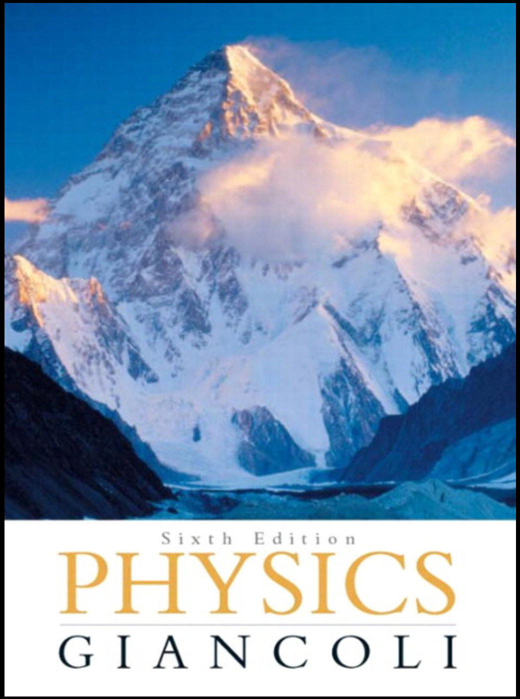


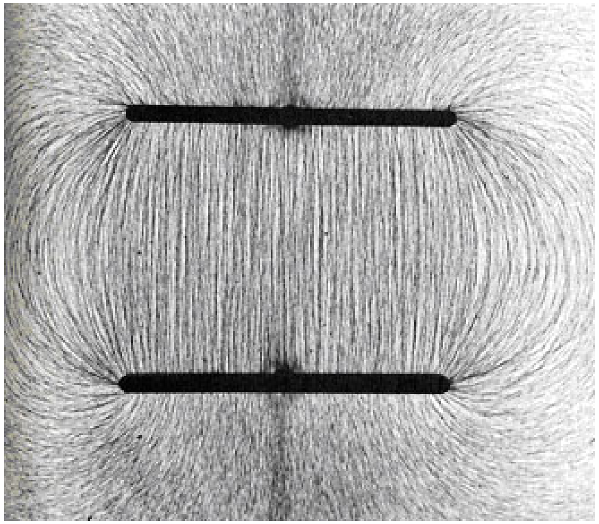
Lecture Power Points

Chapter 17

Physics: Principles with Applications, 6th edition

Giancoli

Electric Potential (Ch 17)



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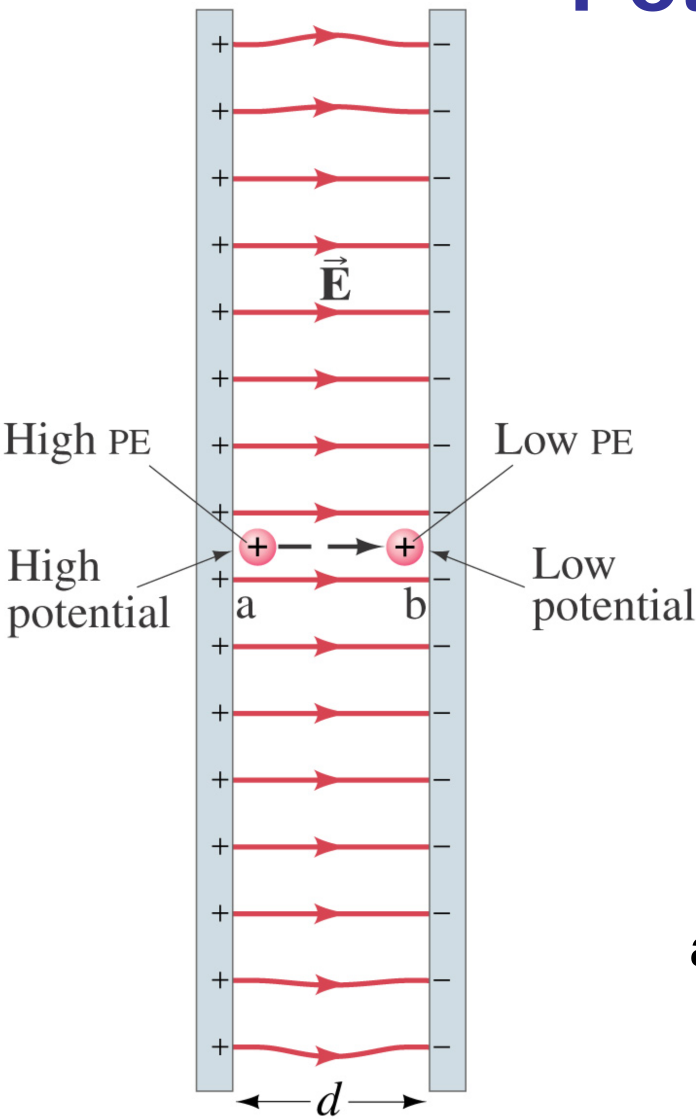
Topics in Chapter 17

- Electric Potential Energy
- Potential Difference (voltage)
- Equipotential Lines
- Acceleration of Charged objects by Electric fields
- The Electron Volt, a Unit of Energy
- Capacitance
- Dielectrics
- Storage of Electric Energy

17.1 Electrostatic Potential Energy and Potential Difference



The electrostatic force is conservative

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

$$PE_b - PE_a = -qEd$$

Change in PE is the work done either against (or by) the field, in moving a charge.

Electric Potential

Electric potential is defined as potential energy per unit charge:

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

Unit of electric potential: the volt (V).

1 V = l J/C.

(Remember Electric Field was Force per unit charge)

Potential Difference

Difference in Potential from one place to another.

Only changes in potential can be measured, there is no “absolute zero” for voltage.

