr{r}_+ \cong \mathscr{r}_- \cong r$$



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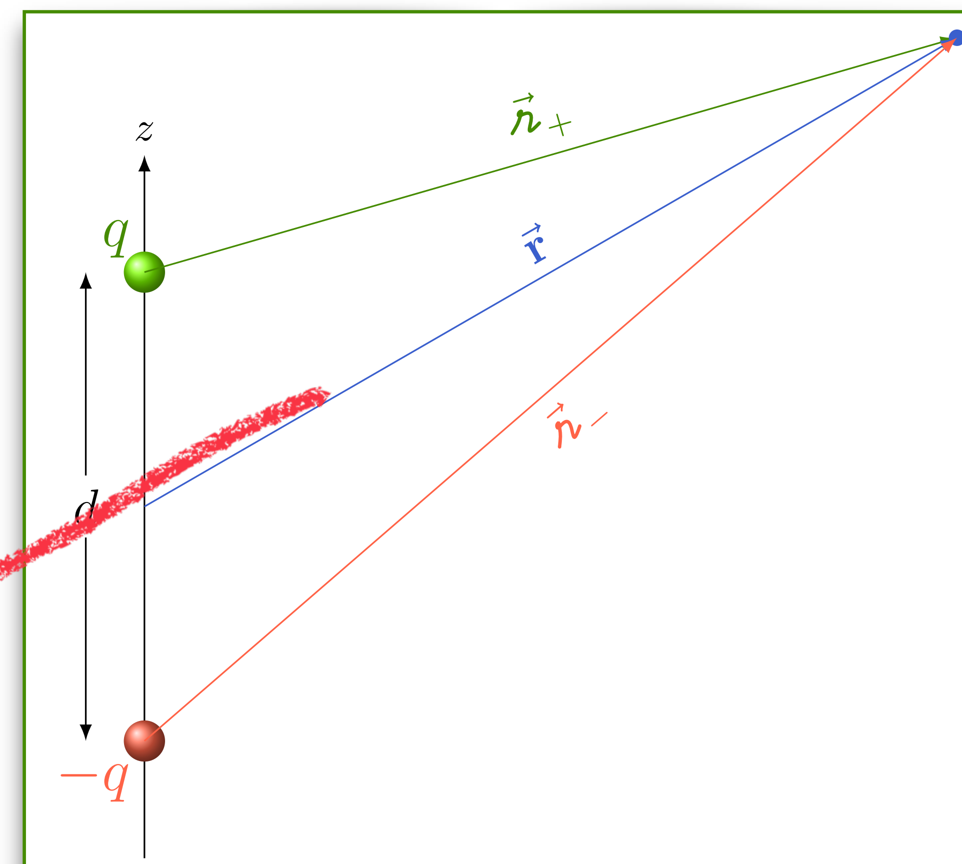
$$V(\vec{\mathbf{r}}, t) = \frac{q_0}{4\pi\epsilon_0 r}\left(\cos\omega(t - \frac{\mathscr{r}_+}{c}) - \cos\omega(t - \frac{\mathscr{r}_-}{c})\right)$$

$$\cos p - \cos q = -2 \operatorname{sen}\frac{p+q}{2} \operatorname{sen}\frac{p-q}{2}$$

$$\mathscr{r}_+ + \mathscr{r}_- \cong 2r$$



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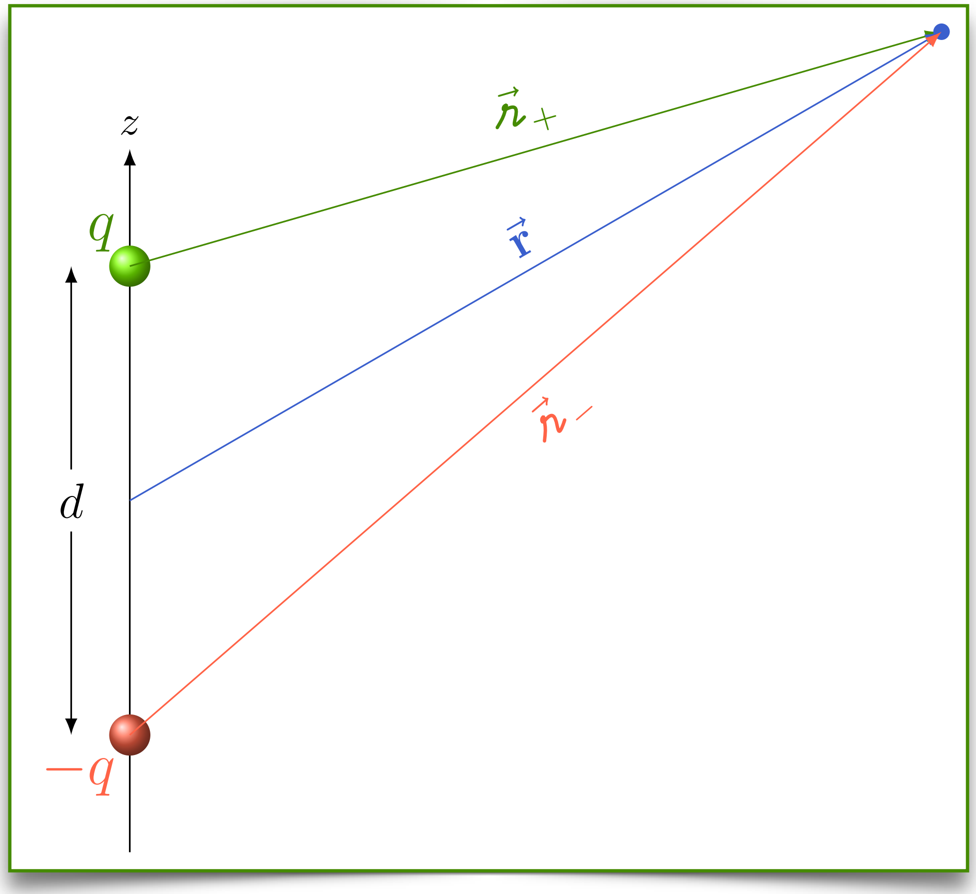

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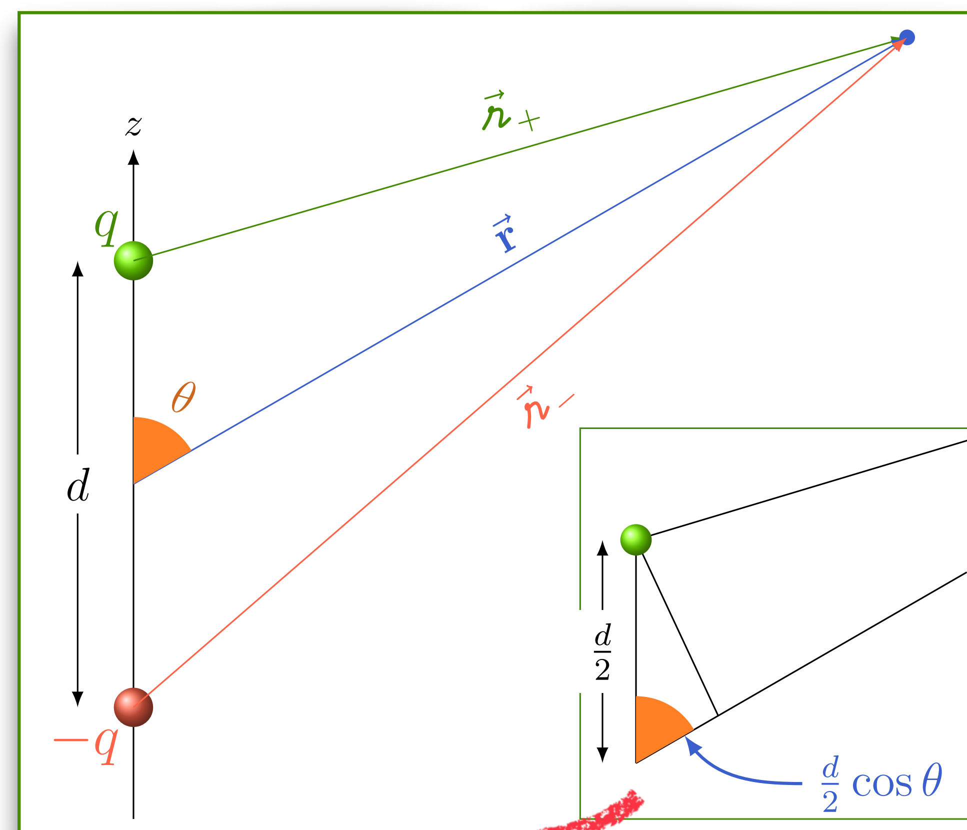
$$V(\vec{\mathbf{r}}, t) = \frac{q_0}{2\pi\epsilon_0 r}\sin\omega(t - \frac{r}{c})\sin\frac{\omega}{2c}(r_+ - r_-)$$

