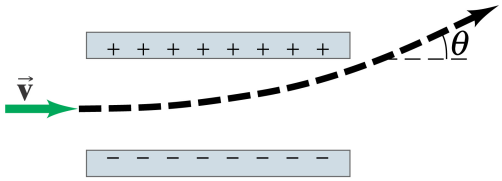
Chapter 23

Electric Potential



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Units of Chapter 23

- Electric Potential Energy and Potential Difference
- Relation between Electric Potential and Electric Field
- Electric Potential Due to Point Charges
- Electric Potential Due to Any Charge Distribution

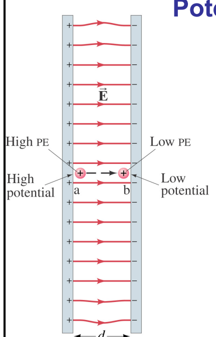
Units of Chapter 23

- Equipotential Surfaces
- Electric Dipoles
- *E* Determined from *V*
- Electrostatic Potential Energy; The Electron Volt
- Cathode Ray Tube: TV and Computer Monitors, Oscilloscope

Units of Chapter 24

- Capacitors
- Determination of Capacitance
- Capacitors in Series and Parallel
- Electric Energy Storage
- Dielectrics
- Molecular Description of Dielectrics

Electrostatic Potential Energy and Potential Difference



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The electrostatic force is conservative – potential energy can be defined

Change in electric potential energy is negative of work done by electric force:

$$U_b - U_a = -qEd$$

Electrostatic Potential Energy and Potential Difference

Electric potential is defined as potential energy per unit charge:

$$V_a = \frac{U_a}{q}$$

Unit of electric potential: the volt (V).

1 V = I J/C.

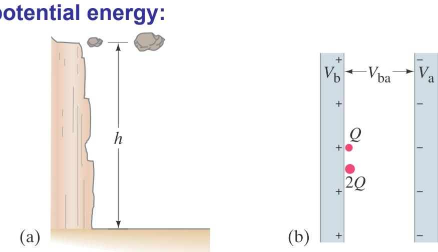
Electrostatic Potential Energy and Potential Difference

Only changes in potential can be measured, allowing free assignment of $V = 0$.

$$V_{ba} = V_b - V_a = \frac{U_b - U_a}{q} = -\frac{W_{ba}}{q}$$

Electrostatic Potential Energy and Potential Difference

Analogy between gravitational and electrical potential energy:



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Relation between Electric Potential and Electric Field

Work is charge multiplied by potential:

$$W = -q(V_b - V_a) = -qV_{ba}$$

Work is also force multiplied by distance:

$$W = Fd = qEd$$

*Relation between Electric Potential and Electric Field

*The difference in potential energy between any tow points in space is given by

$$U_{ba} = U_b - U_a = -\int_a^b \mathbf{F} \bullet d\boldsymbol{l}$$

Substituting F:

$$V_{ba} = V_b - V_a = -\int_a^b \mathbf{E} \bullet d\boldsymbol{l}$$

*Relation between Electric Potential and Electric Field

*The difference in potential energy between any tow points in space is given by

$$U_{ba} = U_b - U_a = -\int_a^b \mathbf{F} \bullet d\boldsymbol{l}$$

$$V_{ba} = V_b - V_a = -\int_a^b \mathbf{E} \bullet d\boldsymbol{l}$$

If *E* is uniform:

$$V_{ba} = V_b - V_a = -\int_a^b \mathbf{E} \bullet d\boldsymbol{l} = -E\int_a^b dl = -Ed$$

Relation between Electric Potential and Electric Field

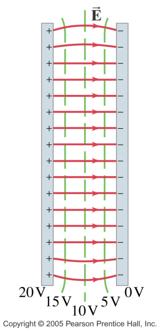
Solving for the field,

$$E = -\frac{V_{\mathrm{ba}}}{d}$$

If the field is not uniform, it can be calculated at multiple points:

$$E_x = -\Delta V / \Delta x$$

Equipotential Lines

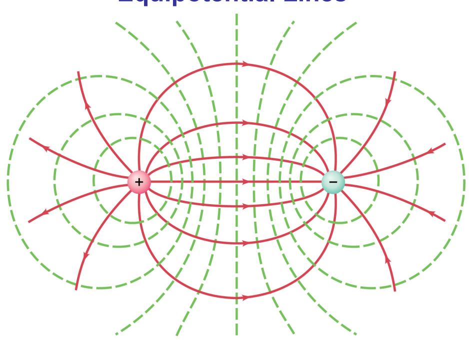


An equipotential is a line or surface over which the potential is constant.