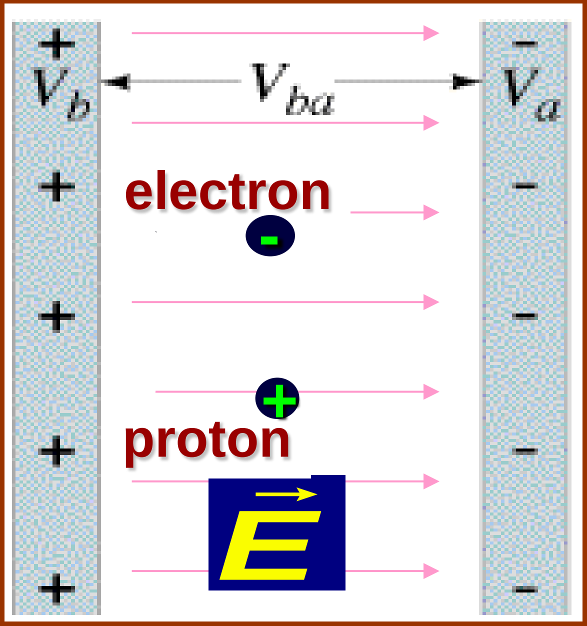
$$V_{\mathrm{ba}} = V_{\mathrm{b}} - V_{\mathrm{a}} = \frac{\mathrm{PE_b} - \mathrm{PE_a}}{q} = -\frac{W_{\mathrm{ba}}}{q}$$

Potential difference is work done per unit charge, so Volts are Joules per Coulomb

ConcepTest 17.1c Electric Potential Energy III

A proton and an electron are in a constant electric field created by oppositely charged plates. You release the proton from the positive side and the electron from the negative side. When it strikes the opposite plate, which one has more KE?

1) proton
2) electron
3) both acquire the same KE
4) neither – there is no change of KE
5) they both acquire the same KE but with opposite signs



ConcepTest 17.1c Electric Potential Energy III

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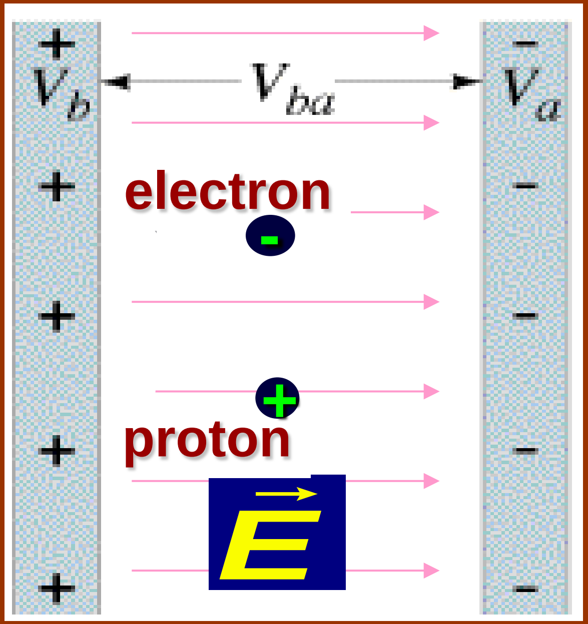
1) proton
2) electron
3) both acquire the same KE
4) neither – there is no change of KE
5) they both acquire the same KE but with opposite signs

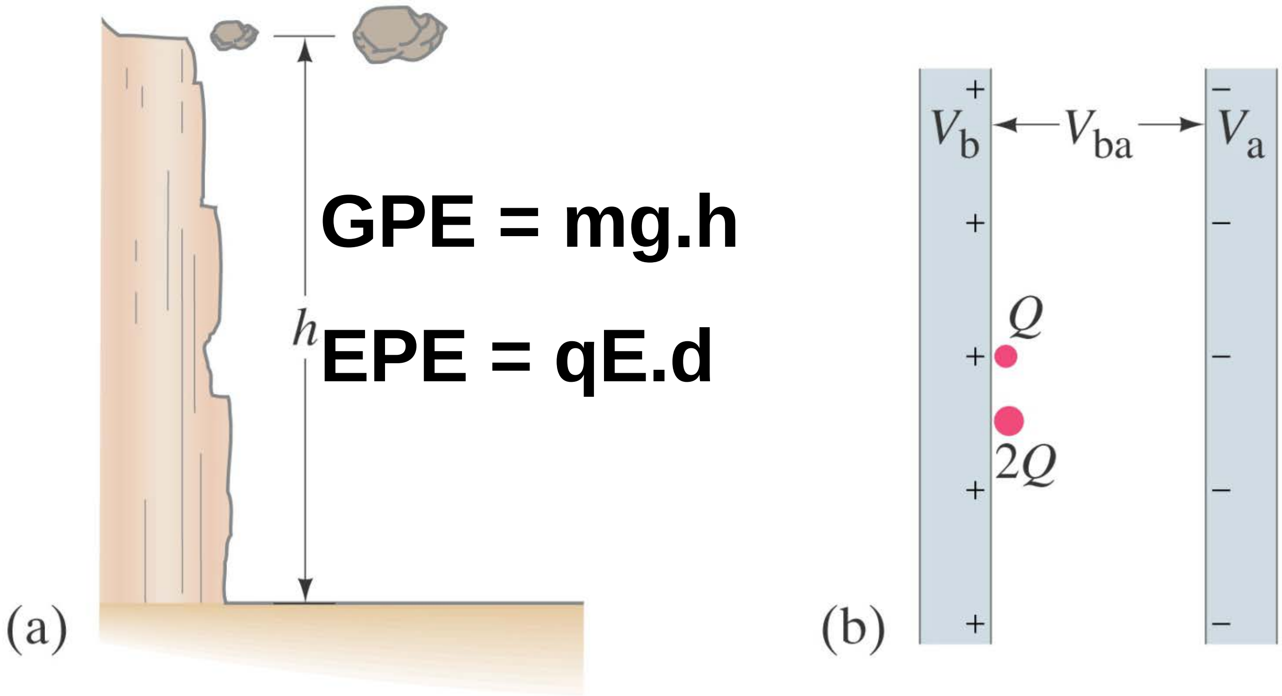
Since PE = qV and the proton and electron have the same charge in magnitude, they both have the same electric potential energy initially. Because energy is conserved, they both must have the same kinetic energy after they reach the opposite plate.



