



# **El campo electrostático**

**F II**

**La carga eléctrica. Ley de Coulomb**

**Campo eléctrico. Teorema de Gauss**

**Potencial eléctrico. Energía potencial**

**El dipolo eléctrico**

**Conductores y dieléctricos**

**Polarización. Vector desplazamiento**

**Capacidad y energía electrostática**

**Corriente eléctrica. Ley de Ohm. Circuitos**



# La carga eléctrica

**Localización en la materia**

**Fluido eléctrico (+) y (-)**

**Paralelismo con masa gravitatoria**

**Descubrimiento electrón**

**J. J. Thomson (1897)**

**Descubrimiento núcleo atómico**

**E. Rutherford (1911)**

UCM



# La carga eléctrica

**F II**

**Localización en la materia**

**Electrones (-) y protones (+)**

**Cuantificación**

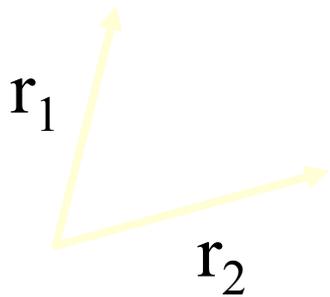
**R. A. Millikan (1913)**

**Conservación**



# Ley de Coulomb (1785)

Ley experimental entre cargas puntuales



$$\mathbf{F}_{2,1} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{|\mathbf{r}_2 - \mathbf{r}_1|^3} (\mathbf{r}_2 - \mathbf{r}_1)$$

$$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2$$

UCM



# Principio de superposición

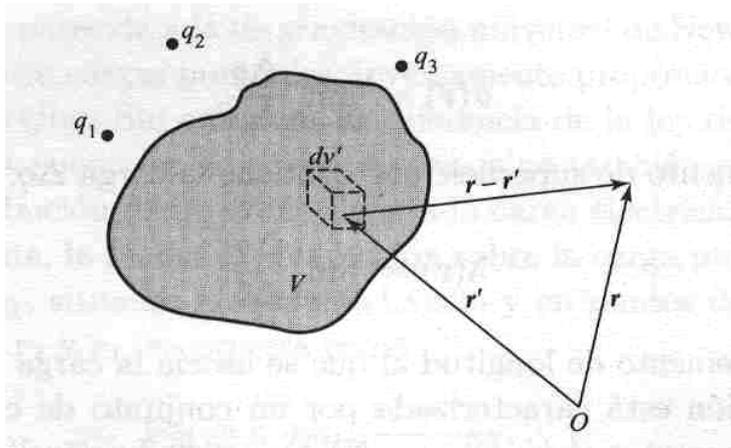
**F II**

- Insuficiencia ley entre cargas puntuales
- Consecuencia linealidad
- Generalización a distribuciones continuas



# Campo eléctrico

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

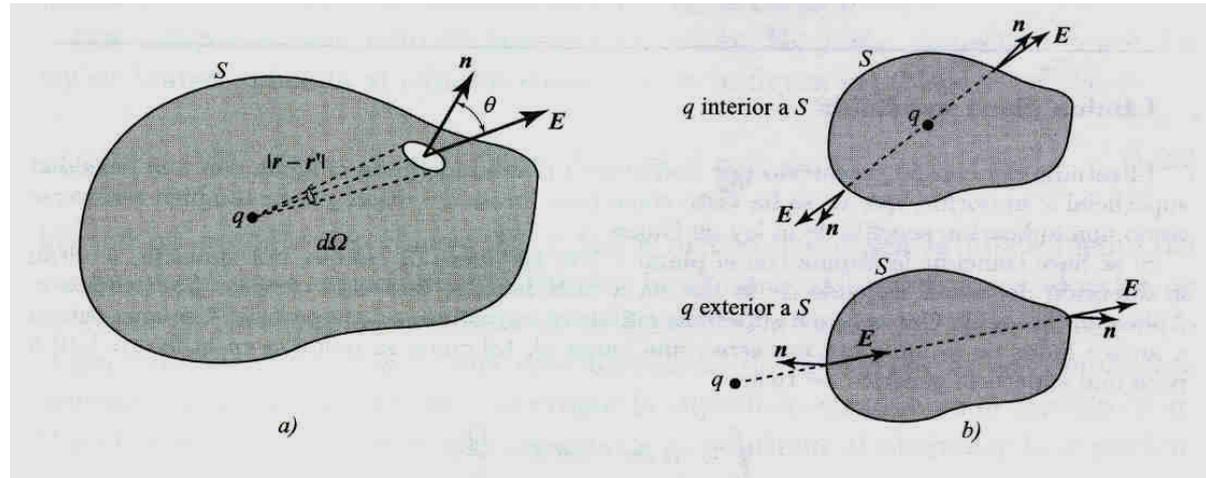


$$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\epsilon_0} \left[ \sum \frac{q_i}{|\mathbf{r} - \mathbf{r}_i|^3} (\mathbf{r} - \mathbf{r}_i) + \int \frac{\lambda d\mathbf{l}'}{|\mathbf{r} - \mathbf{r}'|^3} (\mathbf{r} - \mathbf{r}') \right] +$$

$$\frac{1}{4\pi\epsilon_0} \left[ \int \frac{\sigma da'}{|\mathbf{r} - \mathbf{r}'|^3} (\mathbf{r} - \mathbf{r}') + \int \frac{\rho dv'}{|\mathbf{r} - \mathbf{r}'|^3} (\mathbf{r} - \mathbf{r}') \right]$$



# Teorema de Gauss

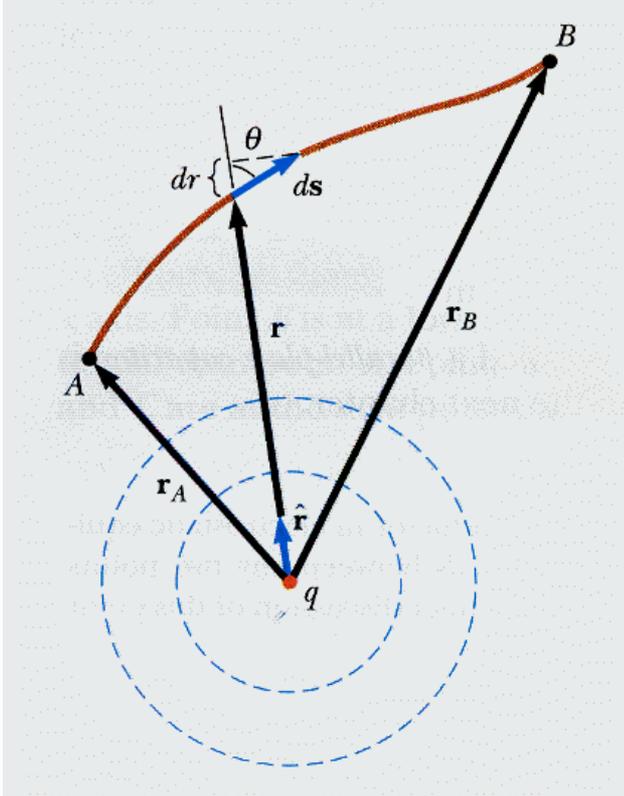


$$\oint_S \mathbf{E} \cdot \mathbf{n} da = \frac{q}{4\pi\epsilon_0} \int_S \frac{\mathbf{r} - \mathbf{r}'}{|\mathbf{r} - \mathbf{r}'|^3} \cdot \mathbf{n} da = \frac{q}{4\pi\epsilon_0} \oint_S d\Omega = \frac{q}{\epsilon_0}$$



