Exam 1 is coming !

- Tues., Feb. 14 (Valentine's day - sorry), 12:30 to 1:55 pm, in this room.
- Covering 6 chapters (21-26)
- 18 multiple-choice questions
  - 15 conceptual/numerical problems, 1 point each
  - 3 questions are numerical (like homework problems) - 2 pts.
  - I will pass out formula4 sheets at the exam. Please familiarize yourself with it. Any constants needed will be given.
  - Personalized exams on CAPA
  - I will enter the grade on your Mastering Physics account ("Exam 1").
- Recovery points
  - Set 1 on sPH2435-04 opens Feb. 15 (Weds., noon) and closes Feb. 17 (Fri., 11:59 pm). Use the "old interface".
  - You need a 4-digit CAPA ID to access it. Will get this from on-class exam.
  - You must try to recover everything, not just the ones you missed. You must get a higher grade on the recovery exam to get any points added to your class score.
- What can I bring to the exam?
  - Pencil
  - eraser
  - calculator
  - That's all (no cell phones for example)

Exam 1 coverage

- Chapter 21: Electric Field and Charge
  - Coulomb’ Law
  - Electric Field Calculations
- Chapter 22: Gauss’ Law
  - Electric Flux
  - Applications
- Chapter 23: Electric Potential
  - Potential Energy
  - Electric Potential
- Chapter 24: Capacitance and Dielectrics
  - Series and Parallel Combinations
  - Effects of Dielectrics
- Chapter 25:Current, Resistance and EMF
  - Resistivity; Resistance
  - Energy and Power
- Chapter 26: DC Circuits
  - Kirchoff’s Rules
  - Measurement Devices
  - R-C Circuits

10 lectures (including this one)
8 homework sets
7 quizzes
1 exam

About 1/3 of the work

Chapter 21

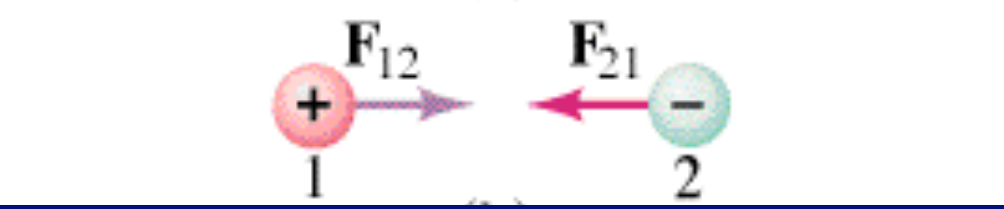
- Electric Charge
- Conductors and Insulators
- Coulomb's Law
- Electric Fields
- Electric Field and Force
- Electric Fields of Continuous Charge Distributions

Coulomb's Law

- Electric force is a field force (acts at a distance)

$$F = k\frac{Q_1 Q_2}{r^2}$$

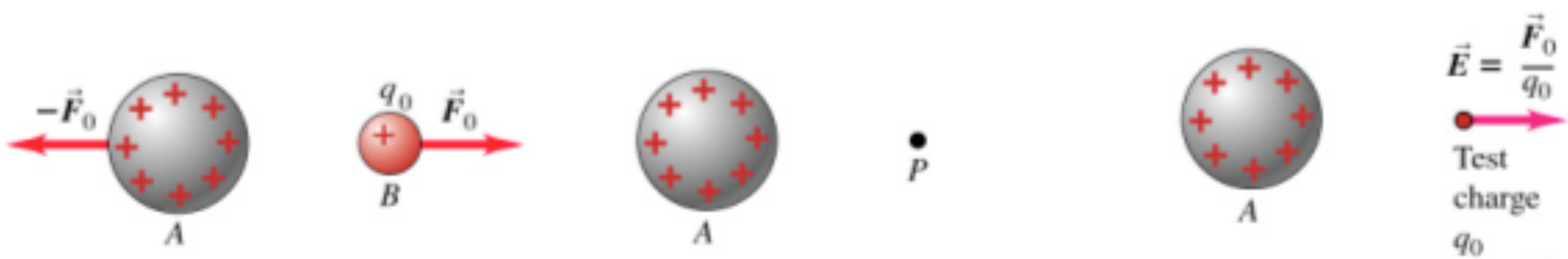
$k = 9 \times 10^9$ N m^2/C^2



The unit for charge is *Coulomb (C)*
The smallest charge: $e = 1.6 \times 10^{-19}$ C.
Two 1-C charges separated by 1 m has Coulomb force of 9×10^9 N!

- Note similarity in form to gravitational force: $F_g = G\frac{M_1 M_2}{r^2}$

The Concept of Electric Field



(a) How does charged body A exert a force on charged body B?

(b) Remove body B and label its former position as P

(c) Body A sets up an electric field $\vec{E}$ at point P: $\vec{E}$ is the force per unit charge exerted by A on a test charge at P

Move around a small test charge and see what electric force it feels!

Definition of the Electric Field:

$$\vec{E} = \frac{\vec{F}}{q_0}$$

- Since ***F*** is a vector, ***E*** is a vector
  - ***field direction*** = direction of force on a small ***positive*** "test" charge

Electric field of a point charge

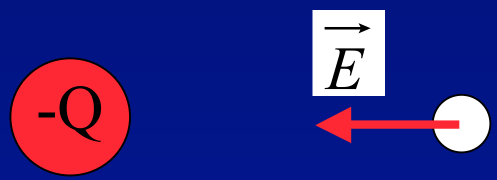
- **Coulomb's law:**

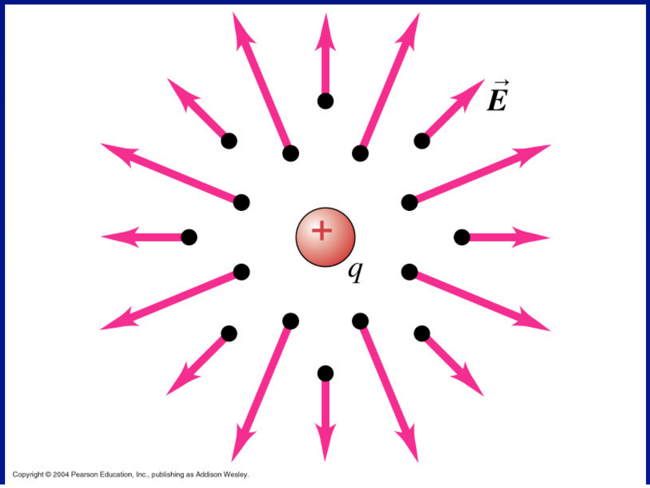
$$F = k\frac{Qq_0}{r^2}$$

- **What about direction?**

- **Electric field:**

$$E = k\frac{Q}{r^2}$$





- Superposition principle

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots$$

Example: A ring of charge

$$E = \int dE_x = \int dE\cos\theta = k\lambda \int \frac{dl}{r^2}\cos\theta$$

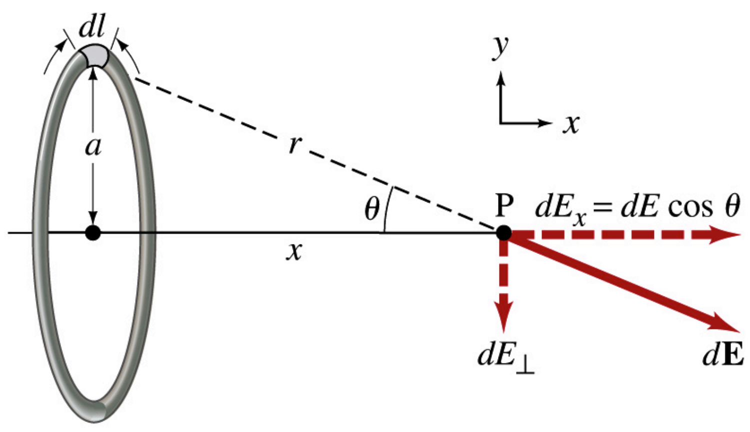
$$\text{Use } \cos\theta = x/r, \quad \text{and} \quad r^2 = x^2 + a^2$$

$$E = \frac{k\lambda x}{(x^2+a^2)^{3/2}} \int_0^{2\pi a} dl = \frac{kQx}{(x^2+a^2)^{3/2}}$$

Special cases:

1) At $x = 0$, $E = 0$

2) At $x >> a$, $E = k\dfrac{Q}{x^2}$



Chapter 22

- Electric Flux
- Gauss's law
- Applications
  - Uniform Charged Sphere
  - Infinite Line of Charge
  - Infinite Sheet of Charge
  - Two infinite sheets of charge

Electric Flux

For uniform field, if E and A are perpendicular, define

$$\Phi_E = EA$$

If E and A are NOT perpendicular, define scalar product

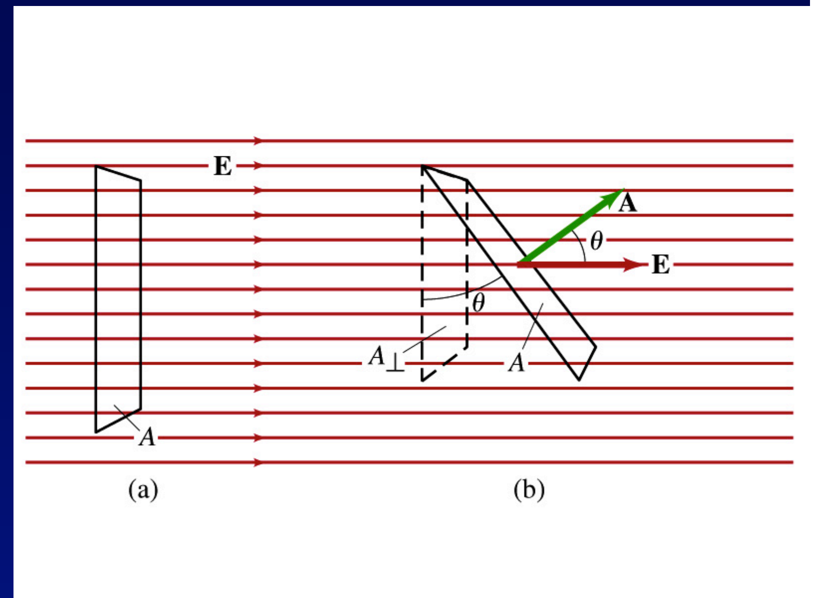
$$\Phi_E = EA\cos\theta = \vec{E}\cdot\vec{A}$$

