Arvind Borde / PHY 12, Week 2: Electric Potential

Electric Potential Energy

This is energy associated with electricity.

Energy is an abstract concept – you cannot see it, taste it, touch it or feel it, but it's a very important abstraction.

(1) Why is energy important?

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We can figure out how systems behave by balancing the energies before and after.

For example, the behavior of objects undergoing elastic collisions can be figured out using energies, *without detailed information on the forces involved.*

If we find that energy does not seem to be conserved, we invent a new form of energy so that the total of old and new energy is still fixed.

When a ball drops, its kinetic energy changes as it picks up speed. We invent gravitational potential energy to keep the total energy fixed.

(2) Can electrical forces appear to create new kinetic energy, just as gravitational ones do?

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(3) What do we do in response?

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The *change* in electric potential energy when a point charge q moves from a point a to another point b is defined as ___________________________

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As with grav. potential energy, _________________

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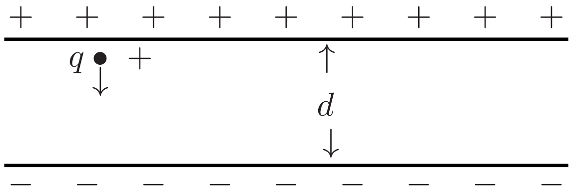
In other words, you pick a reference level arbitrarily as the "zero" level.



The electrical force, F_{elec}, does work, $F_{\text{elec}}d$, on the positive charge. It picks up (positive) kinetic energy, so must _____ electrical potential for energy to be conserved. That's why we define the change in electrical PE as negative: $-F_{\text{elec}}d = -qEd$.

ADDITIONAL NOTES

(4) As a positive test charge moves away from a positive charge, does it gain potential energy or lose it? ____________

(5) What would the analogous statement be for a negative test charge?

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Electric Potential

Just as the electric field is the electric force per unit charge, ______________________________

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$$\text{Electric potential} = \frac{\text{PE}_{\text{Elec}}}{q}.$$

Unit of electric potential is joules/coulomb and is given a special name: ____________.

$$1\ \text{V} = 1\ \text{J/C}$$

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They "make charges move." In practical situations, the earth is taken as the zero.

The electric potential energy of a charge depends on the charge and the electric field in which it is.

The ______________________________________

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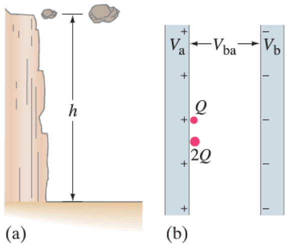

FIGURE 17–3 (a) Two rocks are at the same height. The larger rock has more potential energy. (b) Two positive charges have the same electric potential. The $2Q$ charge has more potential energy.

Equipotential lines and surfaces

A useful way to think of potentials is via lines | where the potential is constant: __________

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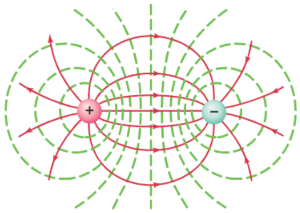
FIGURE 17–7 Equipotential lines (green, dashed) are always perpendicular to the electric field lines (solid red), shown here for two equal but oppositely charged particles (an "electric dipole").



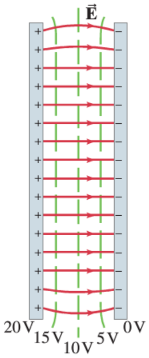


FIGURE 17–6 Equipotential lines (the green dashed lines) between two charged parallel plates are always perpendicular to the electric field (solid red lines).

ADDITIONAL NOTES

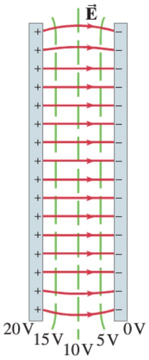
Equipotential plots are like topographical maps:

A topographical map tells you which direction is uphill and which downhill.

If you're a hiker it tells you in which direction you'll need to expend energy.