$-d\cos\theta$

$r_+ \cong r - \frac{d}{2}\cos\theta$

$r_- \cong r + \frac{d}{2}\cos\theta$



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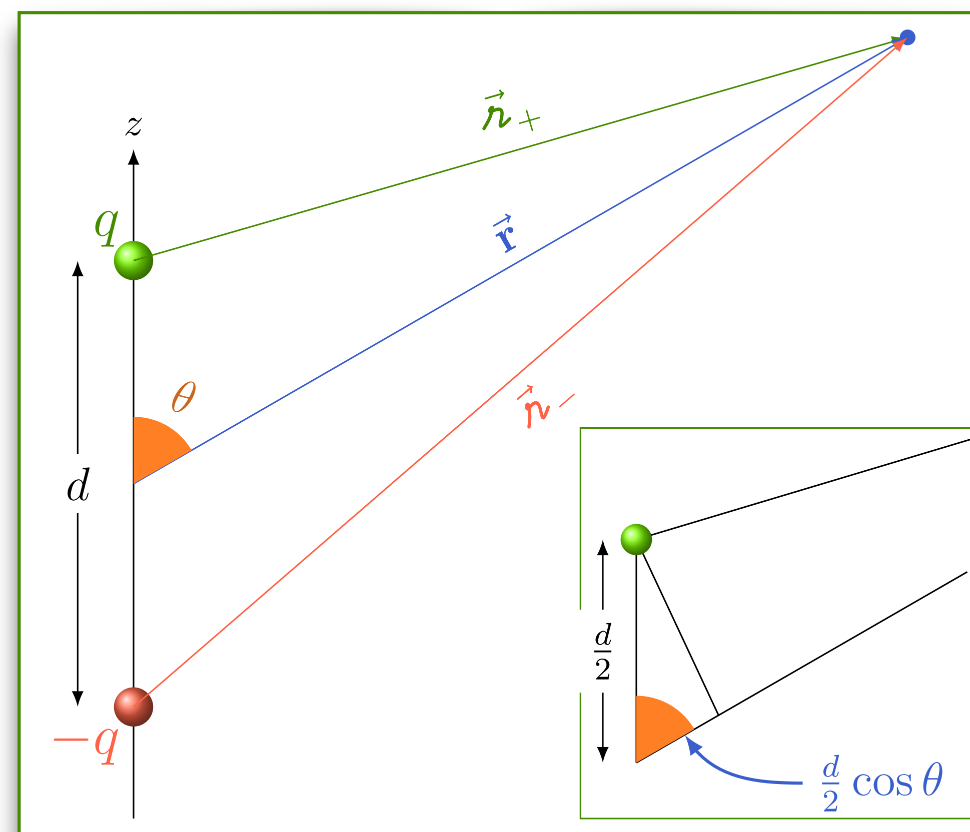

$$V(\vec{\mathbf{r}}, t) = \frac{q_0}{2\pi\epsilon_0 r}\sin\omega(t - \frac{r}{c})\sin\frac{\omega}{2c}(\mathscr{r}_+ - \mathscr{r}_-)$$

$$\mathscr{r}_+ = r - \frac{d}{2}\cos\theta$$

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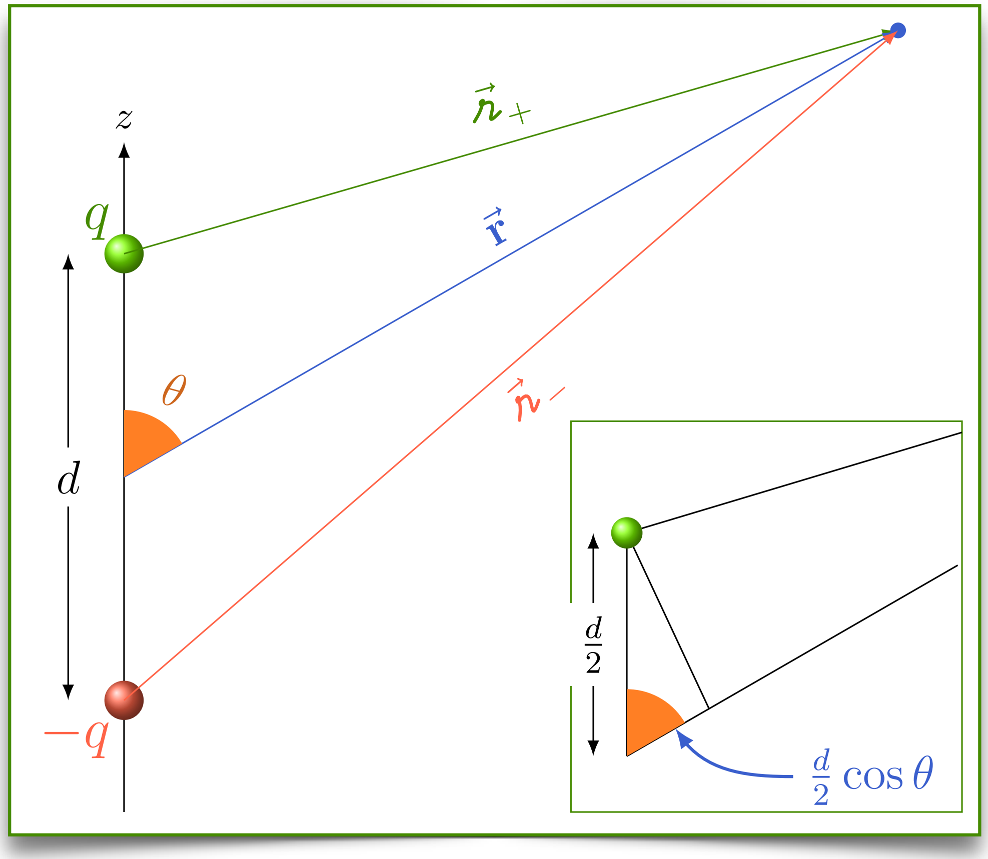

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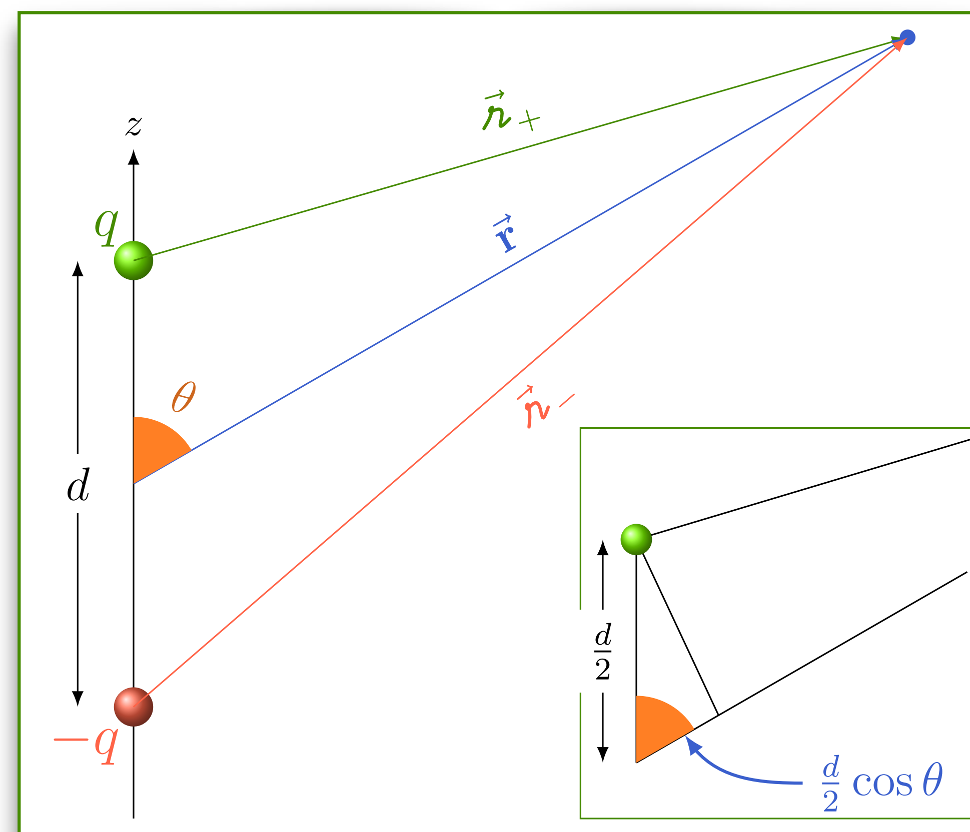
$\ll 1 \Leftarrow d \ll \lambda$



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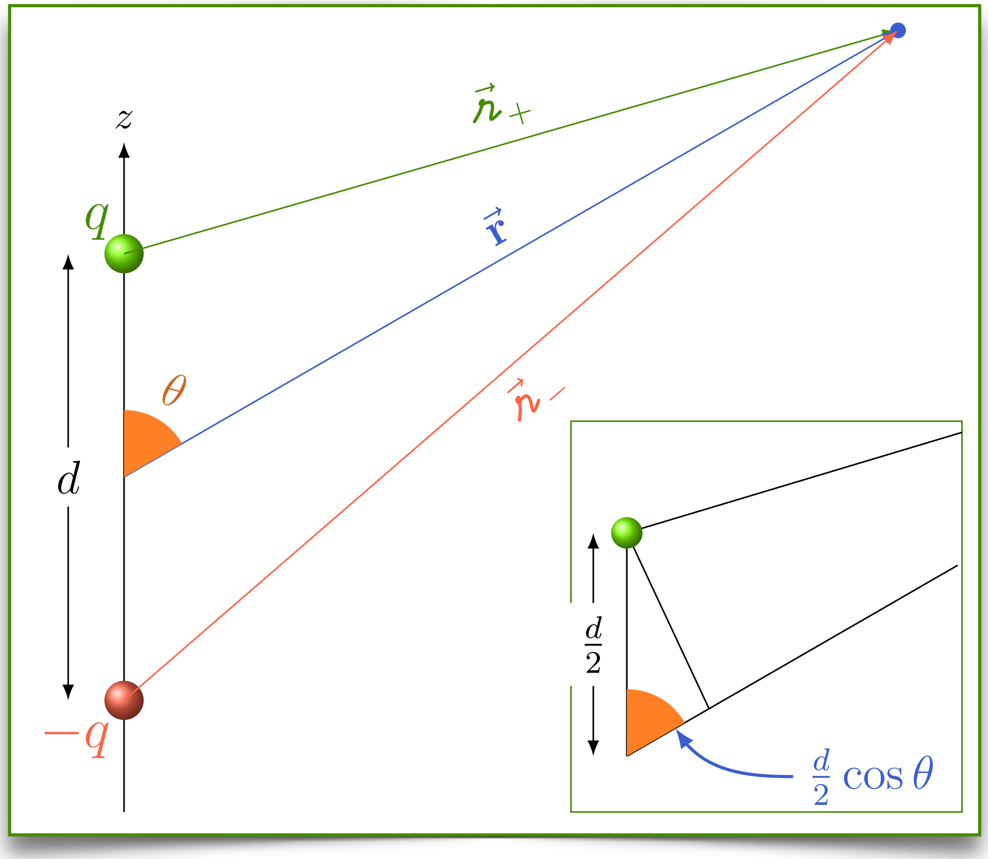