Electrostatic Potential Energy and Potential Difference

ΔPE=W=F*d

Think about this analogy between gravitational and electrical potential energy:



GPE = mg.h

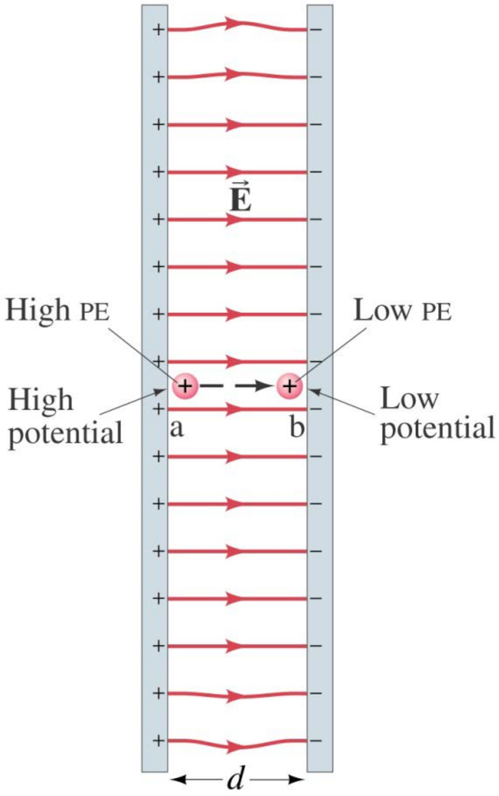
EPE = qE.d

So if you push a charge against the electric field, you do work, increasing the object's EPE.

If you release a charge in an E-field, it accelerates, just like dropping a weight. The change in EPE = KE

17.2 Relation between Electric Potential and Electric Field

Suppose we want to know the change in potential energy per unit charge, we call this quantity the Electric Potential (symbol "V")



EPE = W = F.d **(From Newton's 2nd Law)**

= qE.d

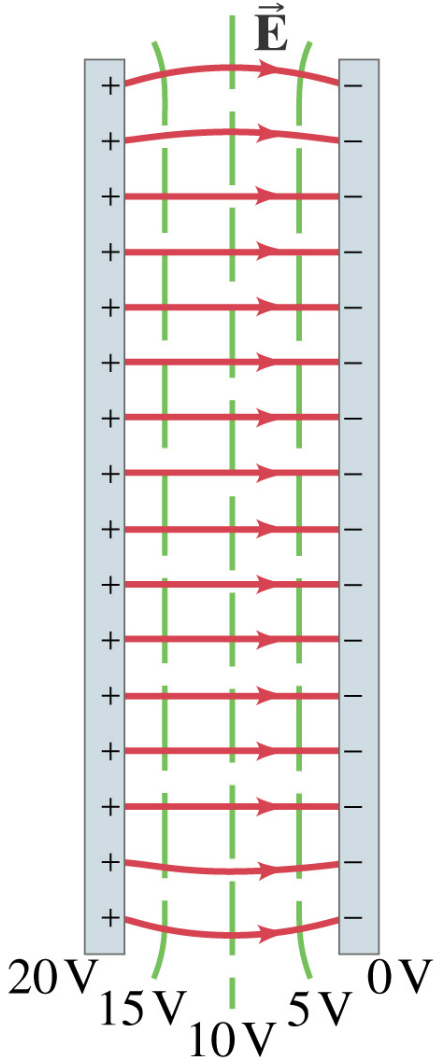
Then "EPE per unit charge" would be

V = EPE/q = qEd/q = Ed

Finally note that due to the definition of Electric field and charge, the potential energy of a positive test charge gets smaller as the field pushes it from high to low potential, so we need a minus sign, so:

$$V = -Ed$$

17.3 Equipotential Lines

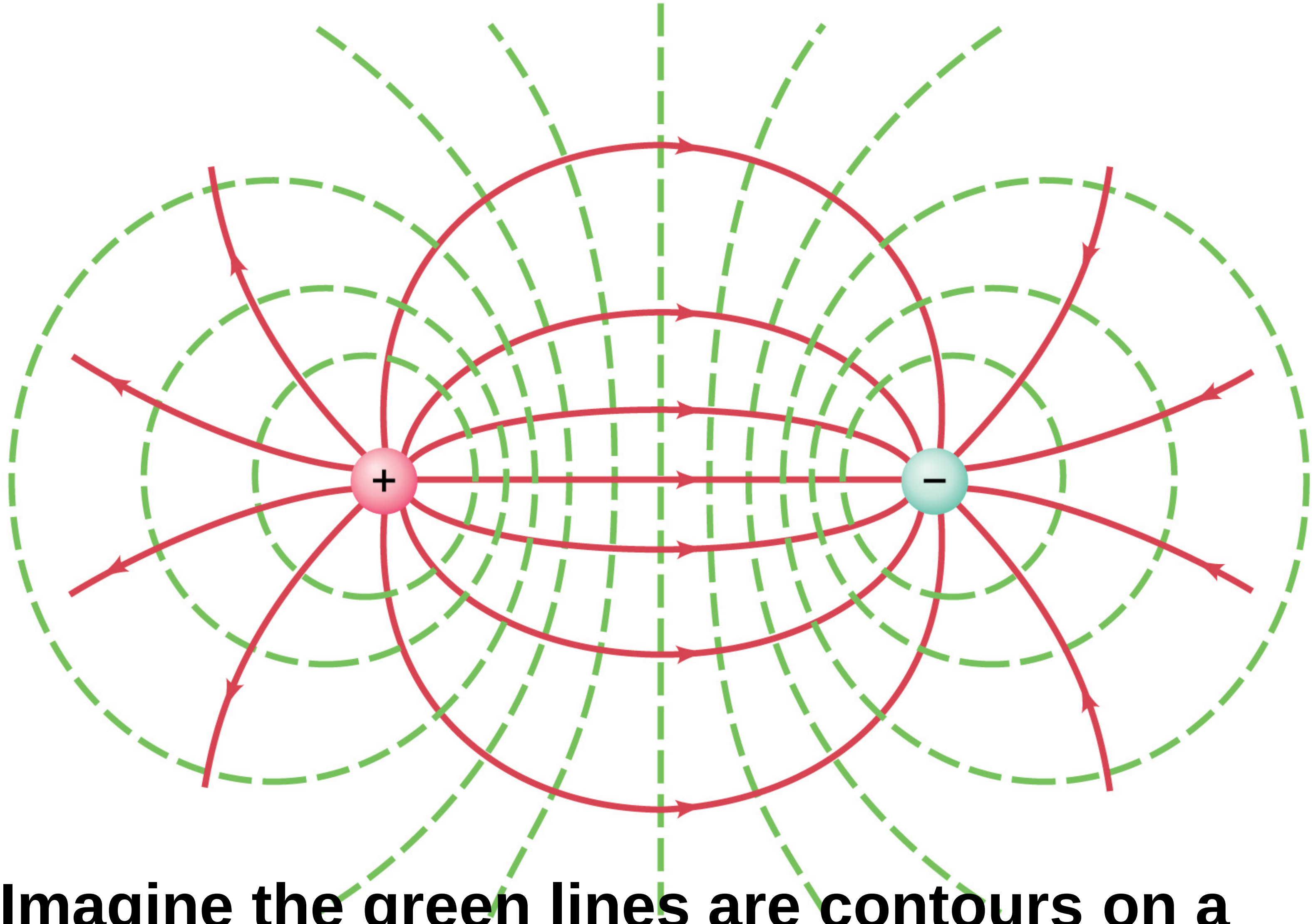


An equipotential is a line or surface over which the potential is constant.

