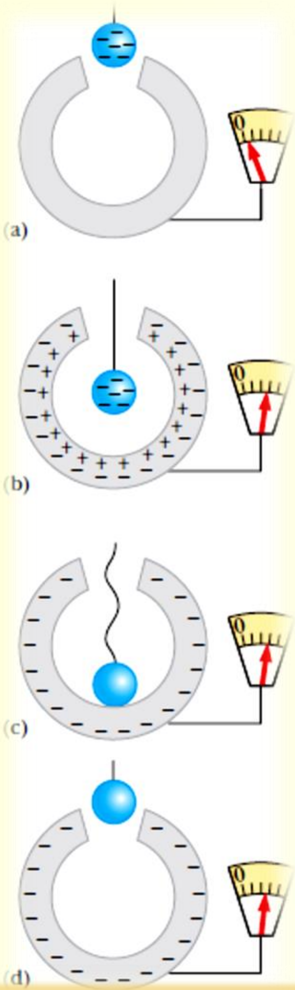
Chap1 Electric Forces & Electric Fields

Conductors in Electrostatic Equilibrium

- When no net motion of charge occurs within a conductor, the conductor is said to be in electrostatic equilibrium.

Properties of an isolated conductor (one that is insulated from ground):

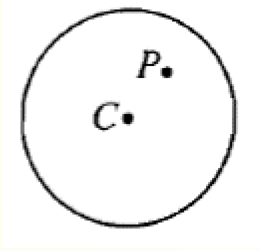
- The electric field is *zero* everywhere *inside* the conducting material.
- Any *excess charge* on an isolated conductor resides entirely on its *surface*.
- The electric field just outside a charged conductor is *perpendicular* to the conductor’s surface.
- On an irregularly shaped conductor, the charge accumulates at *sharp* points, where the radius of curvature of the surface is smallest.



Faraday’s ice-pail experiment

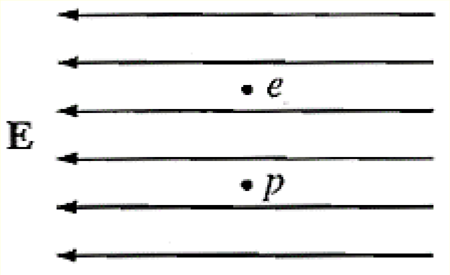
【Exercise】

1. The hollow metal sphere shown below is positively charged. Point *C* is the center of the sphere and point *P* is any other point within the sphere. Which of the following is true of the electric field at these points?



[✓ (A)] It is zero at both points.
(B) It is zero at *C*, but at *P* it is not zero and is directed inward.
(C) It is zero at *C*, but at *P* it is not zero and is directed outward.
(D) It is not zero at either point.

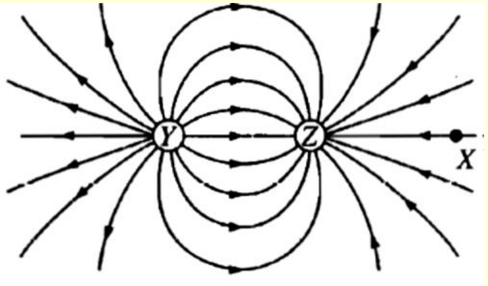
2. An electron *e* and a proton *p* are simultaneously released from rest in a uniform electric field E, as shown below. Assume that the particles are sufficiently far apart so that the only force acting on each particle after it is released is that due to the electric field. At a later time when the particles are still in the field, the electron and the proton will have the same



(A) direction of motion.
(B) speed.
(C) displacement.
(D) magnitude of acceleration.
[✓ (E)] magnitude of force acting on them.

【Exercise】

3. The diagram below shows electric field lines in an isolated region of space containing two small charged spheres, Y and Z. which of the following statements is true?



(A) The charge on Y is negative and the charge on Z is positive.

(B) The strength of the electric field is the same everywhere.

(C) The electric field is strongest midway between Y and Z.

[✓ (D)] A small negatively charged object placed at point X would tend to move toward the right.

(E) Both charged spheres Y and Z carry charge of the same sign.

