Electricity and Magnetism
Isolated Conductors and Potential
Dipole in an Electric field
Millikan's Experiment

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De Anza College

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Last time

- relation between E-field and potential
- potential from many charges
- potential around continuous charge distributions

Warm Up Questions

What is an alternative unit for the electric field?

(A) Vm

(B) V/m

(C) V/m^2

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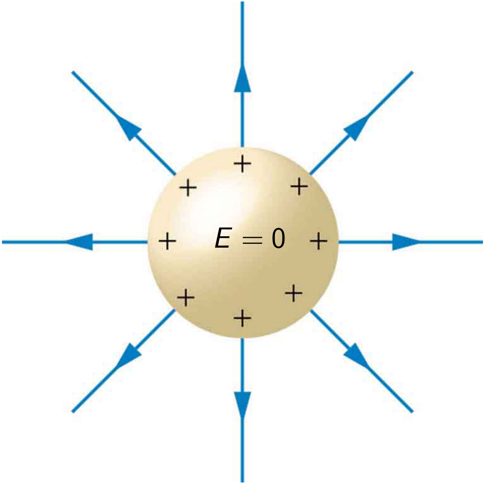
Overview

- Potential of charged conductor
- torque on a dipole in an E-field
- potential energy of a dipole in an E-field
- Millikan's experiment

Conductor in an Electric field

The E-field inside an isolated conductor at equilibrium is zero.

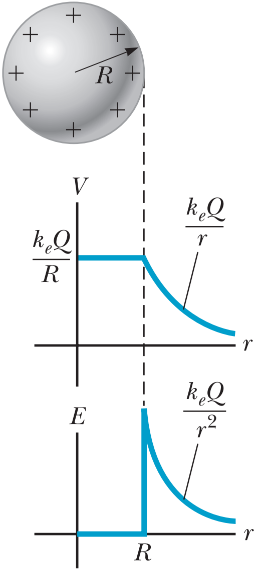
eg. an isolated conductor with excess charge:



[1]Figure from Openstax College Physics.

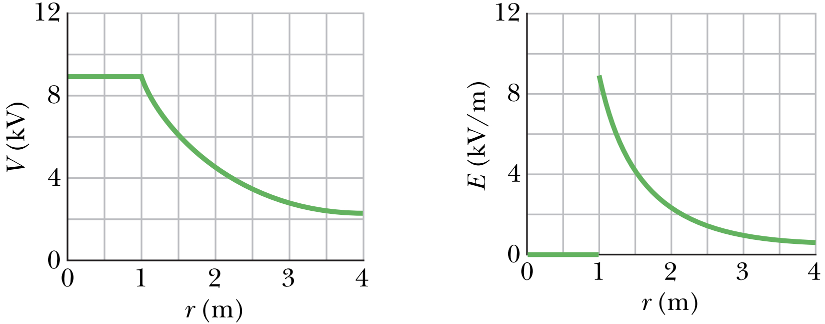
Potential due to an Isolated Charged Conductor

What is the potential at the point R?



Potential due to an Isolated Charged Conductor

All excess charge flows to the outside, in the interior, the electric field is zero.

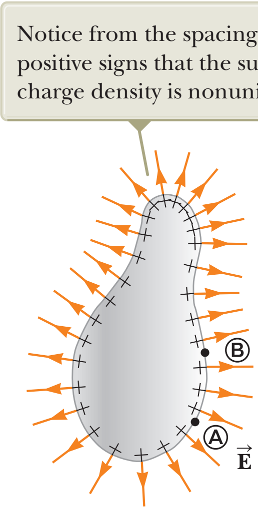


Since $\Delta V = -\int \mathbf{E} \cdot d\mathbf{s}$ the potential inside the conductor is **constant**.

[1]Figure from Halliday, Resnick, Walker, 9th ed.

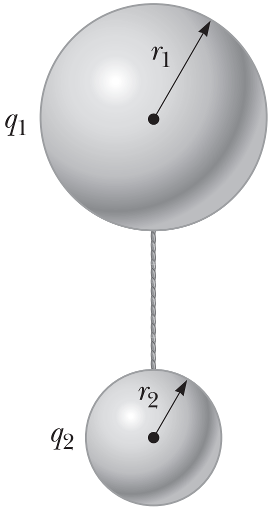
Charge distribution on a conductor

The electric potential is constant everywhere on a conductor (including the surface!), but the charge distribution may vary.



Charge distribution on a conductor

An illustrative example (25.8), electric field around conductor.



