FISICA 1 (PALEONTOLOGÍA)

2DO CUATRIMESTRE 2020

CLASE14

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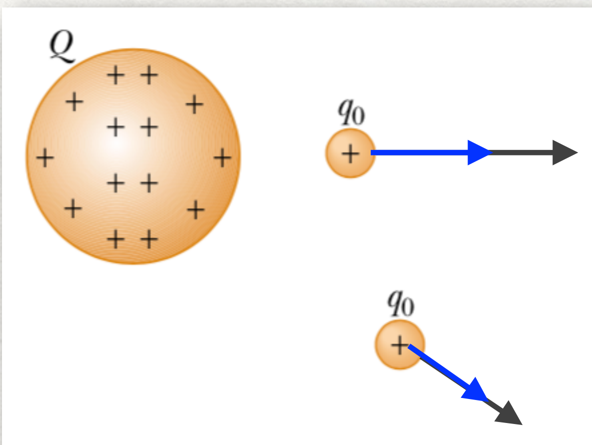
CLASE 14: Electrostática

Temas: Campo eléctrico, lineas de campo.

Ley de Coulomb (clase 13): fuerza entre cargas eléctricas, $\mathbf{F}^{e}_{12} = k_e \dfrac{q_1\, q_2}{r^2}\,\hat{\mathbf{r}}_{12} \quad \sim \mathbf{F}^{g}_{12} = -\,G \dfrac{m_1\, m_2}{r^2}\,\hat{\mathbf{r}}_{12}$

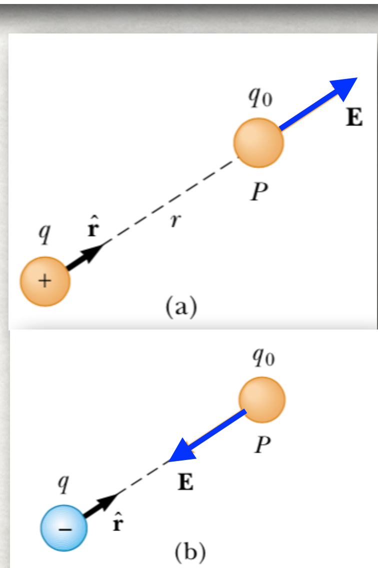
fuerza ejercida por q_1 sobre q_2

campo eléctrico: ~fuerza sobre una carga de prueba q_0, dividida por ella: $\mathbf{E} = \dfrac{\mathbf{F}^{e}}{q_0}$

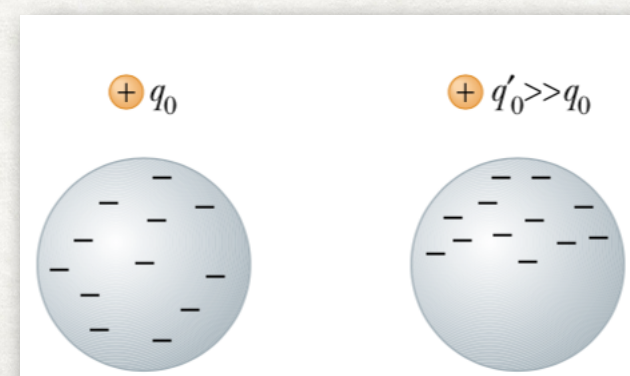


$$\mathbf{F}^{e} = k_e \frac{Q\, q_0}{r^2}\,\hat{\mathbf{r}}_{Qq_0} \qquad \mathbf{E} = \frac{\mathbf{F}^{e}}{q_0} = k_e \frac{Q}{r^2}\,\hat{\mathbf{r}}_{Qq_0} \quad \sim \frac{N}{C}$$

Source	E (N/C)
Fluorescent lighting tube	10
Atmosphere (fair weather)	100
Balloon rubbed on hair	1 000
Atmosphere (under thundercloud)	10 000
Photocopier	100 000
Spark in air	$>$3 000 000
Near electron in hydrogen atom	5×10^{11}



$$\mathbf{F}^{e} = k_e \frac{q\, q_0}{r^2}\,\hat{\mathbf{r}} \qquad \mathbf{E} = \frac{\mathbf{F}^{e}}{q_0}$$



~siempre y cuando q_0 no perturbe la distribución q

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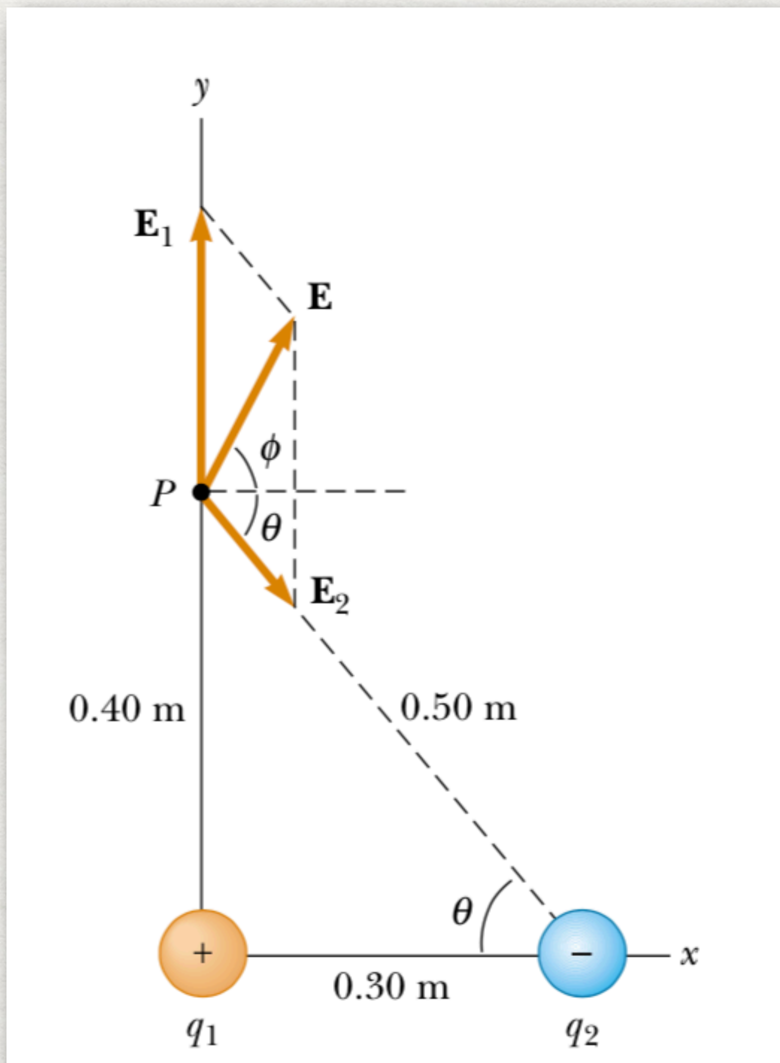
superposición del campo eléctrico: ~el campo debido a un grupo de cargas q_i sobre un punto es la suma vectorial de los campos de cada carga