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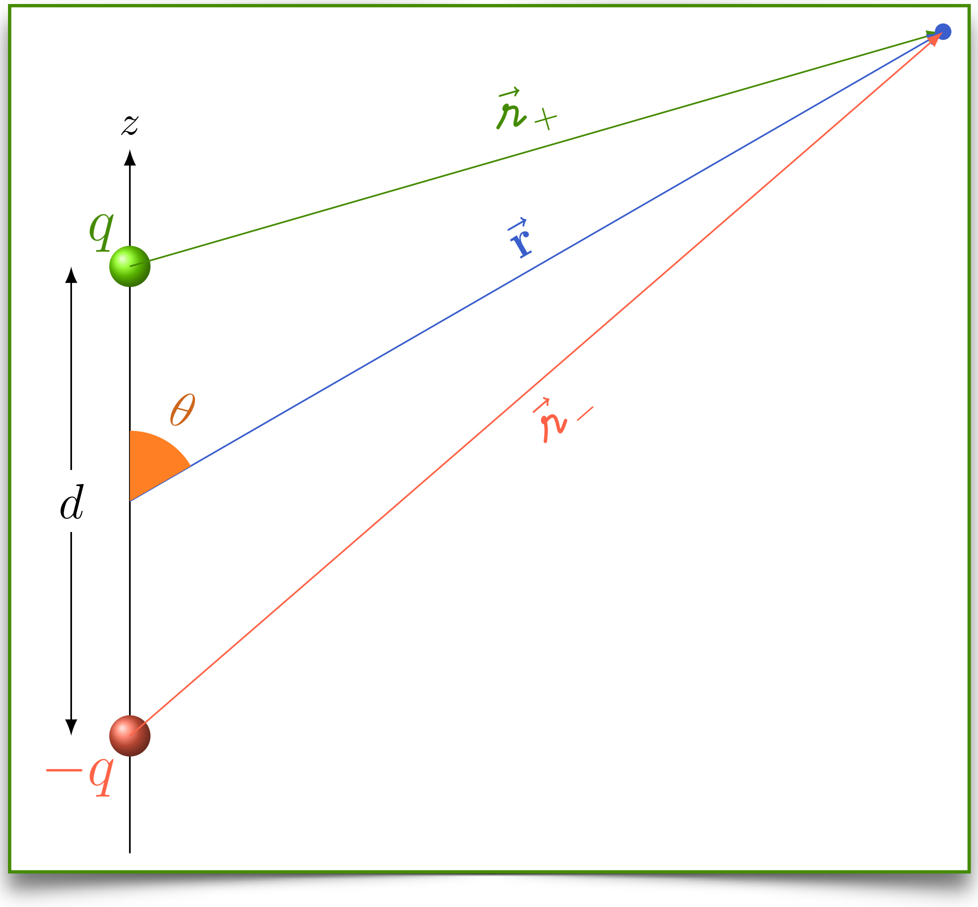

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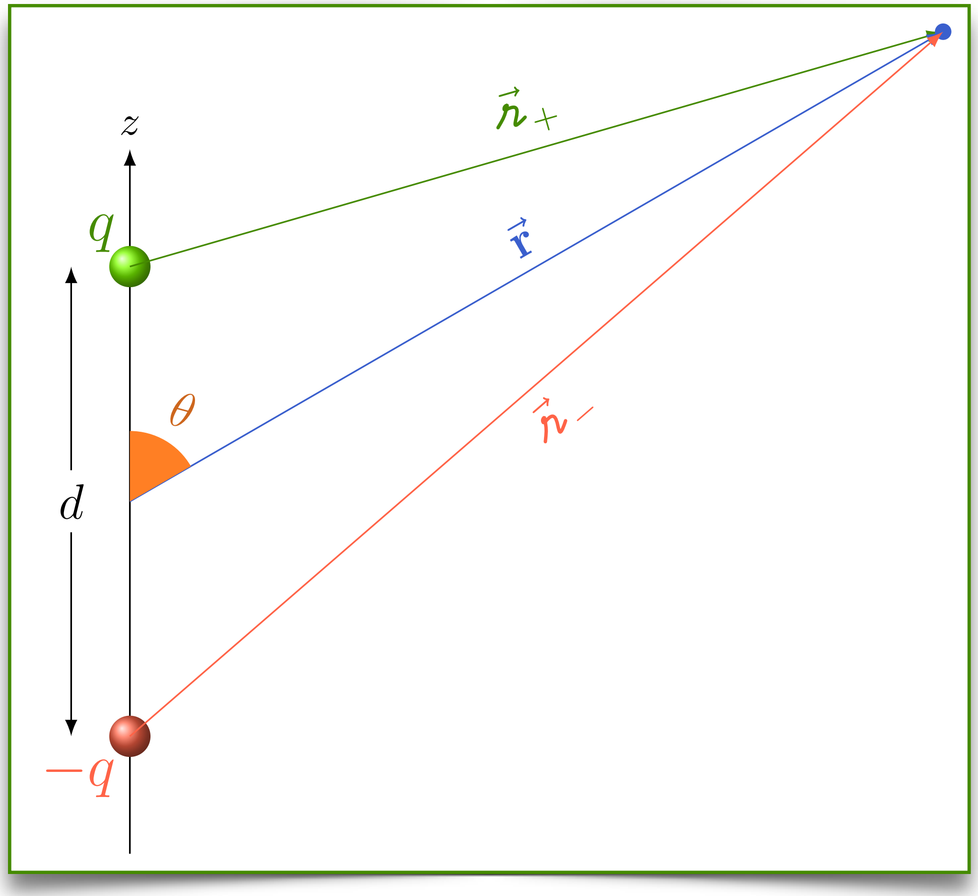
$$\vec{\mathbf{A}}(\vec{\mathbf{r}}, t) = \frac{\mu_0}{4\pi} \int_{-\frac{d}{2}}^{\frac{d}{2}} \frac{\vec{\mathbf{I}}(t_r)}{\mathscr{r}} \, \mathrm{d}z$$



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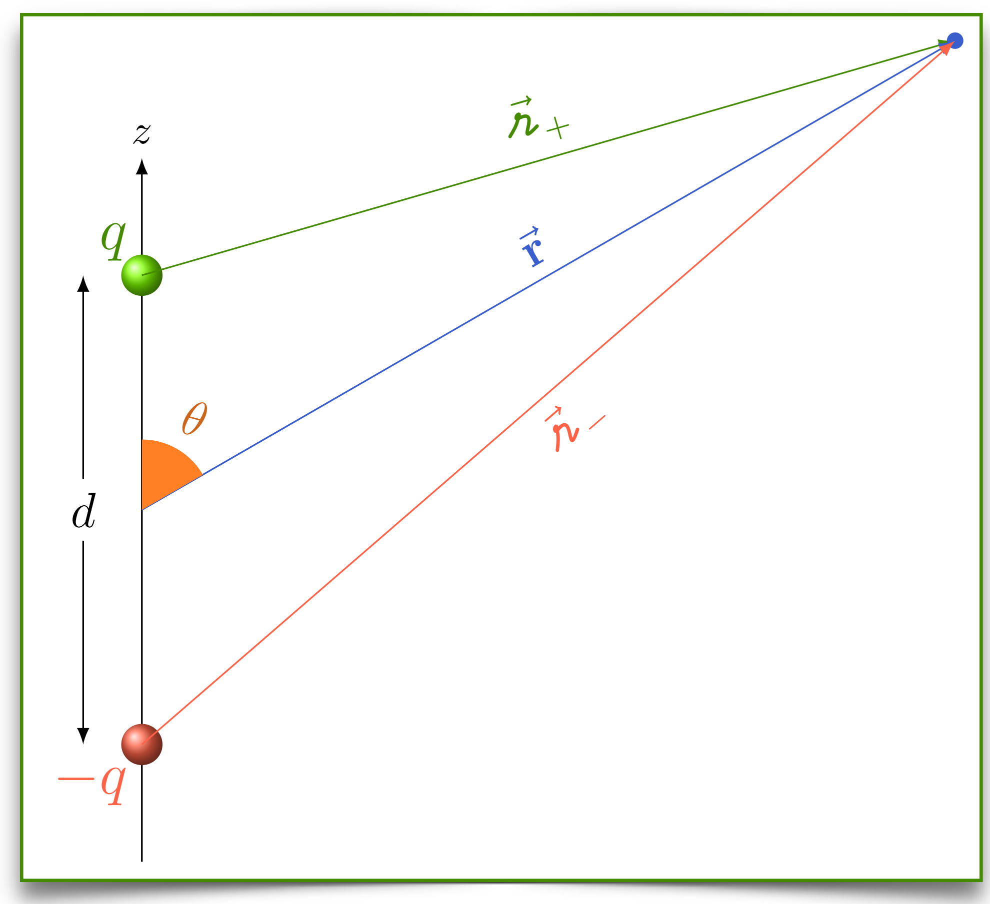

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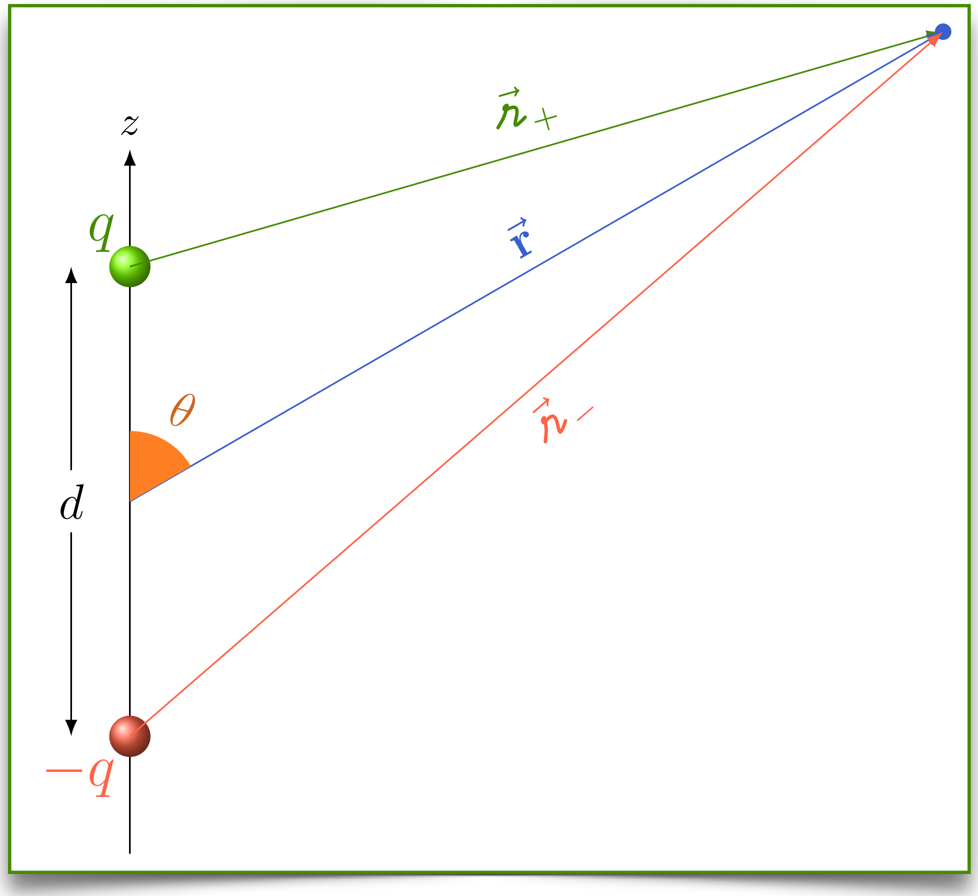

