Chapter 23

Electric Fields

PHYS 2321: Physics 2
Week 2 on Electric Fields & Charge Distributions

Day 1 outline

1) Attendance – Pictures
2) Homework for Friday, 11:59pm, G. Drive:
   a) read Ch. 23 Sec. 5-7, Ch. 24 Sec. 1
   b) Ch. 23 Probs. 25,29,39,43,45,47,49,51,55
   c) try practice quizzes for Ch. 23
   d) watch YouTube videos on E-fields.
3) Today: Electric Fields
   a) basics
   b) point charges
   c) continuous charge distributions

Notes:
Many homeworks were not legible because of scanning issues.
Quiz on Wed on Coulomb's law, charge, E-fields. Bring notebook.

Electric Field – Introduction

- The electric force is a "field force"
- Field forces act without contact, across a vacuum
  - Light = electromagnetic wave
- Faraday developed the concept of a field while studying electric fields
- Similar to gravitational field, $g = GM/R^2$

Electric Field – Definition

- An **electric field** is said to exist in the region of space around a charged object
  - This charged object is the **source charge**
- When another charged object, the **test charge**, enters this electric field, an electric force acts on it
- Even with NO test charge, an energy is stored in an electric field!

Electric Field – Definition, cont

- The electric field vector, $\vec{E}$, at a point in space is defined as the electric force $\vec{F}_{\text{test}}$ acting on a positive test charge, q_{test} placed at that point, divided by the test charge:

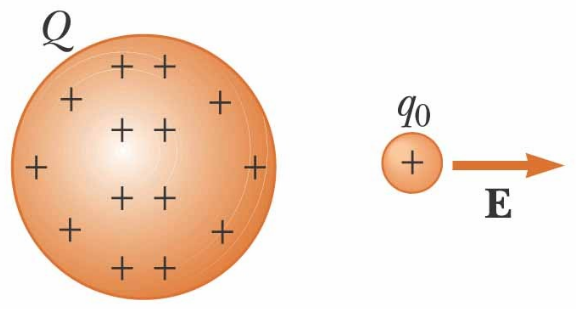
$$\vec{E} \equiv \frac{\vec{F}_{test}}{q_{test}}$$

Electric Field, Notes

- $\vec{E}$ is the field produced by some charge or charge distribution called the *source charge*.
- You must not include the test charge as part of the source charge or you will get "infinity" for $\mathbf{F}_{test}$ and **E**.
- The presence of the test charge is not necessary for the field to exist.
- The test charge serves as a detector of the field
  - It is small
  - It is positive
  - It is located at the point, *P*, of interest
- Ex) Find **F** on q_4 due to $q_1 - q_3$. Use $\mathbf{F} = q_4\mathbf{E}$.

Electric Field Notes, Final

- The direction of $\vec{E}$ is that of the force on a *positive* test charge
- The SI units of $\vec{E}$ are N/C
- $\vec{E}$ points away from positive charges and towards negative
- See PhET “charges-and-fields_en”



Relationship Between F and E

- $\vec{F} = q\,\vec{E}$
  - This is valid for a point charge only
  - One of zero size
  - For larger objects, the field may vary over the size of the object
- If *q* is positive, the force and the field are in the same direction
- If *q* is negative, the force and the field are in opposite directions

Electric Field, Vector Form

- Remember Coulomb's law, between the point source and test charge, q_o, can be expressed as