# Potencial eléctrico

F II



$$-\int_A^B \mathbf{E} \cdot d\mathbf{l} = \frac{q}{4\pi\epsilon_0} \left[ \frac{1}{r_B} - \frac{1}{r_A} \right] = V_B - V_A$$

$$\oint \mathbf{E} \cdot d\mathbf{l} = 0$$

**El campo eléctrico es conservativo**



# Relación entre el campo y el potencial

**F II**

$$dV = \frac{\partial V}{\partial x} dx + \frac{\partial V}{\partial y} dy + \frac{\partial V}{\partial z} dz = -\mathbf{E} \cdot d\mathbf{l} = -(E_x dx + E_y dy + E_z dz)$$

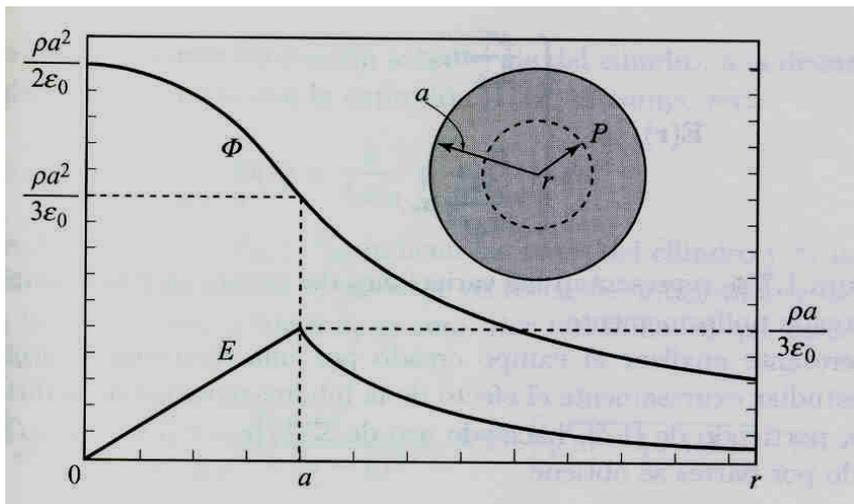
$$E_x = -\frac{\partial V}{\partial x}, E_y = -\frac{\partial V}{\partial y}, E_z = -\frac{\partial V}{\partial z}; \mathbf{E} = -\nabla V$$

**El campo es menos el gradiente del potencial**

# Cálculo de campos



## F II Esfera uniformemente cargada



$$\mathbf{E}(\mathbf{r}) = \begin{cases} \frac{\rho r}{3\epsilon_0} \mathbf{u}_r, r < a \\ \frac{\rho a^3}{3\epsilon_0 r^2} \mathbf{u}_r, r > a \end{cases}$$

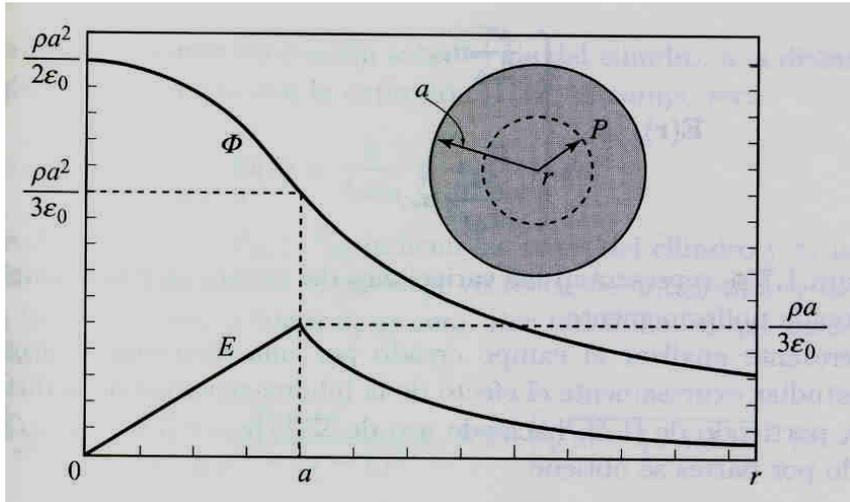
$$\Phi(\mathbf{r}) = \begin{cases} \frac{\rho}{\epsilon_0} \left( \frac{a^2}{2} - \frac{r^2}{6} \right), r < a \\ \frac{\rho a^3}{3\epsilon_0 r}, r > a \end{cases}$$



# Cálculo de potenciales

## F II Esfera uniformemente cargada

$$\mathbf{E}(\mathbf{r}) = \begin{cases} \frac{\rho r}{3\epsilon_0} \mathbf{u}_r, r < a \\ \frac{\rho a^3}{3\epsilon_0 r^2} \mathbf{u}_r, r > a \end{cases}$$



$$\Phi(\mathbf{r}) = \begin{cases} \frac{\rho}{\epsilon_0} \left( \frac{a^2}{2} - \frac{r^2}{6} \right), r < a \\ \frac{\rho a^3}{3\epsilon_0 r}, r > a \end{cases}$$

UCM



# Representaciones gráficas

F II

**Información cualitativa y cuantitativa de los campos**

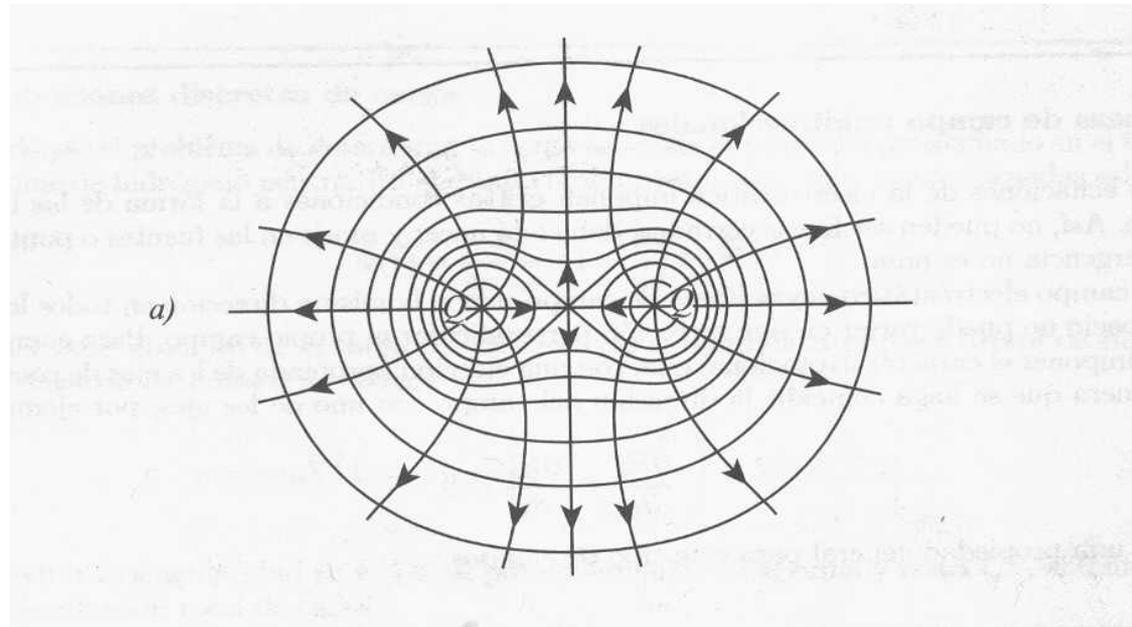
**Información cualitativa y cuantitativa de potenciales y campos**



