Announcements:

When you register your iClicker, use your RUID, not your NETID. If you have already registered with your NETID, please re-register!

Study group schedule: No new information

On line testing:

https://rutgers.qualtrics.com/SE/?SID=SV_7afswlsRd6voexf

Pre-Semester Testing

For students who did not take the required pre-test in recitations on September 6 and 7, the only makeup opportunity will be on Tuesday September 13. You can drop in between 3 PM and 8 PM in NPL 213 on the Busch campus. Note that this venue is not accessible for students with certain disabilities. If you have limited mobility please contact Professor Cizewski cizewski@physics.rutgers.edu for alternate arrangements.
Consider two point-like charges of the same mass: #1 has charge $+q$, and #2 has charge $Q = +10q$. You hang them from threads near each other. The angle between the thread supporting #1 and the vertical is $\alpha_1$, the angle between the thread supporting #2 and the vertical is $\alpha_2$.

Choose the statement with which you agree:

A. $\alpha_1 > \alpha_2$

B. $\alpha_1 < \alpha_2$

C. $\alpha_1 = \alpha_2$

D. You need to know the mass to answer the question.
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Reasons to introduce electric (gravitational, magnetic, etc.) field:


  Cure for the “action-at-a-distance” problem ⇒ charges generate “fields”, and these fields act upon other charges. The field perturbation travels in vacuum with the speed of light.

- The electromagnetic field is an objective reality, it possesses energy and momentum (Sun’s energy reaches us by means of electric and magnetic fields).
Electric Field

Electric Field $\vec{E}(\mathbf{r})$: the force per unit probe charge

Units of the electric field: $\frac{N}{C}$

$F_{Q\rightarrow q} = \frac{1}{4\pi \varepsilon_0} \frac{qQ}{r^2} = q \frac{1}{4\pi \varepsilon_0} \frac{Q}{r^2} = qE_Q(\mathbf{r})$

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$F_{q\rightarrow Q}(\mathbf{r}) = qE(\mathbf{r})$

(Intensity of) the gravitational field at Earth’s surface? Units?

the $E$ field due to $q$ at the location of $Q$

the $E$ field due to $Q$ at the location of $q$
Two charges are placed a certain distance apart. The probe charge is at some point on a line connecting the charges but \textit{not} between them. The force exerted on the probe charge is 0. What is the \textit{most general} thing we can say about the charges?

A. The same sign and magnitude.
B. Opposite signs but the same magnitude.
C. The same sign but must have different magnitudes.
D. Opposite signs but must have different magnitudes.
E. Zero magnitude necessarily for both of them.
Iclicker Question

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\[ F = 0 \]

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E. Zero magnitude necessarily for both of them.
Consider two charges: +Q (at the origin) and +q (at \( \vec{r} \)).

The force (in vector form) exerted by Q on q:

\[
\vec{F}_{Q\rightarrow q}(\vec{r}) = \frac{1}{4\pi \varepsilon_0} \frac{Qq}{r^2} \hat{\mathbf{r}}
\]

The electric field due to Q at the location \( \vec{r} \):

- Vector form:
  \[
  \vec{E}_Q(\vec{r}) \equiv \frac{\vec{F}_{Q\rightarrow q}(\vec{r})}{q} = \frac{1}{4\pi \varepsilon_0} \frac{Q}{r^2} \hat{\mathbf{r}}
  \]

- Magnitude:
  \[
  E_Q(r) \equiv \frac{F_{Q\rightarrow q}(r)}{q} = \frac{1}{4\pi \varepsilon_0} \frac{Q}{r^2}
  \]

\( \vec{E} \) is directed along \( \hat{\mathbf{r}} \) for +Q, along \( -\hat{\mathbf{r}} \) for −Q,

*Or, in simple words, \( E \) has the same direction as the force on a positive charge q.*
Superposition Principle

The electric fields created by different charges do not interact with each other, the net field is the vector sum of the fields due to individual point charges:

\[ \vec{E}_{\text{net}}(\vec{r}) = \sum_i \vec{E}_i(\vec{r}) \]

- the field at the location \( \vec{r} \) due to all other charges

\[ \vec{F}_{\text{net}} = \sum_i \vec{F}_i \]

- the force on a charge at the location \( \vec{r} \) due to all other charges

\[ \vec{E}(\vec{r}) = \sum_i \vec{E}_i(\vec{r}) \]
Electric field lines:

- direction of the field vector is tangential to the field line (curve);
- intensity of the field at a given point is proportional to the local density of field lines.

Density of lines: (relative) number of lines per unit area perpendicular to the lines.
Shown are the electric field lines, the charges that produced the electric field are not shown. Rank the magnitude of the electric field for the points labeled A through F.

\[ E_C \approx E_D > E_E > E_A > E_B > E_F \]
Electric Field Lines (cont’d)

For a point charge, \( E(r) \propto \frac{1}{r^2} \Rightarrow \)

the density of lines \( \propto \frac{1}{r^2} \).

The area of a sphere centered at the charge \( \propto r^2 \).