Electric field lines are perpendicular to equipotentials.

The surface of a conductor is an equipotential.

Equipotential Lines



Imagine the green lines are contours on a map showing a hill and a valley

17.4: The Electron Volt, a Unit of Energy

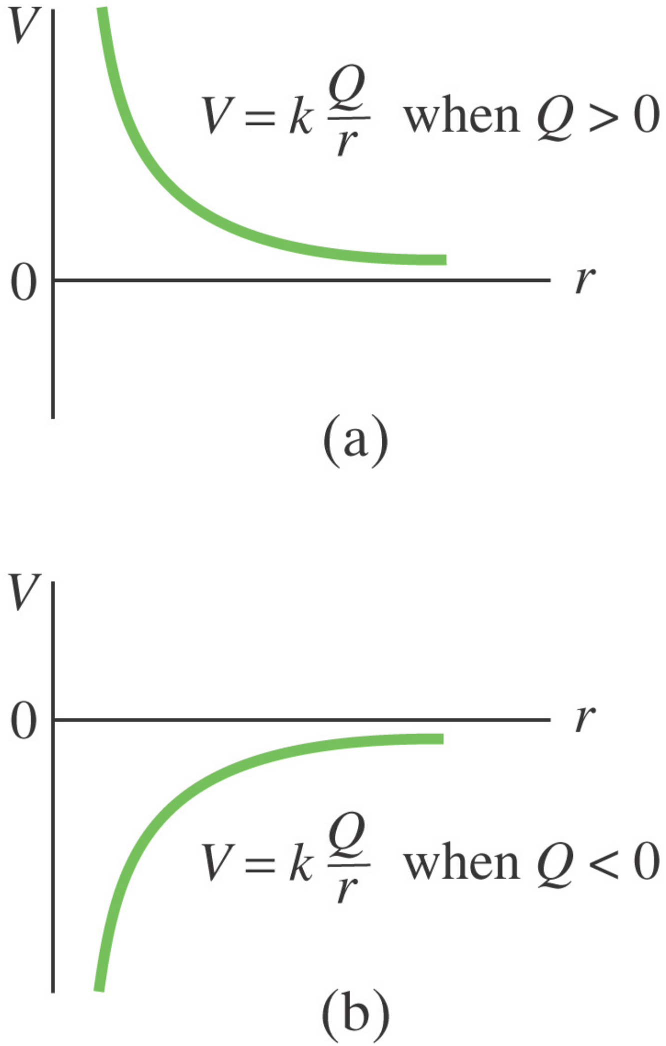
A charge subjected to an Electric field experiences a force, and if it is free to move it accelerates, and hence gains kinetic energy.

(Think of an electron in a TV tube, or X-ray machine)

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

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

17.5 Electric Potential Due to Point Charges



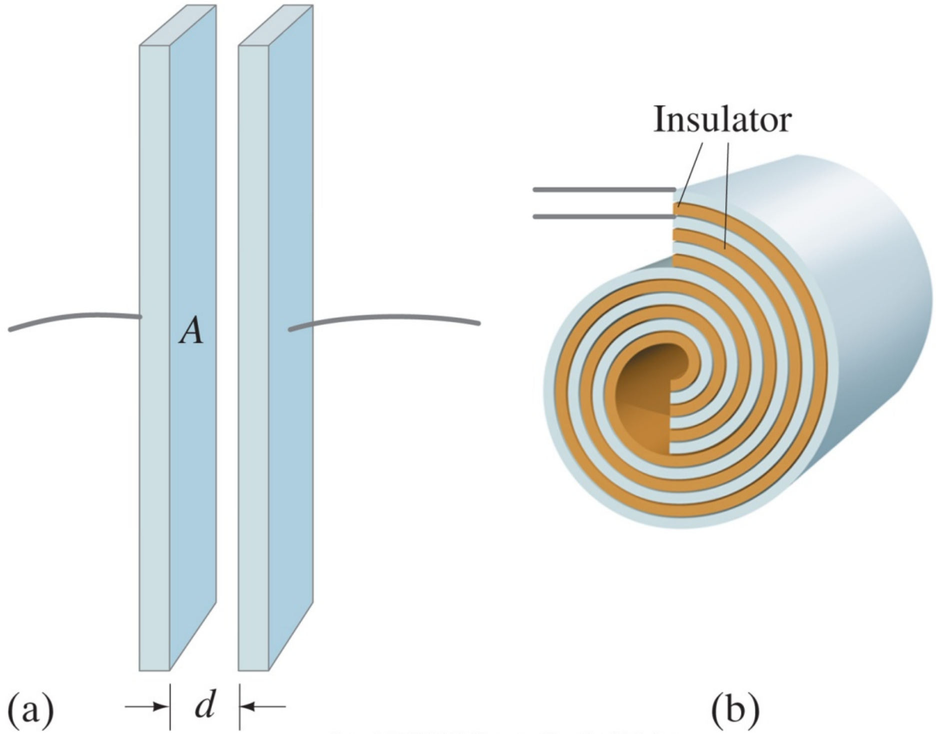
These plots show the potential due to:

(a) positive charge

(b) negative charge

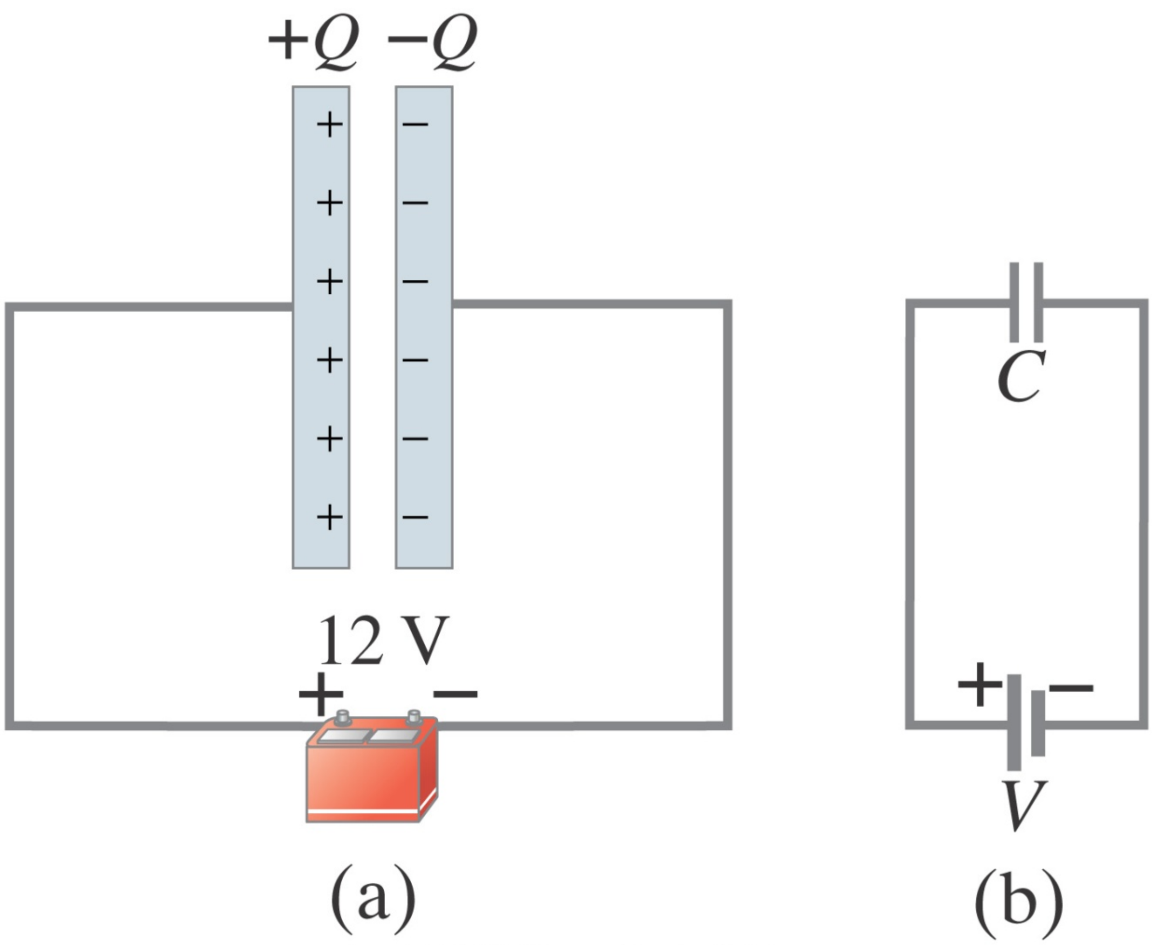
17.7 Capacitance

We have seen that when charges are separated, there is a force-field between them. This field can both store energy, and do work.



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

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



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

$$Q = CV \qquad \textbf{(17-7)}$$

The quantity *C* is called the capacitance.

Unit of capacitance: the farad (F)

1 F = 1 C/V (or Coulombs per volt)

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:

$$C = \epsilon_0 \frac{A}{d} \qquad (17\text{-}8)$$

In other words the Capacitance is fixed, and determines how much charge is stored for a given applied Voltage.

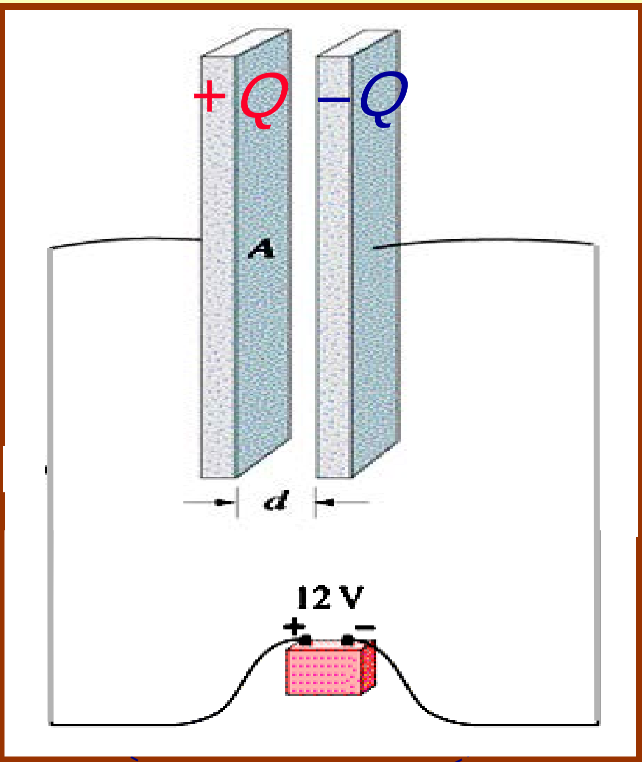
Capacitance depends on THREE factors

- Area
- Separation (think coulomb force)
- Material

ConcepTest 17.8 Capacitors

Capacitor C_1 is connected across a battery of 5 V. An identical capacitor C_2 is connected across a battery of 10 V. Which one has the most charge?