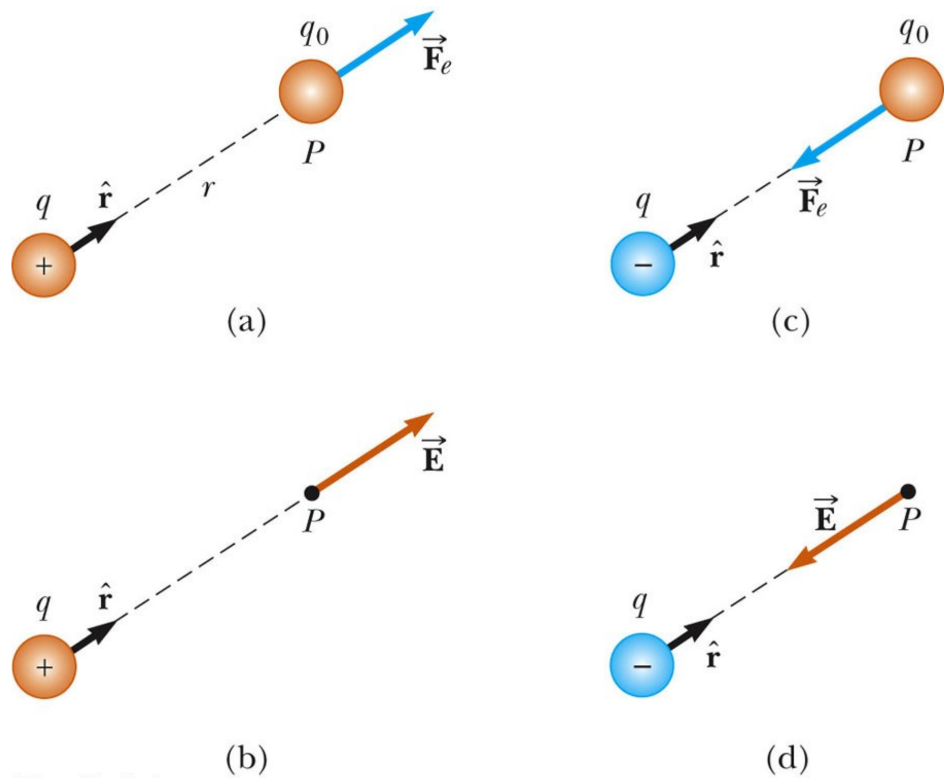
$$\vec{F}_e = k_e \frac{q q_o}{r^2} \hat{r}$$

- Then, the <u>electric field due to a point charge</u> will be

$$\vec{E} = \frac{\vec{F}_e}{q_o} = k_e \frac{q}{r^2} \hat{r}$$

More About Electric Field Direction

- a) *q* is positive, the force is directed away from *q*
- b) The direction of the field is also away from the positive source charge
- c) *q* is negative, the force is directed toward *q*
- d) The field is also toward the negative source charge
- Use the active figure to change the position of point P and observe the electric field



PLAY ACTIVE FIGURE

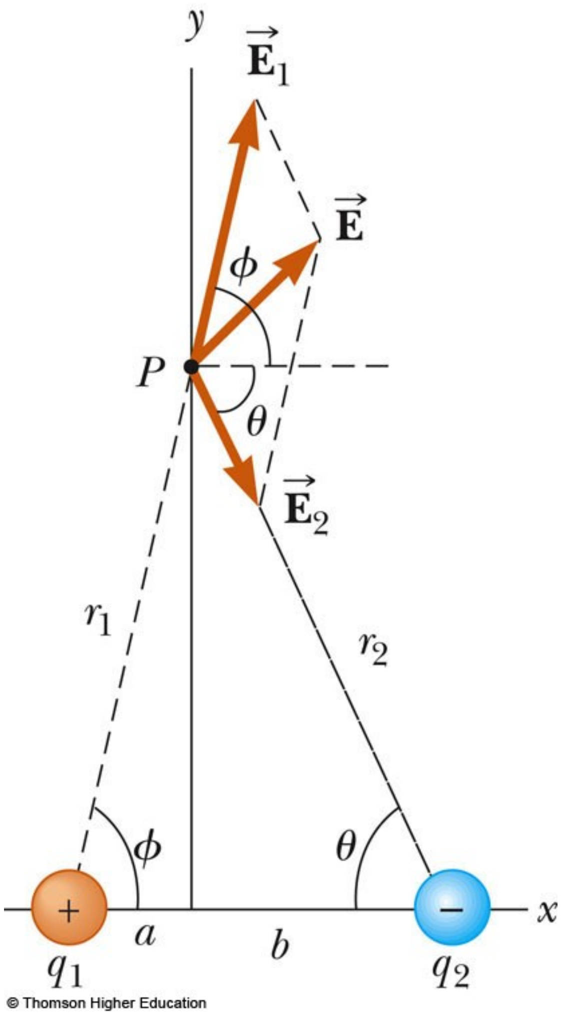
Superposition with Electric Fields

- At any point *P*, the total electric field due to a group of source charges equals the vector sum of the electric fields of all the charges

$$\vec{E} = \frac{\vec{F}_e}{q_o} = k_e \frac{q}{r^2} \hat{r}$$

Superposition Example

- Find the electric field due to q_1, $\vec{E}_1$
- Find the electric field due to q_2, $\vec{E}_2$
- $\vec{E} = \vec{E}_1 + \vec{E}_2$
  - Remember, the fields add as vectors
  - The direction of the individual fields is the direction of the force on a positive test charge