Thus, the total number of lines is fixed: they don’t “vanish into thin air”, must be terminated either at another (negative) charge or continue to infinity.

This picture resembles a laminar flow of some fluid from positive charges (“source”) to negative charges (“sink”), though there is no real displacement of matter in space.
Three point charges are fixed at the vertices of an equilateral triangle as shown. All three charges have the same magnitude, but Charges #1 and #2 are positive (+q) and Charge #3 is negative (−q).

The net electric force that Charges #2 and #3 exert on Charge #1 is in

A. the +x-direction.
B. the −x-direction.
C. the +y-direction.
D. the −y-direction.
E. none of the above
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A. the +x direction. 
B. the −x direction. 
C. the +y direction. 
D. the −y direction. 
E. none of the above
What do the field lines look like for single positive charge?

Next: What do the field lines look like for single negative charge?
How to Draw the Electric Field Lines

Convention:
- the electric field lines originate on positive charges;
- terminate on negative charges.

Field lines don’t form sharp bends (there is only one tangent line to a field “curve” at each point).
Iclicker Question

Which field line configuration correctly represents an electrostatic field?

A

B

C

D

E
**Iclicker Question**

Which field line configuration correctly represents an electrostatic field?

- **A**
  - two tangent lines at (·) O
  - lines form sharp corners

- **B**
  - must be a charge at the intersection

- **C**
  - the line forms a closed loop (OK in electrodynamics, forbidden in electrostatics)

- **D**
  - straight lines belong to a solitary point charge, but the symmetry is broken

- **E**
  - two tangent lines at bends
Experiments on Field Visualization

1. Charge separation by friction.

2. The girl acquires a charge distributed across her surface.

3. Like charges on individual hairs repel each other and force the hairs to stand away from each other and the girl’s head.

4. Girl’s hairs (roughly) follow the field lines.
Demonstration: Van de Graaff Generator

1) hollow metal sphere
2) upper collecting electrode
3) upper roller (for example an acrylic glass)
4) side of the belt with positive charges
5) opposite side of the belt with negative charges
6) lower roller (metal)
7) lower electrode (ground)
8) spherical device with negative charges, used to discharge the main sphere
9) spark between the electrodes

John G. Trump
1907-1985

Robert J. Van de Graaff
1901-1967
Appendix III: Microwave Ovens

**RF heating** (or high-frequency heating) is the process in which a high-frequency alternating electric field (i.e. microwave electromagnetic radiation) heats a dielectric material. At higher frequencies, this heating is caused by *molecular dipole rotation within the dielectric*.

Water molecules feel the torque and align themselves in an electric field. As the field alternates, the molecules reverse direction (dipole rotation). Rotating molecules push, pull, and collide with other molecules (through electrical forces), converting the energy of the electric field into the thermal energy (heat).
Electric polarization – redistribution of charges within a neutral object by an external electric field. As a result, a neutral object acquires a dipole moment.
Electric Field of a Dipole

Dipoles: the second most important (after a point charge) configuration of charges.

2D plot of the field lines in the x-y plane

3D plot of the field intensity in the x-y plane
Electric Field: math. tool and phys. reality

Electric Field Lines

Appendix I: Dipoles in a Uniform External Electric Field

The net force on a dipole is zero; however, there is a non-zero torque:

$$\tau = 2 \times E_q \frac{d}{2} \sin(\phi) = E q d \sin(\phi) = E \sin(\phi)$$

$p$ – the dipole moment

In the vector form: $$\vec{\tau} = \vec{p} \times \vec{E}$$ (\vec{p} directed from $-$ to $+$)

Potential energy of a dipole in an electric field:

$$U(\phi) = -p E \cos(\phi)$$
Appendix II: Polar Water Molecules

Polar = built-in dipole moment

*Life on Earth very much depends on a large dipole moment of water molecules!*

\[ p \approx 6 \times 10^{-30} \text{ C} \cdot \text{m} \]

\[ d = 0.96A \times \cos(52.2^\circ) = 0.6A = 0.6 \times 10^{-10}m \]

\[ q^* = \frac{p}{d} = \frac{6 \times 10^{-30} \text{C} \cdot \text{m}}{0.6 \times 10^{-10} \text{m}} = 1 \times 10^{-19} \text{C} \approx 0.6e \]

- the effective charge on O

Large dipole moment → **Hydrogen Bonding**

3-dimensional bonding network: water looks like a "gel" consisting of a single, huge hydrogen-bonded cluster.

As a result, it’s the most unusual liquid: it is much denser than expected and as a solid it is much lighter than expected when compared with its liquid form.

**Anomalies:** high freezing and melting point (due to this our planet is bathed in liquid water), large heat capacity, high thermal conductivity (high water content in organisms contribute to thermal regulation and prevent local temperature fluctuations), high latent heat of evaporation (resistance to dehydration and considerable evaporative cooling), excellent solvent due to its polarity, high dielectric constant, etc., etc.

http://www.lsbu.ac.uk/water/anmlies.html