$$\mathbf{E} = k_e \frac{q_1}{r_1^2}\,\hat{\mathbf{r}}_1 + k_e \frac{q_2}{r_2^2}\,\hat{\mathbf{r}}_2 + k_e \frac{q_3}{r_3^2}\,\hat{\mathbf{r}}_3 + \ldots = k_e \sum_i \frac{q_i}{r_i^2}\,\hat{\mathbf{r}}_\mathbf{i}$$

ejemplo: $\mathbf{E} = ?\quad P = (0{,}0.4)\,m$



$q_1 = 7\mu C \qquad q_2 = -5\mu C$

$$E_1 = k_e \frac{|q_1|}{{r_1}^2} = \left(8.99 \times 10^9\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)\frac{(7.0 \times 10^{-6}\ \mathrm{C})}{(0.40\ \mathrm{m})^2}$$
$$= 3.9 \times 10^5\ \mathrm{N/C}$$

$$E_2 = k_e \frac{|q_2|}{{r_2}^2} = \left(8.99 \times 10^9\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)\frac{(5.0 \times 10^{-6}\ \mathrm{C})}{(0.50\ \mathrm{m})^2}$$
$$= 1.8 \times 10^5\ \mathrm{N/C}$$

$$\mathbf{E_1} = E_1\,\hat{\mathbf{j}} \quad = 3.9 \times 10^{-5}\,\hat{\mathbf{j}}\ N/C$$

$$\mathbf{E_2} = E_2\,cos\theta\,\hat{\mathbf{i}} - E_2\,sen\theta\,\hat{\mathbf{j}} \ = (1.1 \times 10^{-5}\,\hat{\mathbf{i}} - 1.4 \times 10^{-5}\,\hat{\mathbf{j}})\ N/C$$

$$cos\theta = 0.3/0.5$$
$$sen\theta = 0.4/0.5$$

$$\mathbf{E} = \mathbf{E_1} + \mathbf{E_2} \ = (1.1 \times 10^{-5}\,\hat{\mathbf{i}} + 2.5 \times 10^{-5}\,\hat{\mathbf{j}})\ N/C$$

Si q en P $\quad \mathbf{F} = \mathbf{E}\,q$

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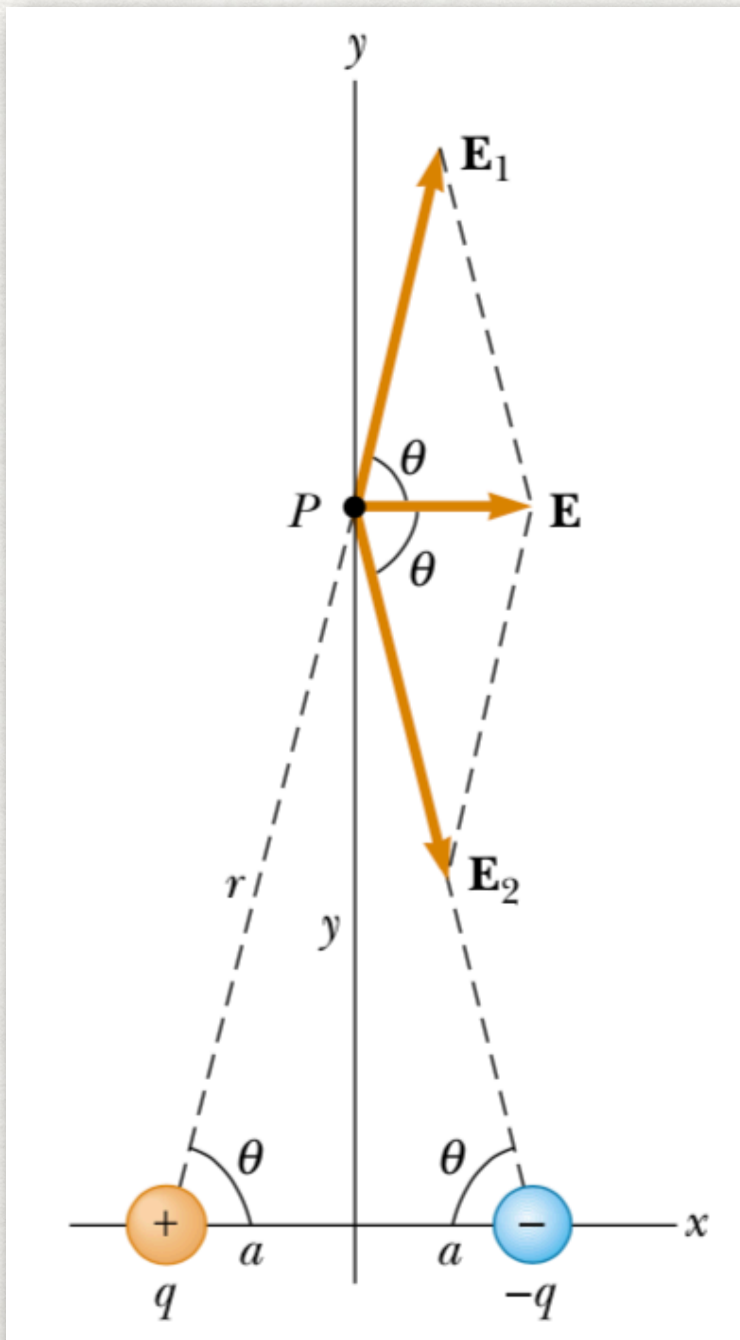
dipolo eléctrico: par de cargas eléctricas opuestas separadas una distancia d