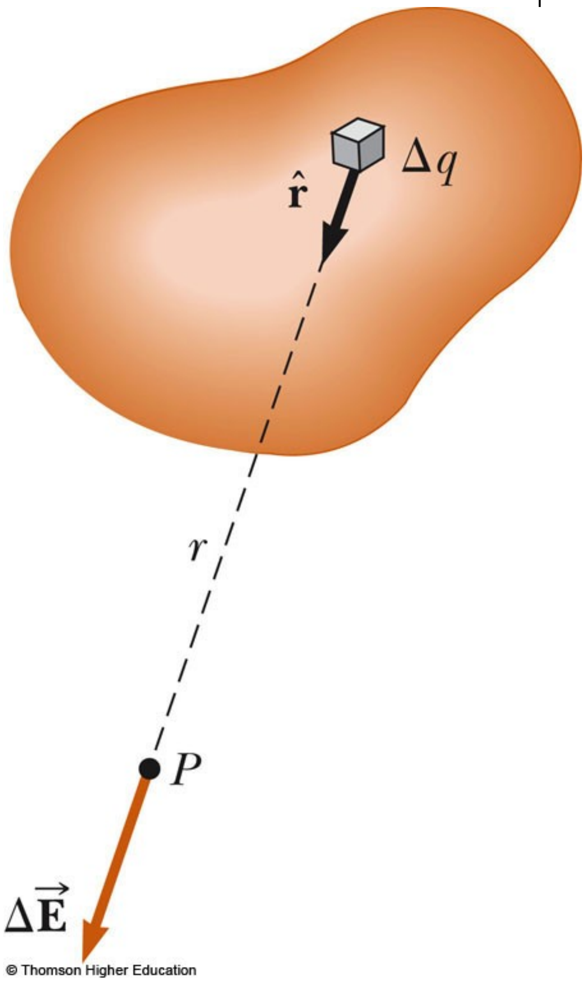


Electric Field – Continuous Charge Distribution

- The distances between charges in a group of charges may be much smaller than the distance between the group and a point of interest
- In this situation, the system of charges can be modeled as continuous
- The system of closely spaced charges is equivalent to a total charge that is continuously distributed along some line, over some surface, or throughout some volume

Electric Field – Continuous Charge Distribution, cont

- Procedure:
  - Divide the charge distribution into small elements, each of which contains Δq
  - Calculate the electric field due to one of these elements at point *P*
  - Evaluate the total field by summing the contributions of all the charge elements



PHYS 2321: Physics 2
Week 2 on Electric Fields & Charge Distributions

Day 2 outline

1) Homework for Friday, 11:59pm, G. Drive:
    a) read Ch. 23 Sec. 5-7, Ch. 24 Sec. 1
    b) Ch. 23 Probs. 25,29,39,43,45,47,49,51,55
    c) try practice quizzes for Ch. 23
    d) watch YouTube videos on E-fields.
2) Today: E-fields due to CCDs
    a) correction
    b) line charge
    c) ring of charge
3) Quiz (11:38am) on charge and Coulomb's Law

Notes:
First home work almost graded.
Make homework 2 legible and show <u>your</u> work.