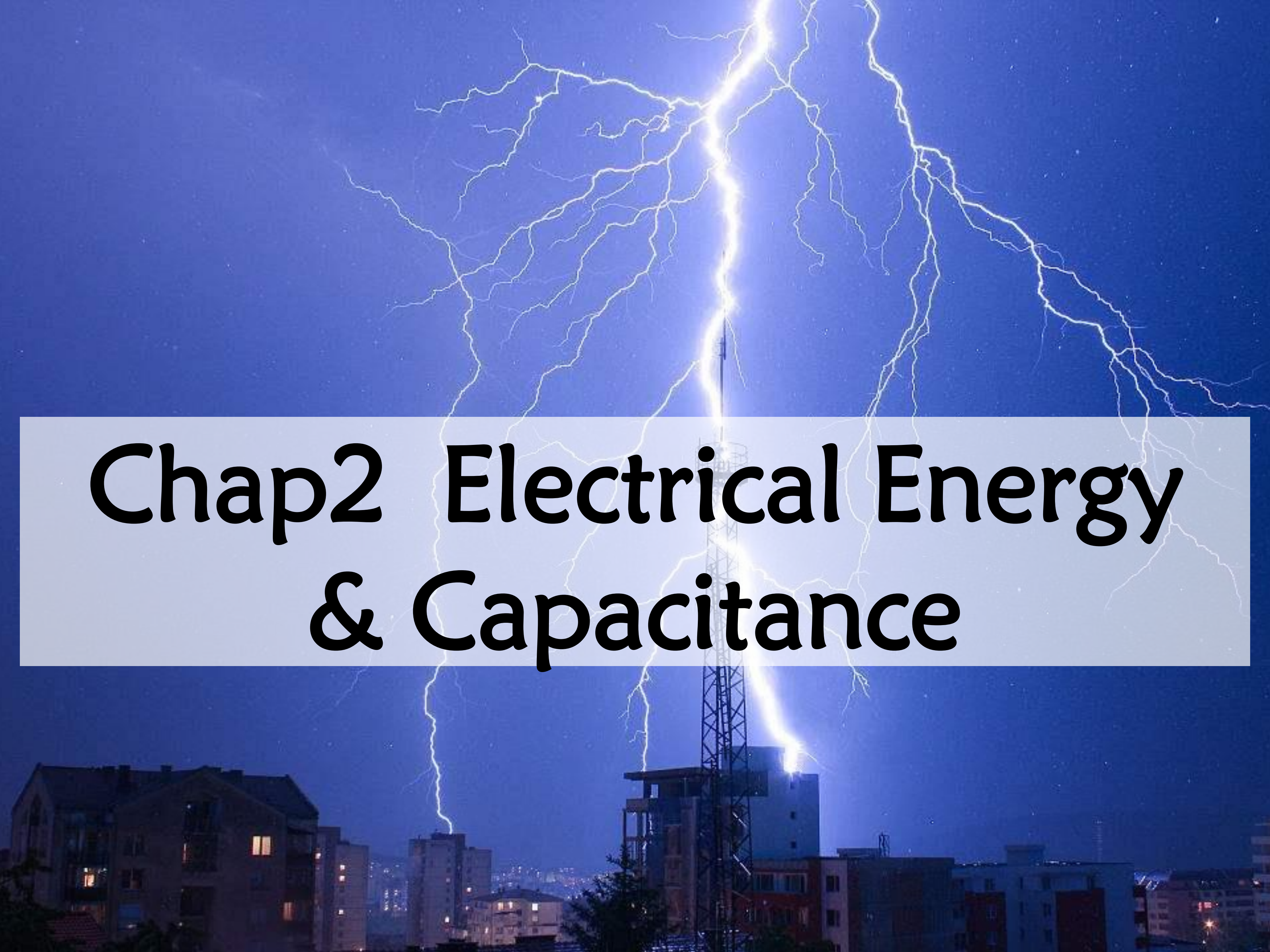
4. A hollow metal sphere 1.0 m in diameter carries a charge of 4.0 μC. The electric field at a distance of 2.0 m from the center of the sphere is most nearly