1) C_1
2) C_2
3) both have the same charge
4) it depends on other factors

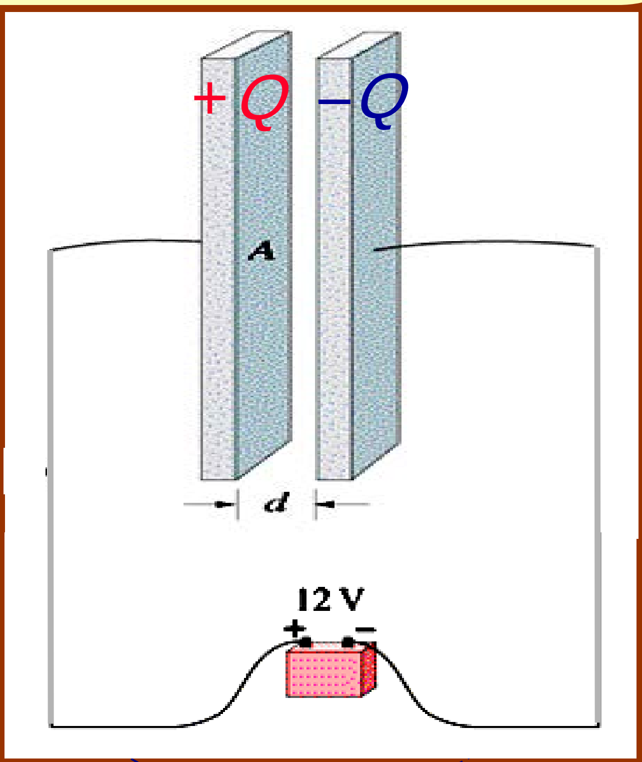


ConcepTest 17.8 Capacitors

Capacitor C_1 is connected across a battery of 5 V. An identical capacitor C_2 is connected across a battery of 10 V. Which one has the most charge?

1) C_1
2) C_2
3) both have the same charge
4) it depends on other factors

Since $Q = C V$ and the two capacitors are identical, the one that is connected to the greater voltage has the most charge, which is C_2 in this case.



17.8 Dielectrics - Improving the basic capacitor

A dielectric is an insulator, placed between the capacitor's plates, and is characterized by a **dielectric constant** K.

Capacitance of a parallel-plate capacitor filled with dielectric:

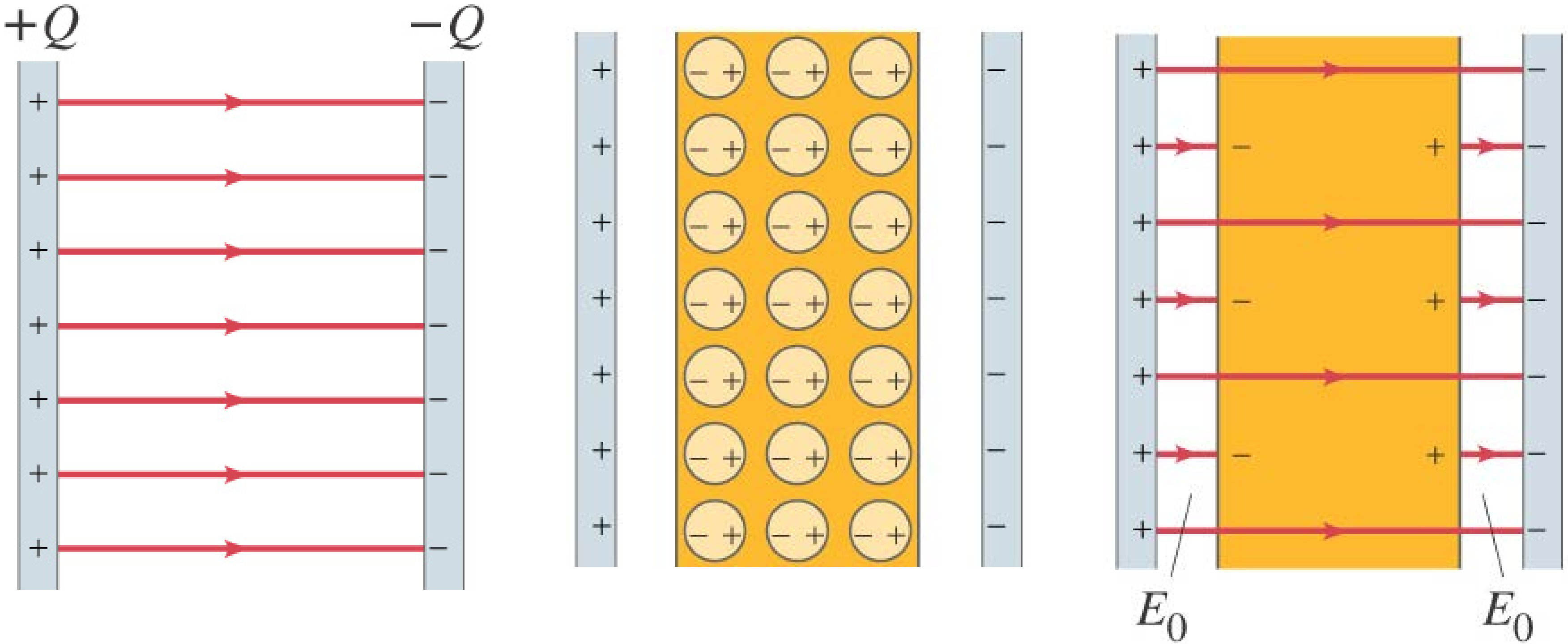
$$C = K\epsilon_0 \frac{A}{d} \qquad (17\text{-}9)$$

Inserting a dialectric INCREASES the capacitance

Why?

Dielectrics - what's going on inside a Capacitor?

Dialectrics increase the amount of charge a capacitor can hold, at a given voltage. The molecules in a dielectric tend to become oriented in a way that reduces the external field.



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.

Alternative conceptual viewpoint: **The induced charges of the molecules in the dialectric (an insulator) attract additional charges onto the plates (from the battery).**

17.8 Dielectrics

TABLE 17–3 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

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

Think about factors affecting suitability in different applications

e.g.

Look at water, but its not usually a good choice!