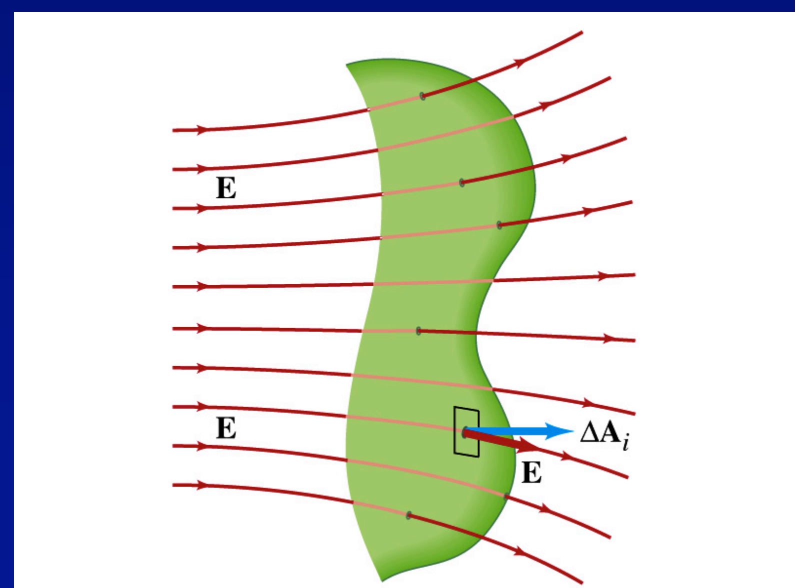
General (surface integral)

$$\Phi_E = \int \vec{E}\cdot d\vec{A}$$

Unit of electric flux: N . m^2 / C

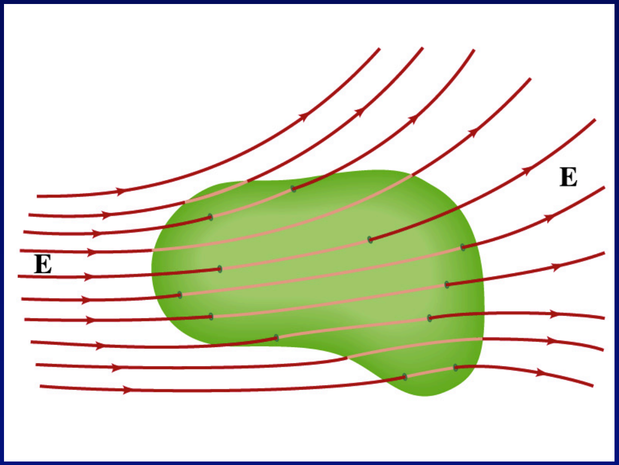
- Electric flux is proportional to the number of field lines passing through the area.

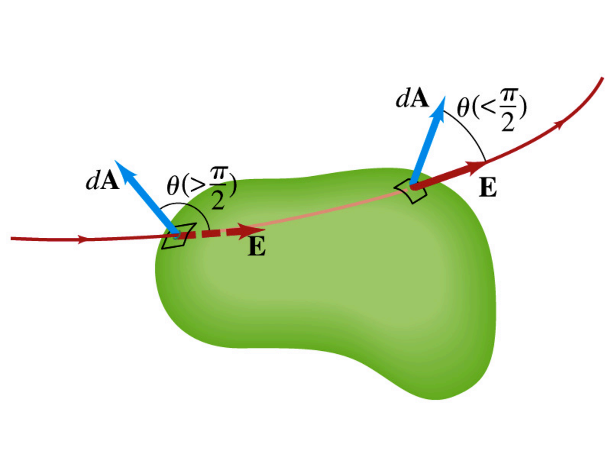




Electric Flux: closed surface

$$\Phi_E = \oint \vec{E} \cdot d\vec{A}$$

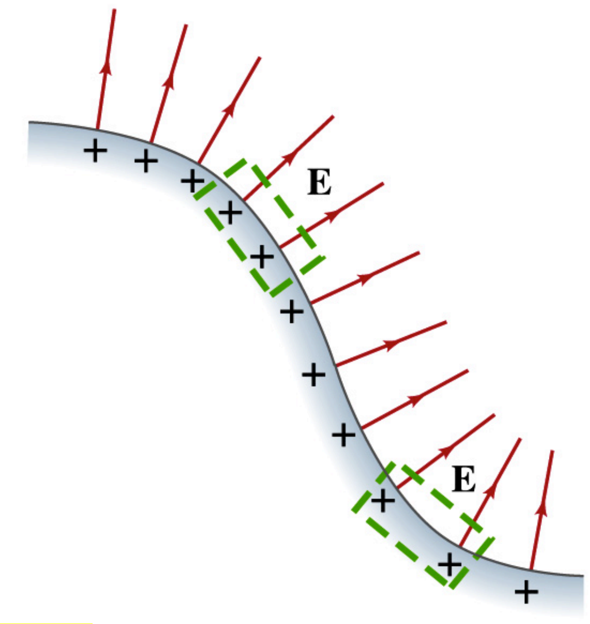




- Flux entering is negative
- Flux leaving is positive

Electric Field near surface of Conductor

- Choose small cylindrical Gaussian box as shown:
  - One end just outside
  - One end just inside
  - The barrel is normal to the surface
- Flux at the end inside is zero
- Flux on the barrel is zero



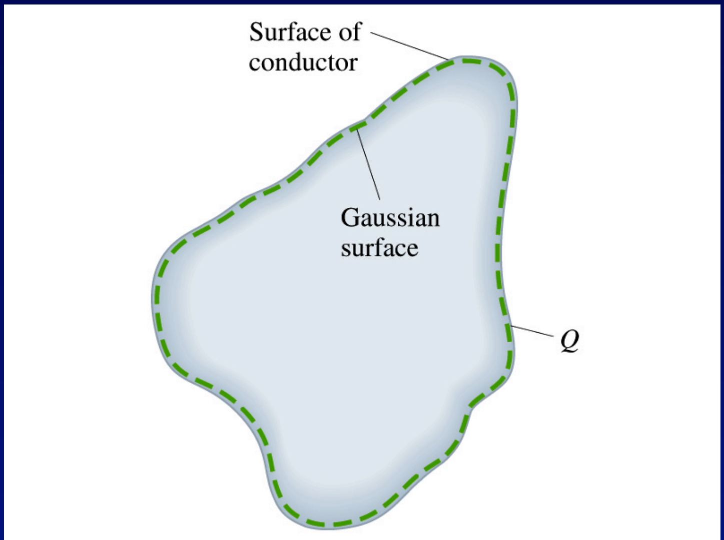
$$\oint \vec{E} \cdot d\vec{A} = EA = Q / \varepsilon_0 = \sigma A / \varepsilon_0$$

$$E = \frac{\sigma}{\varepsilon_0}$$

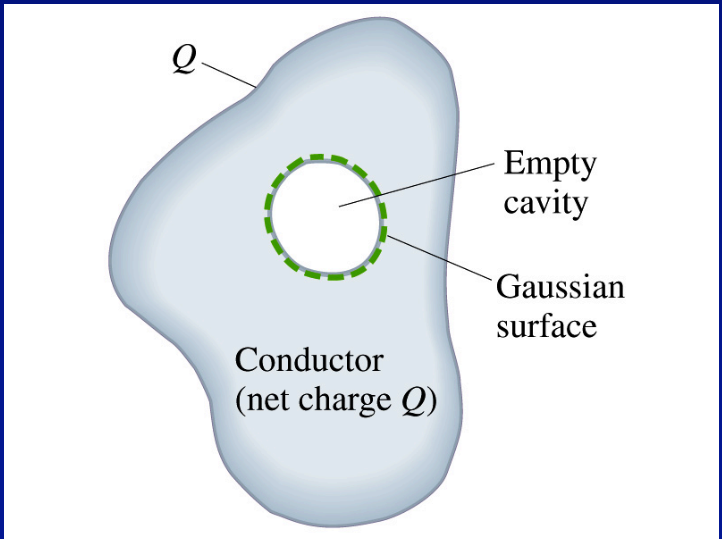
Valid near the surface of conductor of any shape

Charges on a Conductor
(the view from Gauss's Law)

- The E must be zero inside the conductor even if it carries a net charge.

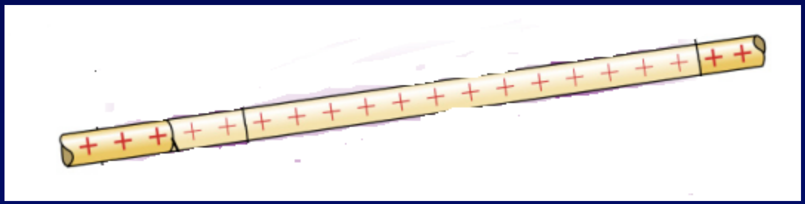


- Any net charge on a conductor must all reside on its outside surface.



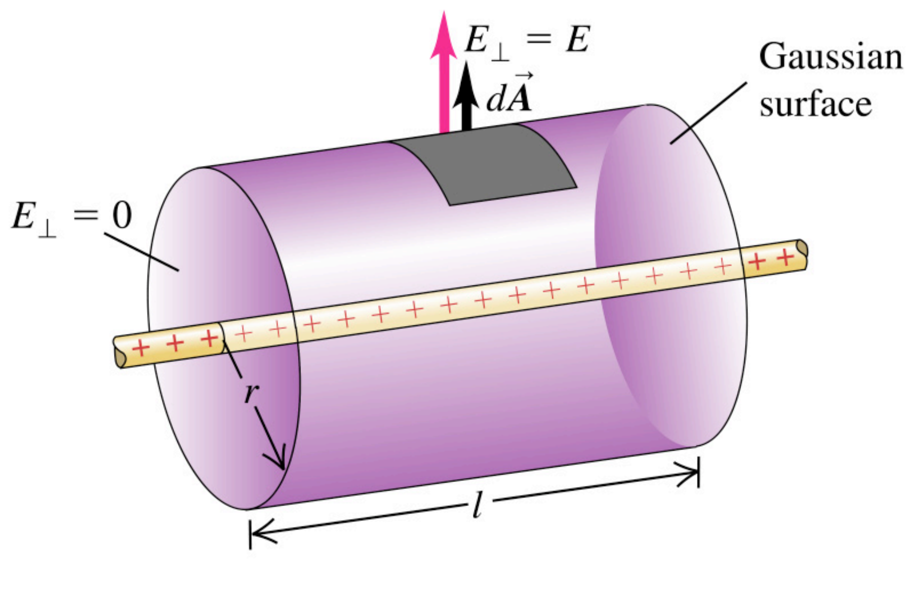
Field of a long line charge

- Electric charge is distributed along a infinitely long, thin wire. The charge per unit length is λ. (assumed positive). Find the electric field around the wire.



This problem has cylindrical symmetry. The E field must be perpendicular to the line.

Choose the Gaussian surface to be a cylinder of radius r and length l (a soda can), with the line as the axis.



