From last time...

Electric fields

Electric field lines

- Local electric field tangent to field line
- Density of lines proportional to electric field strength
- Fields lines can only start on + charge
- Can only end on - charge.
- Electric field lines can never cross

Exam 1
Mon. Sep. 29, 5:30-7 pm, 2103 Ch (here)

Covers Chap. 21.5-7, 22, 23.1-4, 23.7, 24.1-5, 26-27 + lecture, lab, discussion, HW

8 1/2 x 11 handwritten note sheet (both sides) allowed

Students with scheduled class conflicts:
stay after lecture today to arrange alt. exam time

Review Group/Quiz (solutions on website).
Review lab question sheets.
Review sample exams on website.

Electric field lines

- Local electric field tangent to field line
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Question
How are the charges A and B related?

A) A+, B-, |A| < |B|
B) A-, B+, |A| < |B|
C) A+, B-, |A| > |B|
D) A-, B+, |A| < |B|
E) A+, B-, |A| = |B|

Charge Densities

- Volume charge density: when a charge is distributed evenly throughout a volume
  - \( \rho = \frac{Q}{V} \)
  - \( dq = \rho \, dV \)

- Surface charge density: when a charge is distributed evenly over a surface area
  - \( \sigma = \frac{Q}{A} \)
  - \( dq = \sigma \, dA \)

- Linear charge density: when a charge is distributed along a line
  - \( \lambda = \frac{Q}{l} \)
  - \( dq = \lambda \, dl \)

Infinite line of charge

An infinite line of charge has a uniform charge density \( \lambda \) Coulombs / meter. What direction is the electric field at point \( x \)?

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### E-field: Infinite Line of Charge

- **Charge density**: \( \lambda \) Coulombs/meter

\[
\frac{dE}{dy} = \cos \theta \frac{dQ}{dr} = \frac{\lambda}{4\pi \varepsilon_0} \frac{r}{r^2 + x^2} \cos \theta
\]

\[
dQ = \lambda dx
\]

- **Units?**

\[
E_y = \frac{2}{\pi \varepsilon_0} \left( \frac{\lambda}{r^2 + x^2} \right)^{3/2}
\]

### Add All These Up

\[
E_y = \int \frac{1}{4\pi \varepsilon_0} \frac{r rdx}{(r^2 + x^2)^{3/2}} = \frac{\lambda}{2\pi \varepsilon_0} \left( \frac{r}{r^2 + x^2} \right)^{3/2} = \frac{2\lambda}{r}
\]

### Finite Line of Charge

**What direction is the E-field above the end of the line charge?**

### Ring of Uniform Positive Charge

**Which is the graph of the field on the axis?**

- A)
- B)
- C)
- D)
- E)

### Quick Quiz

We have an infinite sheet of charge of uniform charge density \( \sigma \). The electric field

- A. increases with distance from plane
- B. decreases with distance from plane
- C. is independent of distance from plane
- D. changes direction with distance from plane
**Electric fields and forces**

- Original definition of E-field was (Coulomb Force) / charge
- E-field produced force on charged particle.

\[ \mathbf{F} = q \mathbf{E} \]

**Quick Quiz**

A negative charge in outer space is in a uniform E-field that points to the right. What is the motion of the particle?

A) Moves right at constant speed
B) Moves left at constant speed
C) Remains stationary
D) Accelerates to the left
E) None of the above

**Force on charged particle**

- Electric field produces force \( q \mathbf{E} \) on chargedparticle
- Force produces an acceleration \( a = \frac{F}{m} \)

- Uniform E-field (direction & magnitude) produces constant acceleration
- Positive charge accelerates in direction of the field
- Negative charge accelerates in direction opposite the electric field

**Electron in a Uniform Field**

- The electron is projected horizontally into a uniform electric field
- The electron undergoes a downward acceleration
  - It is negative, so the acceleration is opposite E
- Motion is parabolic while between the plates

**Quick Quiz**

A negative charge is released in a fluid with a uniform E-field that points to the right. The fluid imparts a force proportional to and opposite to the velocity \( F_{\text{fluid}} = -bv \)

What is the motion of the particle?

A. Accel left continuously
B. Accel left, then moves at const. speed
C. Accel left, then slows to stop
D. Accel left, then turns around
E. None of the above

**Motion of charged particle**

- If no other forces, positive charge accelerates in direction of E-field.
- But many systems have drag forces (e.g. molecules in a liquid, etc)
- Drag force is complex, but usually depends on velocity
- Particle reaches terminal velocity, determined by force balance
Application: Gel Electrophoresis
- Charged macromolecules in ‘gel’ with applied E-field
- Electric force: \( \mathbf{F}_E = q \mathbf{E} \)
- Drag force: \( \mathbf{F}_D = -c \mathbf{v} \)
- Speed: \( \mathbf{v} = \frac{q \mathbf{E}}{c} \)
- Protein electrophoresis: soak in detergent to give proteins all the same charge density.
- Result, small proteins move faster

Quick Quiz
An electric dipole is in a uniform electric field as shown. The dipole
(a)Accelerates left
B. Accelerates right
C. Stays fixed
D. Accelerates up
E. None of the above

Electric torque on dipoles
- Total torque has magnitude \( \tau = \mathbf{r} \times \mathbf{F} \)
- Dipole moment has magnitude \( |\mathbf{p}| = q s \)
- Torque on dipole in uniform field \( \tau = \mathbf{p} \times \mathbf{E} \)

Dipole in non-uniform field
- A permanent dipole is near a positive point charge in a viscous fluid. The dipole will
A. Rotate CW & move toward charge
B. Rotate CW & move away
C. Rotate CCW & move toward
D. Rotate CCW & move away
E. None of the above