~modelo para moléculas



$$E_1 = E_2 = k_e \frac{|q|}{r^2} = k_e \frac{q}{a^2 + y^2}$$

$$\mathbf{E} = \mathbf{E_1} + \mathbf{E_2} = 2E_1 \cos\theta\, \hat{\mathbf{i}} + 0\, \hat{\mathbf{j}} = 2\, k_e \frac{q}{a^2+y^2} \frac{a}{\sqrt{a^2+y^2}} \hat{\mathbf{i}} = k_e \frac{2\,q\,a}{(a^2+y^2)^{3/2}} \hat{\mathbf{i}}$$

$$\cos\theta = a/r = a/\sqrt{a^2+y^2}$$

si $y \gg a$ $\quad \mathbf{E} \approx k_e \frac{2qa}{y^3} \hat{\mathbf{i}}$

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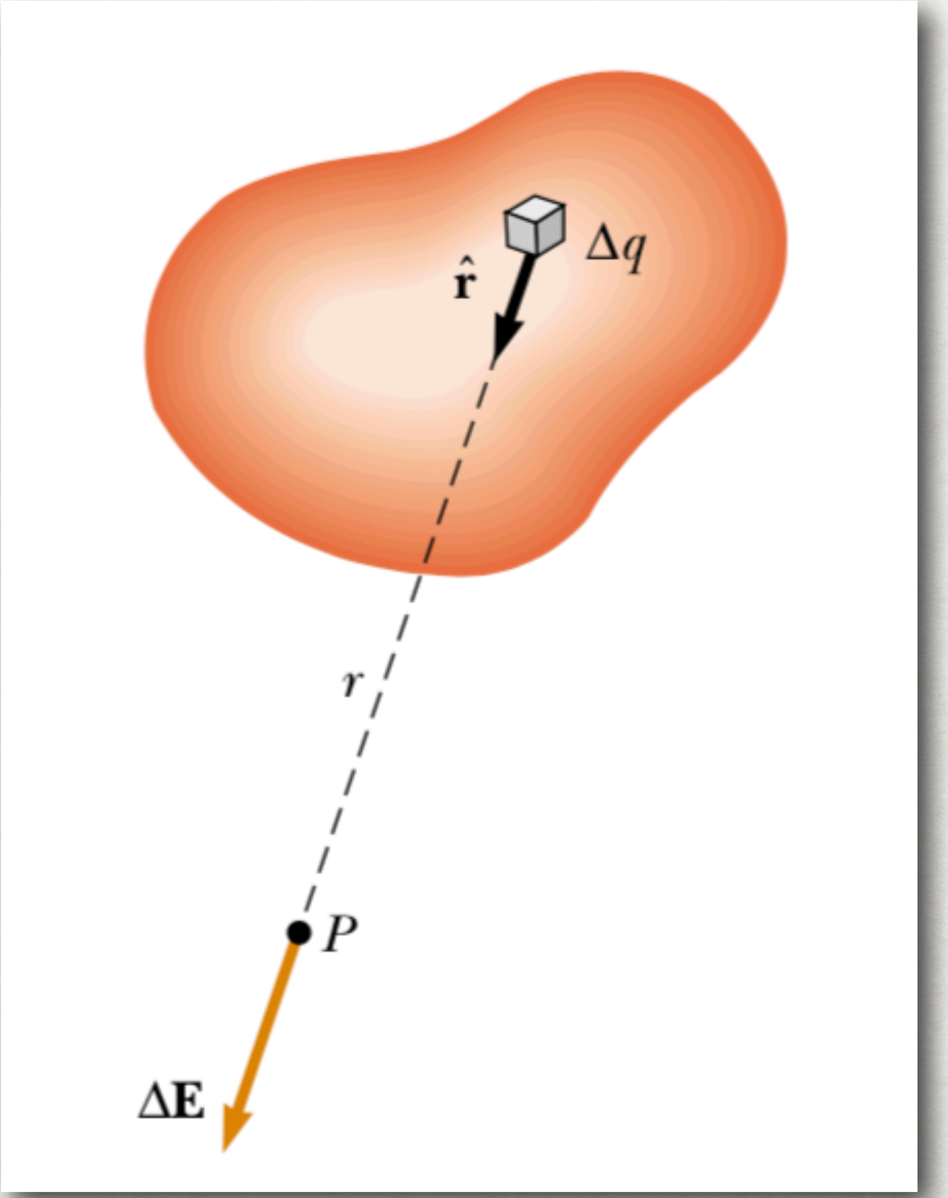
campo eléctrico de una distribución continua de cargas:

~la distancia entre las cargas es pequeña comparada con la del punto de observación

$$\Delta \mathbf{E} = k_e \frac{\Delta q}{r^2}\,\hat{\mathbf{r}} \qquad \mathbf{E} \approx \sum_i \Delta \mathbf{E_i} = k_e \sum_i \frac{\Delta q_i}{r_i^2}\,\hat{\mathbf{r}}_\mathbf{i}$$

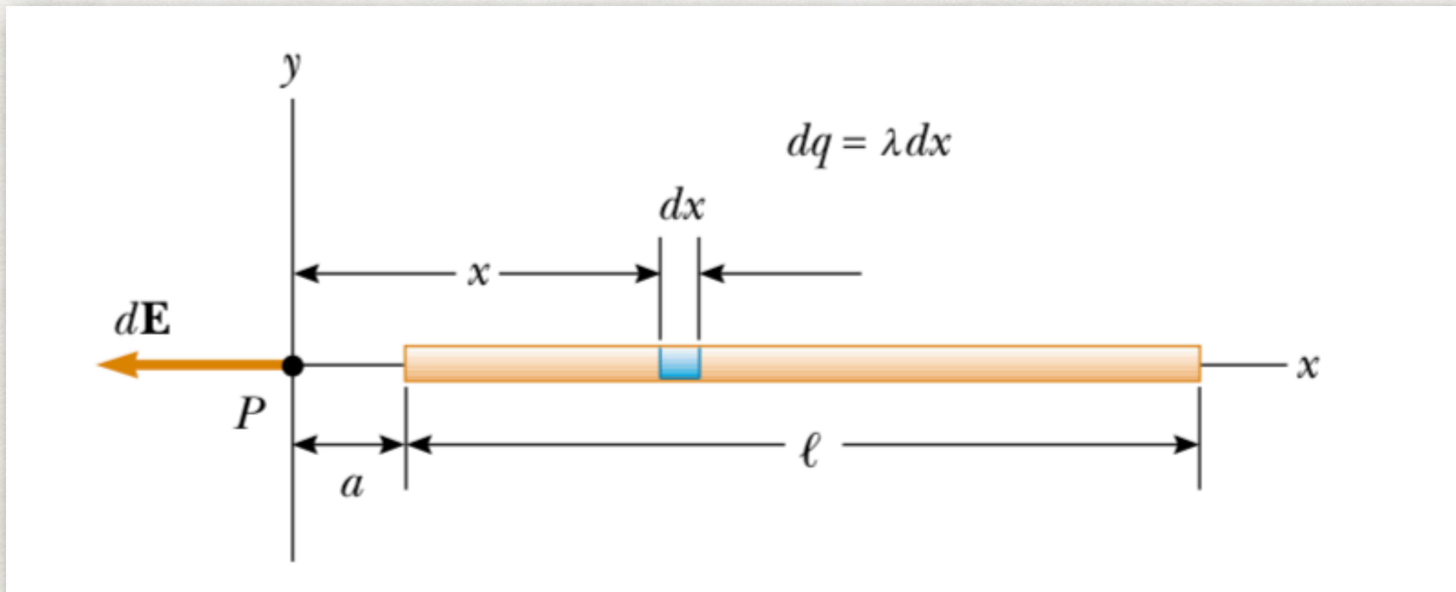
$$\mathbf{E} = lim_{\Delta q_i \to 0}\, k_e \sum_i \frac{\Delta q_i}{r_i^2}\,\hat{\mathbf{r}}_\mathbf{i} = k_e \int_V \frac{dq}{r^2}\,\hat{\mathbf{r}}$$