The flux through the two ends is zero.

The flux through the side is $(2\pi r\, l)\, E$.

The total charge enclosed is $q = \lambda l$.

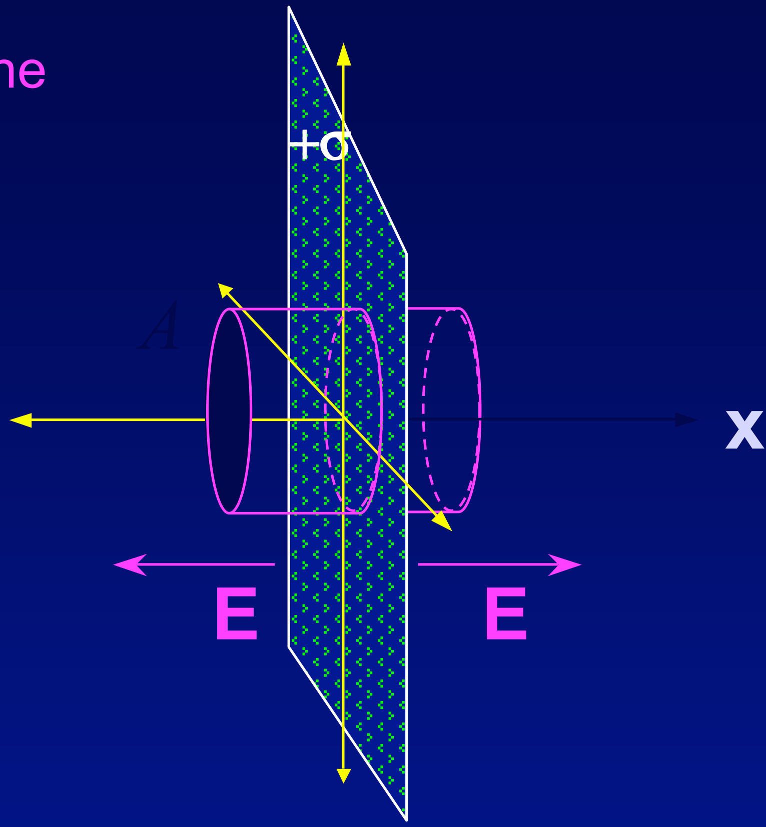
So by Gauss's law $(2\pi r\, l)\, E = \lambda l / \varepsilon_0$.

Or

$$E = \frac{1}{2\pi\varepsilon_0}\frac{\lambda}{r} = \frac{2k\lambda}{r}$$

Infinite sheet of charge

- Symmetry: direction of E is normal to the sheet



- Therefore, CHOOSE Gaussian surface to be a cylinder whose axis is aligned with the x-axis.

- **Apply Gauss' Law:**
  - On the barrel, flux is zero.
  - On the ends, $\oint \vec{E} \bullet d\vec{S} = 2AE$
  - The charge enclosed = σA

Therefore, Gauss' Law $\Rightarrow$ $2EA = \sigma A / \varepsilon_0$ $\Rightarrow$ $E = \dfrac{\sigma}{2\varepsilon_0}$

Conclusion: An infinite plane sheet of charge creates a **CONSTANT** electric field .

Chapter 23

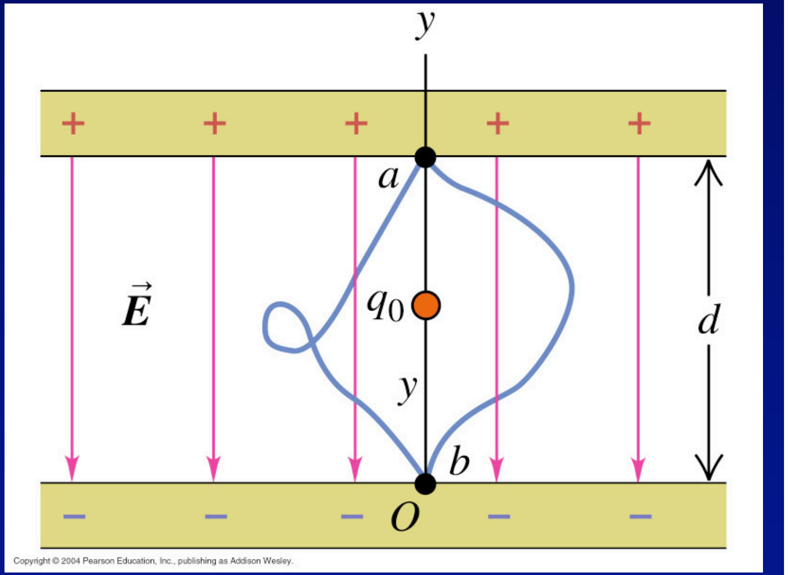
- Electric Potential Energy
- Electric Potential
  - Point charges
  - Charge distributions
- Equipotential Surfaces
- Relation between electric field and electric potential
  - How to get V from E?
  - How to get E from V?

Conservative Forces and Potential Energy

- Conservative force
  - Work done by a conservative force does not depend on the path. It only depends on the initial and final points.

- Define potential energy function *U* via the work done by a conservative force *F* in the following way:

$$W = \int_1^2 \vec{F} \cdot d\vec{l} = U_1 - U_2 = -\Delta U$$



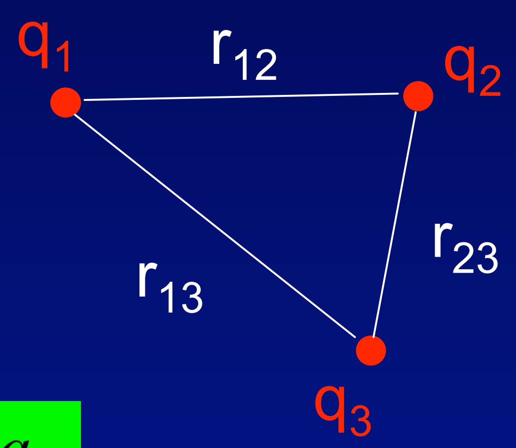
The work done by a conservative force is equal to the decrease in the potential energy function.

Electric Potential Energy in a System of Charges

For a pair of charges

$$U = k\frac{q_1 q_2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

For a system of 3 charges



$$U = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right)$$

Generalization to N charges

$$U = \frac{1}{4\pi\varepsilon_0}\sum_{i<j}^{N}\frac{q_i q_j}{r_{ij}}$$

Avoid double-counting. Watch for sign of charges.

Physical meaning of U: the total work done by us to assemble the charges from infinity to the present configuration.

The Concept of Electric Potential

- Definition: potential is defined as potential energy per unit charge:
- SI unit: volt.   1 V = 1 J/C

$$V = \frac{U}{q_0}$$

For example: the potential energy between two point charges

$$U = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r}$$

Therefore, the potential of point charge q is

$$V = \frac{U}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

For a system of point charges:

$$V = \frac{U}{q_0} = \frac{1}{4\pi\varepsilon_0}\sum_i \frac{q_i}{r_i}$$

(algebraic sum)

Potential is a scalar. There's no direction to worry about.
But you do have to watch about the sign of charges.

Examples of Conservative Forces and Potential Energies

Force F	Work done $W_{1\text{->}2}$	Change in potential energy $\Delta U = U_2 - U_1$	Potential energy function U
$\vec{F} = -mg\,\hat{j}$	$-mg(y_2 - y_1)$	$mg(y_2 - y_1)$	mgy
$\vec{F} = -G\dfrac{m_1 m_2}{r^2}\hat{r}$	$Gm_1m_2\left\{\dfrac{1}{r_2} - \dfrac{1}{r_1}\right\}$	$-Gm_1m_2\left\{\dfrac{1}{r_2} - \dfrac{1}{r_1}\right\}$	$-\dfrac{Gm_1m_2}{r}$
$\vec{F} = -kx\,\hat{i}$	$-\dfrac{1}{2}k\left\{x_2^2 - x_1^2\right\}$	$\dfrac{1}{2}k\left\{x_2^2 - x_1^2\right\}$	$\dfrac{1}{2}kx^2$
$\vec{F} = q\vec{E}$	$-qE(y_2 - y_1)$	$qE(y_2 - y_1)$	qEy
$\vec{F} = k\dfrac{q_1q_2}{r^2}\hat{r}$	$-kq_1q_2\left(\dfrac{1}{r_2} - \dfrac{1}{r_1}\right)$	$kq_1q_2\left(\dfrac{1}{r_2} - \dfrac{1}{r_1}\right)$	$k\dfrac{q_1q_2}{r}$

Potential energy is a relative concept: only the difference in potential energy is meaningful.

Potential of a point charge

- The field is radial, with a magnitude

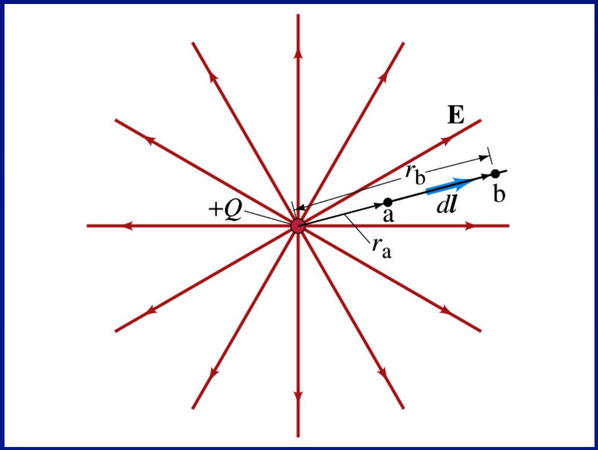
$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

- Choose the line along the normal line, then the line integral becomes

$$V_a - V_b = \int_a^b \vec{E}\cdot d\vec{l} = \int_a^b E dr = \int_{r_a}^{r_b} \frac{Q}{4\pi\varepsilon_0}\frac{dr}{r^2} = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r_a} - \frac{1}{r_b}\right)$$

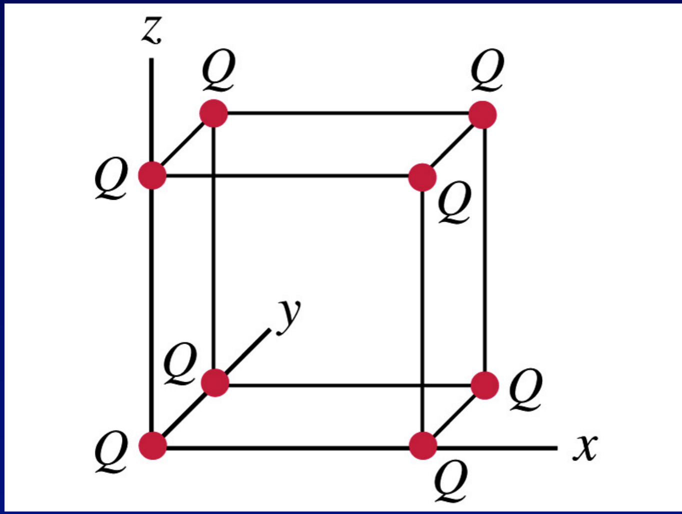
- Choose reference point: $V_b=0$ at r_b=infinity.