[✓ (A)] 9.0×10^{3} N/C

(B) 1.8×10^{4} N/C

(C) 2.4×10^{4} N/C

(D) 3.6×10^{4} N/C



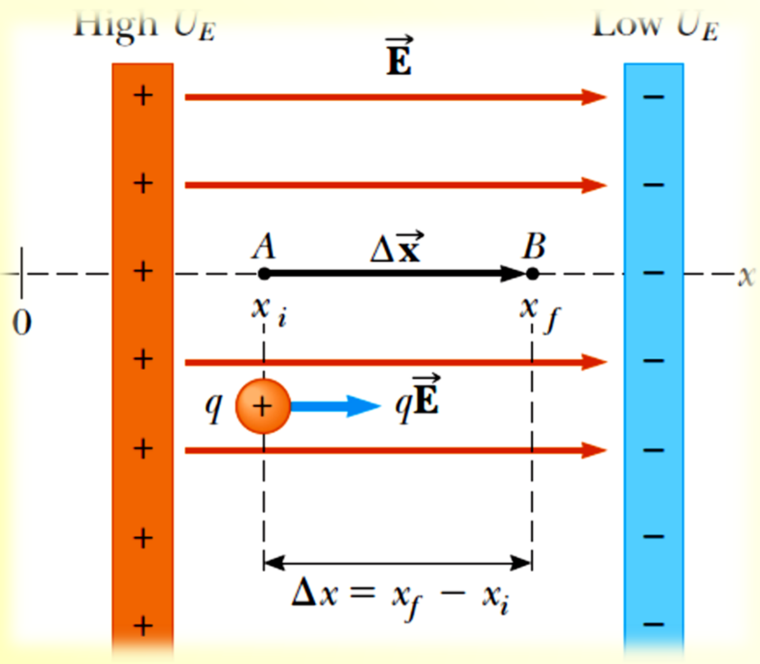
Chap2 Electrical Energy & Capacitance

Work & Electric Potential Energy

scalar

- When a charge q moves in a uniform electric field $\vec{E}$ from point A to point B, the work done on the charge by the electric force: $\boxed{W_{AB} = F \cdot \Delta x = qE \cdot \Delta x}$

- Change in electric potential energy of the charge q: $\boxed{\Delta U_E = -W_{AB} = -qE \cdot \Delta x}$



➢ The Electron Volt:

- An appropriately-sized unit of energy commonly used in atomic and nuclear physics is the electron volt (eV).
- The electron volt is defined as the kinetic energy that an electron gains when accelerated through a potential difference of 1 V.

$$\boxed{1\mathrm{eV} = 1.60 \times 10^{-19}\,\mathrm{C} \cdot \mathrm{V} = 1.60 \times 10^{-19}\,\mathrm{J}}$$

Electric Potential

scalar

- Electric potential at any point in the field: $\boxed{V = \frac{U_E}{q}}$
- SI unit: V [1 V = 1J/C]

Electric Potential Difference

scalar

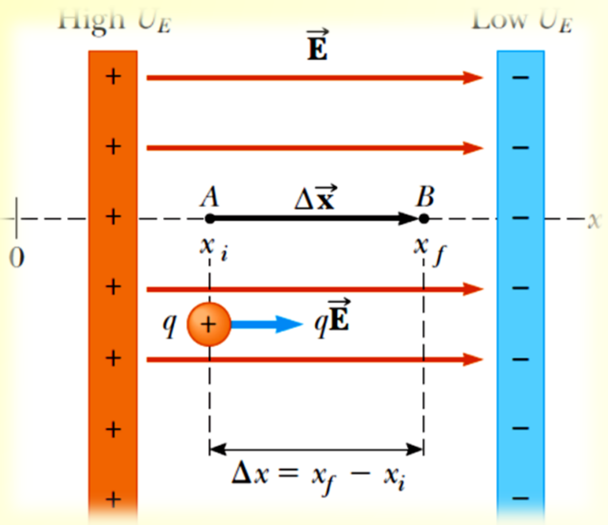
- Electric potential difference between two points *A* and *B* in the field:

$$\boxed{\Delta V = V_B - V_A = \frac{\Delta U_E}{q}}$$

- For a uniform electric field:

$$\left.\begin{array}{r} \Delta U_E = -W_{AB} = -qE\cdot\Delta x \\ \Delta V = \frac{\Delta U_E}{q} \end{array}\right\} \Rightarrow \boxed{E = -\frac{\Delta V}{\Delta x}}$$

The direction of electric field is the direction of potential drop

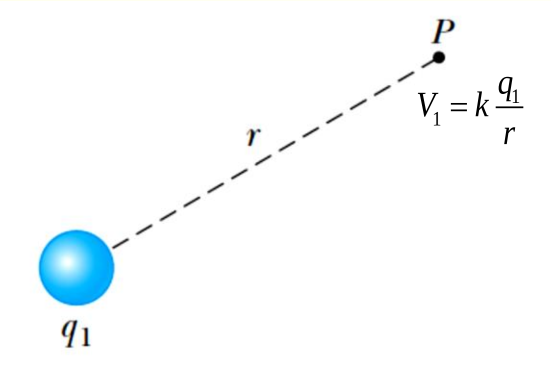


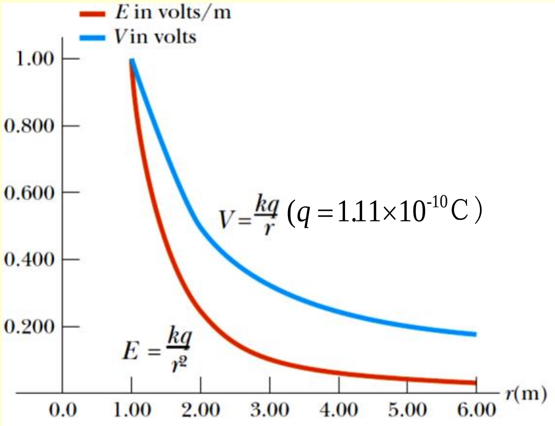
Electric Potential & Potential Energy due to Point Charges

- Electric potential created by a point charge q_1 at any distance r from the charge:

$$\boxed{V = k\frac{q_1}{r}}$$

(Note: The zero point of electric potential is taken to be an infinite distance from the charge.)