Electric Field – Continuous Charge Distribution, equations

- For the individual charge elements

$$\Delta \vec{E} = k_e \frac{\Delta q}{r^2}\hat{r}$$

- Because the charge distribution is continuous

$$\Delta \vec{E} = k_e \lim_{\Delta q_i \to 0} \sum_i \frac{\Delta q_i}{r_i^2}\hat{r}_i = k_e \int \frac{dq}{r^2}\hat{r}$$

Correction:

$$\vec{E} = k_e \lim_{\Delta q_i \to 0} \sum_i \frac{\Delta q_i}{r_i^2}\hat{r}_i = k_e \int \frac{dq}{r^2}\hat{r}$$

Charge Densities

- **Volume charge density**: when a charge is distributed evenly throughout a volume
  - $\rho \equiv Q / V$ with units C/m^3
- **Surface charge density**: when a charge is distributed evenly over a surface area
  - $\sigma \equiv Q / A$ with units C/m^2
- **Linear charge density**: when a charge is distributed along a line
  - $\lambda \equiv Q / \ell$ with units C/m

Amount of Charge in a Small Volume

- If the charge is nonuniformly distributed over a volume, surface, or line, the amount of charge, dq, is given by
  - For the volume: $dq = \rho \, dV$
  - For the surface: $dq = \sigma \, dA$
  - For the length element: $dq = \lambda \, d\ell$

Problem-Solving Strategy

- *Conceptualize*
  - Establish a mental representation of the problem
  - Imagine the electric field produced by the charges or charge distribution
- *Categorize*
  - Individual charge?
  - Group of individual charges?
  - Continuous distribution of charges?

Problem-Solving Strategy, cont

- *Analyze*
  - **Units**: when using the Coulomb constant, k_e, the charges must be in C and the distances in m
  - **Analyzing a group of individual charges**:
    - Use the superposition principle, find the fields due to the individual charges at the point of interest and then add them as vectors to find the resultant field
    - Be careful with the manipulation of vector quantities
  - **Analyzing a continuous charge distribution:**
    - The vector sums for evaluating the total electric field at some point must be replaced with vector integrals
    - Divide the charge distribution into infinitesimal pieces, calculate the vector sum by integrating over the entire charge distribution

Problem Solving Hints, final

- *Analyze, cont.*
  - **Symmetry:**
    - Take advantage of any symmetry to simplify calculations
- *Finalize*
  - Check to see if the electric field expression is consistent with your mental representation
  - Check to see if the solution reflects any symmetry present
  - Imagine varying parameters to see if the mathematical result changes in a reasonable way

PHYS 2321: Physics 2
Week 2 on Electric Fields & Charge Distributions

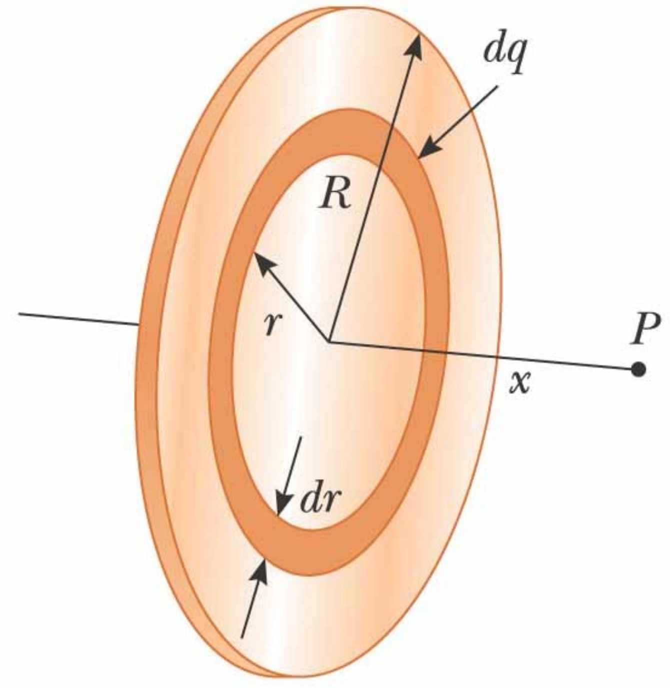
Day 3 outline

1) Homework for Friday, 11:59pm, G. Drive:
   a) read Ch. 23 Sec. 5-7, Ch. 24 Sec. 1
   b) Ch. 23 Probs. 25,29,39,43,45,47,49,51,55
   c) try practice quiz for Ch. 24
   d) watch YouTube videos on E-fields.
2) Today: CCDs, field lines, motion of charge
   a) Quiz 1 review (avg=3.33/6)
   b) E-field due to ring, disk
   c) E-field lines & electric flux, Φ
   d) motion of charged particles

Notes: First homework graded.
See me in SA 111 if you want to get your quiz.
Make homework 2 legible. Original and wrong is better than copied.