# Representaciones gráficas

F II

Dos cargas puntuales iguales



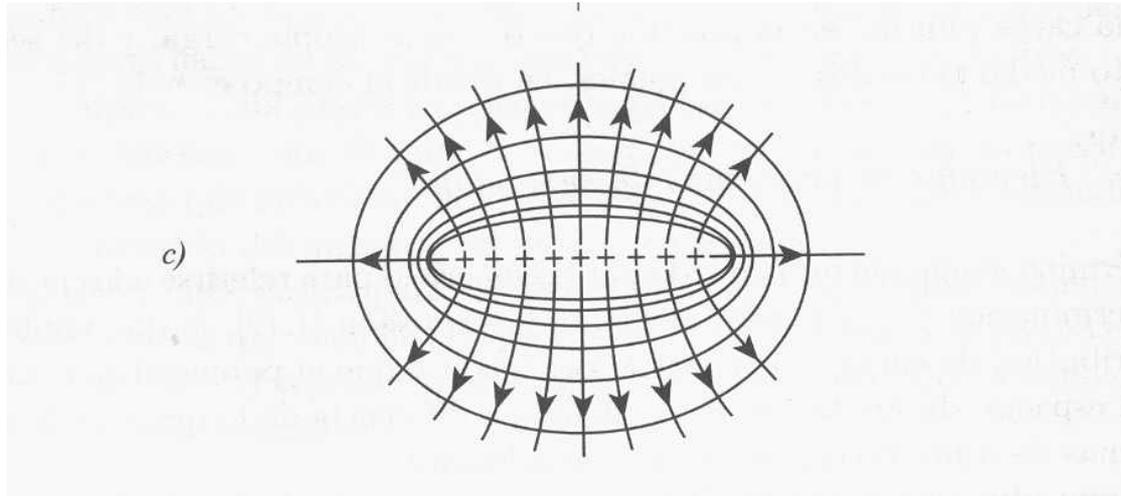
Equipotenciales y líneas de campo



# Representaciones gráficas

F II

Línea cargada uniformemente



Equipotenciales y líneas de campo



# Formulación integral del campo eléctrico

**F II**

1ª Ecuación

$$\oint_C \mathbf{E} \cdot d\mathbf{l} = 0$$

**Propiedad intrínseca del campo: conservativo**  
**Fuerza central**

2ª Ecuación

$$\oint_S \mathbf{E} \cdot \mathbf{n} da = \frac{q}{\epsilon_0}$$

**Relación campo-fuentes**  
**Ley inversa cuadrado de la distancia**



# Energía potencial eléctrica

F II

$$\mathbf{F} = q\mathbf{E}$$

.

$$\int_A^B q' \mathbf{E} \cdot d\mathbf{l} = q'(V_A - V_B) = U_A - U_B$$

$$U = qV$$



# Energía potencial eléctrica

**F II**

▪

$$U = \sum_i \frac{1}{2} q_i V_i + \frac{1}{2} \int_L \lambda V dl + \frac{1}{2} \int_A \sigma V da + \frac{1}{2} \int_V \rho V dv$$

**Energía localizada en las cargas**



# Conductores en equilibrio electrostático

F II

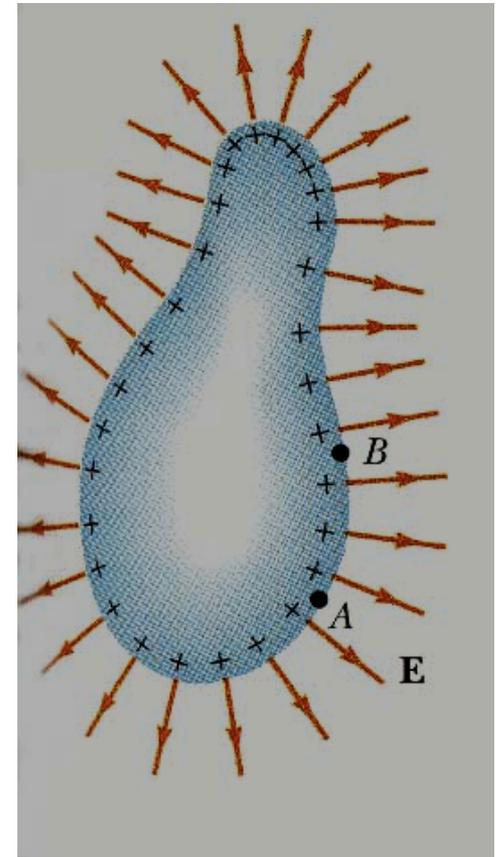
**Campo nulo en su interior**

**Carga neta sobre superficie**

**Volumen equipotencial**

**Campo en sus proximidades**

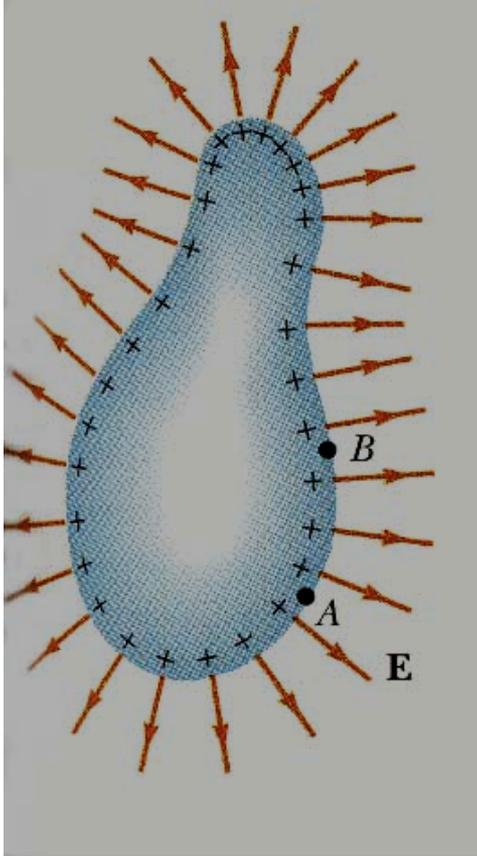
$$E = \frac{\sigma}{\epsilon_0}$$



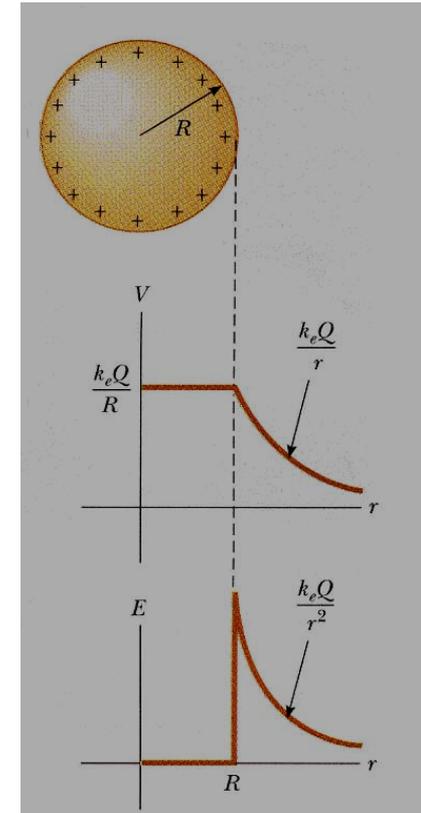


# Conductores

F II



Conductor arbitrario



Esfera conductora



# Capacida y energía

**F II**

**Capacidad de un conductor**

**Esfera de radio  $a$**

$$C = \frac{q}{V} = 4\pi\epsilon_0 a$$

**Capacidad de un condensador: dos conductores con**

**+Q y -Q a los potenciales  $V$  y 0**

$$C = \frac{q}{V}$$

**Energía de un condensador**

$$U = \frac{1}{2} qV = \frac{1}{2} CV^2 = \frac{1}{2} \frac{q^2}{C}$$

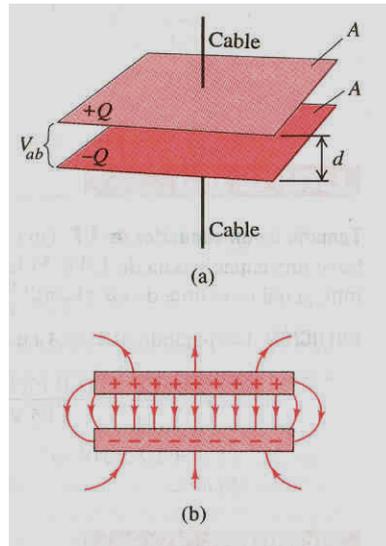
**Energía “localizada” en las cargas**



# Condensadores

F II

Plano



$$V = Ed = \frac{\sigma}{\epsilon_0} d$$

$$C = \frac{Q}{V} = \frac{\sigma S}{V} = \epsilon_0 \frac{S}{d}$$

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

$$w = \text{densidad volúmica de energía} = \frac{1}{2} \epsilon_0 E^2$$

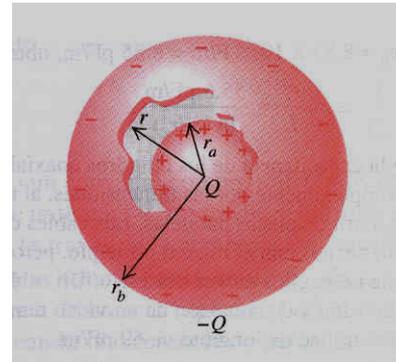
**Energía localizada en el campo**



# Condensadores

**F II**

**Esférico**



$$V = \int_a^b \frac{Q}{4\pi\epsilon_0 r^2} dr = \frac{Q}{4\pi\epsilon_0} \left( \frac{1}{a} - \frac{1}{b} \right)$$