$$V(r) = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

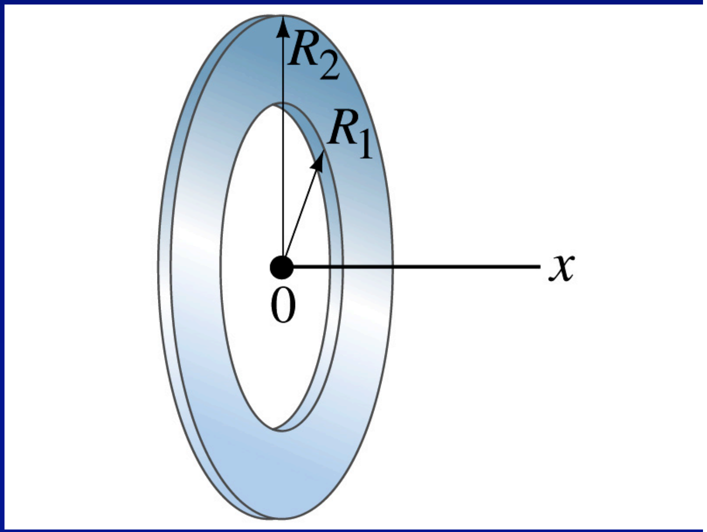


Electric Potential from Continuous Charge Distributions

$$\text{discrete}: \quad V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{Q_i}{r_i}$$

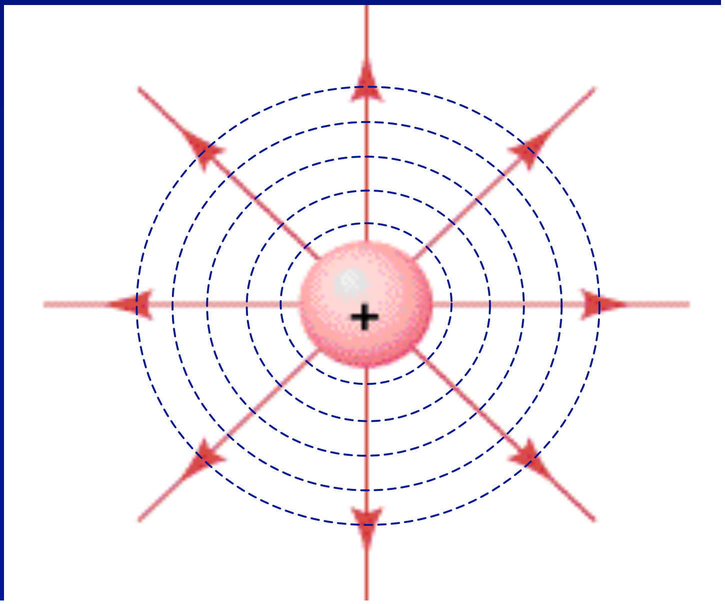


$$\text{continuous}: V = \frac{1}{4\pi\varepsilon_0} \int \frac{dq}{r}$$



Equipotential Surfaces

- contours of constant potential
  - all points on the contour have the same value of V
- no work is required to move charge along an equipotential surface
  - $W = -\Delta PE = -q(V_B - V_A) = 0$ if $V_B = V_A$
- $\vec{E} \perp$ equipotential surface



How to get V from $\vec{E}$?

$$V_b - V_a = \frac{U_b - U_a}{q_0} = -\frac{W_{ab}}{q_0} = -\frac{\int_a^b \vec{F} \cdot d\vec{l}}{q_0} = -\int_a^b \vec{E} \cdot d\vec{l}$$

$$V_a - V_b = \int_a^b \vec{E} \cdot d\vec{l}$$

Potential difference is equal to the line integration over field over any path that connects the two points.

(In practice, pick the line that makes the integral the easiest to do)

€

Another unit for electric field: volt / meter

1 V/m = 1 N/C

How to get $\vec{E}$ from V ?

- We can obtain the electric field E from the potential V by inverting our previous relation between E and V:

$$V_a - V_b = \int_a^b \vec{E} \cdot d\vec{l}$$

$$-dV = \vec{E} \cdot d\vec{l} = E_x dx + E_y dy + E_z dz$$

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

- **Expressed as a vector, E is the negative gradient of V**

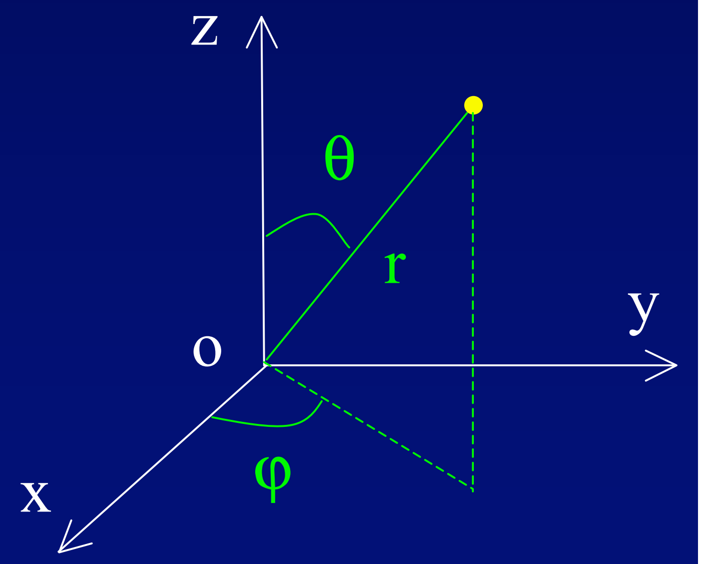
$$\vec{E} = -\vec{\nabla} V$$

Cartesian coordinates:

$$\vec{\nabla} V = \frac{\partial V}{\partial x}\hat{x} + \frac{\partial V}{\partial y}\hat{y} + \frac{\partial V}{\partial z}\hat{z}$$

Spherical coordinates:

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

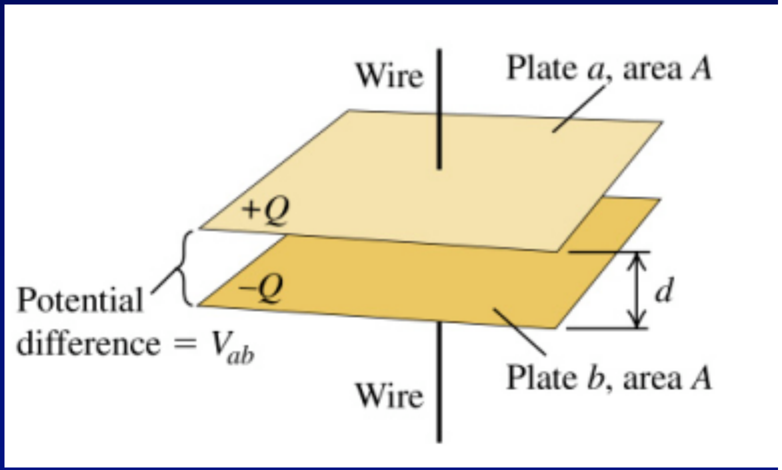


Chapter 24

- **Definition of Capacitance**
  - Parallel Plate Capacitor
  - Cylindrical Capacitor
  - Spherical Capacitor
- **Example Calculations**
  - Capacitors in Parallel
  - Capacitors in Series
- **Combinations of Capacitors**
- **Energy in Capacitors**
- **Dielectrics**

Capacitors

- device to store charge and energy
- connect capacitor to battery (V)
  - plates become charged (Q)



charge ∝ potential difference

$$Q = C\,V$$

- C is called *capacitance*
  - units: coulomb / volt ≡ Farad
  - larger C ⇒ bigger Q (fixed V) ("capacity" to hold charge)

Example: Parallel Plate (the simplest capacitor)

- The electric field in between is

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}$$

The potential difference is

$$V = Ed = \left(\frac{d}{\varepsilon_0 A}\right) Q$$

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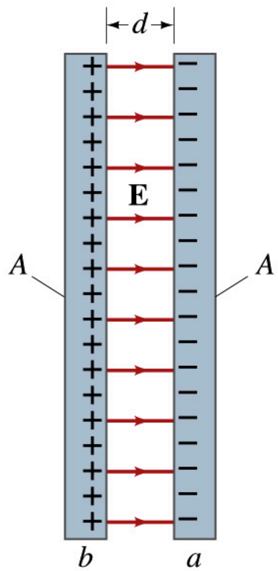
Thus from $C = \frac{Q}{V}$, we get



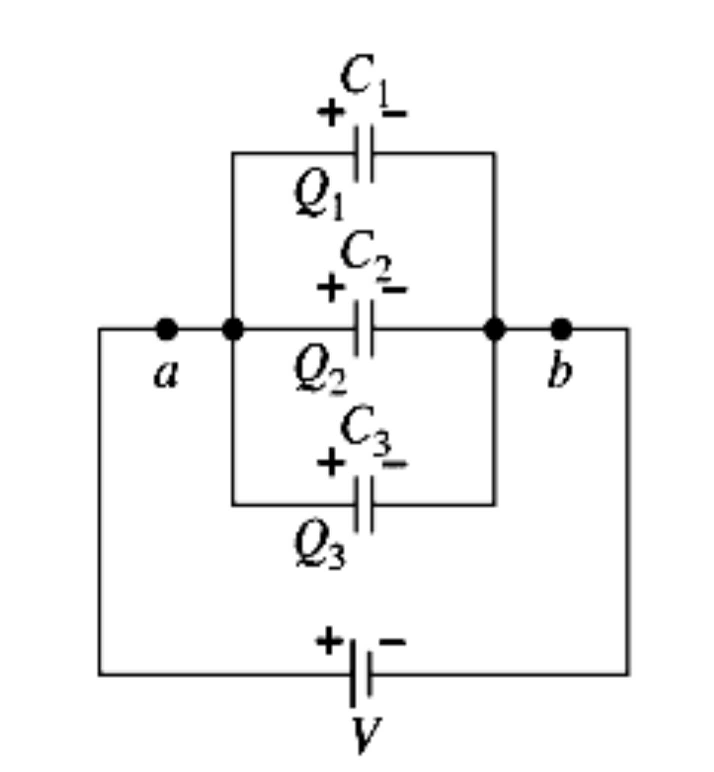
$$C = \varepsilon_0 \frac{A}{d}$$

Capacitance only depends on the geometry.