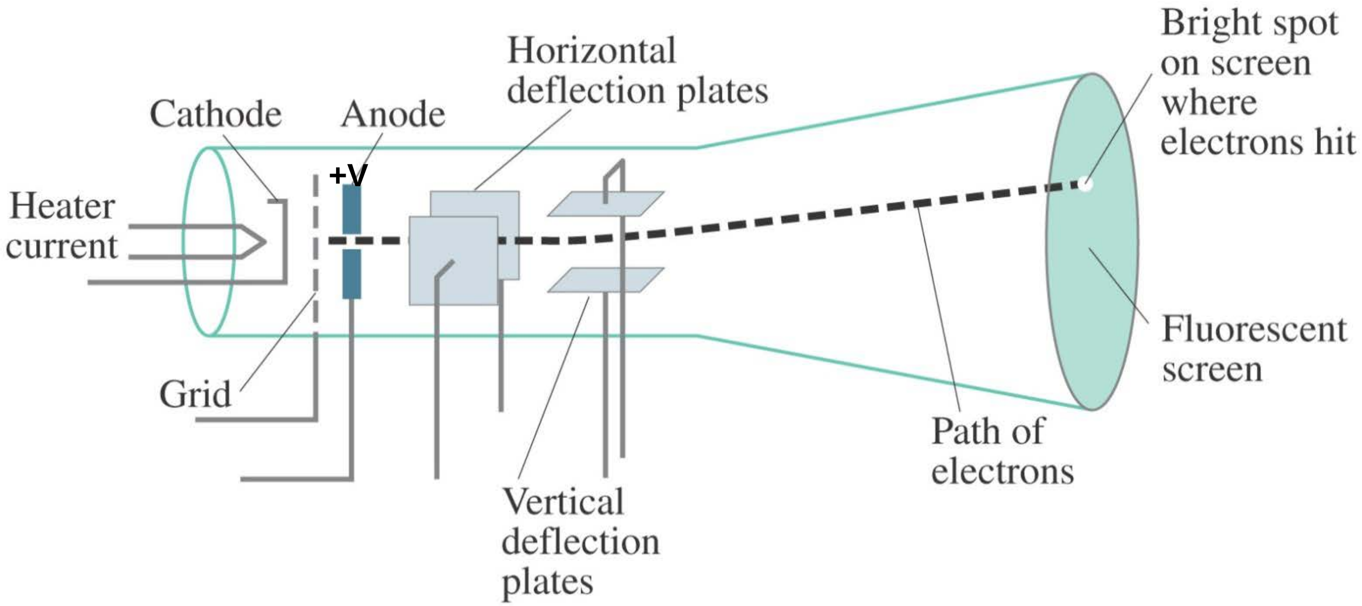
17.9 Storage of Electric Energy

A Capacitor's main use is to store energy. It can be charged slowly and then discharged rapidly. For example in a camera flash unit.

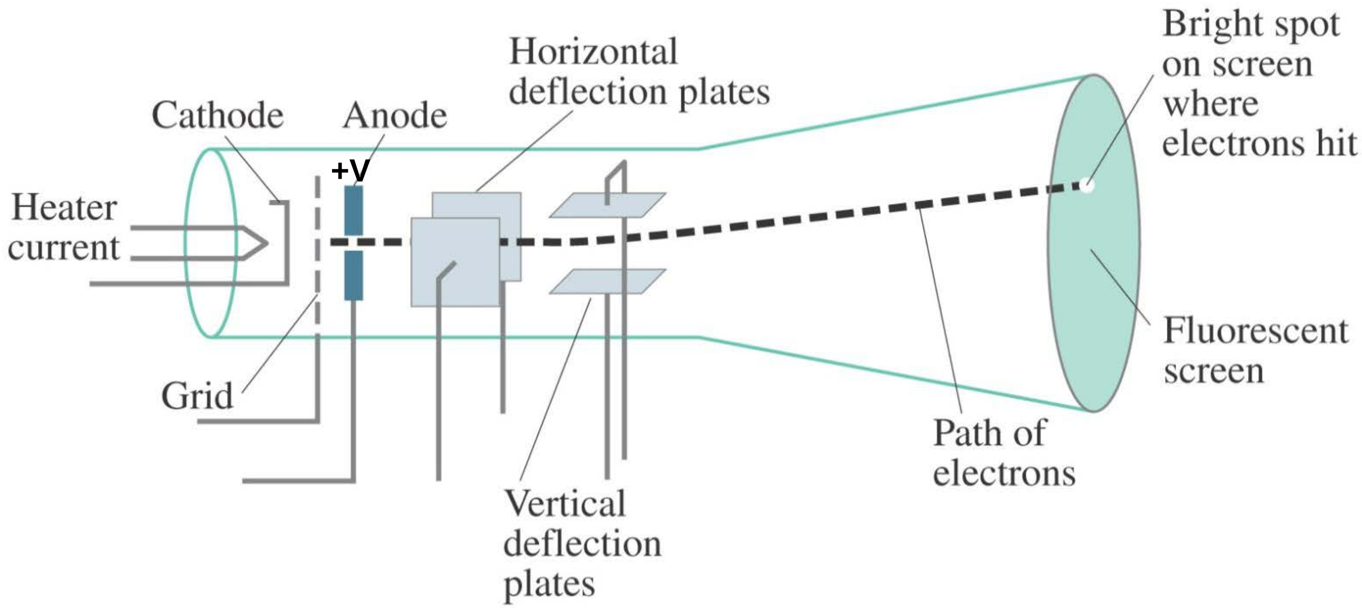
A charged capacitor stores electric energy; the energy stored is equal to the work done to charge the capacitor.

$$\text{PE} = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\frac{Q^2}{C} \qquad \textbf{(17-10)}$$

17.10 Cathode Ray Tube: TV and Computer Monitors, Oscilloscope



Imagine an electron accelerated by the electric field inside a TV tube, how fast does it go ?



Say V = 20,000 volts

Change in EPE = qV = $1.6\times10^{-19} * 20\times10^{3}$
= 3×10^{-15} Joules

Change in EPE = change in KE = $1/2\ mv^2$

so: v = sqrt (2KE/m)
= sqrt(2 * 3×10^{-15} / 9.1×10^{-31})