Electric field lines are perpendicular to equipotentials.

The surface of a conductor is an equipotential.

Equipotential Lines



The Electron Volt, a Unit of Energy

One electron volt (eV) is the energy gained by an electron moving through a potential difference of one volt.

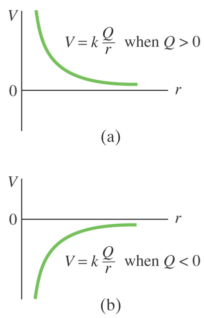
$$1\ \text{eV} = 1.6 \times 10^{-19}\ \text{J}$$

Electric Potential Due to Point Charges

The electric potential due to a point charge can be derived using calculus.

$$V = k\frac{Q}{r} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r}$$

Electric Potential Due to Point Charges



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These plots show the potential due to (a) positive and (b) negative charge.

Electric Potential Due to Point Charges

Using potentials instead of fields can make solving problems much easier – potential is a scalar quantity, whereas the field is a vector.

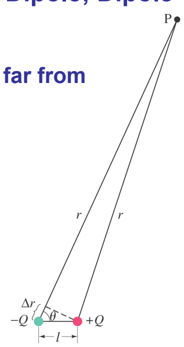
Potential Due to Electric Dipole; Dipole Moment

The potential due to an electric dipole is just the sum of the potentials due to each charge, and can be calculated exactly.

Potential Due to Electric Dipole; Dipole Moment

Approximation for potential far from dipole:

$$V \approx \frac{kQl\cos\theta}{r^2}$$



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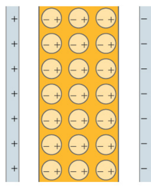
Potential Due to Electric Dipole; Dipole Moment

Or, defining the dipole moment ***p*** **=** ***Ql***,

$$V \approx \frac{kp\cos\theta}{r^2}$$

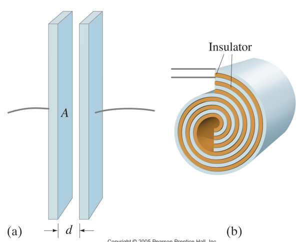
Chapter 24

Capacitance, Dielectrics, Electric Energy Storage



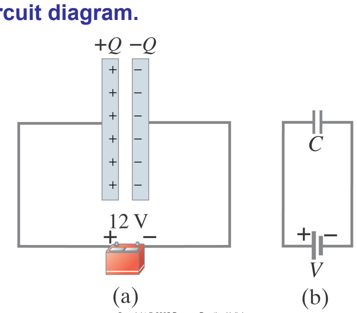
Capacitance

A capacitor consists of two conductors that are close but not touching. A capacitor has the ability to store electric charge.



Capacitance

Parallel-plate capacitor connected to battery. (b) is a circuit diagram.



Capacitance

When a capacitor is connected to a battery, the charge on its plates is proportional to the voltage:

$$Q = CV$$

The quantity C is called the capacitance.

Unit of capacitance: the farad (F)

1 F = 1 C/V

Capacitance

The capacitance does not depend on the voltage; it is a function of the geometry and materials of the capacitor.

For a parallel-plate capacitor:

$$C = \epsilon_0 \frac{A}{d}$$

Dielectrics

A dielectric is an insulator, and is characterized by a dielectric constant K.

Capacitance of a parallel-plate capacitor filled with dielectric:

$$C = K\epsilon_0 \frac{A}{d}$$

TABLE 24-13 Dielectric constants (at 20°C)

Material	Dielectric constant K	Dielectric strength (V/m)
Vacuum	1.0000	
Air (1 atm)	1.0006	3×10^6
Paraffin	2.2	10×10^6
Polystyrene	2.6	24×10^6
Vinyl (plastic)	2–4	50×10^6
Paper	3.7	15×10^6
Quartz	4.3	8×10^6
Oil	4	12×10^6
Glass, Pyrex	5	14×10^6
Rubber, neoprene	6.7	12×10^6
Porcelain	6–8	5×10^6
Mica	7	150×10^6
Water (liquid)	80	
Strontium titanate	300	8×10^6

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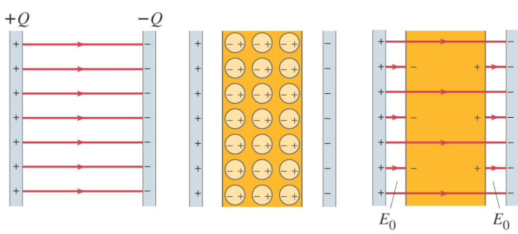
Dielectrics

Dielectric strength is the maximum field a dielectric can experience without breaking down.