If you're a ball, it tells you in which direction you'll roll: from higher altitudes (greater gravitational potential energy) to lower (less gravitational potential energy).

Similarly, an equipotential map tells you in which direction a positive test charge will move: higher to lower potential.



(6) In what "direction" (in terms of electric potential) will a negative test charge move?

Here's a fun, fun, fun scenario:

(7) How/where will all the charges move?

q_1:

q_2:

q_3:

q_4:

(8) How will the potential energies change?

q_1:

q_2:

q_3:

q_4:

ADDITIONAL NOTES

(**9**) How will the *potentials* of the charges change?

q_1:

q_2:

q_3:

q_4:

(**10**) Why do + and − charges behave the same in the language of PE, but the opposite in the language of potentials?

Typical potential differences

- ▷ Household outlet in the US: $110\,\mathrm{V}$.
- ▷ Flashlight batteries (AA, C, D, etc.): $1.5\,\mathrm{V}$.
- ▷ Lightning (to ground): $10^8\,\mathrm{V}$.

(**11**) If an electron is accelerated from rest through a potential difference of $100\,\mathrm{V}$, what is the change in its PE? What is its final velocity?

Electric Field and Electric Potential

For a uniform electric field, E, the electric potential difference, V, across a distance d is given by

$$V = -Ed,$$

or

$$E = -V/d.$$

The Electron Volt

This is the energy acquired by an object whose charge has the magnitude of one electron charge when it moves through a potential difference of 1 volt. Therefore

ADDITIONAL NOTES

The Electric Potential of a Point Charge

$$V = k\frac{Q}{d}$$

(**12**) What's the potential 2 mm from an electron?

$V =$

The electric field is a vector.
The electric potential is a scalar.

As such, the potential is usually much easier to work with. If you want the potential due to multiple charges, you simply calculate each separately and add.

The potential energy of two point charges

If two charges, q_1 and q_2 are separated by a distance d,

$$\text{PE} = k\frac{q_1 q_2}{d}$$

Capacitance

____________________________________ Its ________________, measured in Farads, is the amount of charge it can hold per volt of potential difference applied to it:

or

A Farad is a coulomb/volt.

Standard capacitors are parallel plates of area A separated by distance d. The capacitance is

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

where ϵ is called the permittivity of the substance between the plates. If the substance is space, we represent the permittivity by ϵ_0. Its value is

$$\epsilon_o = \frac{1}{4\pi k}$$

(**13**) Calculate ϵ_0.

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(**14**) What is the capacitance of a capacitor formed by plates of area $1\,\text{cm}^2$, separated by a distance of $1\,\text{mm}$?

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ADDITIONAL NOTES

(15) What is the charge on the previous capacitor if a $15\,$V battery is attached to it?

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Dielectrics

This is an insulating layer between the charged plates of a capacitor. The permittivity is usually expressed as a multiple of ϵ_0:

$$\epsilon = K\epsilon_0,$$

where K is called the dielectric constant. Usually $K > 1$, so $\epsilon > \epsilon_0$. We'll assume that's the case.

(16) For a capacitor attached to a battery of fixed voltage, what does increasing ϵ do to (a) the capacitance, and (b) the charge held?

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(17) For a charged capacitor not attached to a battery, what does increasing ϵ do to (a) the capacitance, and (b) the charge held?

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The Energy of a Capacitor

We get this from asking how much work is done to move the charge Q from one plate to another.

(18) Express the energy in terms of (a) C and V, and (b) Q and C.

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ADDITIONAL NOTES

(**19**) A parallel plate capacitor will have a roughly constant electric field between the plates. In that case, what is V in terms of the electric field, E?

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(**20**) What is the PE of such a capacitor in terms of E? __________________________________

(**21**) Rewrite this using the formula for C in terms of A and d.

(**22**) What is Ad geometrically? ________________

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So, the energy per unit volume in this case is

This is _______________________, not just for parallel plate capacitors.

(**23**) The electric field of a point charge is $E \propto 1/d^2$. What happens to the energy density as you approach the charge?

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ADDITIONAL NOTES

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