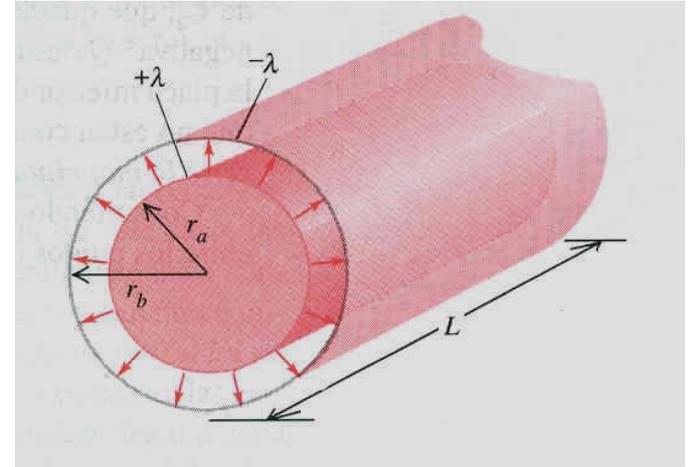
$$C = \frac{Q}{V} = 4\pi\epsilon_0 \frac{ab}{b-a}$$



# Condensadores

**F II**

**Cilíndrico**



$$V = \int_a^b \frac{\lambda}{2\pi\epsilon_0 r} dr = \frac{\lambda}{2\pi\epsilon_0} \ln \frac{b}{a}$$

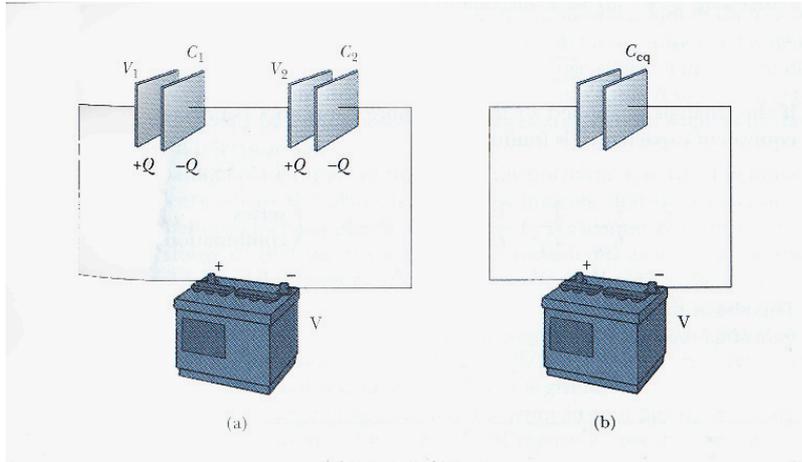
$$C = \frac{Q}{V} = \frac{\lambda l}{V} = 2\pi\epsilon_0 \frac{l}{\ln \frac{b}{a}}$$



# Asociación de condensadores

F II

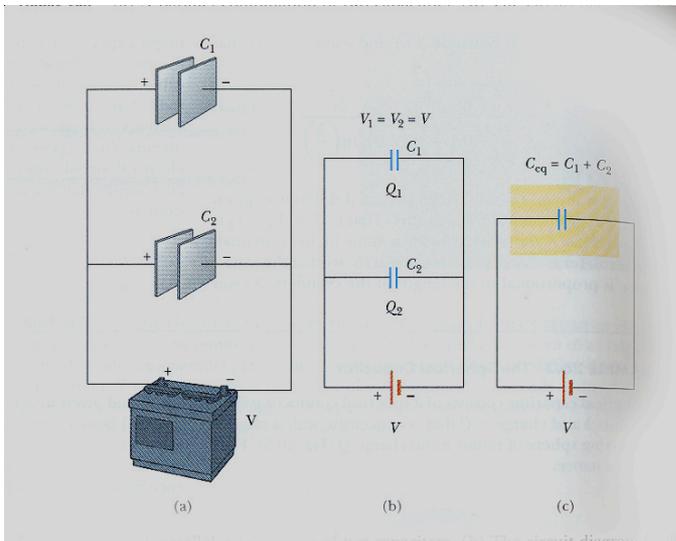
## ➤ Serie



Comparten carga

Distribuyen tensión

## ➤ Paralelo



Comparten tensión

Distribuyen carga



# Asociación de condensadores

**F II**

## ➤ Serie

$$\frac{1}{C_T} = \sum_i \frac{1}{C_i}$$

➤ Comparten carga

➤ Distribuyen tensión

## ➤ Paralelo

$$C_T = \sum_i C_i$$

➤ Comparten tensión

➤ Distribuyen carga



# Movimiento de cargas en un campo eléctrico

**F II**

**Típico problema de dinámica**

$$\mathbf{a} = \frac{\mathbf{F}}{m} = \frac{q}{m} \mathbf{E}$$

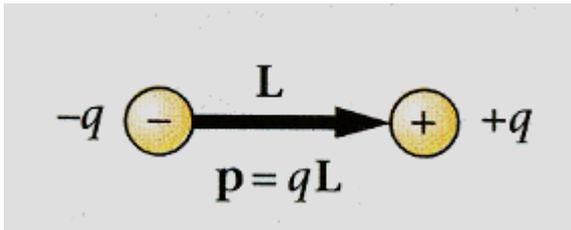
**Leyes de conservación**

$$qV_A = qV_B + \frac{1}{2}mv^2$$

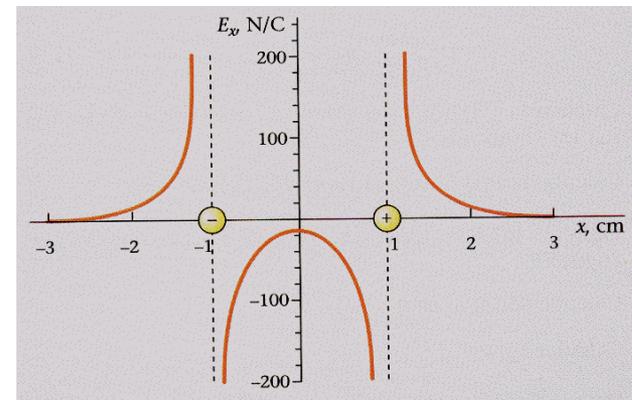
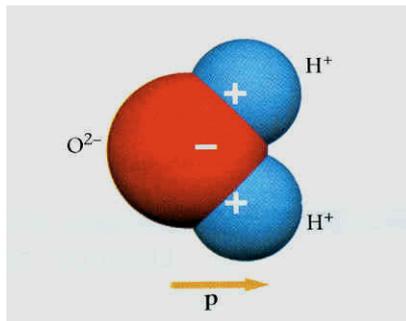