Example – Charged Disk

- The ring has a radius *R* and a uniform charge density *σ*
- Choose *dq* as a ring of radius *r*
- The ring has a surface area $2\pi r\, dr$

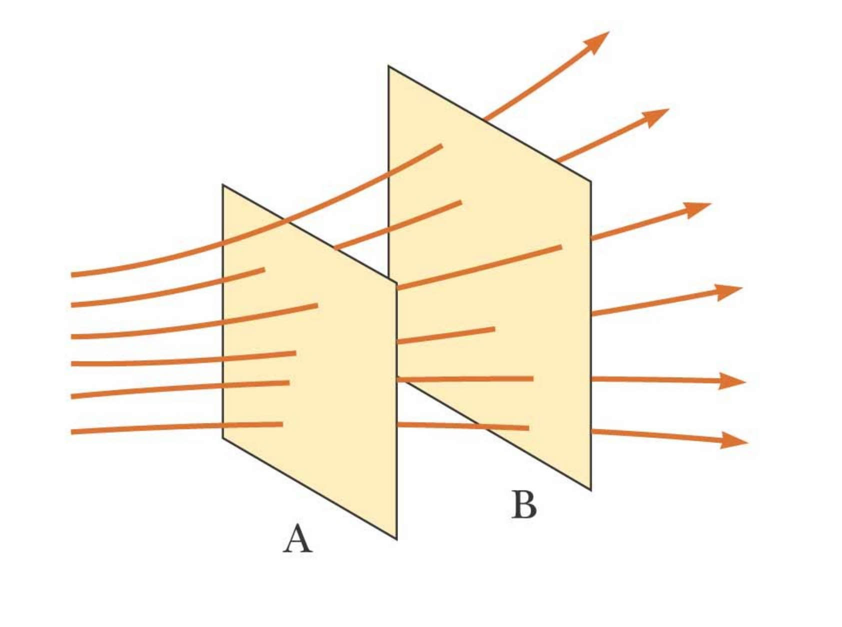


Electric Field Lines

- Field lines give us a means of representing the electric field pictorially
- The electric field vector **E** is tangent to the electric field line at each point
  - The line has a direction that is the same as that of the electric field vector
- The number of lines per unit area through a surface perpendicular to the lines is proportional to the magnitude of the electric field in that region

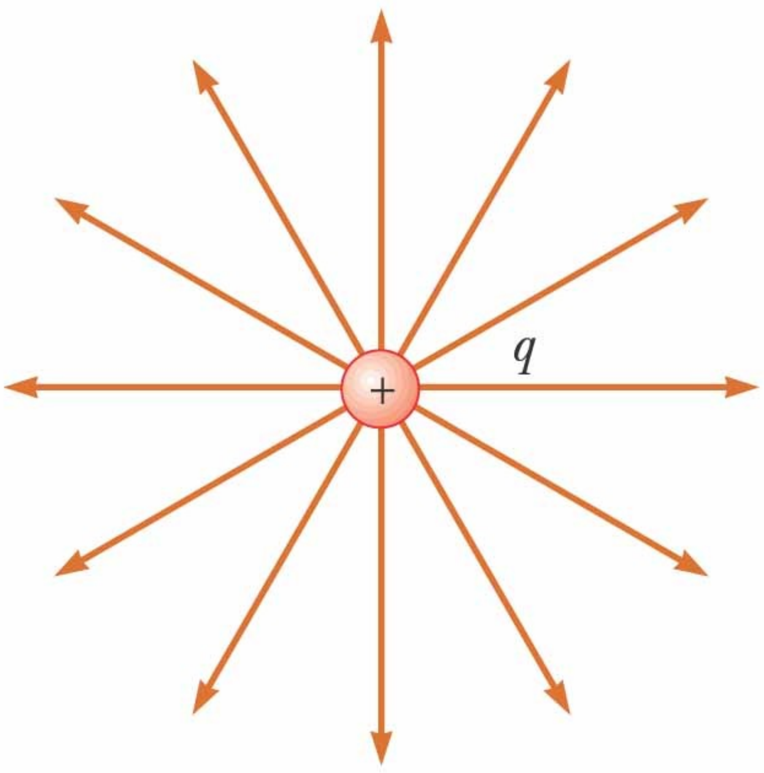
Electric Field Lines, General

- The density of lines through surface A is greater than through surface B
- The magnitude of the electric field is greater on surface A than B
- The lines at different locations point in different directions
  - This indicates the field is nonuniform



