Electricity and Magnetism
Electric Potential Energy

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De Anza College

Oct 8, 2015

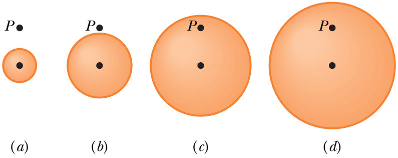
Last time

- electric flux
- Gauss's law
- implications of Gauss's law
- Coulomb's law from Gauss's law
- some rules to help solve problems

Warm Up Question

Page 621, #8

The figure shows four solid spheres, each with charge Q uniformly distributed through its volume.



Rank the spheres according to their volume charge density, greatest first. The figure also shows a point P for each sphere, all at the same distance from the center of the sphere.

(A) a, b, c, d

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[1] Halliday, Resnik, Walker

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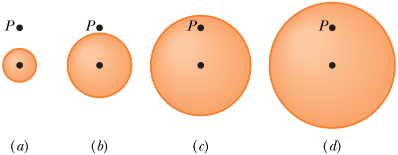

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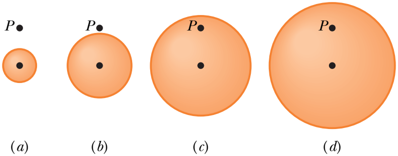

Rank the spheres according to the magnitude of the electric field they produce at point P, greatest first.

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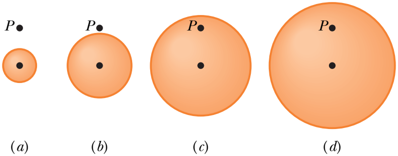

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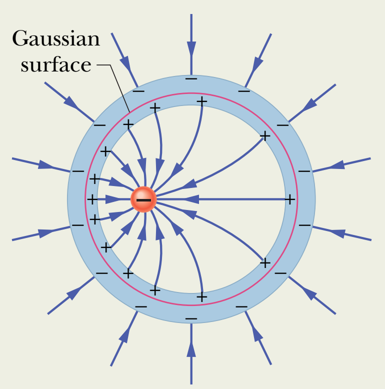
Some Implications of Gauss's Law

Faraday Ice Pail



A charge placed inside a conducting shell appears on the outside of the conductor.

(**E** $= 0$ for the Gaussian surface shown.)

Overview

- electrical potential energy
- dipole energy in a electric field

Potential Energy

Recall from 2A, there are many kinds of potential or stored energy:

- gravitational ($U = mgh$)
- elastic ($U = \frac{1}{2}kx^2$)

potential energy

energy that a system has as a result of its configuration; stored energy

mechanical energy

the sum of a system's kinetic and potential energies, $E_{\text{mech}} = K + U$

Conservative Forces

Conservative forces are forces that do not dissipate energy.

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If you do work to lift a book, the book stores potential energy, because its height has increased.

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The work done by a conservative force is always related to potential energy:

$$\Delta U = U_f - U_i = -W$$

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Only for conservative forces, we can write:

$$W = -\Delta U$$

where W is the work done *by* the system and ΔU is the change in the potential energy of the system.

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Example: The system is a compressed spring. It does work on a massive block, pushing the block. The amount of work done *by* the spring is equal to the decrease in potential energy of the spring (*ie.* $-\Delta U$).

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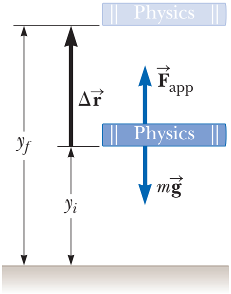
Examples of non-conservative forces:

- Friction
- Air resistance

Mechanical energy is converted to heat or other inaccessible forms.

Potential Energy



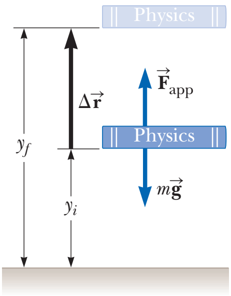
The work done by gravity pulling down a mass near the Earth's surface:

$$\begin{aligned} W &= Fd\cos\theta \\ &= F(y_f - y_i)\cos(180°) \\ &= -mg(y_f - y_i) \end{aligned}$$

Change in gravitational potential energy

$$\Delta U_g = mg(y_f - y_i)$$

Potential Energy



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$$W_g = -\Delta U_g$$

where W is the work done *by* gravity and ΔU is the potential energy change of the system.