# El dipolo eléctrico

## Campo y potencial de un dipolo



$$V \propto \frac{p}{r^2}, \quad E \propto \frac{p}{r^3}$$

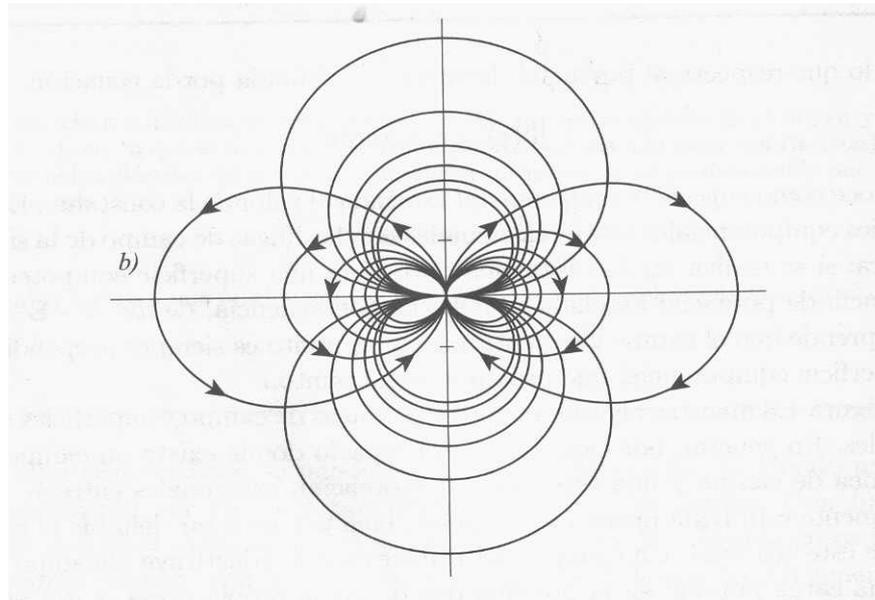




# Representaciones gráficas

F II

Dipolo puntual

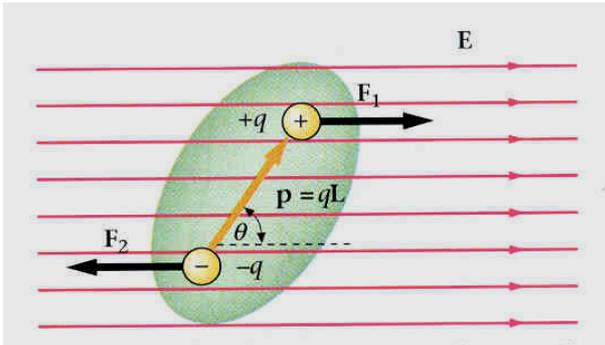


Equipotenciales y líneas de campo



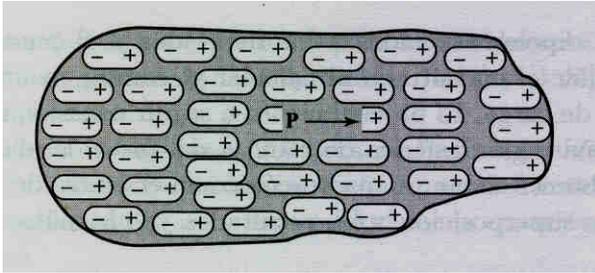
# El dipolo eléctrico

## Interacción campo-dipolo



$$\boldsymbol{\Gamma} = \mathbf{p} \times \mathbf{E}$$

$$U = -\mathbf{p} \cdot \mathbf{E} = -pE \cos \theta$$



$$\mathbf{p} = \alpha \mathbf{E}$$

$$\mathbf{P} = \frac{d\mathbf{p}}{dv} = \epsilon_0 \chi_e \mathbf{E}$$

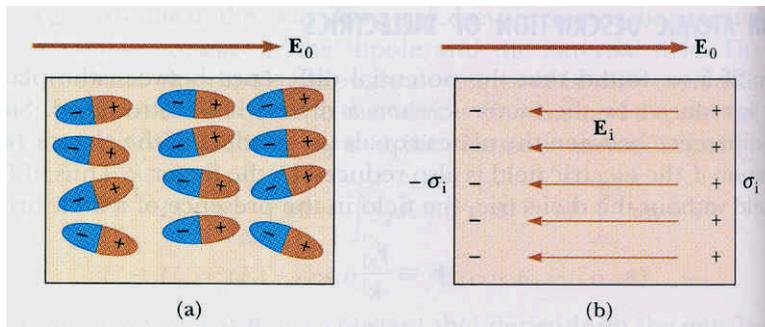
# Dieléctricos

- Estructura atómica-molecular de la materia
  - Centros carga positiva y negativa
- El dipolo eléctrico como ente puntual en aislantes
- Respuesta de un dieléctrico a un campo  $\mathbf{E}$ . Polarizabilidad  $\alpha$
- Vector polarización  $\mathbf{P}$
- Susceptibilidad eléctrica  $\chi_e$



# Extensión del vacío a dieléctricos

## F II Condensador plano-paralelo



- Dato experimental:  $C_0 \Rightarrow \epsilon_r C_0$
- Equivalencia en carga al estado de polarización

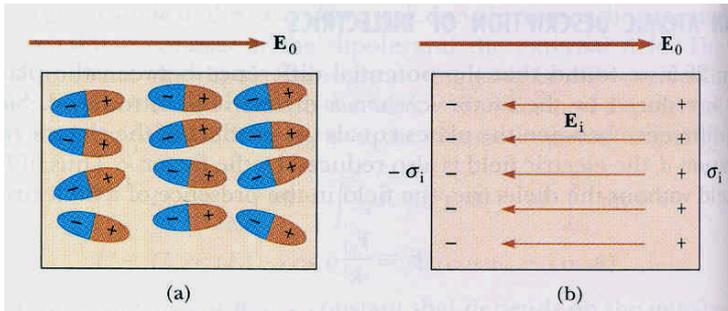
$$\sigma_P = \mathbf{P} \cdot \mathbf{n}, \quad E = \frac{\sigma + \sigma_P}{\epsilon_0} = \frac{\sigma}{\epsilon_0(1 + \chi_e)} = \frac{\sigma}{\epsilon_0 \epsilon_r} = \frac{E_0}{\epsilon_r}$$

$$\epsilon_r = 1 + \chi_e, \text{ permitividad relativa} \quad \epsilon = \epsilon_0 \epsilon_r, \text{ permitividad absoluta}$$

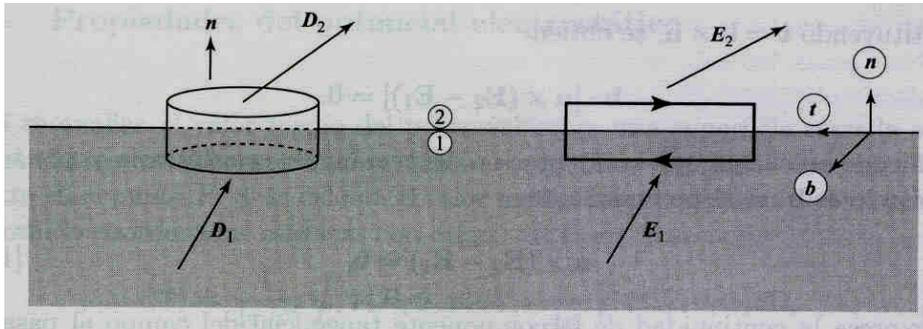


# Fronteras entre dieléctricos

## F II



$$\mathbf{P} = \frac{d\mathbf{p}}{dv} = \epsilon_0 \mathbf{E} + \mathbf{P}, \quad \mathbf{D} = \epsilon \mathbf{E} = \sigma \mathbf{n}$$