Electric Field Lines, Positive Point Charge

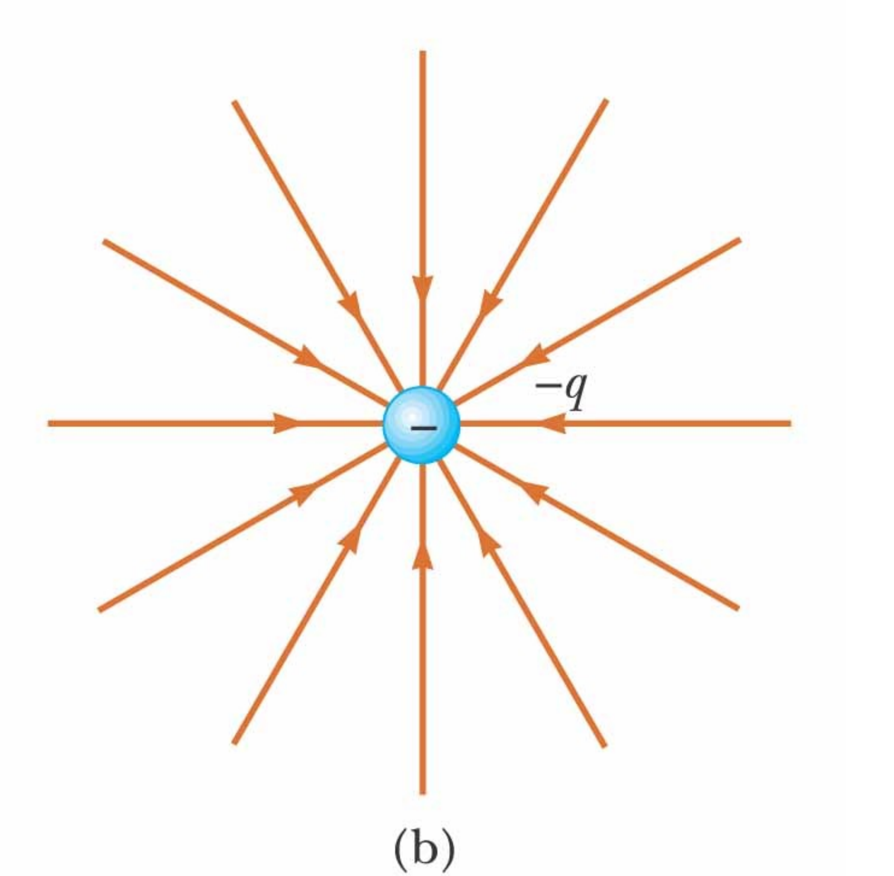
- The field lines radiate outward in all directions
  - In three dimensions, the distribution is spherical
- The lines are directed away from the source charge
  - A positive test charge would be repelled away from the positive source charge



(a)

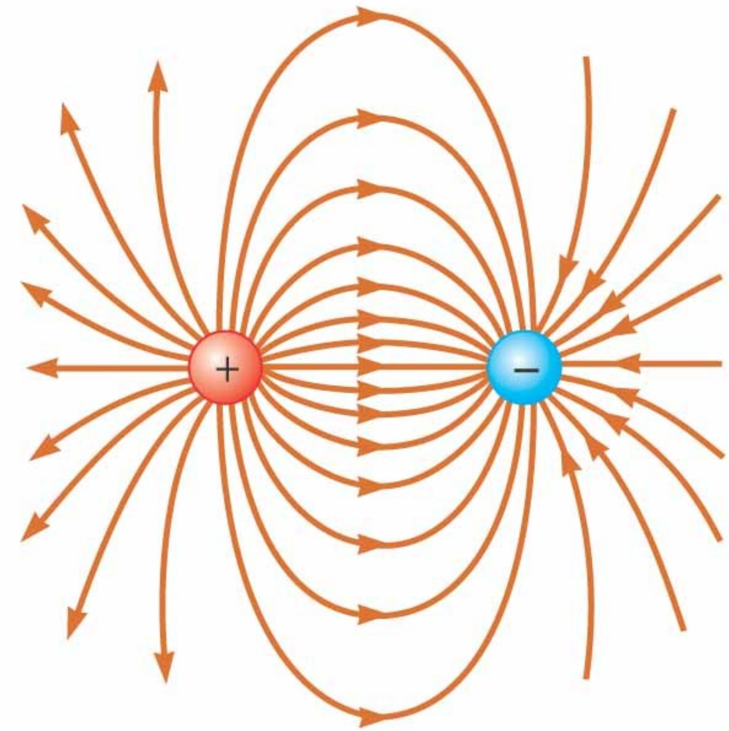
Electric Field Lines, Negative Point Charge