	si la carga está uniformemente distribuida	*si no lo está*
densidad volumétrica de carga:	$\rho \equiv \frac{Q}{V}$	$\rho \equiv \frac{dQ}{dV}$
densidad superficial de carga:	$\sigma \equiv \frac{Q}{S}$	$\sigma \equiv \frac{dQ}{dS}$
densidad lideal de carga:	$\lambda \equiv \frac{Q}{l}$	$\lambda \equiv \frac{dQ}{dl}$

campo eléctrico de una distribución continua de cargas:

ejemplo: barra de longitud ℓ cargada uniformemente



$$\lambda \equiv \frac{dq}{dx} = \frac{Q}{l}$$

$$d\mathbf{E} = k_e \frac{dq}{x^2}(-\hat{\mathbf{i}}) = k_e \frac{\lambda\, dx}{x^2}(-\hat{\mathbf{i}})$$

$$\mathbf{E} = \int_a^{l+a} k_e \lambda \frac{dx}{x^2}(-\hat{\mathbf{i}}) = k_e \lambda \left[-\frac{1}{x}\right]_a^{l+a} (-\hat{\mathbf{i}}) = k_e \lambda \left[-\frac{1}{l+a} + \frac{1}{a}\right] (-\hat{\mathbf{i}}) = k_e \lambda \left[\frac{l+a-a}{a(l+a)}\right] (-\hat{\mathbf{i}})$$

$$= k_e \lambda \left[\frac{l}{a(l+a)}\right] (-\hat{\mathbf{i}}) = -\frac{k_e Q}{a(l+a)}\hat{\mathbf{i}}$$

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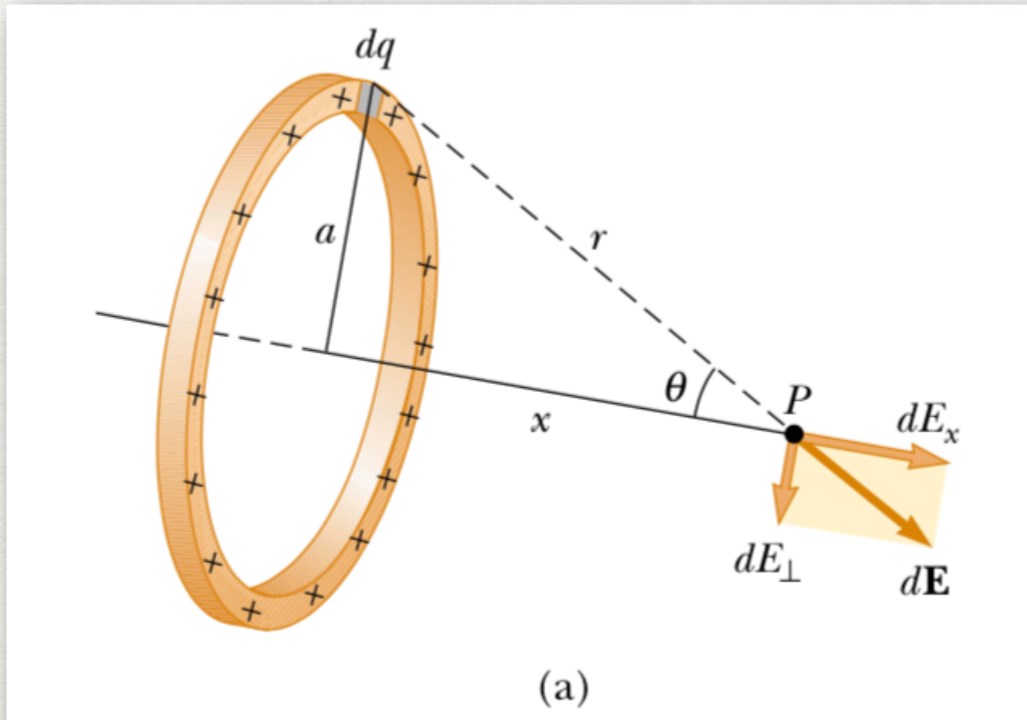
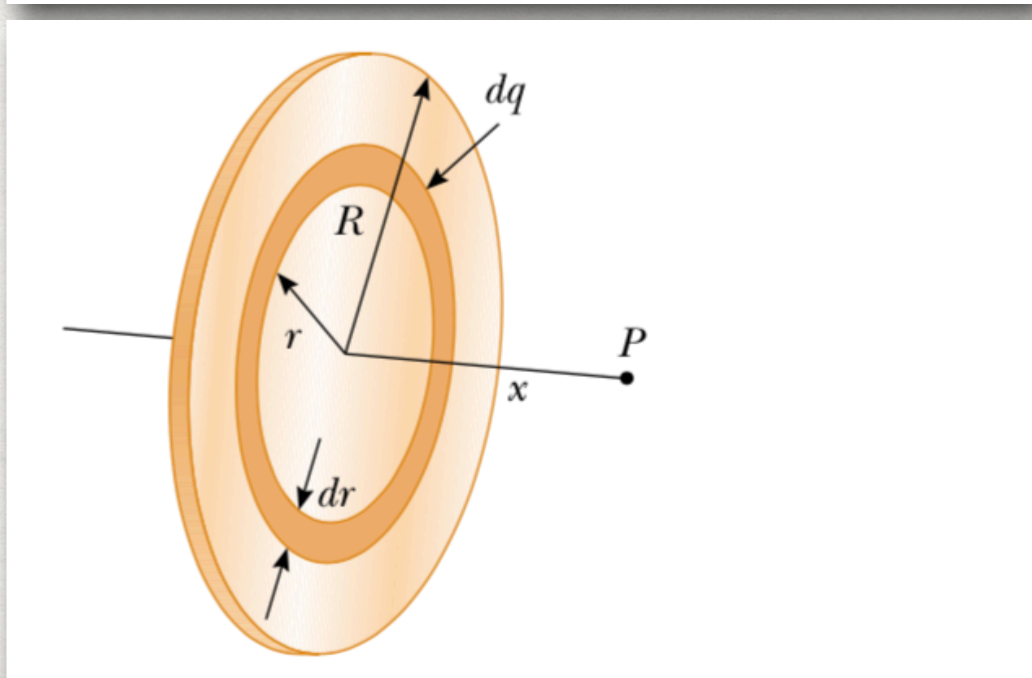
campo eléctrico de una distribución continua de cargas:

ejemplo: anillo y disco cargado uniformemente



(a)



$$cos\theta = \frac{x}{r}$$

$$d\mathbf{E} = k_e \frac{dq}{r^2}(cos\theta\, \hat{\mathbf{i}} + sen\theta\, \hat{\perp})$$

$$r = \sqrt{a^2 + x^2}$$

$$\mathbf{E} = k_e \int \frac{dq}{r^2} \frac{x}{r}\, \hat{\mathbf{i}} = k_e \int \frac{x\, dq}{(a^2 + x^2)^{3/2}}\, \hat{\mathbf{i}}$$

$$= \frac{k_e\, x}{(a^2 + x^2)^{3/2}} \int dq\, \hat{\mathbf{i}} = \frac{k_e\, x}{(a^2 + x^2)^{3/2}}\, Q\, \hat{\mathbf{i}}$$

$$dS = 2\pi\, r\, dr \qquad dq = \sigma\, dS = 2\pi\, \sigma\, r\, dr$$

$$d\mathbf{E} = \frac{k_e\, x}{(r^2 + x^2)^{3/2}}\, dq\, \hat{\mathbf{i}} = \frac{k_e\, 2\pi\, \sigma\, x\, r}{(r^2 + x^2)^{3/2}}\, dr\, \hat{\mathbf{i}}$$

$$\mathbf{E} = \int_0^R \frac{k_e\, 2\pi\, \sigma\, x\, r}{(r^2 + x^2)^{3/2}}\, dr\, \hat{\mathbf{i}} = k_e\, 2\pi\, \sigma \left(\frac{x}{|x|} - \frac{x}{(x^2 + R^2)^{1/2}} \right) \hat{\mathbf{i}}$$

si $R \gg x$ $\qquad \mathbf{E} \approx k_e\, 2\pi\, \sigma\, \hat{\mathbf{i}} = \frac{\sigma}{2\epsilon_0}\, \hat{\mathbf{i}} \qquad k_e = \frac{1}{4\pi\, \epsilon_0}$

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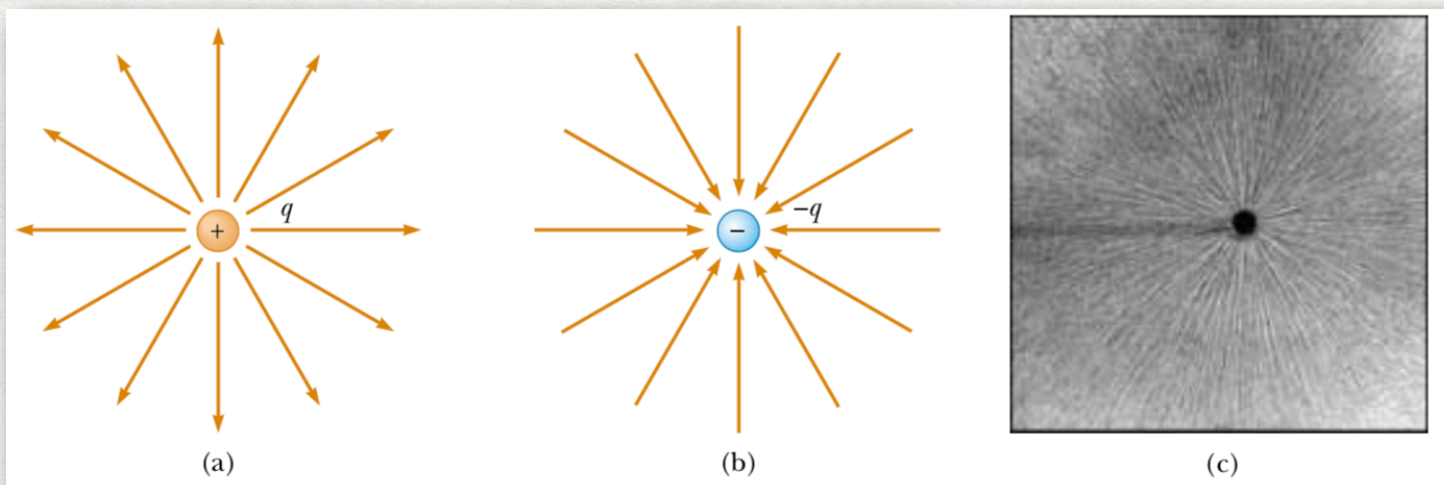
líneas de campo: líneas que en cada punto del espacio sigan la dirección del campo $\mathbf{E}$

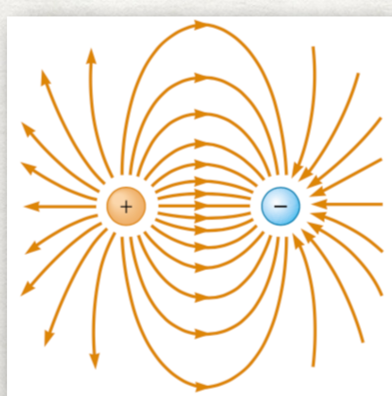
~forma de visualización

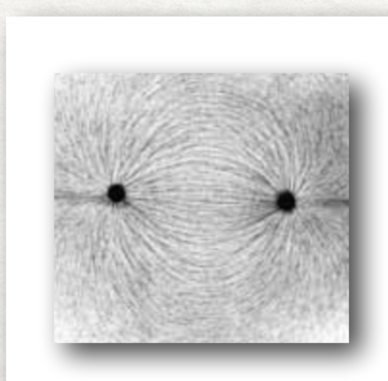
- el vector $\mathbf{E}$ es tangente a la línea en cada punto
- el número de líneas por unidad de área es proporcional a la magnitud (módulo) de $\mathbf{E}$
- las líneas comienzan en una carga positiva (y terminan en una carga negativa)
- el número de líneas partiendo de la carga positiva es proporcional a $|\mathbf{E}|$
- las líneas no se cruzan