$$\mathbf{n} \cdot (\mathbf{D}_2 - \mathbf{D}_1) = \sigma,$$

$$\mathbf{t} \cdot (\mathbf{E}_2 - \mathbf{E}_1) = 0$$



# Corriente eléctrica

Densidad de corriente  $\mathbf{j}$ . Ley de Ohm

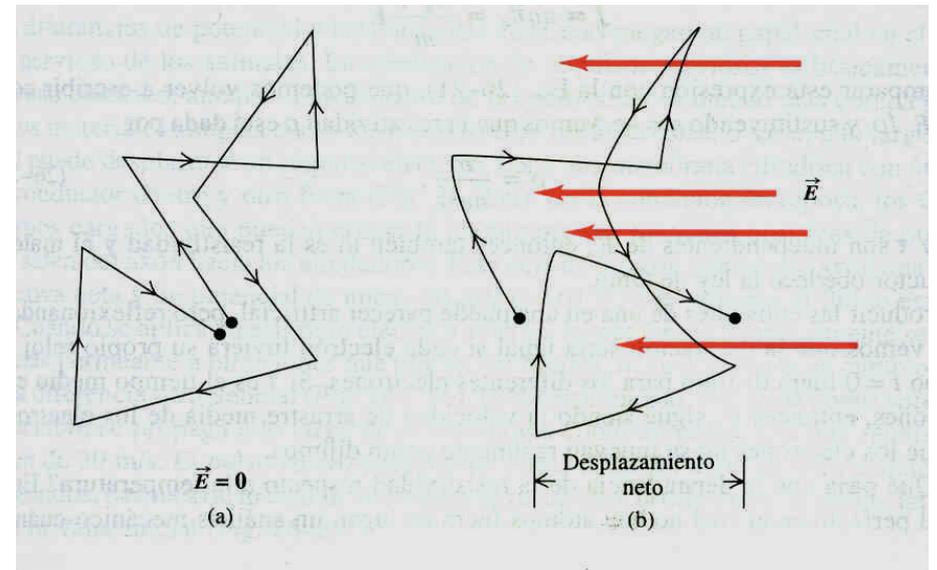
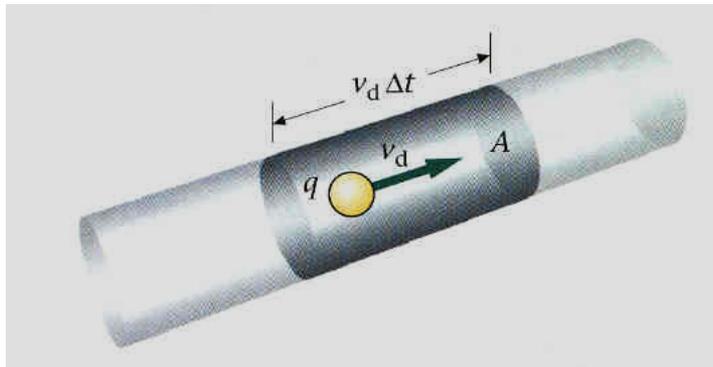
$$\mathbf{j} = nq\mathbf{v}_d = \sigma\mathbf{E}$$

Intensidad de corriente  $I$

$$I = \int_A \mathbf{j} \cdot \mathbf{n} da$$



# Corriente eléctrica

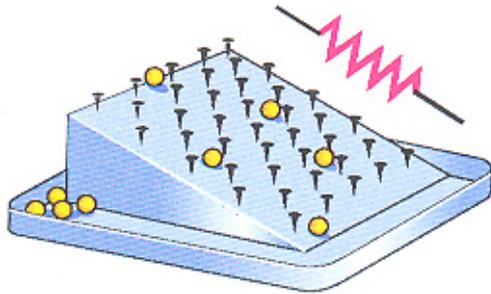




# Fuerza electromotriz

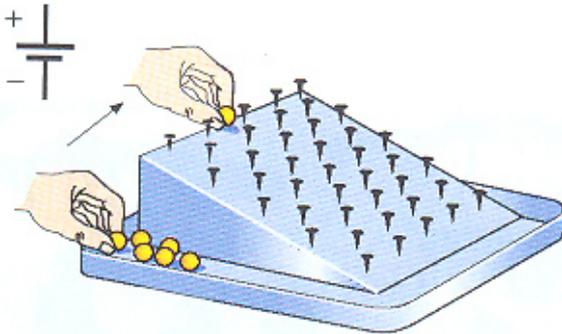
F II

Analogía mecánica R y  $\mathcal{E}$



(a)

Resistencia



(b)

Fuerza electromotriz



# Corriente eléctrica

**Fuerza electromotriz**

$$\mathcal{E} = \oint_C \mathbf{E} \cdot d\mathbf{l}$$

**Resistencia de una barra conductora**

$$\Delta V = RI, \text{ con } R = \frac{1}{\sigma} \frac{l}{A} = \rho \frac{l}{A}$$

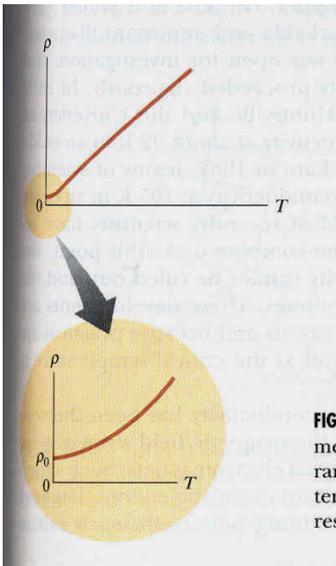
**Ley de Ohm macroscópica**



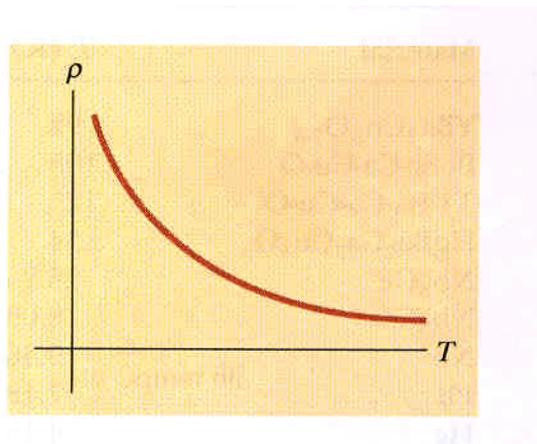
# Comportamiento con la temperatura

F II

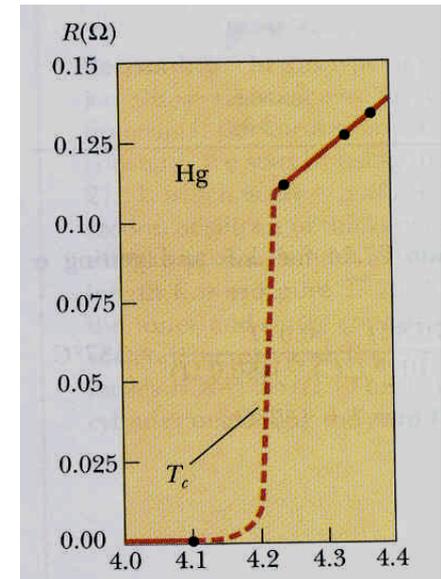
$$\rho = \rho_0 [1 + \alpha(T - T_0)]$$



**Conductor**



**Semiconductor**



**Superconductor**

# Propiedades eléctricas



F II

Configuración electrónica

Estructura cristalina

## PERIODIC TABLE OF THE ELEMENTS

Table of Selected Radioactive Isotopes

Table of Selected Radioactive Isotopes																	
Selected Radioactive Isotopes																	
Naturally occurring radioactive isotopes are designated by a mass number in blue (although some are also manufactured). Letter in parentheses indicates an isomer of another isotope of the same mass number. Half-lives follow in parentheses, where a, min, h, d, and y stand respectively for seconds, minutes, hours, days, and years. The table includes only the longer-lived radioactive isotopes; many others have been prepared isotopes known to be radioactive but with half-lives exceeding 10 <sup>10</sup> y have not been included. Symbols describe the principal mode for modes of decay are as follows (these processes are generally accompanied by gamma radiation):																	
α alpha particle emission β <sup>-</sup> beta particle (electron) emission β <sup>+</sup> positron emission EC orbital electron capture IT isomeric transition from upper to lower isomeric state or spontaneous fission																	
I		II		III		IV		V		VI		VII		VIII		IX	
GROUP IA		IIA		IIIA		IVA		VA		VIA		VIIA		VIIIA		IIB	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H	He	Li	Be	B	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	Ar
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104
Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

The A & B subgroup designations, applicable to elements in rows 4, 5, 6, and 7, are those recommended by the International Union of Pure and Applied Chemistry. It should be noted that some authors and organizations use the opposite convention in distinguishing these subgroups.