- The field lines radiate inward in all directions
- The lines are directed toward the source charge
  - A positive test charge would be attracted toward the negative source charge



Electric Field Lines – Dipole

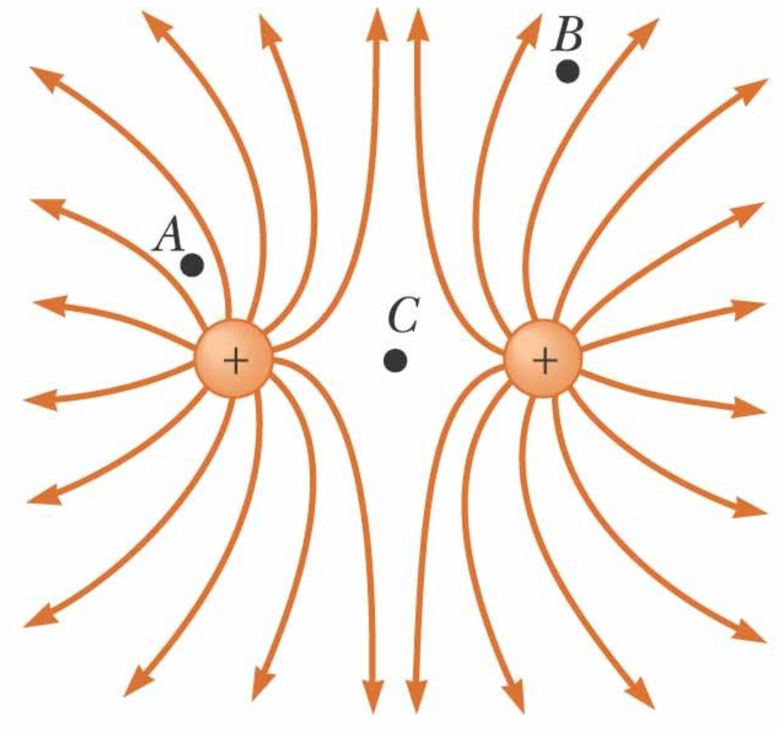
- The charges are equal and opposite
- The number of field lines leaving the positive charge equals the number of lines terminating on the negative charge



(a)