$\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/N\text{-}m^2$ (permittivity of free space)

Capacitors in parallel

- Potential difference between points *a* and *b* is the *same* for all 3 capacitors
  - $V_1 = V_2 = V_3 = V$



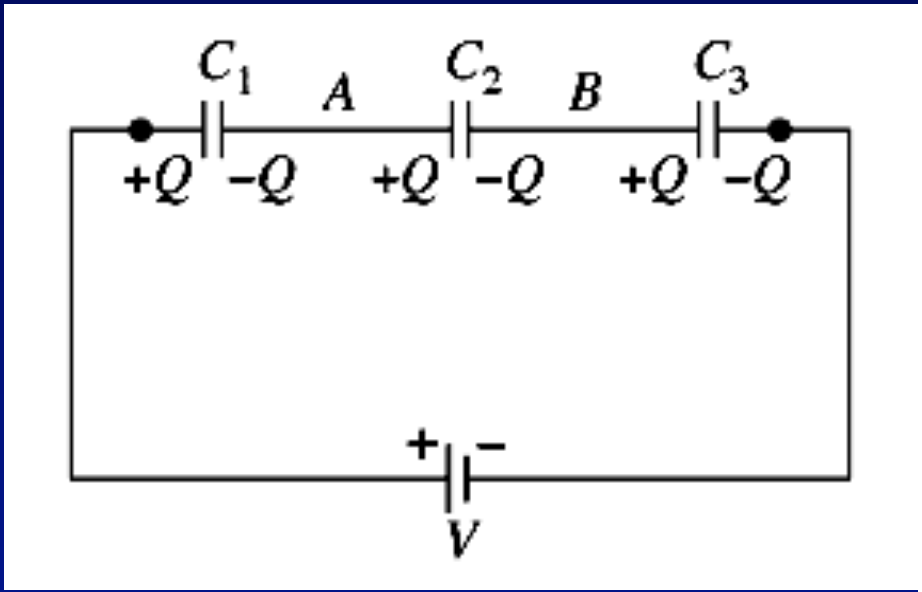
- However, charges add:
  - $Q_1 + Q_2 + Q_3 = Q$
- Since $Q = C\,V$, we have
  - $C_1V + C_2V + C_3V = CV$

$$C = C_1 + C_2 + C_3$$

C is called an equivalent capacitor.

Capacitors in series

- Each capacitor has to hold the *same charge:*
  - $Q_1 = Q_2 = Q_3 = Q$



- However, voltages add:
  - $V_1 + V_2 + V_3 = V$

- Since *V = Q/C, we have*
  - $Q/C_1 + Q/C_2 + Q/C_3 = Q/C$

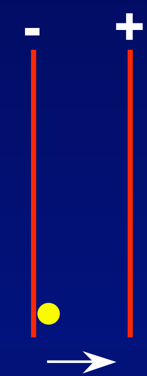
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Energy of a Capacitor

- How much energy is stored in a charged capacitor?
  - Calculate the work provided (usually by a battery) to charge a capacitor to +/- Q:

Calculate incremental work dW needed to add charge dq to capacitor at voltage V:

$$dW = dq(V) = dq\left(\frac{q}{C}\right)$$



- **The total work W to charge to Q is then given by:**

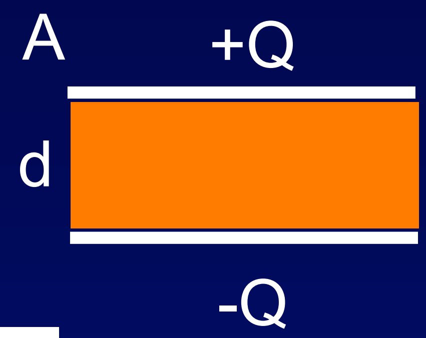
$$W = \frac{1}{C}\int_0^Q q\,dq = \frac{1}{2}\frac{Q^2}{C}$$

$$U = \frac{1}{2}\frac{Q^2}{C}$$

- **Since Q=CV, we can write:**

$$U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$$

Dielectrics



$$\text{permittivity of vacuum}: \varepsilon_0$$

$$\text{permittivity of dielectric}: \quad \varepsilon = K\varepsilon_0$$

Replace everywhere: $\varepsilon_0 \Rightarrow \varepsilon = K\varepsilon_0$

For example: $C_0 = \varepsilon_0 \dfrac{A}{d} \Rightarrow C = \varepsilon \dfrac{A}{d} = KC_0$

For constant Q, electric field $E_0=\sigma/\varepsilon_0$. With dielectrics: $E=\sigma/\varepsilon = E_0/K$. Then $V=Ed=V_0/K$. Then $U=1/2\ QV=K^{-1}\ U_0$.

For constant V, electric field $E_0=V/d$. With dielectrics: $E= E_0$. Then $E_0=\sigma/\varepsilon_0$, so $Q = KQ_0$. Then $U=1/2\ QV=K\ U_0$.

Chapter 25

- Electric current
- Resistance and Resistivity
  - *Ohm's Law*
- Electric motive force
  - Battery
  - Simple circuits
  - Energy and power in circuits

Electric Current

- The presence of electric field leads to a force on a free charge:

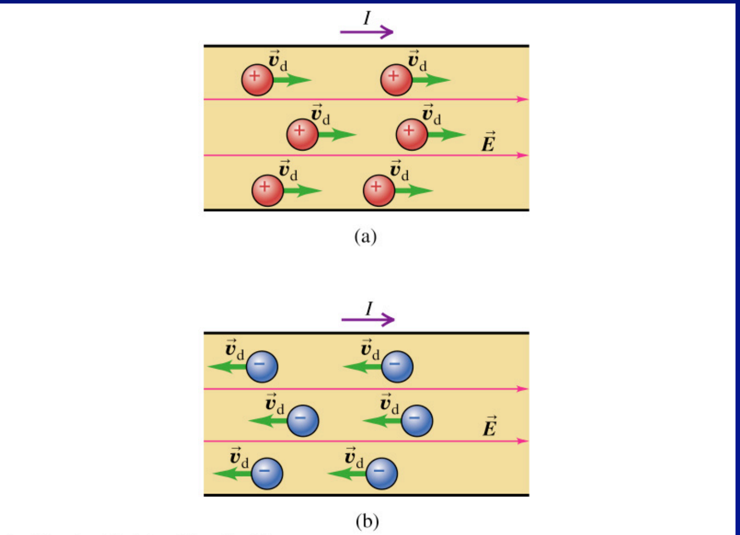
$$\vec{F} = q\vec{E}$$

- The motion of charges leads to an *electric current:*

$$I = \frac{dQ}{dt}$$

- SI unit: *Coulomb/second = Ampere*
- *1 A = 1 C/s*

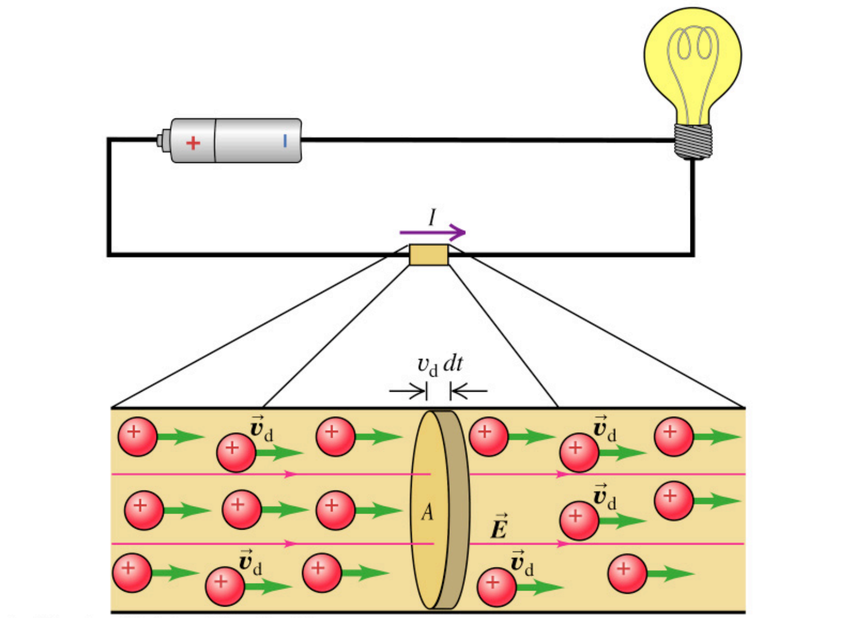
- The same current can be produced by motion of *positive charge or negative charge.*



Current: microscopic view

Current can be related to the drift velocity of moving charges:

$$I = \frac{dQ}{dt} = n\,|\,q\,|\,v_d A$$



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n is the number of free charges per unit volume.

Define current density:

$$J = \frac{I}{A} = n\,|\,q\,|\,v_d$$

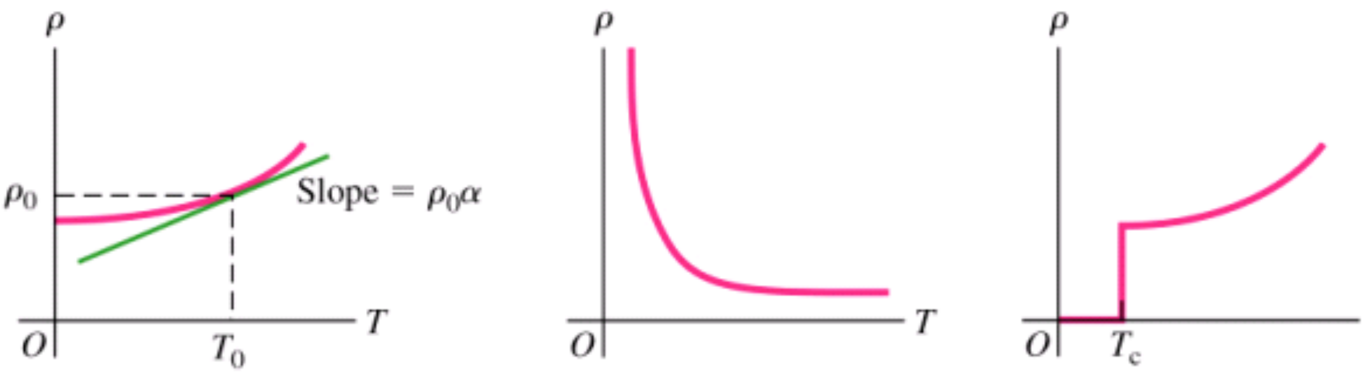
Or in vector form

$$\vec{J} = nq\vec{v}_d$$

Temperature dependence of Resistivity

- The resistivity of a material depends on ***temperature.***

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



(a) Metal: ρ increases with increasing T

(b) Semiconductor: ρ decreases with increasing T

(c) Superconductor: ρ = 0 for T < Tc

Table 25.2 Temperature Coefficients of Resistivity (Approximate Values Near Room Temperature)