Potential Energy and the Electrostatic Force

The electrostatic force is a conservative force.

We can ask what is the stored energy (potential energy) of some particular configuration of charge.

electric potential energy

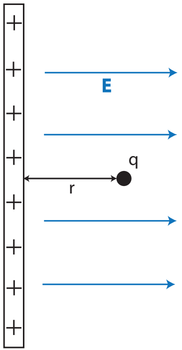
The electric potential energy of a system of fixed point charges is equal to the work that must be done on the system by an external agent to assemble the system, bringing each charge in from an infinite distance.

Potential Energy and the Electrostatic Force

An example!

Consider an infinite sheet of charge, density σ. It causes and electric field E.

Potential energy change of a charge q moving a distance $r_f - r_i$?



Work done bringing q in from r_i to r_f?

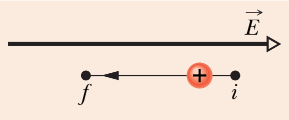
$$\begin{aligned} W &= Fd\cos\theta \\ &= (qE)(r_f - r_i)\cos(0) \\ &= qE(r_f - r_i) \end{aligned}$$

Similar to lifting a book.

Question

In the figure, a proton moves from point i to point f in a uniform electric field directed as shown.

(a) Does the force of the electric field do positive or negative work on the proton?



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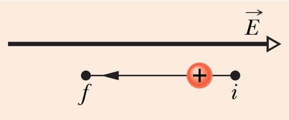

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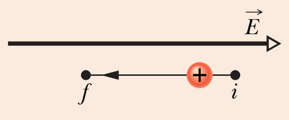

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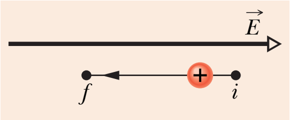

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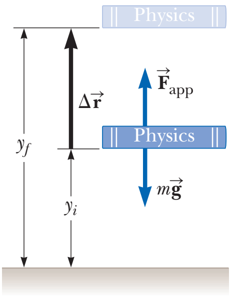
Work done against Gravity by an Applied Force



The work done on the book by an external agent:

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Change in gravitational potential energy

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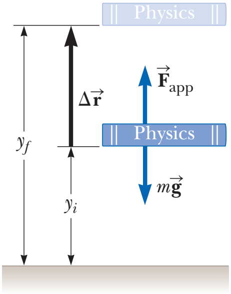

The work done on the book by an external agent:

$$
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where W is the work done *on* the system and ΔU is the potential energy change of the system.

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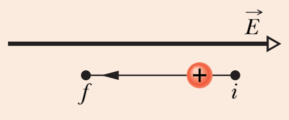

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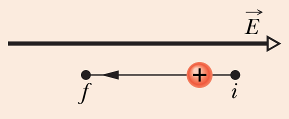

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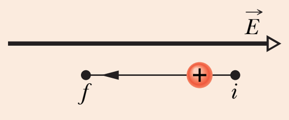

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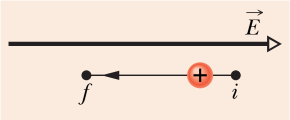

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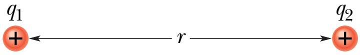
Potential Energy of two point charges

Consider two charges q_1 and q_2 at a distance r.

They repel each other. Bringing them to that configuration requires work.



Define $U(\infty) = 0$ so that $U(r) = \Delta U = U(r) - U(\infty)$

Then, the potential energy of two point charges is:

$$U(r) = \frac{kq_1 q_2}{r}$$

Potential Energy of many point charges

Suppose we have three point charges.

Let

$$U_{12} = \frac{k\, q_1 q_2}{r_{12}}$$

Then the total potential energy of the configuration is:

$$U_{\text{net}} = U_{12} + U_{13} + U_{23}$$

Just add up all the pairwise potential energies!

Potential Energy

We already talked about the potential energy charge has due to the electric field of other charges in its vicinity.

Now, we think about the potential energy of a dipole in an electric field.