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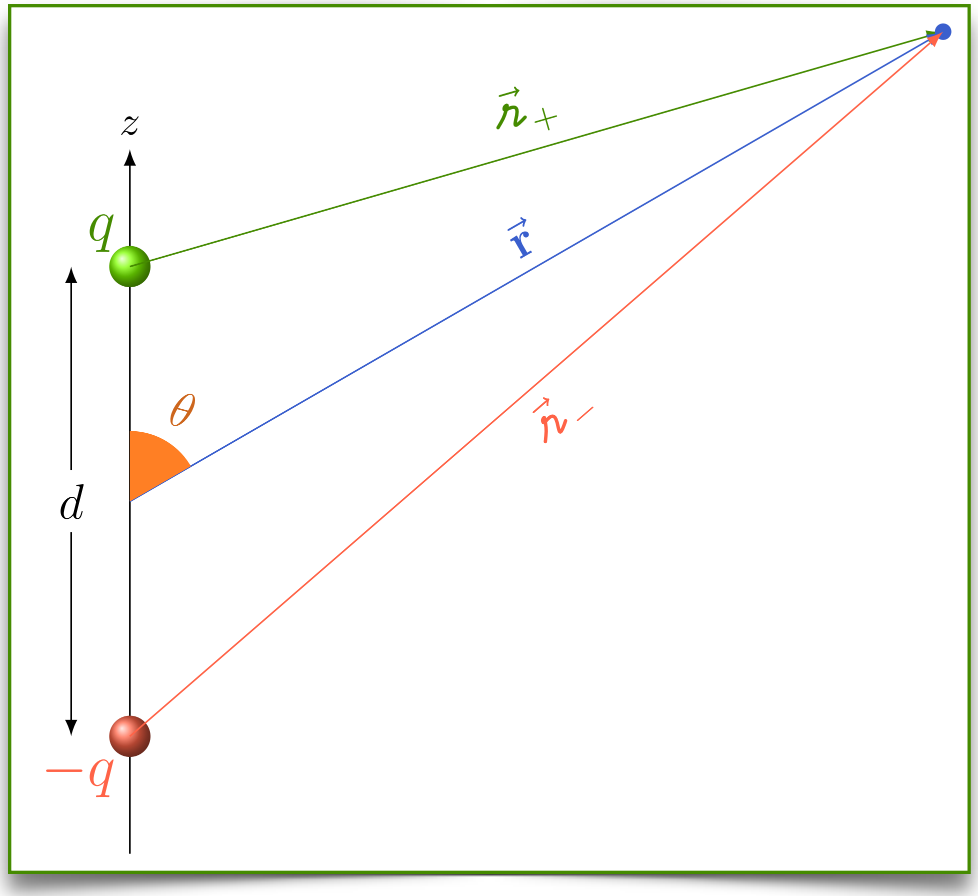
$$\vec{\mathbf{A}}(\vec{\mathbf{r}}, t) \approx \frac{\mu_0}{4\pi} \frac{\vec{\mathbf{I}}(t - \frac{r}{c})}{r} d$$



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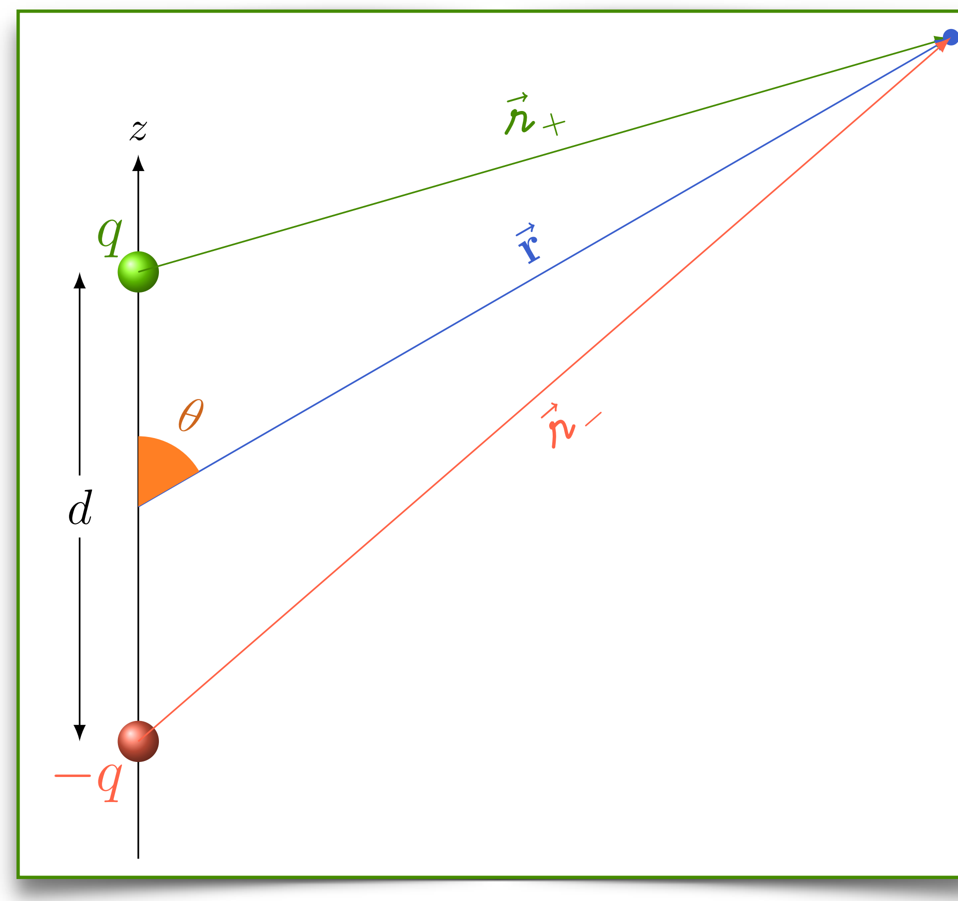

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CAMPOS?

$$V(\vec{\mathbf{r}}, t) = -\frac{p_0 \omega}{4\pi\epsilon_0 c} \frac{\cos\theta}{r} \sin\omega(t - \frac{r}{c})$$

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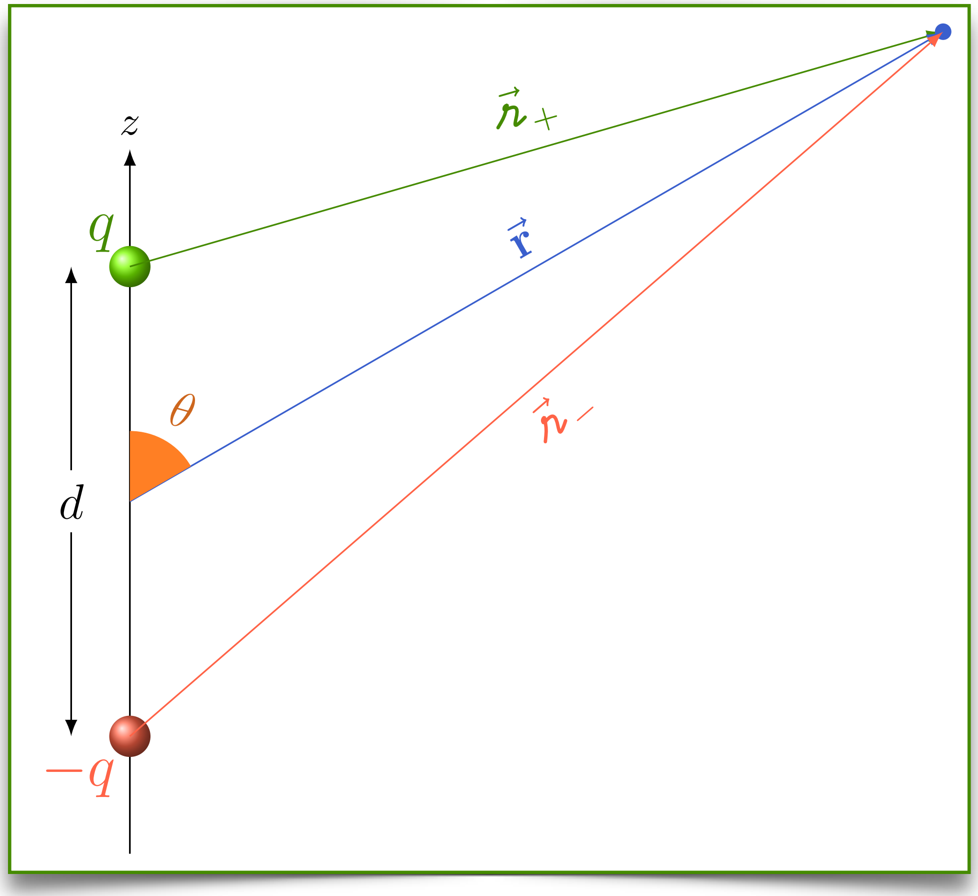

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$$\vec{\mathbf{E}} = -\vec{\boldsymbol{\nabla}} V - \frac{\partial \vec{\mathbf{A}}}{\partial t}$$