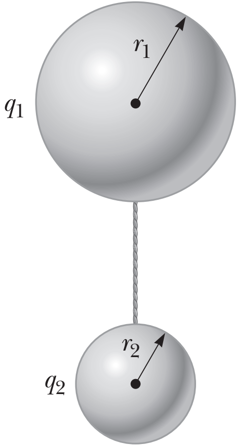
At all points on the object V is constant.

$$\begin{aligned} V_1 &= V_2 \\ \frac{k_e q_1}{r_1} &= \frac{k_e q_2}{r_2} \\ \frac{q_1}{q_2} &= \frac{r_1}{r_2} \end{aligned}$$

Since $r_1 > r_2$, $q_1 > q_2$.

$\Rightarrow$ sharper curvature of surface, higher charge density

Question: Charge Density



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$$

What is the ratio of the surface charge densities σ_1/σ_2 on the spheres?

(A) $\frac{r_1}{r_2}$

(B) $\frac{r_1^2}{r_2^2}$

(C) $\frac{r_2}{r_1}$

(D) $\frac{r_2^3}{r_1^3}$

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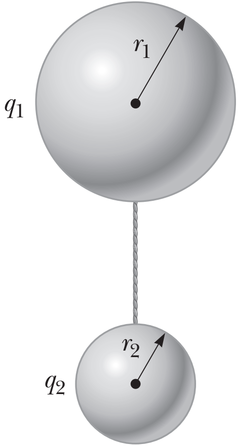

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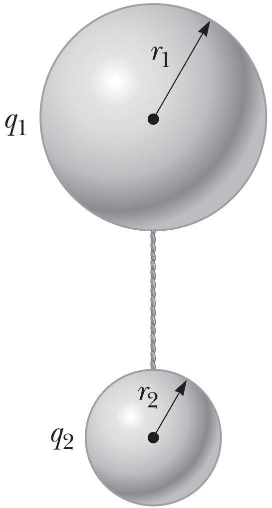

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Since $r_2 < r_1$, $E_1 < E_2$.

$\Rightarrow$ sharper curvature of surface, stronger electric field

Corona Discharge

A corona discharge occurs when a conductor at a very high potential ionizes a fluid (*eg.* air) that surrounds it.

The fields that form around sharp edges of the conductor are high enough to form small plasma regions, but not full electric breakdown.

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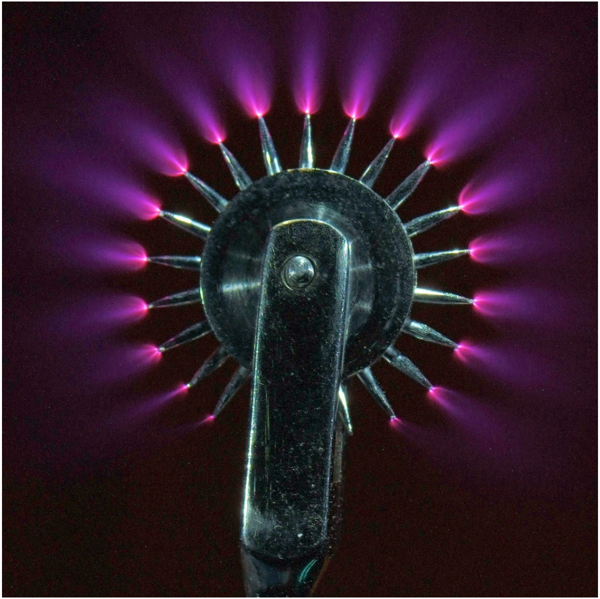
- responsible for significant power losses in high voltage lines
- useful for
  - pool sanitation
  - ozone manufacture
  - ionizers
  - air purifiers
  - nitrogen lasers (TEA lasers)

Coronal Discharge



[1] Photo "Wartenburg Pinwheel" by Giles Read. 30–50kV

Corona Discharge

Fork in a microwave.

(Microwave ovens generate electric fields.)

https://www.youtube.com/watch?v=b1MFWbX3Bfc

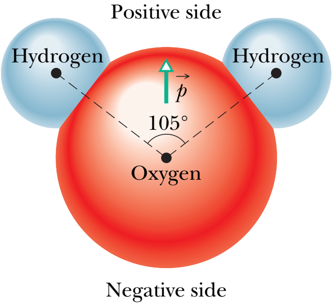
Potential Energy: Electric Dipole in an E-Field

Remember:

electric dipole

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

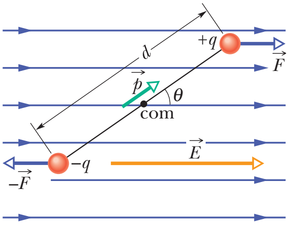
A water molecule is an example



Electric Dipole in an Electric Field (26.6)

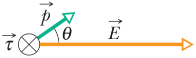
Because the net charge of a dipole is zero, the net force is zero also. But there is a torque!

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



(a)

The dipole is being torqued into alignment.