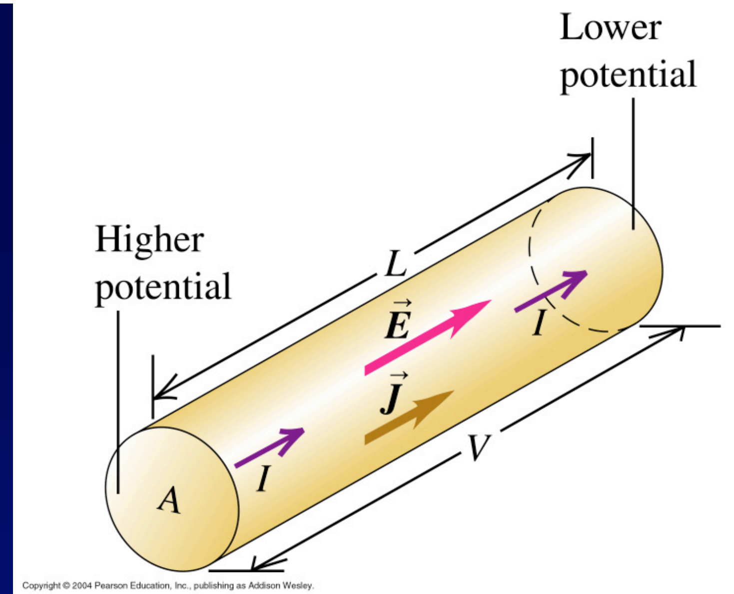
Material	$\alpha\,[(^\circ C)^{-1}]$	Material	$\alpha\,[(^\circ C)^{-1}]$
Aluminum	0.0039	Lead	0.0043
Brass	0.0020	Manganin	0.00000
Carbon (graphite)	−0.0005	Mercury	0.00088
Constantan	0.00001	Nichrome	0.0004
Copper	0.00393	Silver	0.0038
Iron	0.0050	Tungsten	0.0045

Resistance

- Consider a piece of wire

$$I = JA \qquad V = EL \qquad E = \rho J$$

$$V = \frac{\rho L}{A} I$$



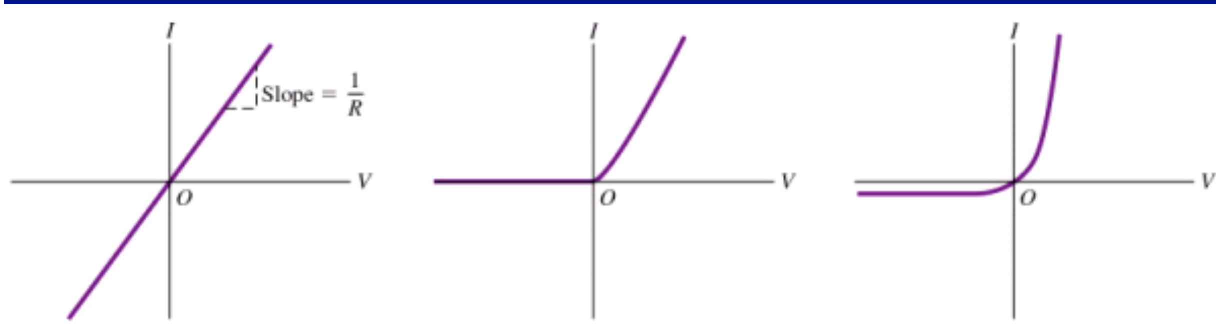
Resistance $$R = \frac{\rho L}{A}$$

Same temperature dependence as ρ

$$R(T) = R_0\left[1 + \alpha (T - T_0)\right]$$

Ohm's Law $$V = IR$$

SI unit: 1 V/A = 1 Ω (ohm)



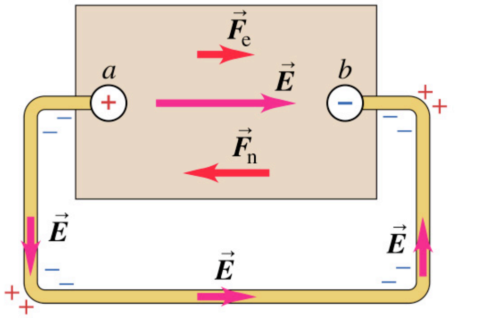
(a) Resistor that obeys Ohm's law

(b) Vacuum diode (does not obey Ohm's law)

(c) Semiconductor diode (does not obey Ohm's law)

Electromotive Force (EMF)

- To sustain a current flow, there must be a source that can convert other forms of energy into electric potential energy
  - batteries
  - electric generators
  - solar cells
  - …
- The voltage such a source produces is called an emf, denoted by $\mathcal{E}$.



Source of emf connected to a complete circuit: electric-field force $\vec{F}_e$ has a smaller magnitude than non-electrostatic force $\vec{F}_n$

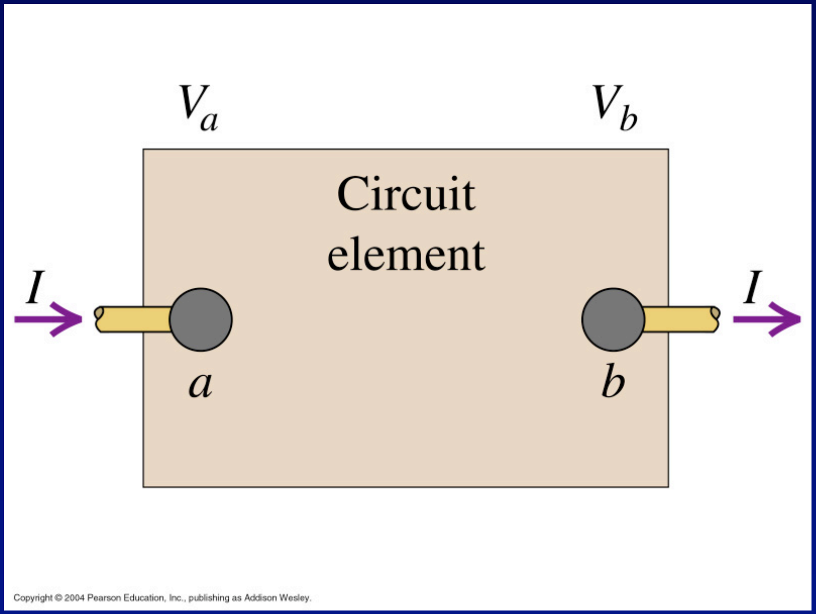
Terminal voltage: $V_{ab} = \mathcal{E}$ **(perfect)**

$V_{ab} = \mathcal{E} - Ir$ **(internal resistance)**

Energy and Power in Electric Circuits

- The work done to move charge $dQ = I\,dt$ across a potential difference of V_{ab} is $dW = V_{ab}\,dQ = V_{ab}\,I\,dt$. Therefore the power delivered is

$$P = IV_{ab}$$



For a pure resistor that obeys $V=IR$, one can write

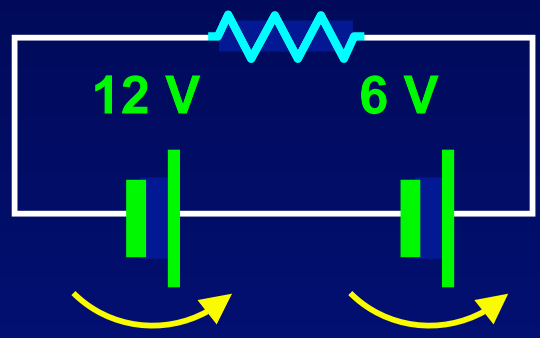
$$P = IV_{ab} = I^2R = \frac{V_{ab}^2}{R}$$

Chapter 26

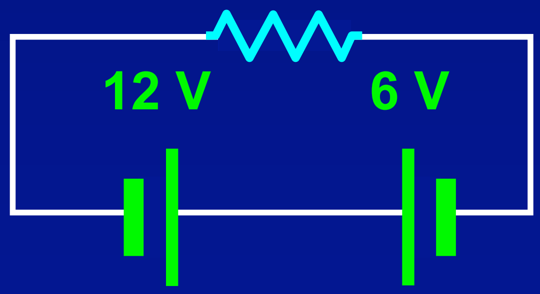
- Batteries in Series and Parallel
- Resistors in Series and Parallel
- Kirchoff's Rules
- Electrical measuring Instruments
- RC Circuits
- Electrical Safety

Batteries in series

- **Batteries in series:**
  - first battery does work on charge
  - second battery does <u>more</u> work
    - » voltages add (18 V across R)

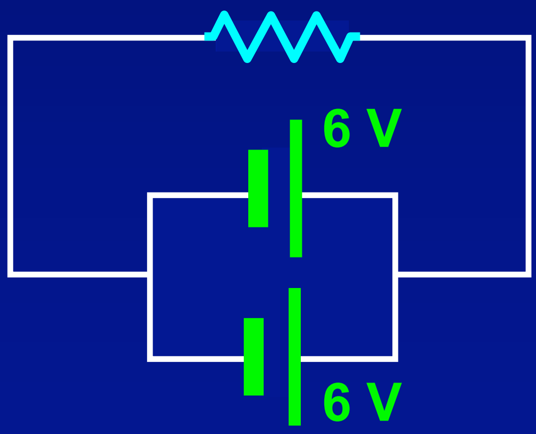


- **Batteries in series:**
  - first battery does work on charge
  - charge <u>does work</u> on <u>second battery</u>
    - » voltages subtract (6 V across R)
    - » second battery is being charged by the first one



Batteries in parallel

- Batteries in parallel:
  - each charge only goes through one of the batteries
    - » voltage is the same (6 V across R)
  - but each battery does less work (since only some of the charge goes through it)
    - » Batteries last longer
    - » Can be used to recharge

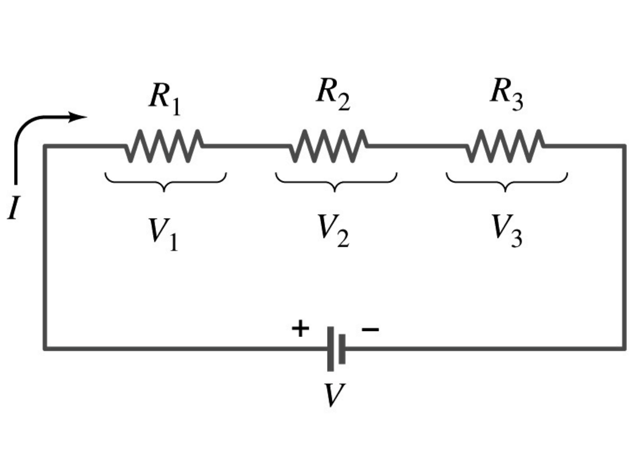


Resistors in series

- Same charge has to flow through all the resistors

  same current: $I_1 = I_2 = I_3 = I$

- Total work done by battery must equal sum of energy lost as charge moves through resistors
  - voltages add: $V = V_1 + V_2 + V_3$