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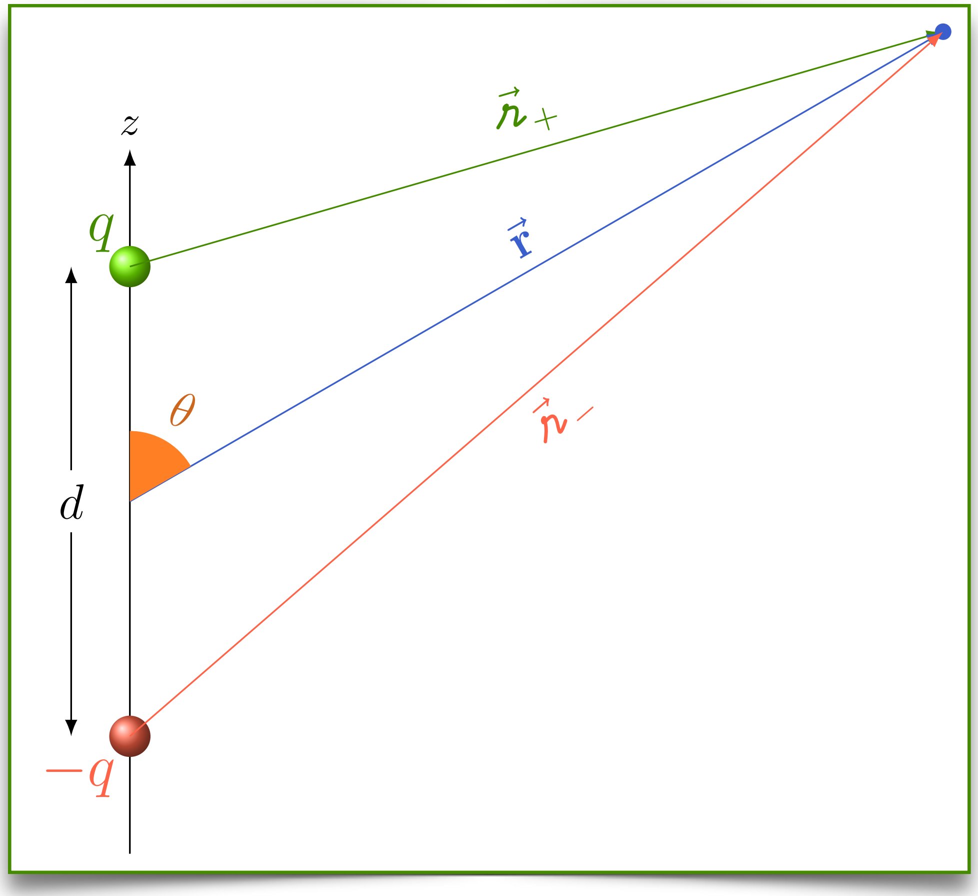
$$\vec{\mathbf{A}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega}{4\pi r} \sin\omega(t - \frac{r}{c})\, \hat{\mathbf{z}}$$



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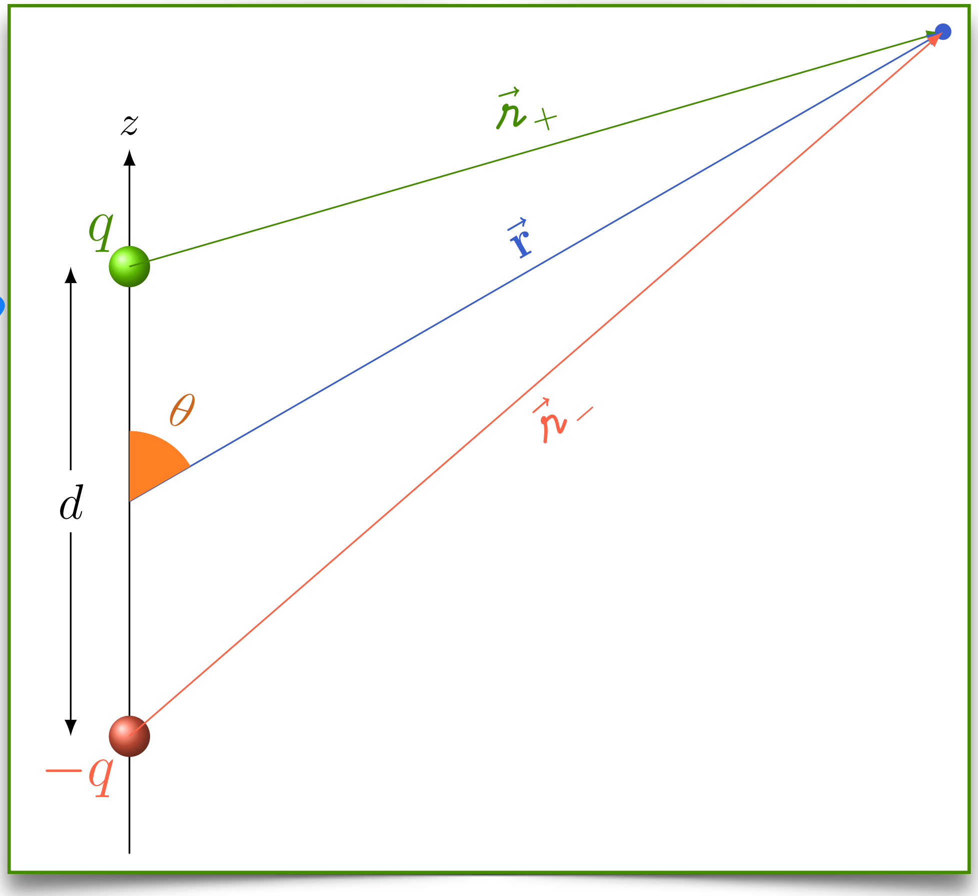
$$\vec{\mathbf{E}} = -\vec{\mathbf{\nabla}} V - \frac{\partial \vec{\mathbf{A}}}{\partial t}$$

$$\vec{\mathbf{\nabla}} V = \frac{\partial V}{\partial r}\hat{\mathbf{r}} + \frac{1}{r}\frac{\partial V}{\partial \theta}\hat{\theta}$$

→ TORNA ESTE TERMO PEQUENO



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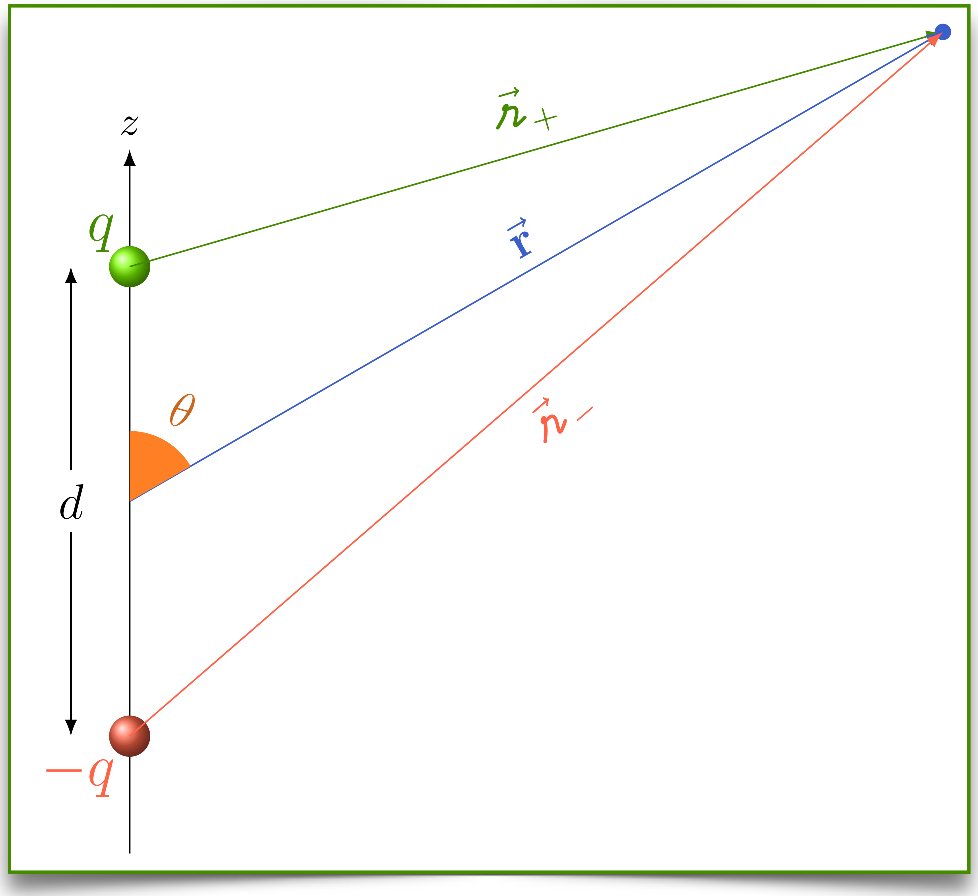
$$\vec{\boldsymbol{\nabla}}V = \frac{p_0\omega^2}{4\pi\epsilon_0 c^2}\frac{\cos\theta}{r}\cos\omega(t - \frac{r}{c})\hat{\mathbf{r}}(1 + \mathcal{O}(\lambda/r))$$



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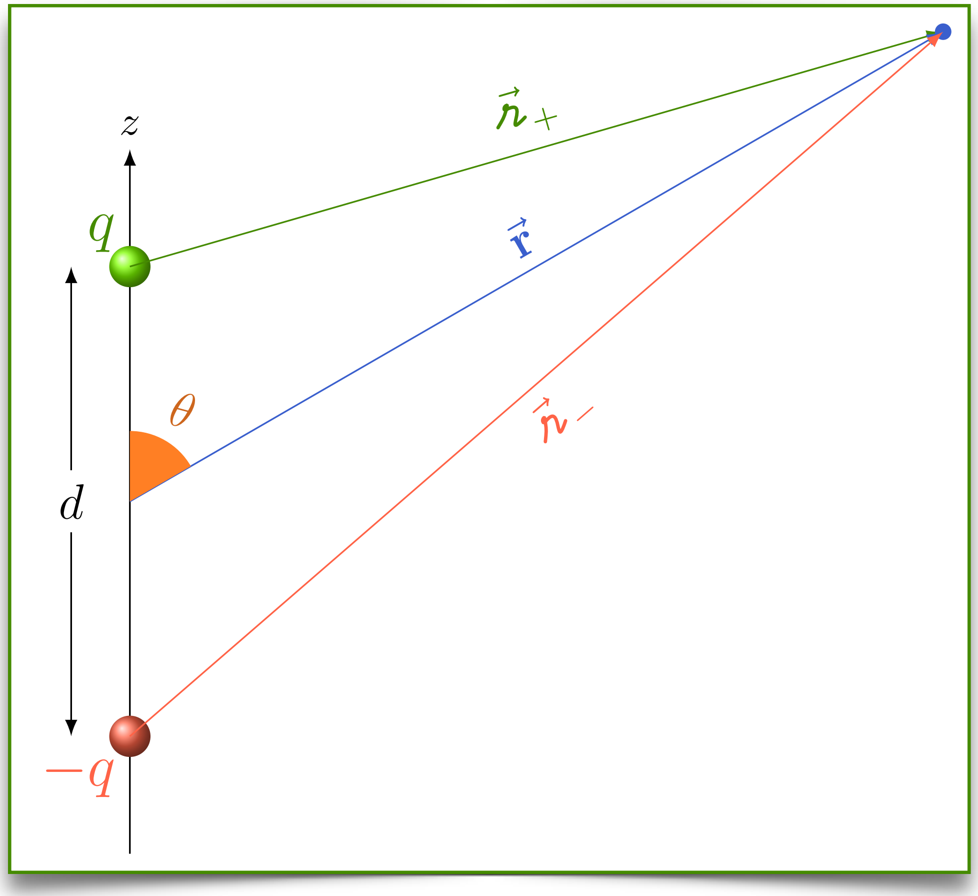

$$\vec{\mathbf{E}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega^2}{4\pi}\frac{\sin\theta}{r}\cos\omega(t - \frac{r}{c})\,\hat{\theta}$$