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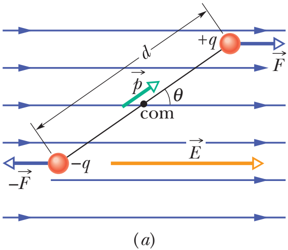

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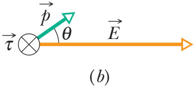


θ is the angle between the **p** and **E**

$$\begin{aligned} \boldsymbol{\tau} &= \mathbf{r} \times \mathbf{F} \\ &= 2(d/2)(qE)\sin\theta \quad \text{[clockwise]} \end{aligned}$$

and $\mathbf{p} = q\mathbf{d}$

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

In general,

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

Electric Dipole in an Electric Field (26.6)

We can also find an expression for the potential energy of a dipole in an E-field. Define $U = 0$ when $\theta = \frac{\pi}{2}$ (the dipole is $\perp$ to the field lines). For a conservative force:

$$\begin{aligned} \Delta U &= -W_{\text{int}} \\ U(\theta) - \cancelto{0}{U(\pi/2)} &= -\int_{\pi/2}^{\theta} \boldsymbol{\tau} \cdot d\boldsymbol{\theta}' \\ U(\theta) &= -\int_{\pi/2}^{\theta} -\tau d\theta' \end{aligned}$$

where the minus sign inside the integral is due to $\boldsymbol{\tau}$ being clockwise, while θ increases counter clockwise.

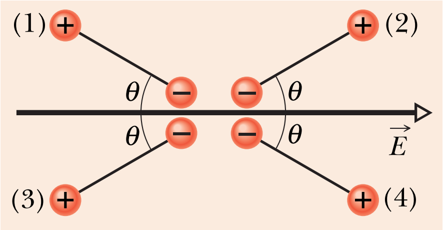
$$\begin{aligned} U &= pE[-\cos\theta]_{\pi/2}^{\theta} \\ &= -pE\cos\theta \end{aligned}$$

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

can be positive or negative.

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.



(A) 1, 2, 3, 4

(B) (1 and 3), (2 and 4)

(C) (2 and 4), (1 and 3)

(D) all the same

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

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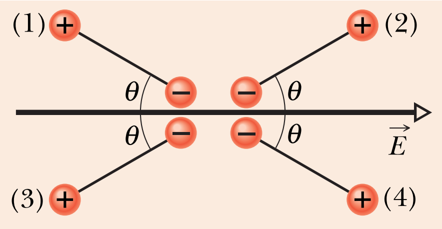

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Question: Electric Dipole in an Electric Field

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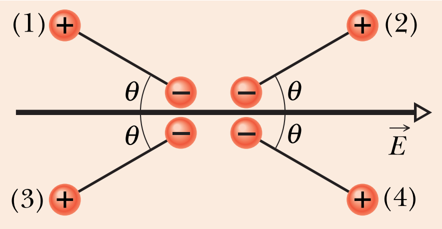

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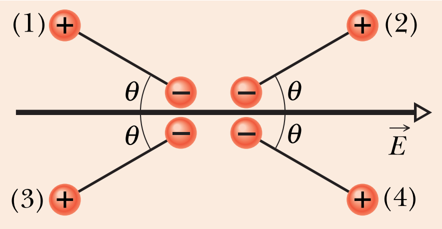

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Microwave Ovens

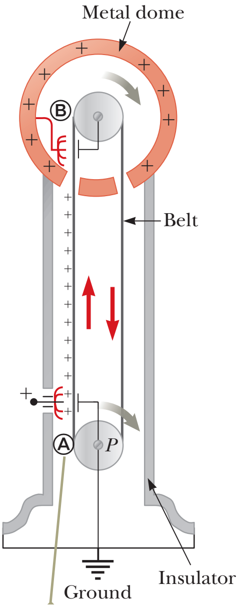
An application of the fact that a dipole experiences a torque in an electric field is microwave cooking.

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.

Van de Graaf generator



Can (in principle) build up to 3 million Volts when used in air.

Milikan's Oil Drop Experiment

The value of e, the basic unit of charge was found in this experiment.

From 1908–1913 Robert Millikan worked with Harvey Fletcher on the experiment.

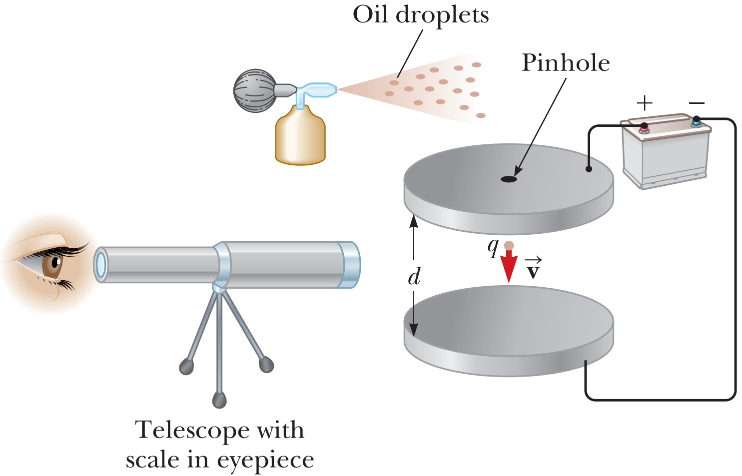
At the time the idea of both atoms and subatomic particles was only just gaining acceptance.