ATOMIC NUMBER	ATOMIC WEIGHT (2)	OXIDATION STATES (Bold most stable)	SYMBOL (1)	ELECTRON CONFIGURATION
30	65.38		Zn	[Ar]3d <sup>10</sup> 4s <sup>2</sup>
58	140.12		Ce	[Xe]4f <sup>1</sup> 5d <sup>1</sup> 6s <sup>2</sup>
59	140.907		Pr	[Xe]4f <sup>3</sup> 6s <sup>2</sup>
60	144.24		Nd	[Xe]4f <sup>4</sup> 6s <sup>2</sup>
61	145		Pm	[Xe]4f <sup>5</sup> 6s <sup>2</sup>
62	150.4		Sm	[Xe]4f <sup>6</sup> 6s <sup>2</sup>
63	151.96		Eu	[Xe]4f <sup>7</sup> 6s <sup>2</sup>
64	157.25		Gd	[Xe]4f <sup>7</sup> 5d <sup>1</sup> 6s <sup>2</sup>
65	158.9254		Tb	[Xe]4f <sup>9</sup> 6s <sup>2</sup>
66	162.50		Dy	[Xe]4f <sup>10</sup> 6s <sup>2</sup>
67	164.9303		Ho	[Xe]4f <sup>11</sup> 6s <sup>2</sup>
68	167.26		Er	[Xe]4f <sup>12</sup> 6s <sup>2</sup>
69	168.9348		Tm	[Xe]4f <sup>13</sup> 6s <sup>2</sup>
70	173.04		Yb	[Xe]4f <sup>14</sup> 6s <sup>2</sup>
71	174.967		Lu	[Xe]4f <sup>14</sup> 5d <sup>1</sup> 6s <sup>2</sup>
90	232.0381		Th	[Rn]6d <sup>2</sup> 7s <sup>2</sup>
91	231.0369		Pa	[Rn]5f <sup>2</sup> 6d <sup>1</sup> 7s <sup>2</sup>
92	238.0289		U	[Rn]5f <sup>3</sup> 6d <sup>1</sup> 7s <sup>2</sup>
93	237.0482		Np	[Rn]5f <sup>4</sup> 6d <sup>1</sup> 7s <sup>2</sup>
94	238.0289		Pu	[Rn]5f <sup>6</sup> 6d <sup>1</sup> 7s <sup>2</sup>
95	237.0482		Am	[Rn]5f <sup>7</sup> 7s <sup>2</sup>
96	243.0613		Cm	[Rn]5f <sup>7</sup> 6d <sup>1</sup> 7s <sup>2</sup>
97	247.0771		Bk	[Rn]5f <sup>7</sup> 6d <sup>2</sup> 7s <sup>2</sup>
98	251.1088		Cf	[Rn]5f <sup>10</sup> 7s <sup>2</sup>
99	252.0832		Es	[Rn]5f <sup>11</sup> 7s <sup>2</sup>
100	257.1037		Fm	[Rn]5f <sup>12</sup> 7s <sup>2</sup>
101	259.1037		Md	[Rn]5f <sup>13</sup> 7s <sup>2</sup>
102	259.1037		No	[Rn]5f <sup>14</sup> 7s <sup>2</sup>
103	260.1037		Lr	[Rn]5f <sup>14</sup> 6d <sup>1</sup> 7s <sup>2</sup>

NOTES:  
 (1) Black — solid.  
 Red — gas.  
 Blue — liquid.  
 Outline — synthetically prepared.  
 (2) Based upon carbon-12. (.) indicates most stable or best known isotope.  
 (3) Entries marked with asterisks refer to the gaseous state at 273 K and 1 atm and are given in units of g/l.

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# Relaciones energéticas

**F II**

**Potencia suministrada  
por una batería**

$$P_b = \mathcal{E}I$$

**Potencia disipada por  
una resistencia**

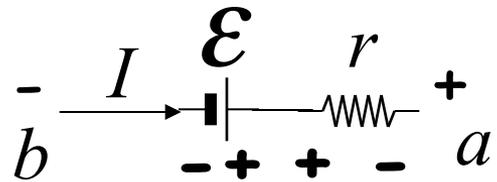
$$P_R = \Delta VI = RI^2 = \frac{V^2}{R}$$