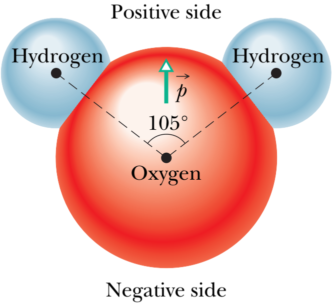
Electric Dipole in an Electric Field

Remember:

electric dipole

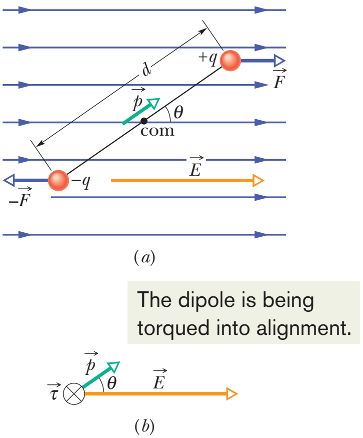
A pair of charges of equal magnitude q but opposite sign, separated by a distance, d.

A water molecule is an example



Electric Dipole in an Electric Field

Because the net charge of a dipole is zero, the net force is zero also. But there is a torque!



θ is the angle between the **p** and **E**

$$\begin{aligned}\tau &= Fd\sin\theta \\ &= (qE)d\sin\theta\end{aligned}$$

and $p = qd$

$$\tau = pE\sin\theta \quad \text{clockwise}$$

(It is clockwise for this diagram, but in general you must consider the direction of the field and the orientation of the dipole.)

$$\boldsymbol{\tau} = \mathbf{p} \times \mathbf{E}$$

Electric Dipole in an Electric Field

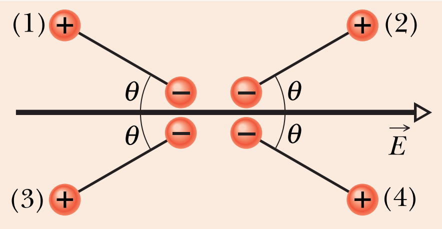
We can also find an expression for the potential energy of a dipole in an E-field.
Define $U = 0$ when $\theta = 90^\circ$ (the dipole is $\perp$ to the field lines).

$$U = -pE\cos\theta$$

$$U = -\mathbf{p} \cdot \mathbf{E}$$

Question: Electric Dipole in an Electric Field

The figure shows four orientations of an electric dipole in an external electric field. Rank the orientations according to the magnitude of the torque on the dipole, greatest first.



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[1] Page 595, Halliday, Resnick, Walker.

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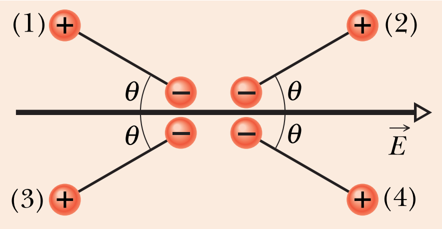

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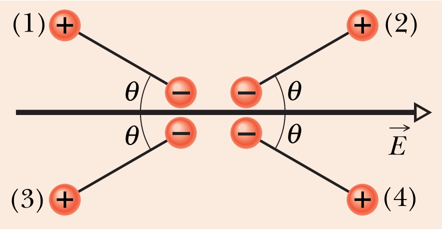

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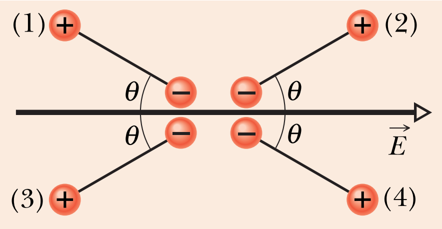

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Microwave Ovens

An application of the fact that a dipole experiences a torque in an electric field is microwave cooking.

Microwave ovens produce electric fields that change direction rapidly.

Since water molecules are dipoles, they begin to rotate to align with the field, back and forth.

This motion becomes thermal energy in the food.

Summary

- electric potential energy

Homework Halliday, Resnick, Walker:

- work through the sample problems on page 643 and 644
- Ch 24, onward from page 646. Problems: 98, 102
- Ch 22, onward from page 597. Problems: 57