Milikan's Oil Drop Experiment

Some history:

- early 1800s – John Dalton realized chemical reactions could be explained if there were element-particles
- 1827 – Robert Brown noticed that pollen particles vibrated randomly when viewed with a microscope
- early 1870s – Ludwig Boltzmann explained thermodynamic behavior in terms of statistics of particles
- 1897 – JJ Thompson discovered the electron in "cathode rays"; noticed it had a charge and very small mass
- 1905 – Albert Einstein explained Brown's "Brownian motion" in terms of atoms
- 1909 – Ernest Rutherford's experiment done by Hans Geiger and Ernest Marsden discovered the nucleus

Milikan's Oil Drop Experiment



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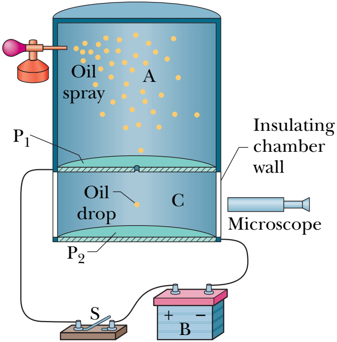
In an experiment, a potential difference (voltage) of $\Delta V = 10V$ is supplied to a pair of conducting plates separated by a distance $d = 20$ cm. What is the electric field strength between the plates?



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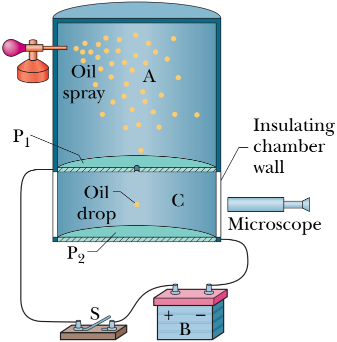

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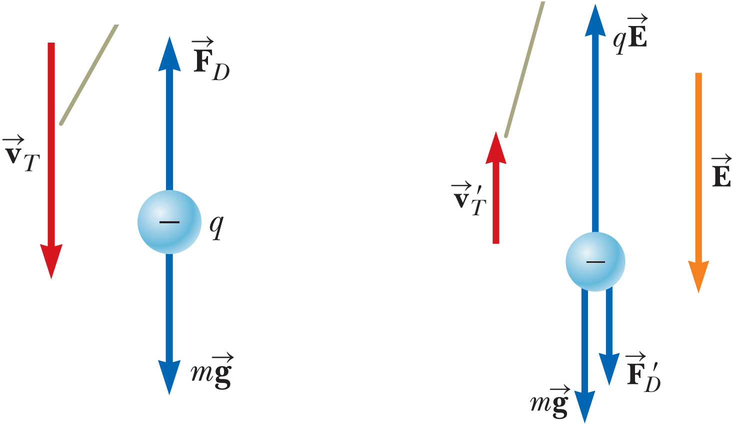

$F_D \propto v_T$, w is weight of droplet

$$qE = w + w\left(\frac{v'_T}{v_T}\right)$$

Milikan's Oil Drop Experiment

Conclusion: all drops had a charge that was some number of multiples of e.

$$q = ne \;; \quad n \in \mathbb{Z}$$

Accepted value:

$$e = 1.602176565(35) \times 10^{-19} C$$

Millikan's value:

$$e = 1.5924(17) \times 10^{-19} C$$

A bit low...

Milikan's Oil Drop Experiment

Richard Feynman:

Millikan measured the charge on an electron by an experiment with falling oil drops, and got an answer which we now know not to be quite right. It's a little bit off because he had the incorrect value for the viscosity of air. It's interesting to look at the history of measurements of the charge of an electron, after Millikan. If you plot them as a function of time, you find that one is a little bit bigger than Millikan's, and the next one's a little bit bigger than that, and the next one's a little bit bigger than that, until finally they settle down to a number which is higher.

Why didn't they discover the new number was higher right away? ... When they got a number that was too high above Millikan's, they thought something must be wrong—and they would look for and find a reason why something might be wrong. When they got a number close to Millikan's value they didn't look so hard.

Summary

- conductor in an electric field
- dipole in an electric field
- Millikan's experiment

Homework

- Study for test tomorrow.

Serway & Jewett:

- Ch 25, Problems: 49, 51