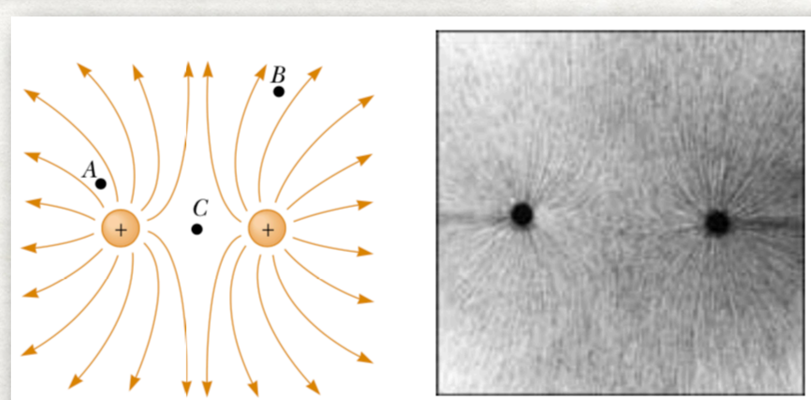


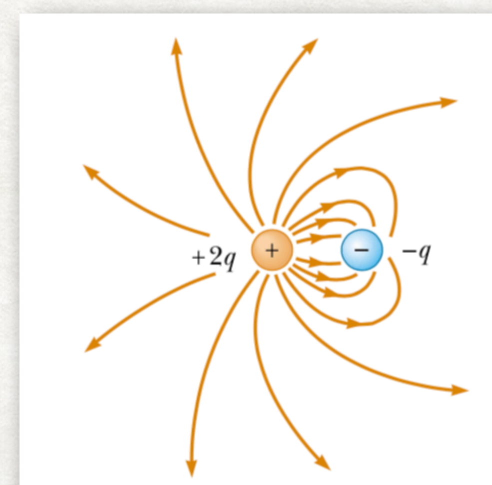
$|\mathbf{E}| \sim 1/r^2$ $\quad$ $A = 4\pi r^2$

$N/A \sim 1/r^2$









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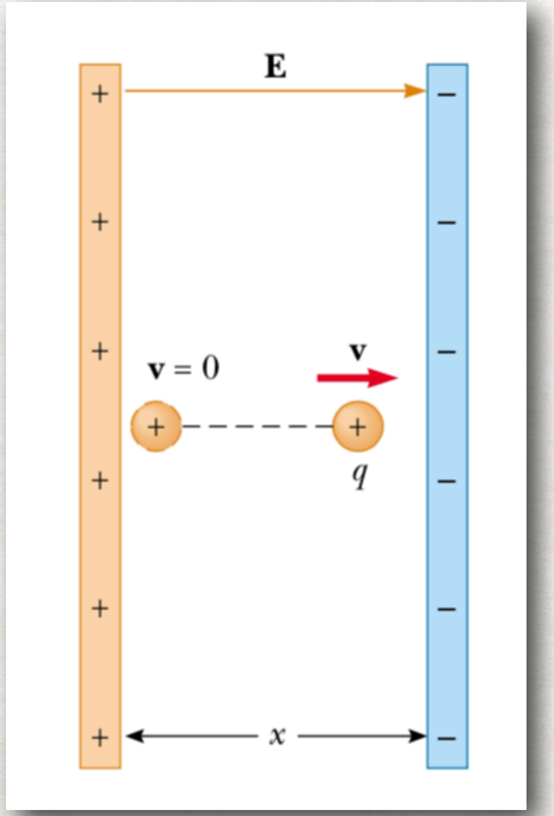
movimiento de partículas cargadas en un campo uniforme:

$$\mathbf{F} = m\,\mathbf{a}$$ *~2da ley de Newton*

$$\mathbf{F^e} = q\,\mathbf{E}$$

$$q\,\mathbf{E} = m\,\mathbf{a} \qquad \mathbf{a} = \frac{q\,\mathbf{E}}{m}$$ *si el campo es uniforme, la aceleración es constante*

ejemplo: placas paralelas ("infinitas"= arbitrariamente grandes)



$$\mathbf{a} = \frac{q\,\mathbf{E}}{m} \qquad a_x\,\hat{\mathbf{i}} = \frac{q\,|\mathbf{E}|}{m}\hat{\mathbf{i}}$$

$$v(t) = v_0 + a_x\,t$$

$$x(t) = x_0 + v_0\,t + \frac{1}{2}a_x\,t^2$$

$$x_0 = 0 \quad v_0 = 0 \qquad v(t) = \frac{qE}{m}\,t \qquad x(t) = \frac{qE}{2m}\,t^2$$

$$v^2(t) = \left(\frac{qE}{m}\right)^2 t^2 = 2\left(\frac{qE}{m}\right)x \qquad \Delta K = \frac{1}{2}m\,v^2 = qE\,x$$

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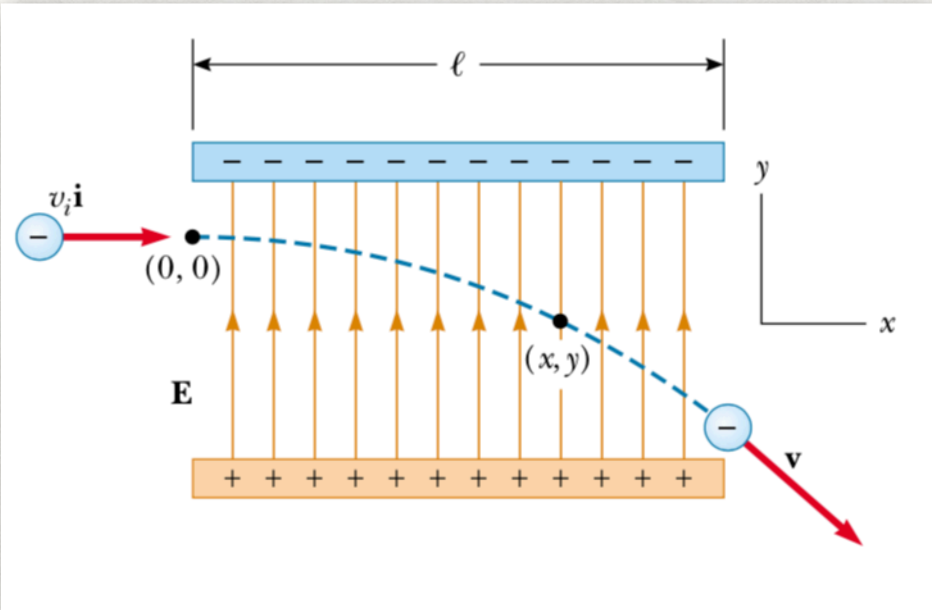
movimiento de partículas cargadas en un campo uniforme:



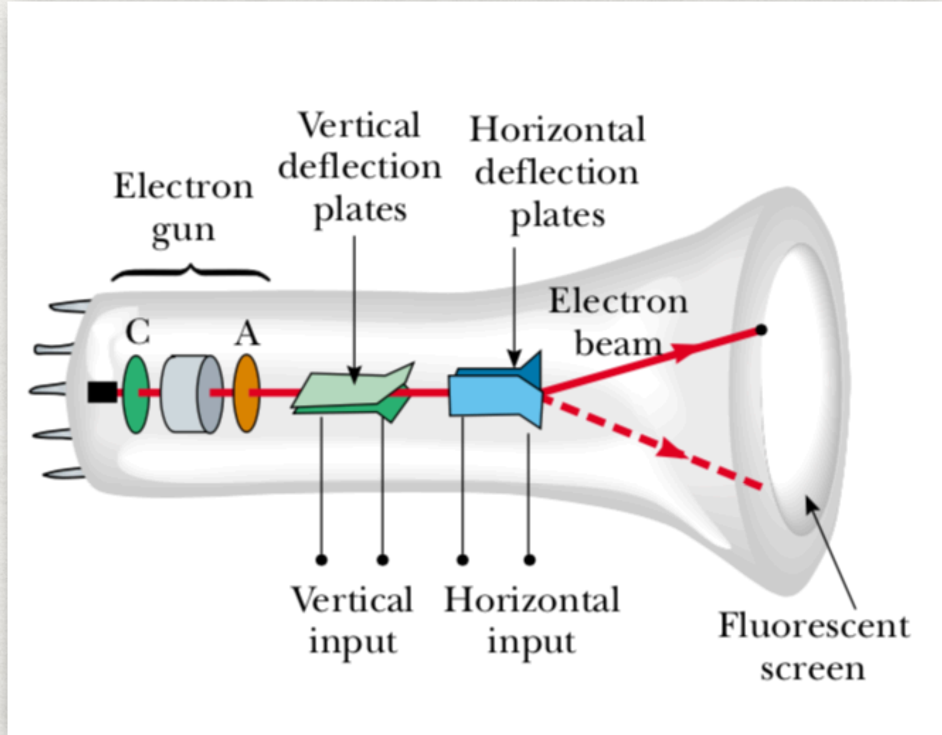
~trayectoria con $g = cte$

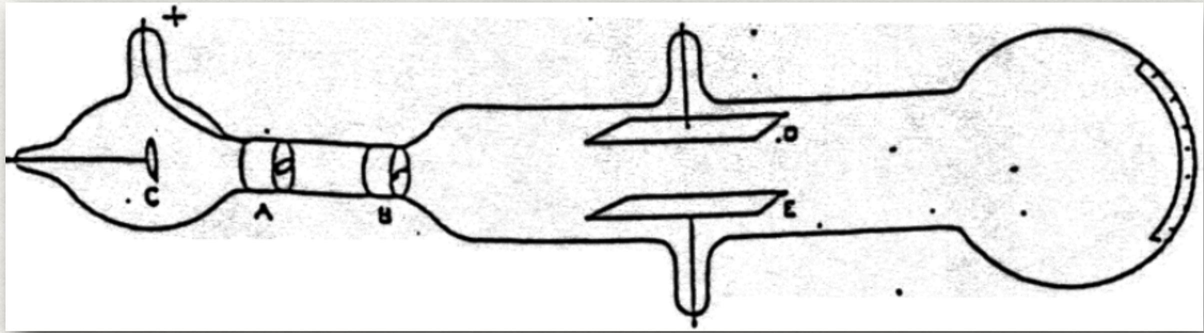
$$a_y \hat{\mathbf{i}} = -\frac{q|\mathbf{E}|}{m}\hat{\mathbf{j}} \qquad a_x \hat{\mathbf{i}} = 0$$

$$v_y = a_y t \qquad v_x = cte$$

$$y = \frac{1}{2} a_y t^2 = -\frac{qE}{2m} t^2 \qquad x = v_i t$$

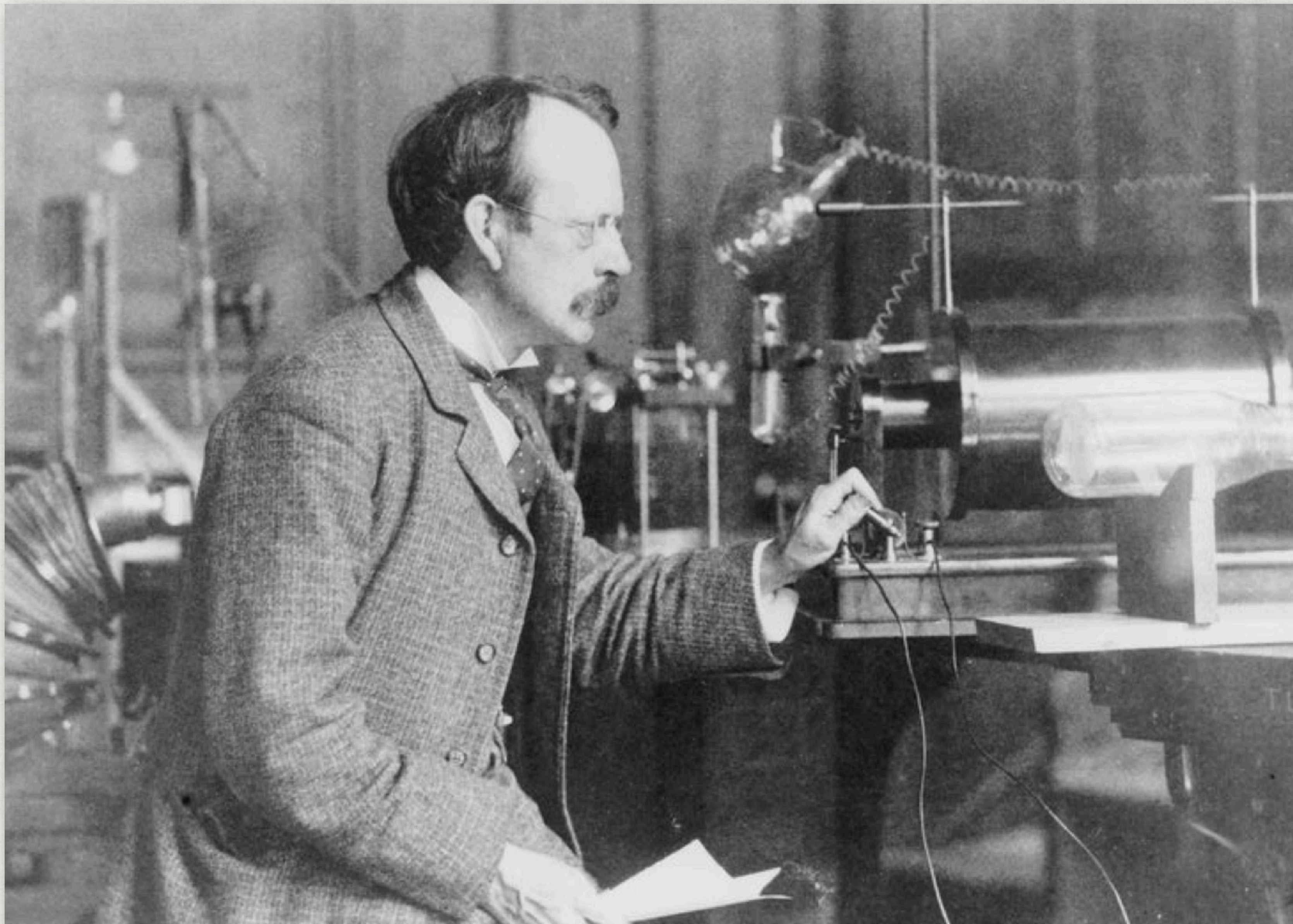
$$= -\frac{qEx^2}{2mv_i^2} \qquad \frac{q}{m}\,!$$