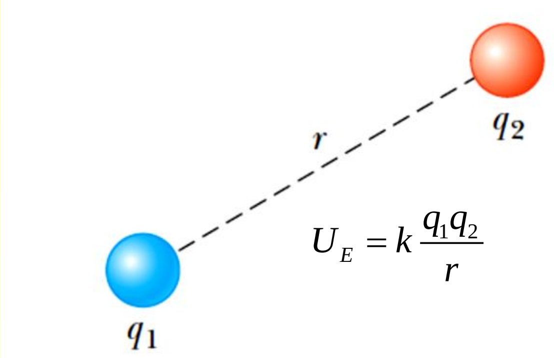




- Superposition principle as for the electric potential of two or more charges: the **algebraic sum** of the electric potentials due to the individual charges.

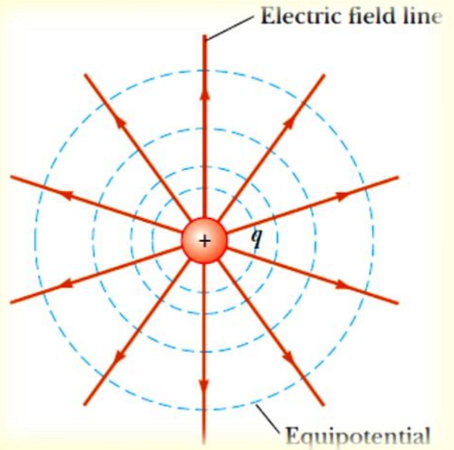
- When a second charge, q_2, is brought from infinity to P, the potential energy of the pair:

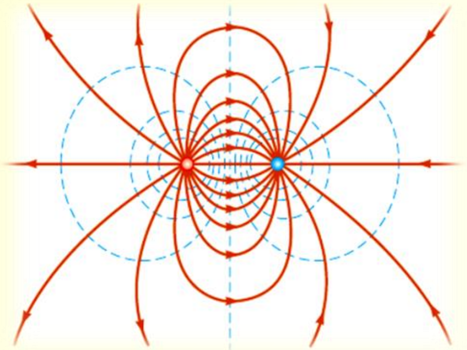
$$\boxed{U_E = k\frac{q_1 q_2}{r}}$$



Equipotential Surfaces

- **Equipotential surface**: a surface on which all points are at the *same* potential.
- The potential difference between any two point on an equipotential surface is *zero*.
- *No work* is required to move a charge at constant speed on an equipotential surface.
- The electric field at every point of an equipotential surface is *perpendicular* to the surface.
- **Equipotential contours** (*or* **equipotentials**): two-dimensional views of the intersections of the equipotential surfaces with the plane of the drawing.
- The equipotentials of a point charge are a family of spheres centered on the point charge.



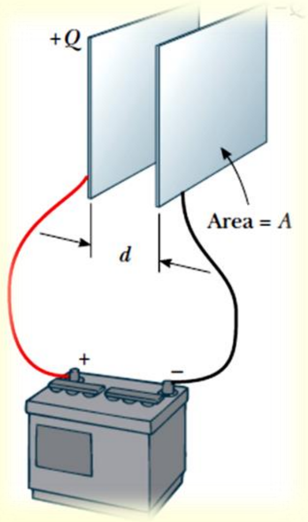


Capacitors

scalar

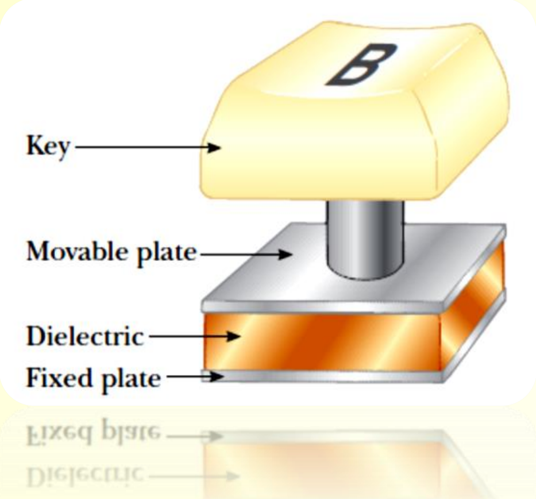
- Capacitance of a pair of conductors (plates): $C \equiv \frac{Q}{\Delta V}$
- SI unit: F [1 F = 1C/V]
- Common units: μF, pF (1 μF = 1×10^{-6} F, 1 pF = 1×10^{-12} F)
- Capacitance of a parallel-plate capacitor: $C=\varepsilon_0 \frac{A}{d}$