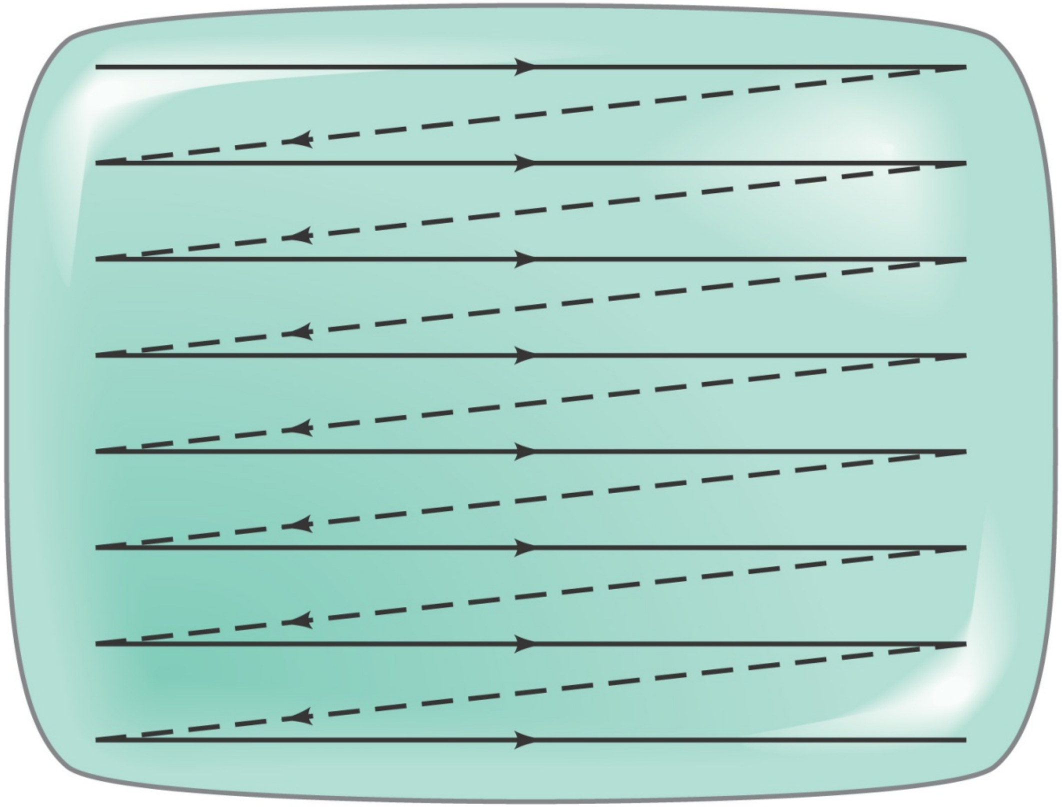
= 8.4×10^{7} m/s

In physics we often use eV because it is a “natural“ unit.

By definition, the electrons here have a kinetic energy of 20 keV

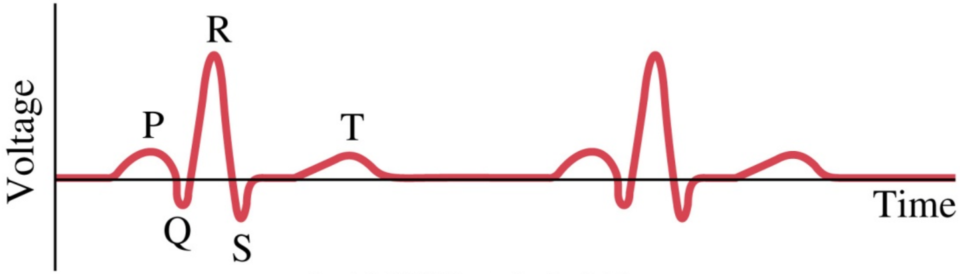
Cathode Ray Tube: TV and Computer Monitors, Oscilloscope

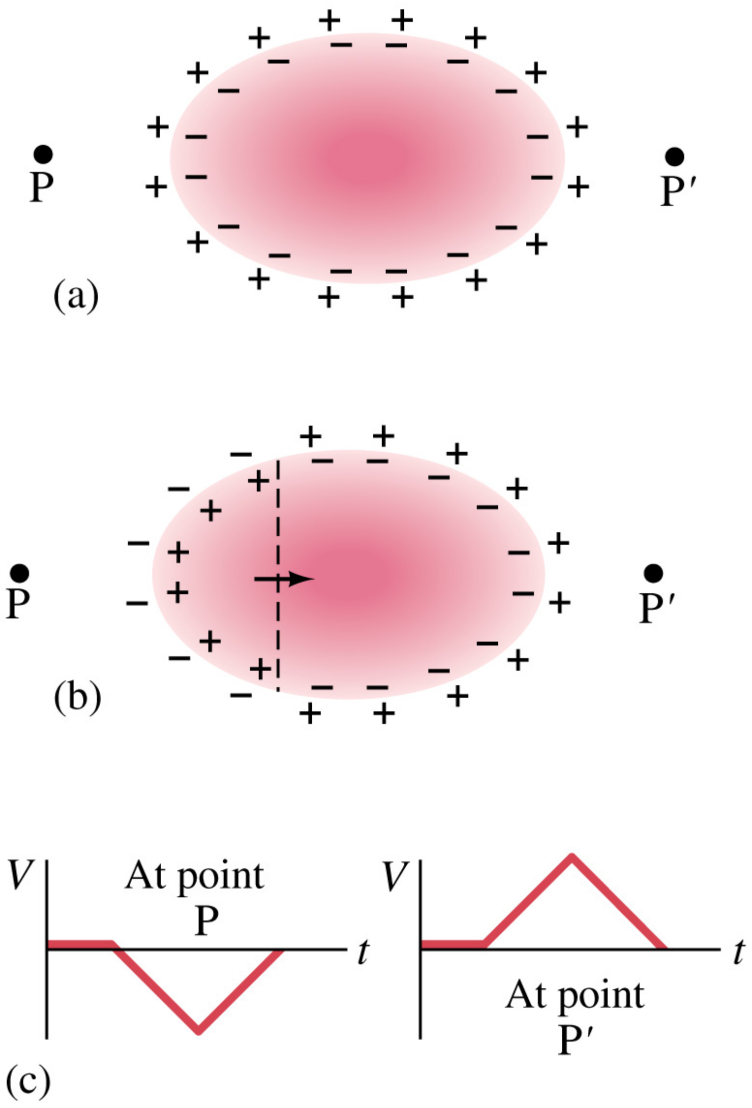
Old style Televisions and computer monitors oscilloscopes etc… have a large cathode ray tube as their display. Variations in the field steer the electrons on their way to the screen.



17.11 The Electrocardiogram (ECG or EKG)

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





Summary

• **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:**

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

• **Work done by (or against) an Electric Field**

W = qV

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

Capacitors

- Nontouching conductors carrying equal and opposite charge. Shape irrelevant.

- Capacitance: $Q = CV$

  unit is the Farad (joule per coulomb)

- Capacitance of a parallel-plate capacitor:

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

- Energy stored in a capacitor

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