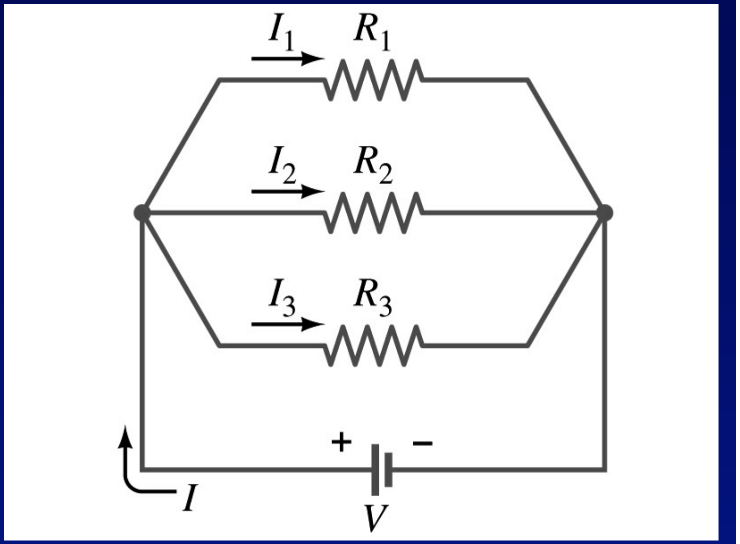
- Ohm's Law, V = I R, gives:

$$IR_{eq} = IR_1 + IR_2 + IR_3$$

$$R_{eq} = R_1 + R_2 + R_3$$

Resistors in parallel

- Current splits up into several branches. However, total current must be conserved!
  - currents add: $I = I_1 + I_2 + I_3$



- But the voltage is the same across each resistor
  - $V = V_1 = V_2 = V_3$

- From Ohm's Law, V = I R, we find:

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

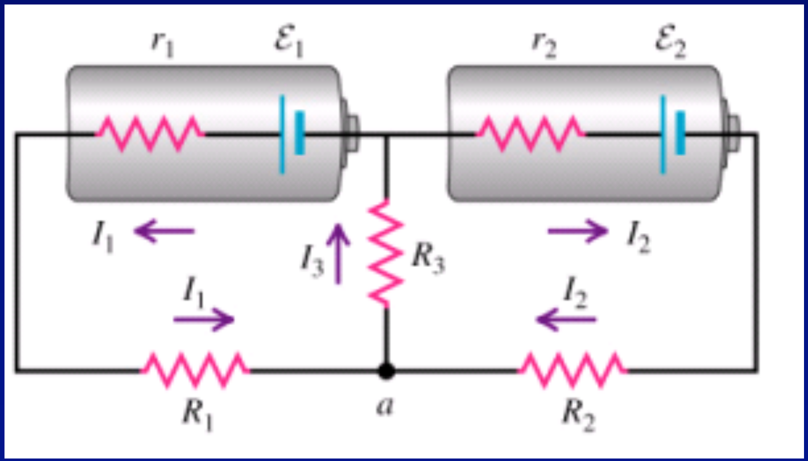
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Kirchhoff's Junction Rule

- **At any junction point, the sum of all currents entering the junction must equal the sum of all currents leaving.**

(or: what goes in has to come out!)

$$I_3 = I_1 + I_2$$



This rule follows from *conservation of charge* !

Kirchhoff's Loop Rule

- "The sum of voltage drops and gains around any closed circuit loop must be zero"

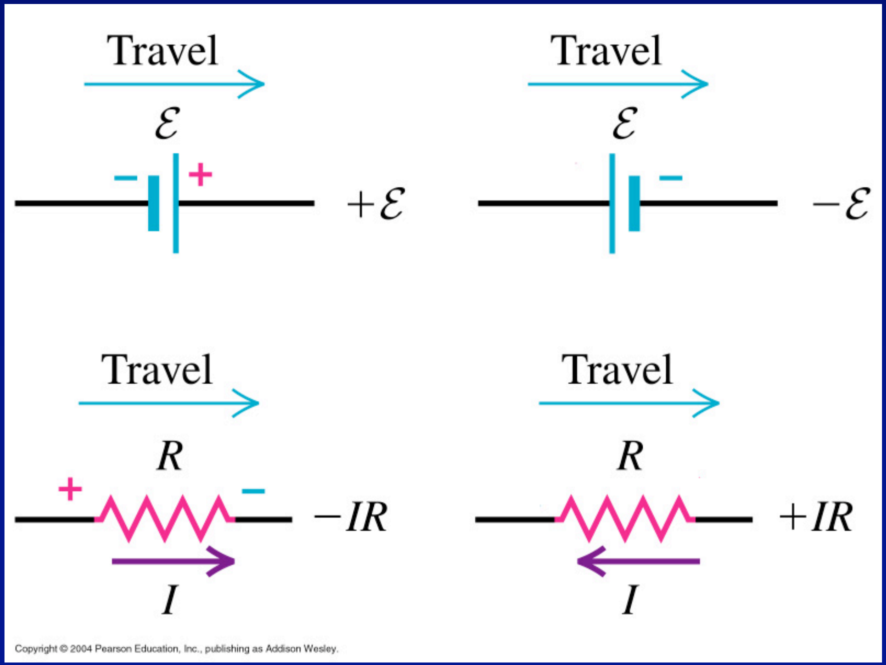
$$\Delta V_1 + \Delta V_2 + \Delta V_3 + \Delta V_4 + \ldots = 0$$

- This rule follows from *conservation of energy*

Sign convention:

– sign for voltage drop and

+ sign voltage gain.

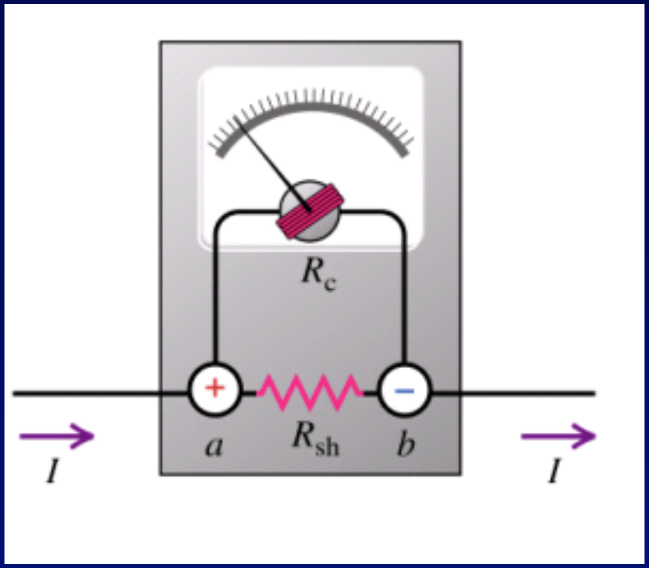


It depends on several factors:

1. emf or resistor
2. direction of current
3. direction of loop travel

Ammeter

- Ammeter can be adapted to measure larger currents by connecting a shunt resistor in parallel as shown



Example: What shunt resistance is required to make the 1.00-mA, 20-Ω meter into an ammeter with a range of 0 A to 50.0 mA ? (Example 26.8)

$$I_{fs}R_c = (I_a - I_{fs})R_{sh}$$

$$R_{sh} = \frac{I_{fs}R_c}{I_a - I_{fs}} = \frac{1\times 20}{50-1} = 0.408\,\Omega$$

$$R_{eq} = 0.400\,\Omega$$

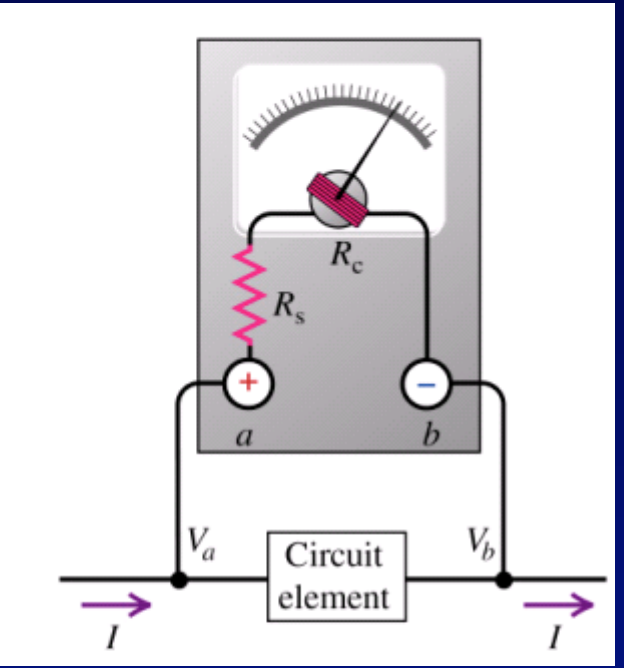
Question: how much current is in each resistor?

Answer: 1 mA in the coil and 49 mA in the shunt resistor.

Voltmeter

Question: How can we make a 1.00-mA, 20-Ω galvanometer into a voltmeter with a maximum range of 10.0 V ? (Example 26.9)

- Answer: by connecting a large resistor in series as shown.



$$V_{ab} = I_{fs}(R_c + R_s)$$

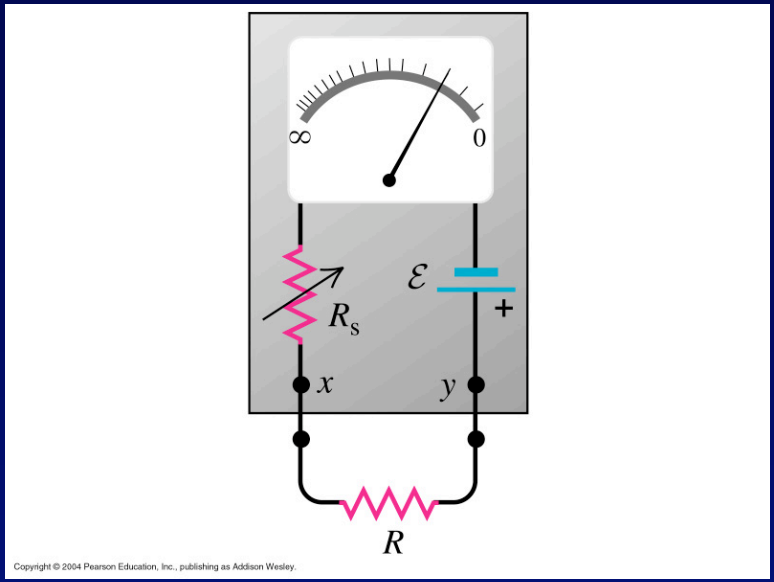
$$R_s = \frac{V_{ab}}{I_{fs}} - R_c = \frac{10}{0.001} - 20 = 9980\,\Omega$$

$$R_{eq} = 10000\,\Omega$$

The voltage across the coil is $I_{fs} R_c$ **= 0.02 V.**
The voltage across the added resistor is 9.98 V.