(Note: A is the area of one of the plates, d is the distance between the plates, and ε_0 *is the permittivity of vacuum.)*



♠ Application of capacitors:

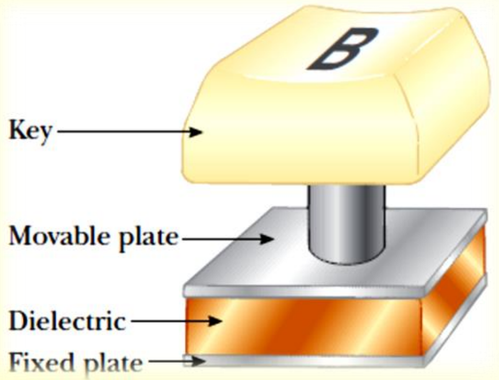
- ✓ Camera flash attachment
- ✓ Computer keyboards
- ✓ Portable emergency defibrillators
- ✓ Electrostatic confinement on the fusion research



Capacitors with Dielectrics

- A **dielectric** is an insulating material, such as rubber, plastic, or waxed paper.

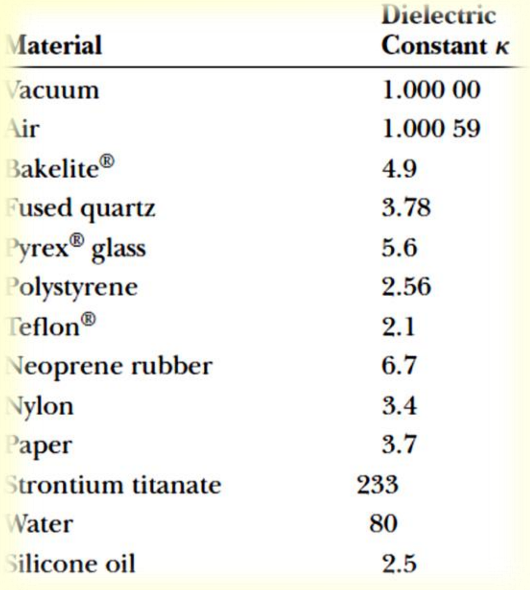
- When a dielectric is inserted between the plates of a capacitor, the capacitance *increases*.



- If the dielectric completely fills the space between the plates, the capacitance is multiplied by the factor κ, called the **dielectric constant**.

- Capacitance of a parallel-plate capacitor with a dielectric: $\boxed{C=\kappa\varepsilon_0\frac{A}{d}}$

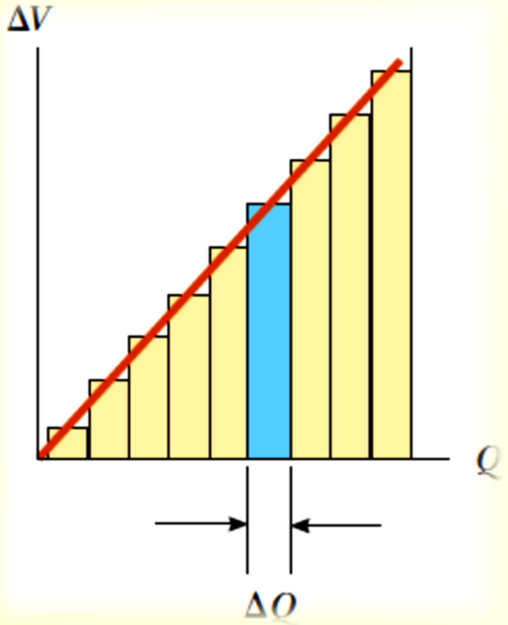
- For any given plate separation, there is a maximum electric field that can be produced in the dielectric before it breaks down and begins to conduct. This maximum electric field is called the **dielectric strength**, and for air its value is ~ 3×10^6 V/m.



Material	Dielectric Constant κ
Vacuum	1.000 00
Air	1.000 59
Bakelite®	4.9
Fused quartz	3.78
Pyrex® glass	5.6
Polystyrene	2.56
Teflon®	2.1
Neoprene rubber	6.7
Nylon	3.4
Paper	3.7
Strontium titanate	233
Water	80
Silicone oil	2.5

Energy Stored in a Charged Capacitors

(*Capacitance C is constant*)



- The work required to move a charge of $\triangle Q$ through a potential difference of $\triangle V$ across the capacitor plates:

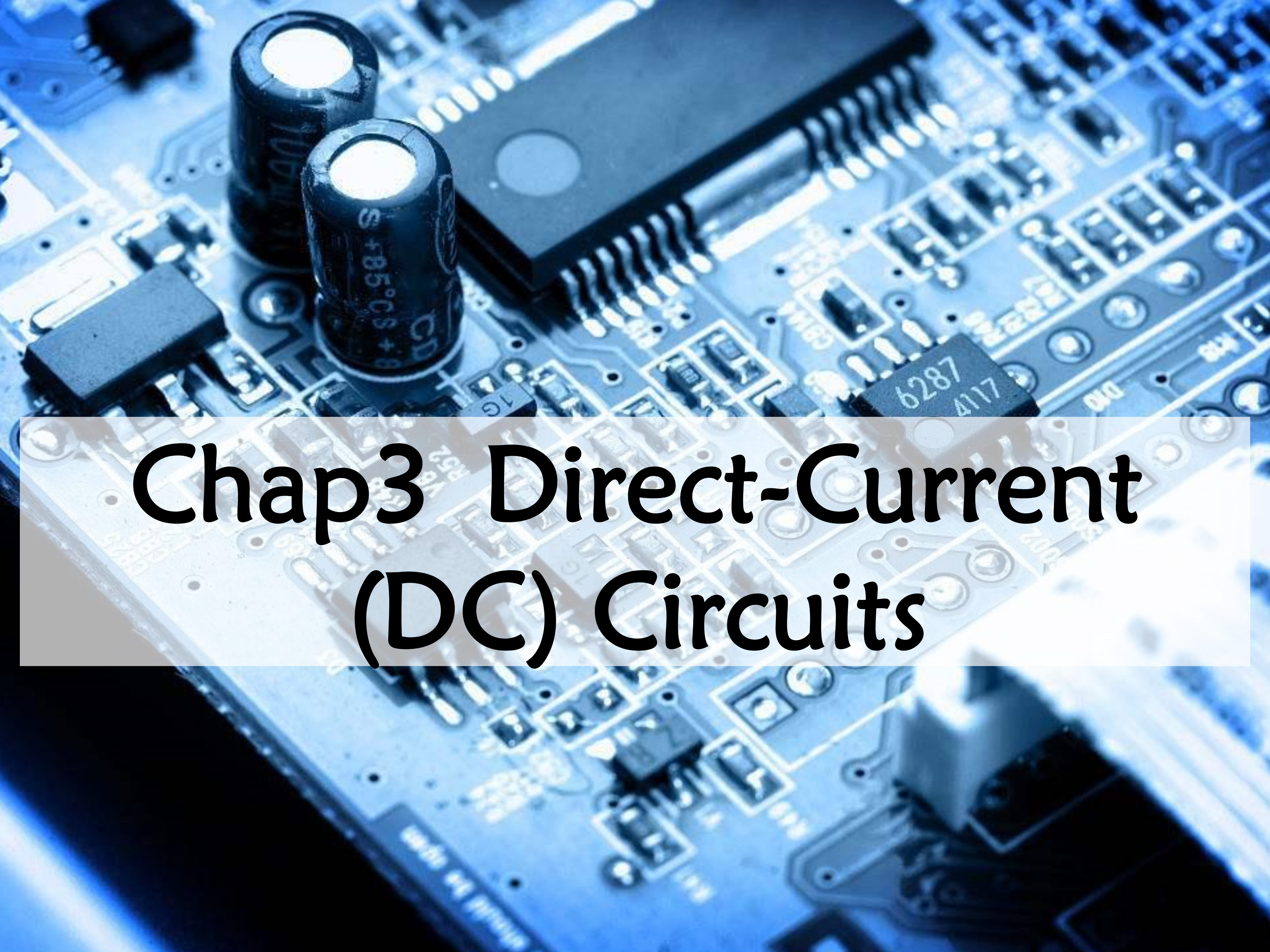
$$\Delta W = \Delta V \cdot \Delta Q$$

- The total work required to charge the capacitor to a final charge of Q:

$$W = \frac{1}{2} Q \cdot \Delta V$$

- W is also the energy stored in the capacitor:

$$\left.\begin{array}{l} U_E = \frac{1}{2} Q \cdot \Delta V \\ Q = C \cdot \Delta V \end{array}\right\} \Rightarrow \boxed{U_E = \frac{1}{2} Q\Delta V = \frac{1}{2} C(\Delta V)^2 = \frac{Q^2}{2C}}$$