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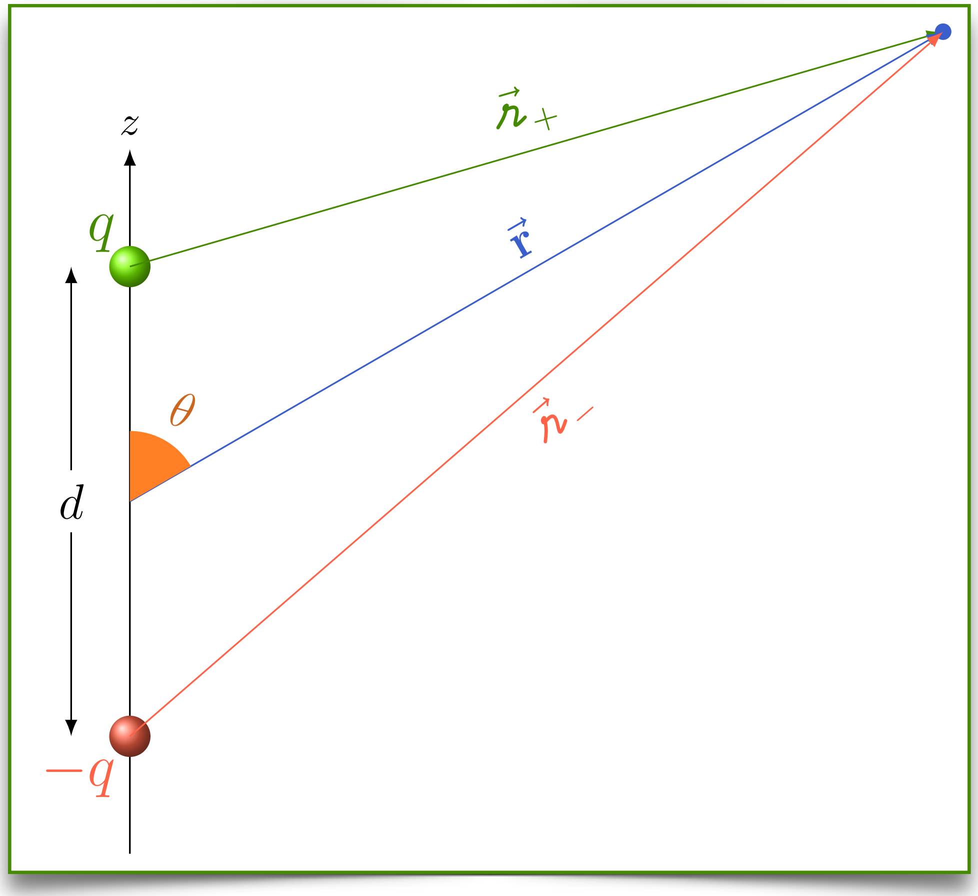

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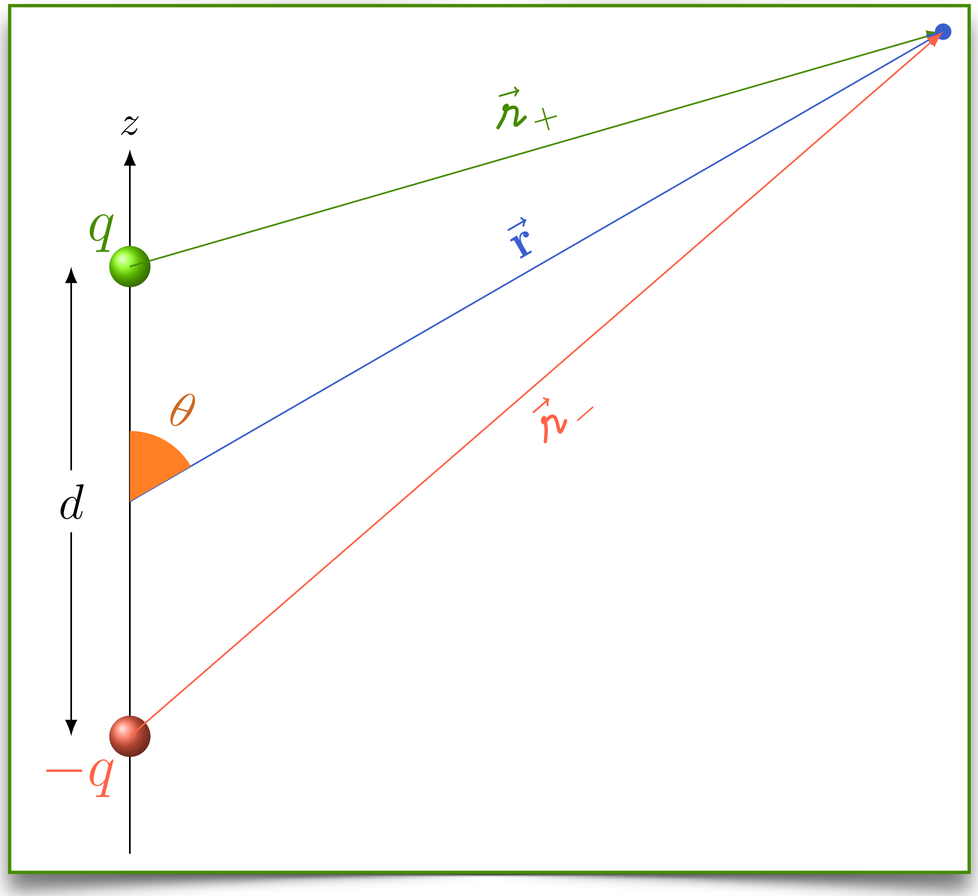

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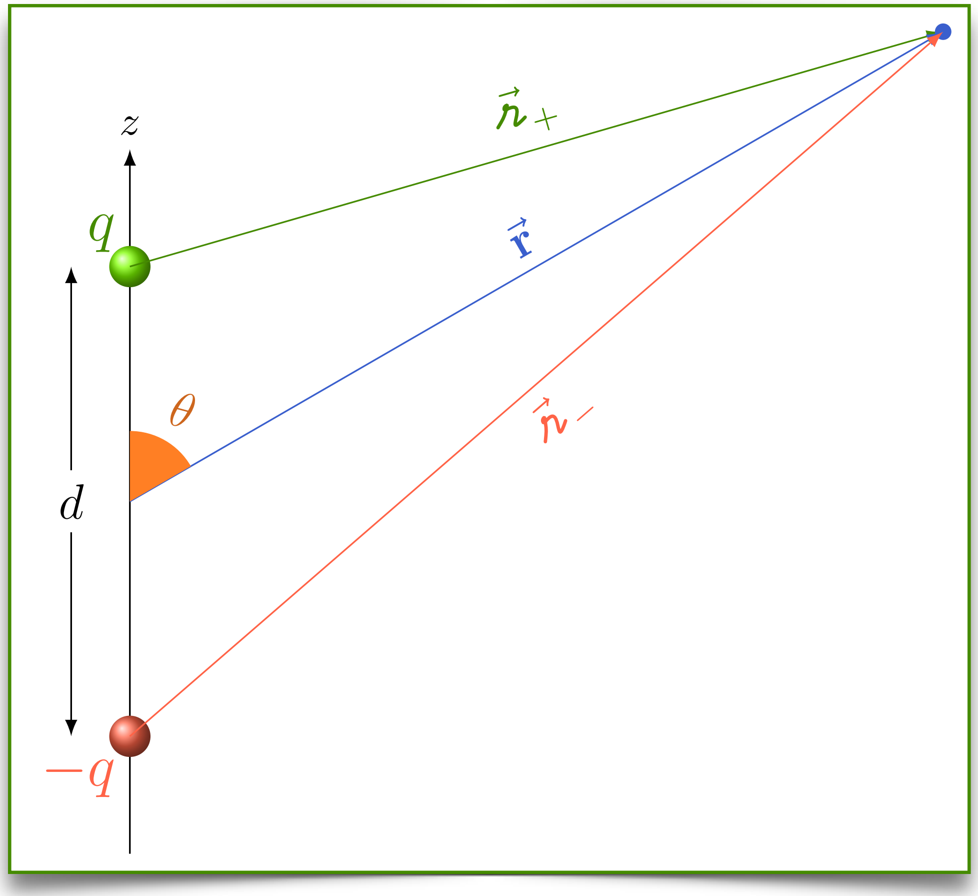
$$\vec{\mathbf{A}} = -\frac{\mu_0 p_0 \omega}{4\pi r} \sin\omega(t - \frac{r}{c}) \left(\cos\theta\, \hat{\mathbf{r}} - \sin\theta\, \hat{\theta}\right)$$

$$\vec{\mathbf{E}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega^2}{4\pi} \frac{\sin\theta}{r} \cos\omega(t - \tfrac{r}{c})\, \hat{\theta}$$

$$\vec{\mathbf{B}} = \vec{\mathbf{\nabla}} \times \vec{\mathbf{A}} = \frac{1}{r}\left(\frac{\partial(r A_\theta)}{\partial r} - \frac{\partial A_r}{\partial \theta}\right) \hat{\phi}$$