# Generadores/Motores

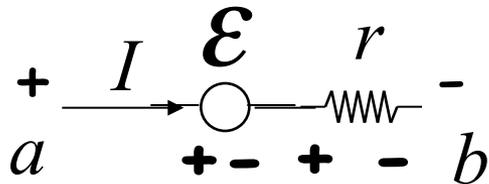
F II

**Bateria: energía química  $\longrightarrow$  energía eléctrica**



$$V_a - V_b = \mathcal{E} - rI$$

**Motor: energía eléctrica  $\longrightarrow$  energía mecánica**

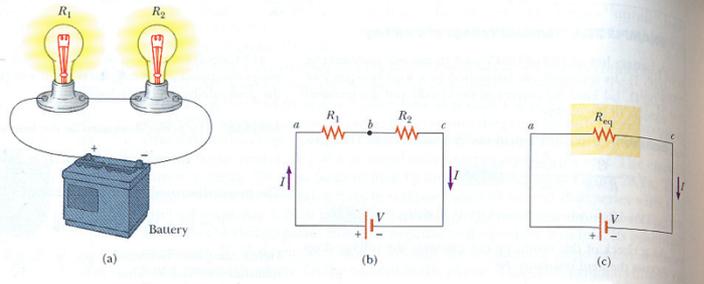


$$V_a - V_b = \mathcal{E} + rI$$



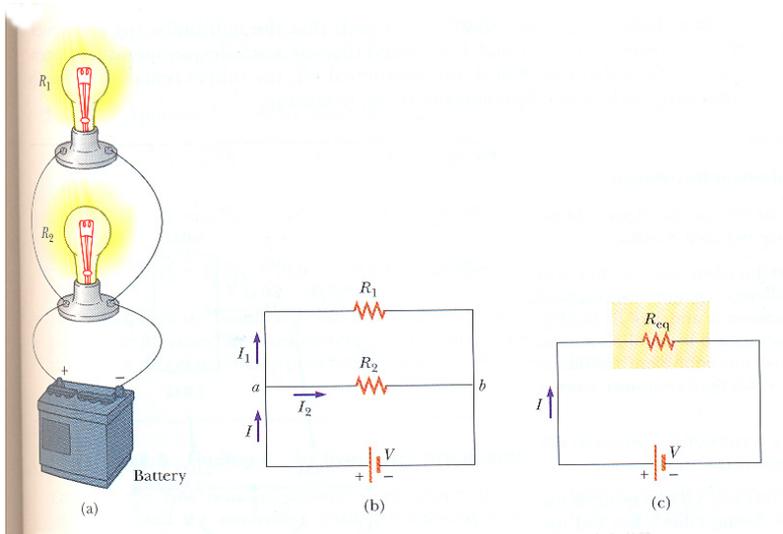
# Asociación de resistencias

## F II



### ➤ Serie

- Comparten corriente
- Distribuyen tensión



### ➤ Paralelo

- Comparten tensión
- Distribuyen corriente



# Asociación de resistencias

**F II**

$$R_T = \sum_i R_i$$

## ➤ Serie

- Comparten corriente
- Distribuyen tensión

$$\frac{1}{R_T} = \sum_i \frac{1}{R_i}$$

## ➤ Paralelo

- Comparten tensión
- Distribuyen corriente



# Circuitos de c.c.

**F II**

## Leyes de Kirchhoff

**1ª Ley de los nudos**

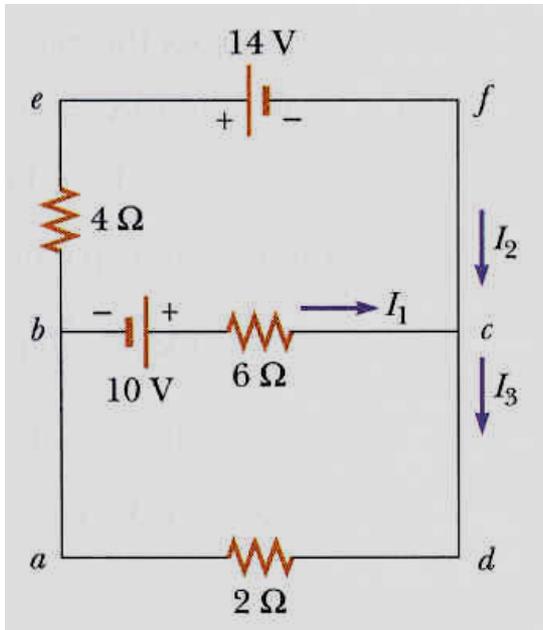
$$\sum_j I_j = 0$$

**2ª Ley de las mallas**

$$\sum \Delta V = 0$$



# Circuitos de c.c.



$$I_1 + I_2 - I_3 = 0$$

$$10 - 6I_1 - 2I_3 = 0$$

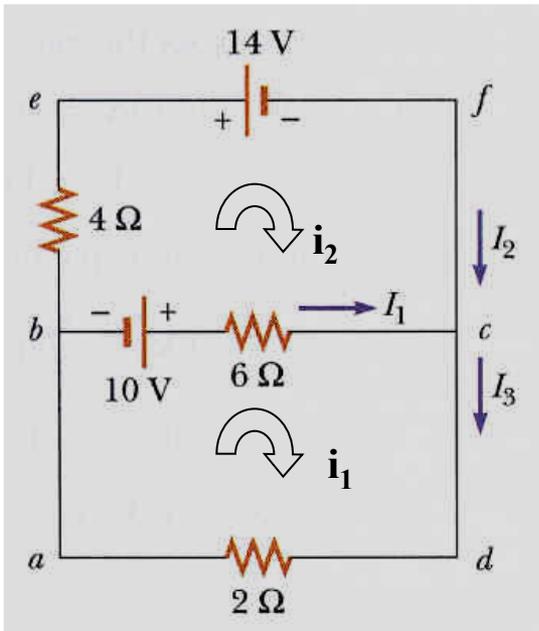
$$-14 - 10 + 6I_1 - 4I_2 = 0$$

$$I_1 = 2A, I_2 = -3A, I_3 = -1A$$



# Método de Mallas

F II



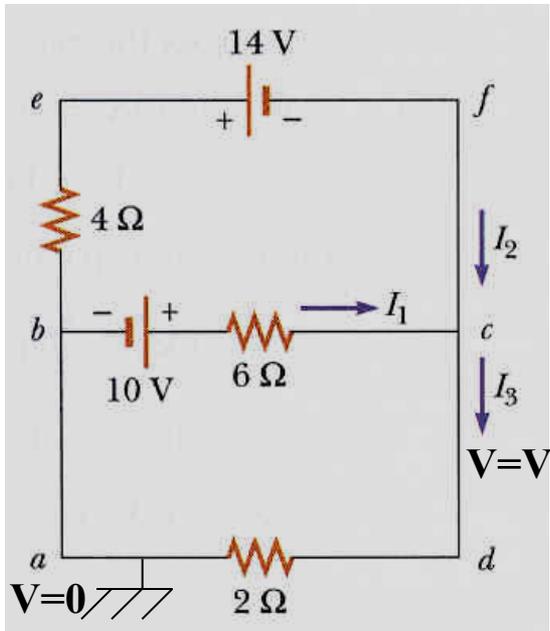
$$10 = 8i_1 - 6i_2$$
$$-24 = -6i_1 + 10i_2$$

$$i_1 = -1A, \quad i_2 = -3A$$



# Método de Nudos

## F II

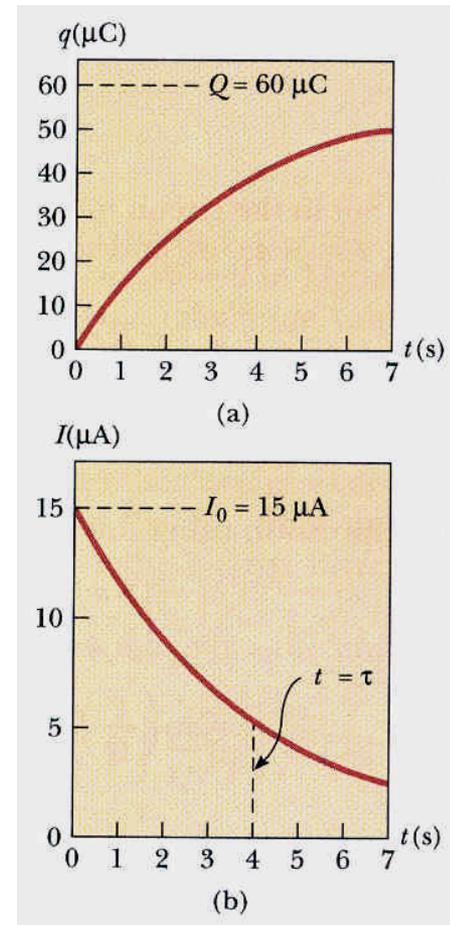
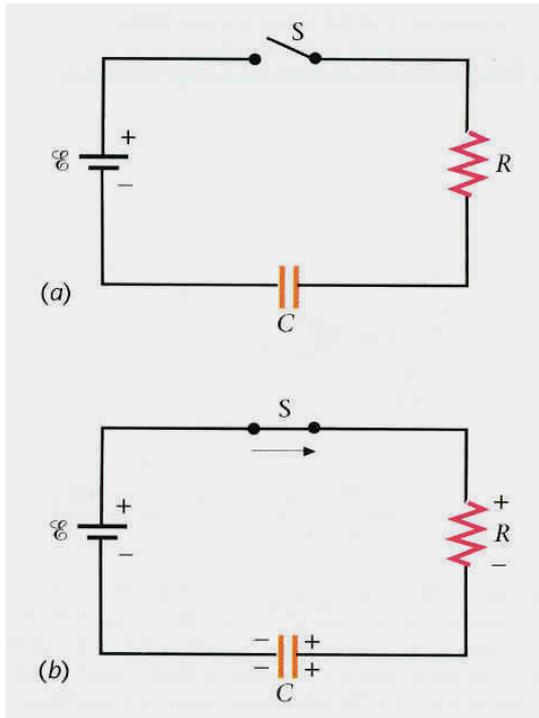


$$\frac{V + 14}{4} + \frac{V - 10}{6} + \frac{V}{2} = 0$$

$$V = -2 \text{ Voltios}$$



# Circuitos R-C





# Circuitos R-C

## FF II

Ley de las mallas

$$\mathcal{E} - \frac{q}{C} - IR = 0, \quad \frac{dq}{dt} + \frac{q}{RC} = \frac{\mathcal{E}}{R}$$

Solución ec. diferencial

$$q(t) = C\mathcal{E}\left(1 - e^{-t/RC}\right)$$

$$I(t) = \frac{\mathcal{E}}{R} e^{-t/RC}$$