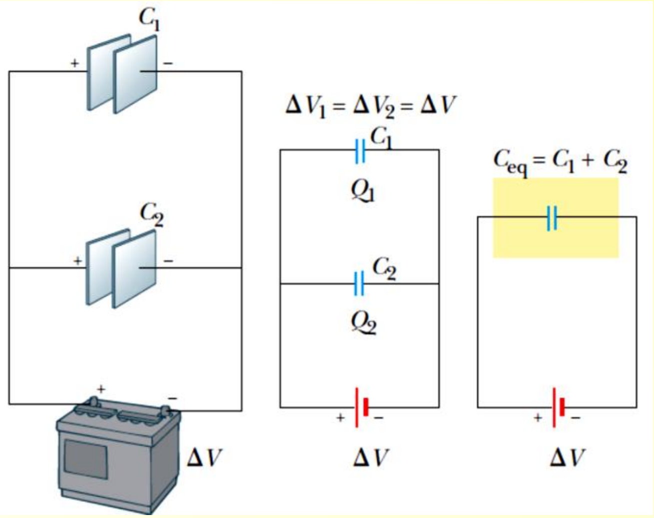


Chap3 Direct-Current (DC) Circuits

Capacitors in Circuits

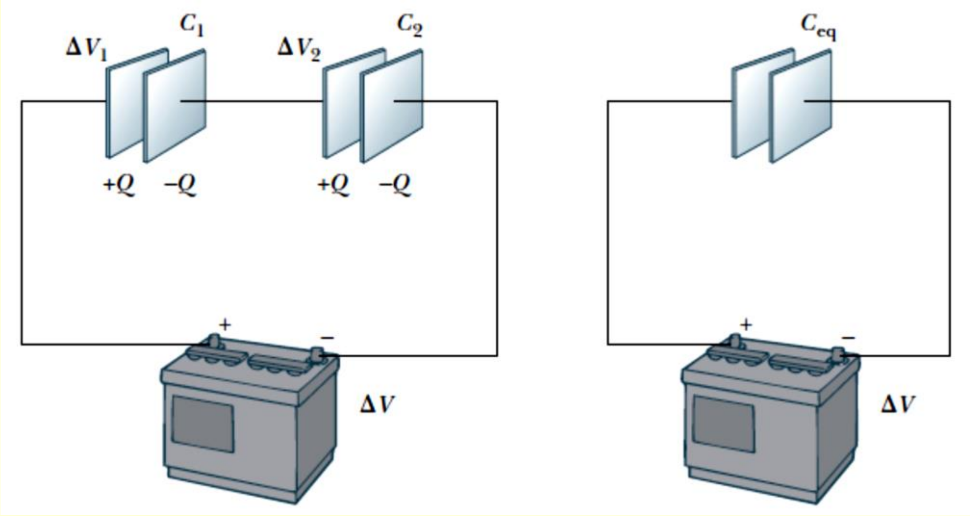
- Two or more capacitors can be combined in circuits in several ways, but most reduce to two simple configurations, called *parallel* and *series*.
- The rules for capacitors in circuits are *opposite* to the rules for resistors.

➢ Capacitors in parallel:



$$\boxed{\Delta V_i = \Delta V,\ \ Q_p = \sum_i Q_i,\ \ C_p = \sum_i C_i}$$

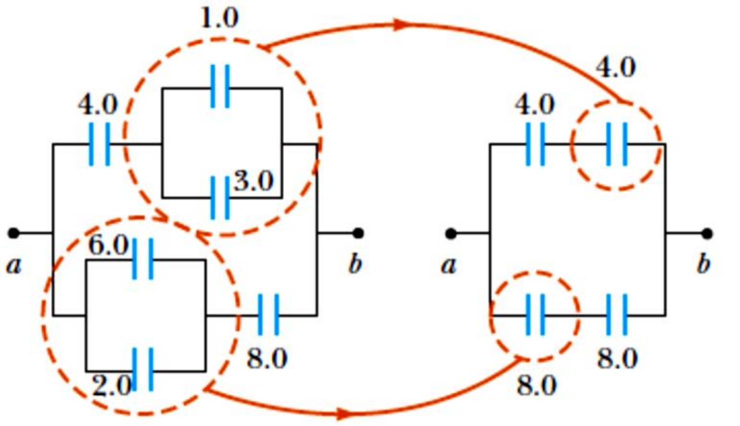
➢ Capacitors in series:



$$\boxed{Q_i = Q,\ \ \Delta V = \sum_i \Delta V_i,\ \ \frac{1}{C_s} = \sum_i \frac{1}{C_i}}$$

Exercise: Equivalent Capacitance

(a) Calculate the equivalent capacitance between *a* and *b* for the combination of capacitors. All capacitance are in micro-farads. (b) If a 12-V battery is connected across the system between points *a* and *b*, find the charge on the 4.0-μF capacitor in the first diagram and the voltage drop across it.