Molecular Description of Dielectrics

The molecules in a dielectric tend to become oriented in a way that reduces the external field.



Molecular Description of Dielectrics

This means that the electric field within the dielectric is less than it would be in air, allowing more charge to be stored for the same potential.

Electric Energy Storage

A charged capacitor stores electric energy; the energy stored is equal to the work done to charge the capacitor.

$$\text{PE} = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\frac{Q^2}{C}$$

Electric Energy Storage

The energy density, defined as the energy per unit volume, is the same no matter the origin of the electric field:

$$\text{energy density} = \frac{\text{PE}}{\text{volume}} = \tfrac{1}{2}\epsilon_0 E^2$$

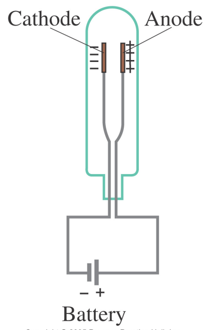
The sudden discharge of electric energy can be harmful or fatal. Capacitors can retain their charge indefinitely even when disconnected from a voltage source – be careful!

17.9 Storage of Electric Energy

Heart defibrillators use electric discharge to "jump-start" the heart, and can save lives.

17.10 Cathode Ray Tube: TV and Computer Monitors, Oscilloscope

A cathode ray tube contains a wire cathode that, when heated, emits electrons. A voltage source causes the electrons to travel to the anode.



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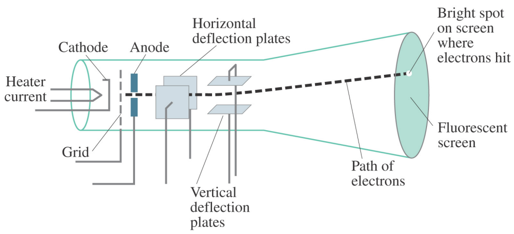
17.10 Cathode Ray Tube: TV and Computer Monitors, Oscilloscope

The electrons can be steered using electric or magnetic fields.



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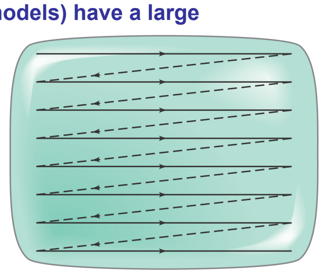
17.10 Cathode Ray Tube: TV and Computer Monitors, Oscilloscope

Televisions and computer monitors (except for LCD and plasma models) have a large cathode ray tube as their display. Variations in the field steer the electrons on their way to the screen.



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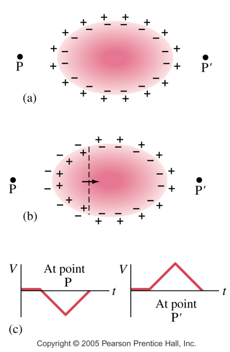
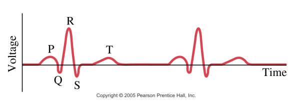
17.10 Cathode Ray Tube: TV and Computer Monitors, Oscilloscope

An oscilloscope displays en electrical signal on a screen, using it to deflect the beam vertically while it sweeps horizontally.

17.11 The Electrocardiogram (ECG or EKG)

The electrocardiogram detects heart defects by measuring changes in potential on the surface of the heart.





Summary of Chapter 17

- Electric potential energy:

$$\mathrm{PE_b} - \mathrm{PE_a} = -qEd$$

- Electric potential difference: work done to move charge from one point to another
- Relationship between potential difference and field:

$$E = -\frac{V_{\mathrm{ba}}}{d}$$

Summary of Chapter 17

• Equipotential: line or surface along which potential is the same

• Electric potential of a point charge:

$$V = k\frac{Q}{r} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r}$$

• Electric dipole potential: $V \approx \frac{kp\cos\theta}{r^2}$

Summary of Chapter 17

• Capacitor: nontouching conductors carrying equal and opposite charge

•Capacitance:

$$Q = CV$$

• Capacitance of a parallel-plate capacitor:

$$C = \epsilon_0\frac{A}{d}$$

Summary of Chapter 17

• A dielectric is an insulator

• Dielectric constant gives ratio of total field to external field

• Energy density in electric field:

$$\text{energy density} = \frac{\text{PE}}{\text{volume}} = \tfrac{1}{2}\epsilon_0 E^2$$