Radiação de dipolo

$$q(t) = q_0 \cos(\omega t)$$

$$r \gg \lambda \gg d$$

$$V(\vec{\mathbf{r}}, t) = -\frac{p_0 \omega}{4\pi\epsilon_0 c}\frac{\cos\theta}{r}\sin\omega(t - \frac{r}{c})$$

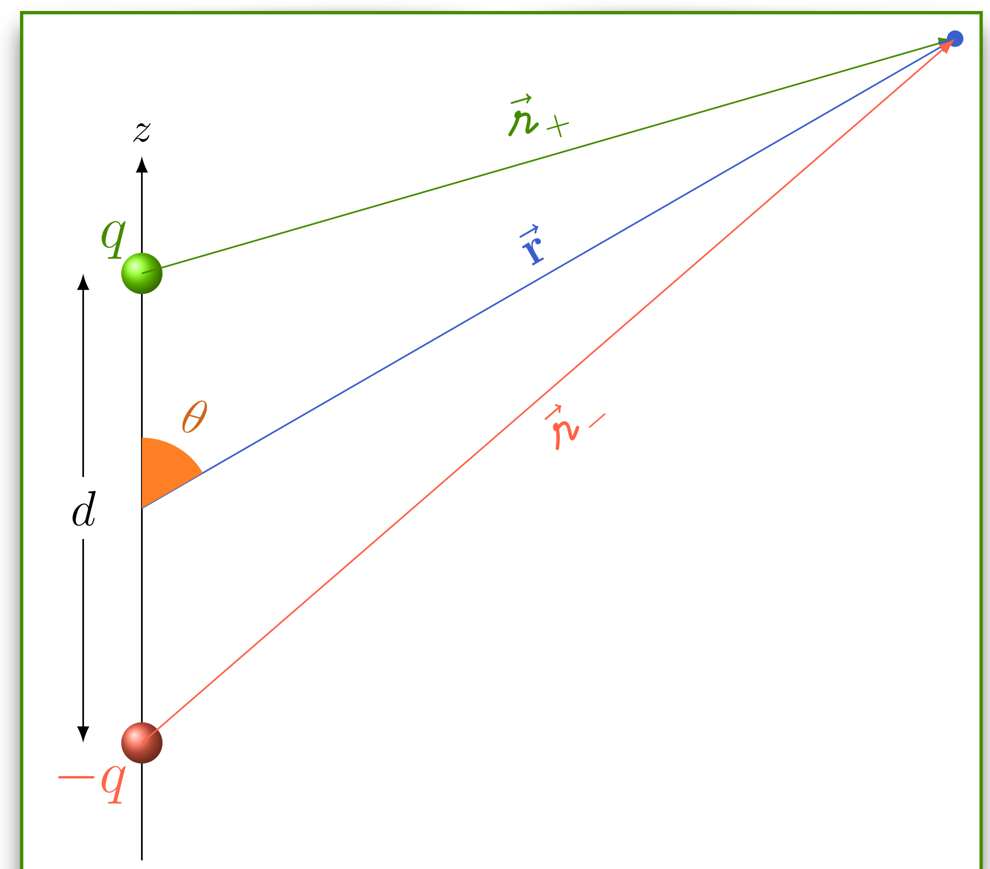
$$\vec{\mathbf{A}} = -\frac{\mu_0 p_0 \omega}{4\pi r}\sin\omega(t - \frac{r}{c})\,(\cos\theta\,\hat{\mathbf{r}} - \sin\theta\,\hat{\theta})$$

$$\vec{\mathbf{E}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega^2}{4\pi}\frac{\sin\theta}{r}\cos\omega(t - \tfrac{r}{c})\,\hat{\theta}$$

$$\vec{\mathbf{B}} = \vec{\nabla} \times \vec{\mathbf{A}} = \frac{1}{r}\left(\frac{\partial(r A_\theta)}{\partial r} - \frac{\partial A_r}{\partial \theta}\right)\hat{\phi}$$

PEQUENO

$$\vec{\mathbf{B}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega^2}{4\pi c}\frac{\sin\theta}{r}\cos\omega(t - \tfrac{r}{c})\,\hat{\phi}$$



Radiação de dipolo

$$q(t) = q_0 \cos(\omega t)$$

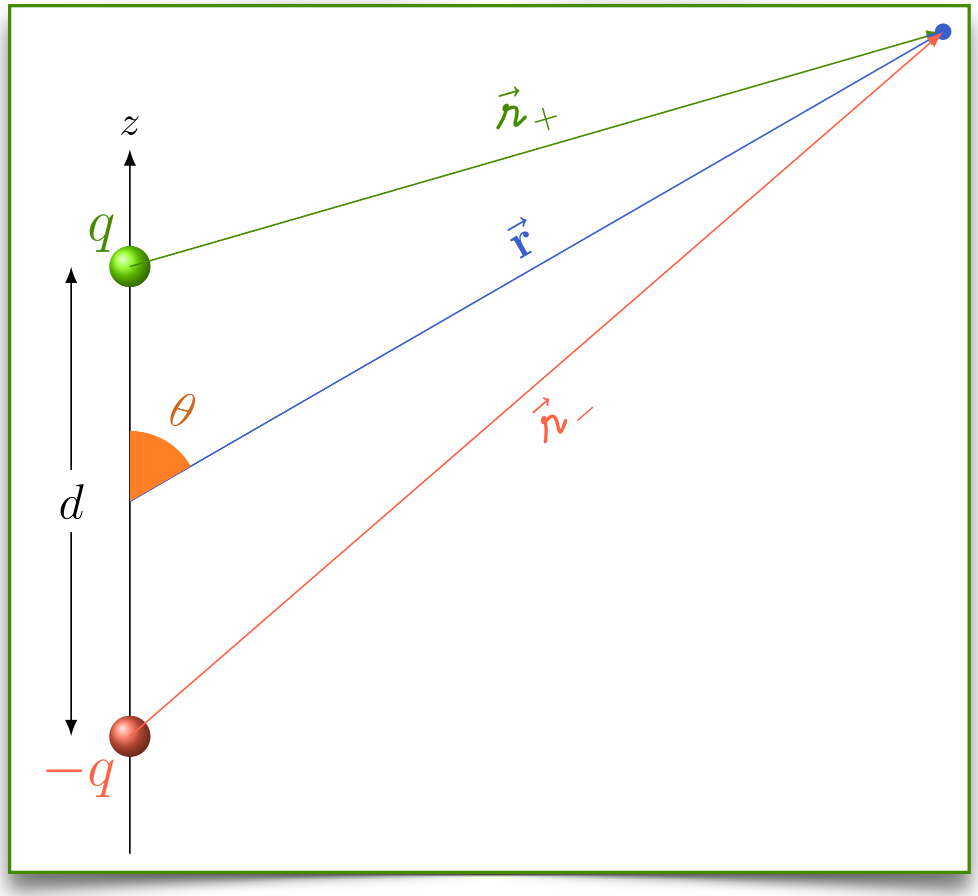
$$r \gg \lambda \gg d$$

$$V(\vec{\mathbf{r}}, t) = -\frac{p_0 \omega}{4\pi\epsilon_0 c} \frac{\cos\theta}{r} \sin\omega(t - \frac{r}{c})$$

$$\vec{\mathbf{A}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega}{4\pi r} \sin\omega(t - \frac{r}{c})\, \hat{\mathbf{z}}$$

$$\vec{\mathbf{E}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega^2}{4\pi} \frac{\sin\theta}{r} \cos\omega(t - \tfrac{r}{c})\, \hat{\theta}$$

$$\vec{\mathbf{B}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega^2}{4\pi c} \frac{\sin\theta}{r} \cos\omega(t - \tfrac{r}{c})\, \hat{\phi}$$



Radiação de dipolo

$$q(t) = q_0 \cos(\omega t)$$

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$$V(\vec{\mathbf{r}}, t) = -\frac{p_0 \omega}{4\pi\epsilon_0 c}\frac{\cos\theta}{r}\sin\omega(t - \frac{r}{c})$$

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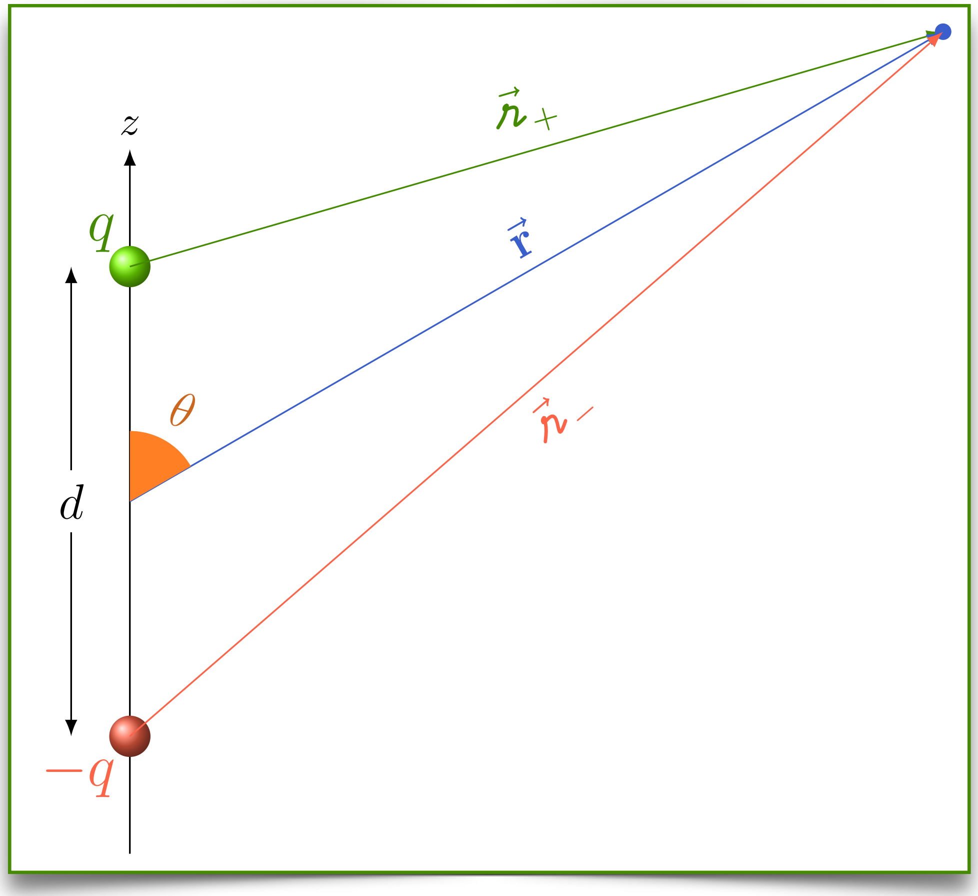
$$\vec{\mathbf{E}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega^2}{4\pi}\frac{\sin\theta}{r}\cos\omega(t - \tfrac{r}{c})\,\hat{\theta}$$

$$\vec{\mathbf{B}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega^2}{4\pi c}\frac{\sin\theta}{r}\cos\omega(t - \tfrac{r}{c})\,\hat{\phi}$$



$$\vec{\mathbf{S}} = \frac{1}{\mu_0}\vec{\mathbf{E}} \times \vec{\mathbf{B}}$$

$$\vec{\mathbf{S}}(\vec{\mathbf{r}}, t) = \frac{\mu_0 p_0^2 \omega^4}{4\pi c}\frac{\sin^2\theta}{4\pi r^2}\cos^2\omega(t - \frac{r}{c})\,\hat{\mathbf{r}}$$