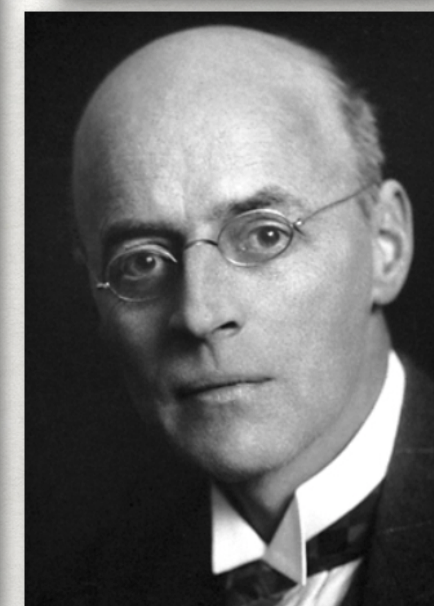
Joseph Thomson (1897)

Joseph Thomson (Nobel 1906)

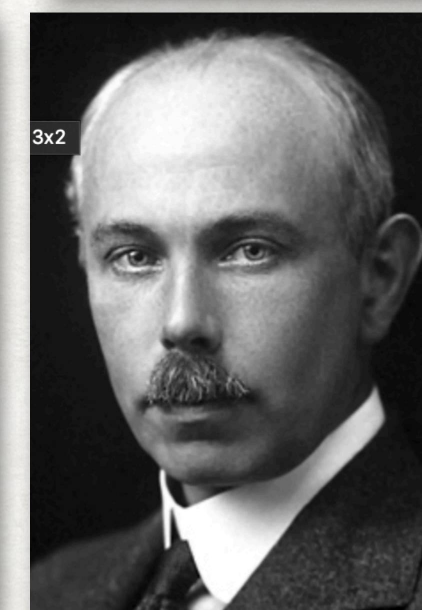


George Thomson (Nobel 1937)

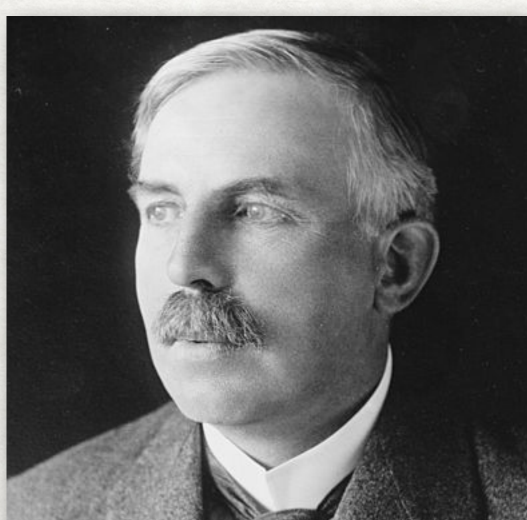
Charles Glover (Nobel 1917)



Owen Richardson (Nobel 1928)

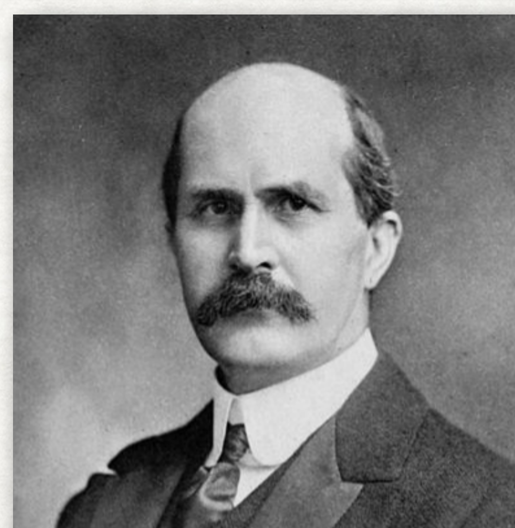


Francis Aston (Nobel 1922)

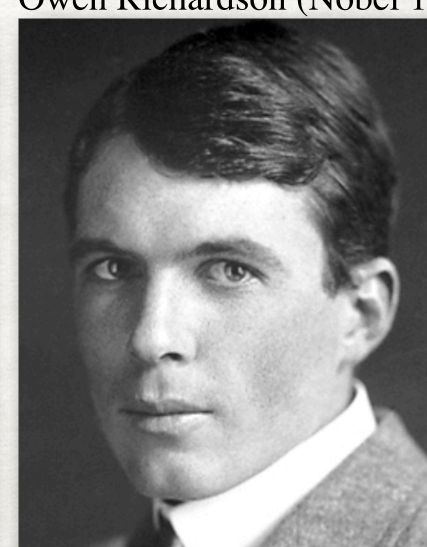


Ernest Rutherford (Nobel 1908)

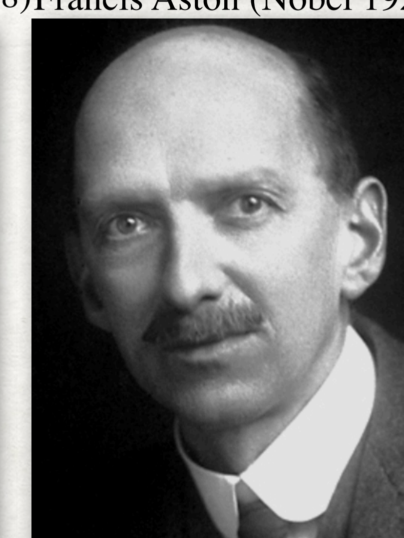
Niels Bohr (Nobel 1922)



William Bragg (Nobel 1915)



Lawrence Bragg (Nobel 1915)



Charles Wilson (Nobel 1927)