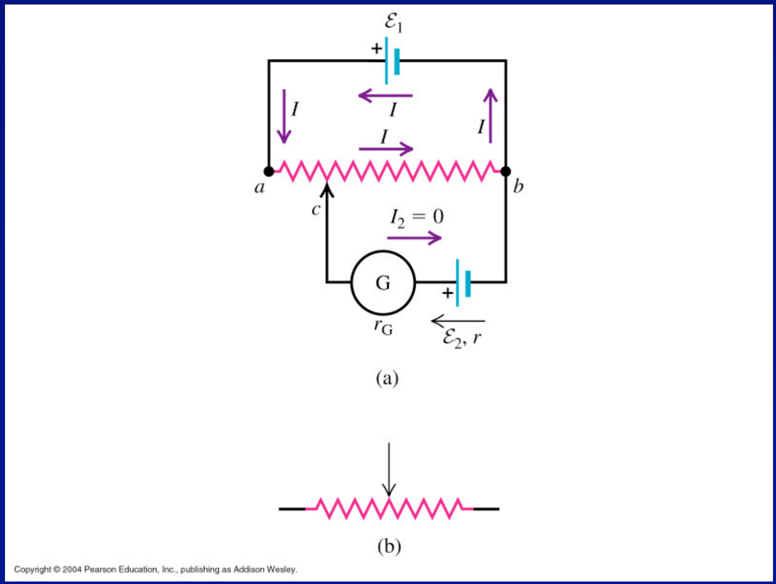
Ohmmeter

Open **between x and y, no deflection (R=∞).** Short between x and y: full-deflection (R=0). Any R in between is read directly.



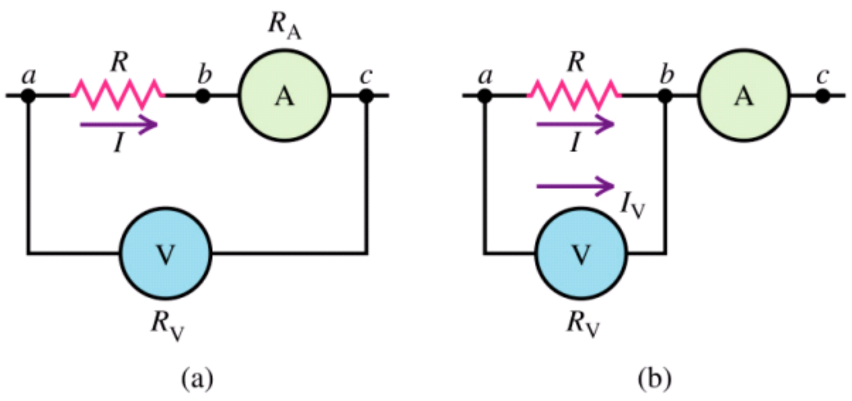
Potentiometer

A known voltage is balanced by sliding the contact c until the current through the unknown emf is zero: $\mathcal{E}_2 = IR_{cb}$



Impact of Ammeter and Voltmeter on measurements (Examples 26.10,11)

- Let's do the numbers.
  - Ammeter reading 0.1 A, resistance R_A=2.0 Ω.
  - Voltmeter reading 12.0 V, resistance R_V=10 kΩ



Ideal case (R_A=0, R_V=∞):
R=V/I=12/0.1=120 Ω

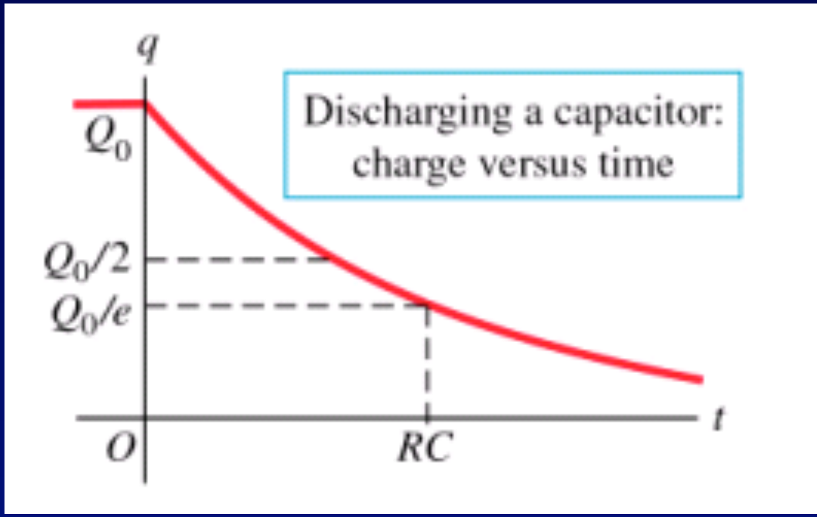
Case (a): voltage across R is less than 12V.
R_a=(12-0.1*2.0)/0.1=118 Ω

Case (b): Current in R is less than 0.1 A.
R_b=12/(0.1-12/10000)=121 Ω

Small difference, but must be taken into account in precision measurements.

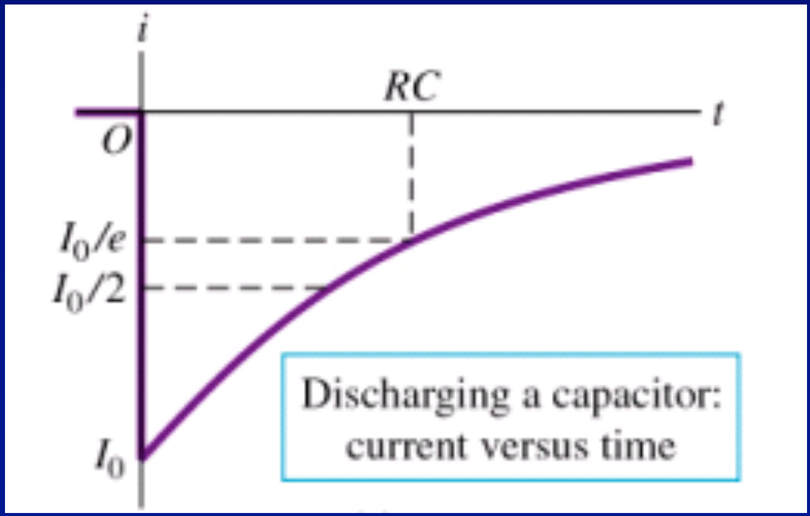
RC Circuit: discharging

$$q(t) = Q_0 e^{-t/RC}$$



At **t=RC**, charge decreases to 37% of its maximum value.

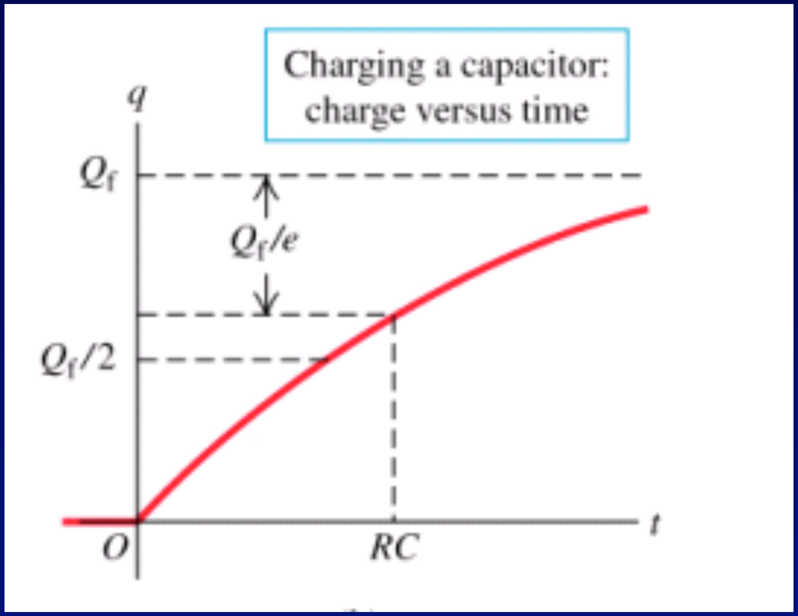
$$i(t) = \frac{dq}{dt} = -\frac{Q_0}{RC} e^{-t/RC}$$



At **t=RC**, current increases to 37% of its maximum value.

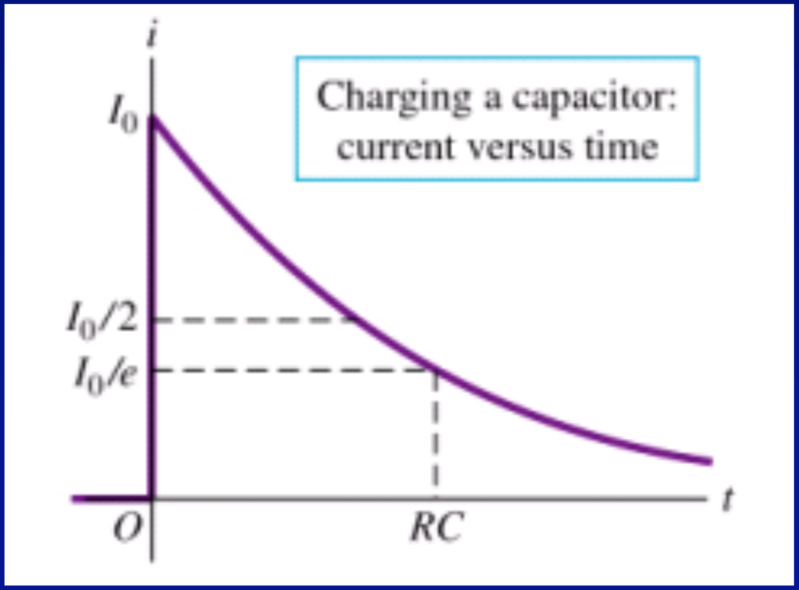
RC Circuit: charging

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



At t=RC, charge increases to 63% of its maximum value. (recall e=2.713)

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



At t=RC, current decreases to 37% of its maximum value.