(a) The equivalent capacitance between *a* and *b*: $C_{eq} = 6.0\mu\text{F}$

(b) The voltage drop across the 4.0-μF capacitor: $\Delta V = 6.0\text{V}$

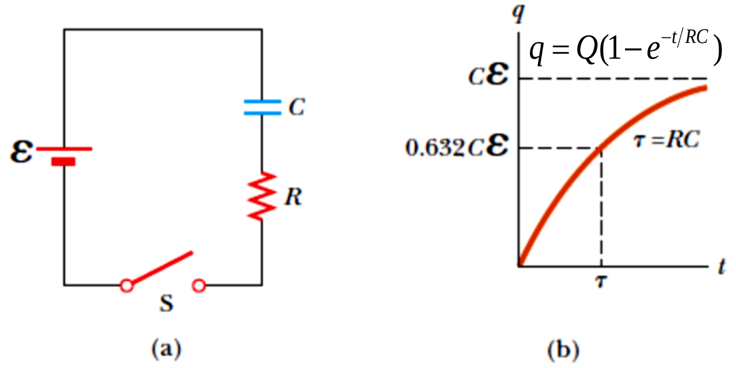
The charge on the 4.0-μF capacitor: $Q = C\Delta V = (4.0\mu\text{F})(6.0\text{V}) = 24\mu\text{C}$

- For capacitors in circuits:
  - ✓ If the battery is *connected*, the *voltage drop* across the capacitor *remains*.
  - ✓ If the battery is *disconnected*, the *charge* on the capacitor *remains*.

RC Circuits

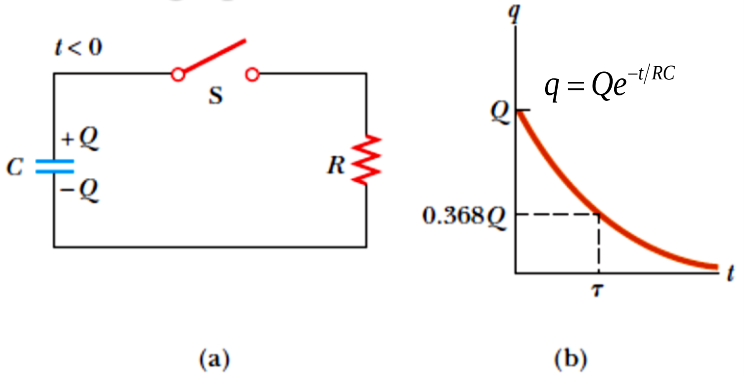
- As the capacitor is being charged, the circuit carries a changing current.
- The charging process continues until the capacitor is charged to its maximum equilibrium value Q ($Q = C\varepsilon$).
- Time constant of an RC circuit: $\boxed{\tau = RC}$
- When the switch in the RC circuit has just been closed, the capacitor is treated like a wire with *negligible* resistance.
- When the switch in the RC circuit has been closed for a long time, the capacitor behaves like an *infinite* resistor.

Charging process:



(a) (b)

Discharge process:



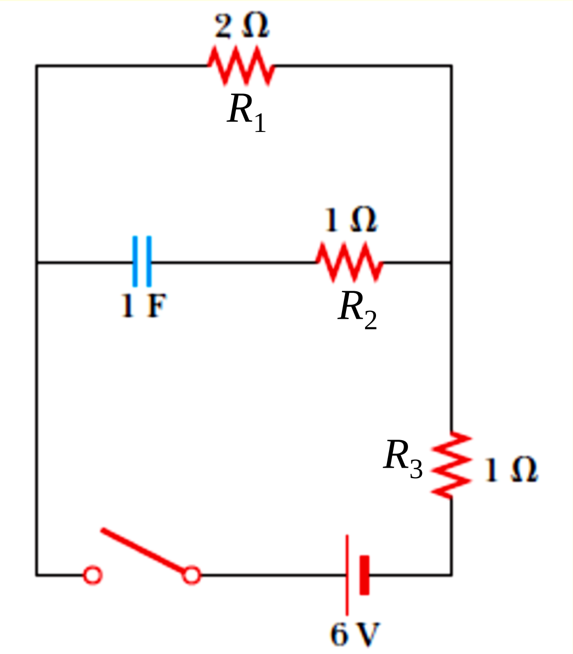
(a) (b)

【Exercise】

Determine the current through each electrical element in the following circuit when

(a) the switch has just been closed.

(b) the switch has been closed for a long time.



(a) The current through R_1:

$$I_1 = \frac{2.4\text{V}}{2\ \Omega} = 1.2\text{A}$$

The current through R_2:

$$I_2 = \frac{2.4\text{V}}{1\Omega} = 2.4\text{A}$$

The current through R_3:

$$I_3 = \frac{3.6\text{V}}{1\Omega} = 3.6\text{A}$$

The current through the capacitor: $I_2 = 2.4\text{A}$

(b) The current through R_1:

$$I_1 = \frac{4\text{V}}{2\ \Omega} = 2.0\text{A}$$

The current through R_2: $I_2 = 0\text{A}$

The current through the capacitor:

$$I_2 = 0\text{A}$$

The current through R_3: $I_3 = \frac{2\text{V}}{1\Omega} = 2.0\text{A}$