Radiação de dipolo

$$q(t) = q_0 \cos(\omega t)$$

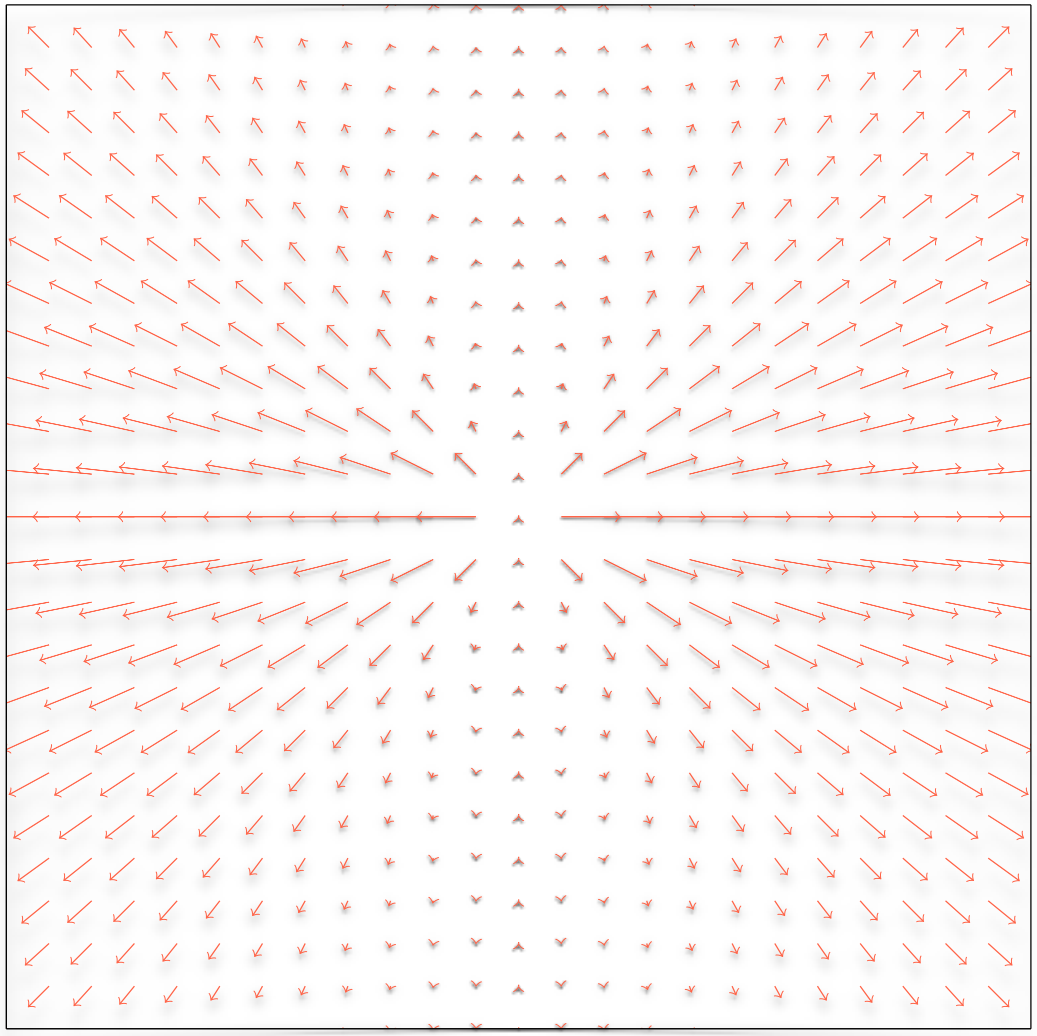
$$r \gg \lambda \gg d$$

$$V(\vec{\mathbf{r}}, t) = -\frac{p_0 \omega}{4\pi\epsilon_0 c} \frac{\cos\theta}{r} \sin\omega(t - \frac{r}{c})$$

$$\vec{\mathbf{A}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega}{4\pi r} \sin\omega(t - \frac{r}{c})\,\hat{\mathbf{z}}$$

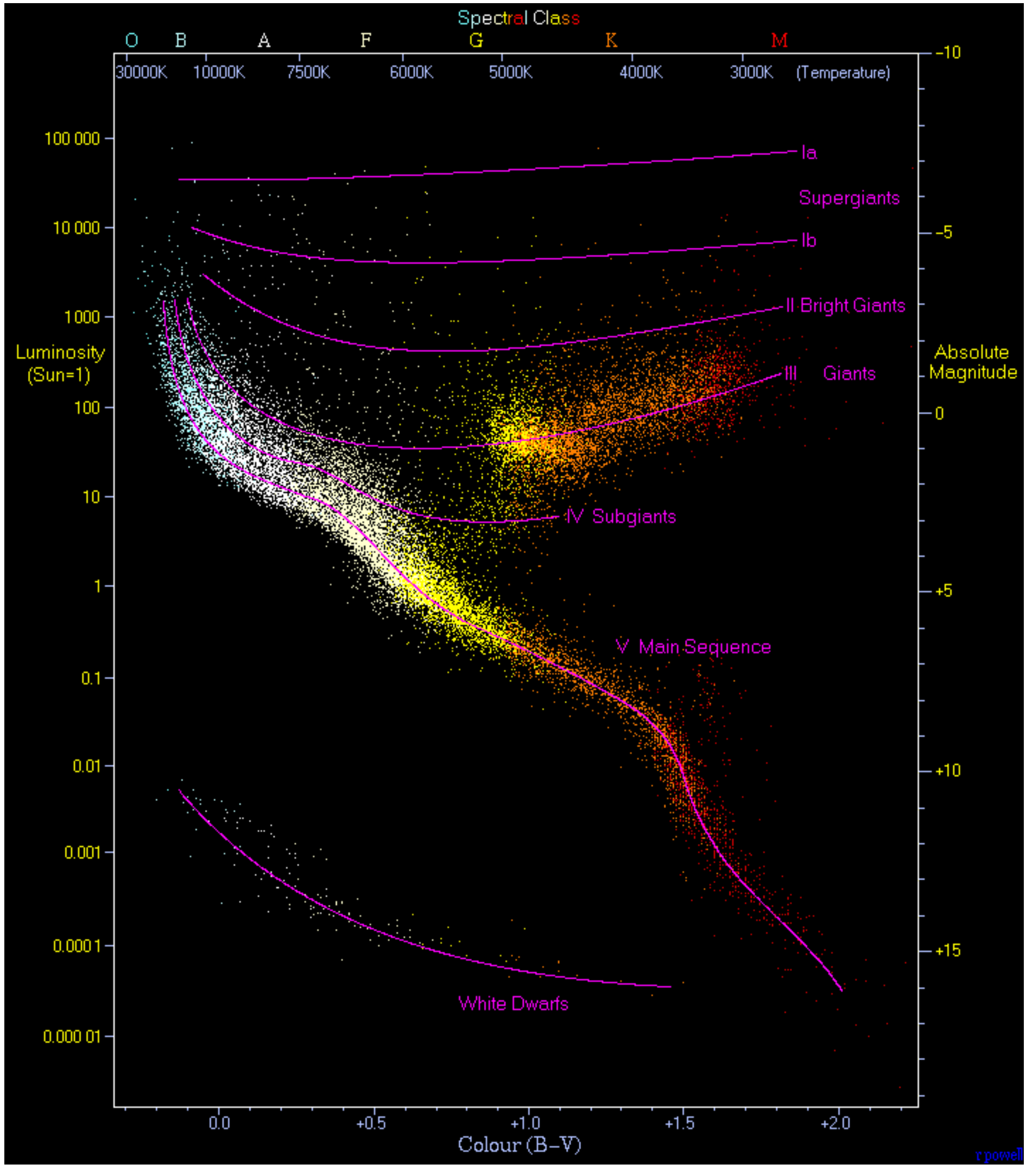
$$\vec{\mathbf{E}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega^2}{4\pi} \frac{\sin\theta}{r} \cos\omega(t - \tfrac{r}{c})\,\hat{\theta}$$

$$\vec{\mathbf{B}}(\vec{\mathbf{r}}, t) = -\frac{\mu_0 p_0 \omega^2}{4\pi c} \frac{\sin\theta}{r} \cos\omega(t - \tfrac{r}{c})\,\hat{\phi}$$



$$\langle \vec{\mathbf{S}} \rangle = \frac{\mu_0 p_0^2 \omega^4}{8\pi c} \frac{\sin^2\theta}{4\pi r^2}\,\hat{\mathbf{r}}$$

→ $\langle \vec{S} \rangle = 0$ PARA $\theta = 0, \pi$



Spectral Class
O
B
A
F
G
K
M
30000K
10000K
7500K
6000K
5000K
4000K
3000K
(Temperature)
100 000
10 000
1000
Luminosity
(Sun=1)
100
10
1
0.1
0.01
0.001
0.0001
0.000 01
-10
-5
Absolute
Magnitude
0
+5
+10
+15
Ia
Supergiants
Ib
II Bright Giants
III Giants
IV Subgiants
V Main Sequence
White Dwarfs
0.0
+0.5
+1.0
+1.5
+2.0
Colour (B–V)
r powell