Electric Field Lines – Like Charges

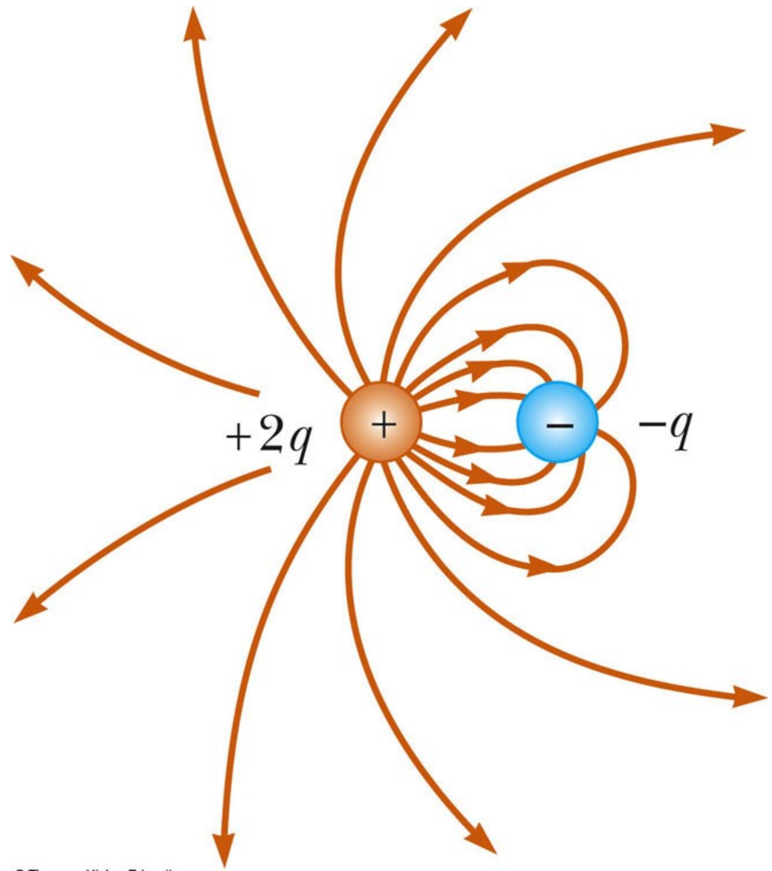
- The charges are equal and positive
- The same number of lines leave each charge since they are equal in magnitude
- At a great distance, the field is approximately equal to that of a single charge of 2*q*



(a)

Electric Field Lines, Unequal Charges

- The positive charge is twice the magnitude of the negative charge
- Two lines leave the positive charge for each line that terminates on the negative charge
- At a great distance, the field would be approximately the same as that due to a single charge of $+q$
- Use the active figure to vary the charges and positions and observe the resulting electric field



PLAY ACTIVE FIGURE

Electric Field Lines – Rules for Drawing*

- The lines must begin on a positive charge and terminate on a negative charge
  - In the case of an excess of one type of charge, some lines will begin or end infinitely far away
- The number of lines drawn leaving a positive charge or approaching a negative charge is proportional to the magnitude of the charge
- No two field lines can cross
- Remember field lines are **not** material objects, they are a pictorial representation used to qualitatively describe the electric field

* Go by my 9 rules on my YouTube video.

Motion of Charged Particles

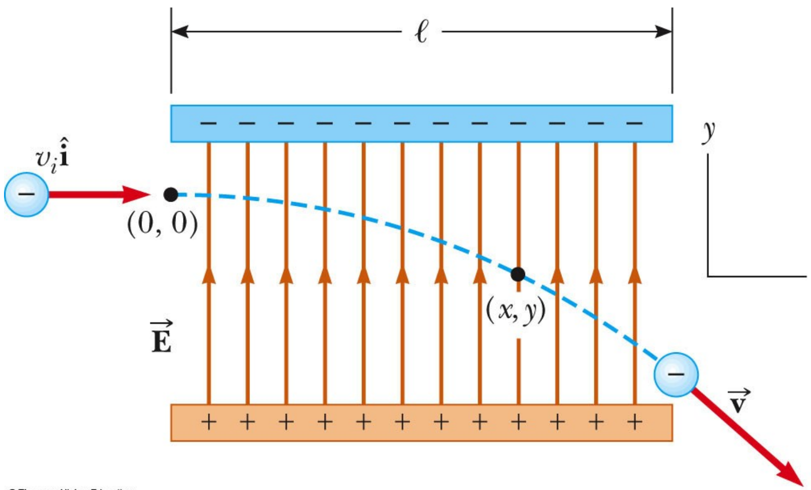
- When a charged particle is placed in an electric field, it experiences an electrical force
- If this is the only force on the particle, it must be the net force
- The net force will cause the particle to accelerate according to Newton's second law

Motion of Particles, cont

- When only Coulomb force exists, **F**=q**E** = m**a**
- If **E** is uniform, then the acceleration is constant
- If the particle has a positive charge, its acceleration is in the direction of the field
- If the particle has a negative charge, its acceleration is in the direction opposite the electric field
- Since the acceleration is constant, the kinematic equations can be used

Electron in a Uniform Field, Example

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



Use the active figure to vary the field and the characteristics of the particle.

PLAY ACTIVE FIGURE