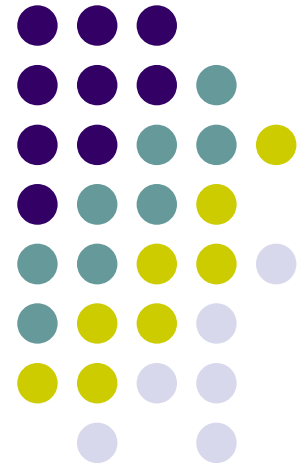


Chapter 21

Electric Fields



PHYS 2321: Physics 2

Week 2 on Electric Fields & Charge Distributions



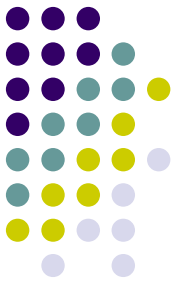
Day 1 outline

- 1) Attendance
- 2) Homework for Friday
 - a) Ch. 21 read sec. 6-10(11), Ch. 22 sec. 1 (flux)
 - b) Ch. 21 Probs. 22-25, 27, 30, 33, 39, 47,48, 55,57
MisQ. 4,5,7,8,11
 - c) Try both practice quizzes on web page
 - d) Try “Questions” 15-26 and compare with Moodle key
 - e) Watch YouTube videos on E-fields.
- 3) Today: Electric Fields
 - a) basics
 - b) due to point charges

Notes: c) due to continuous charge distributions

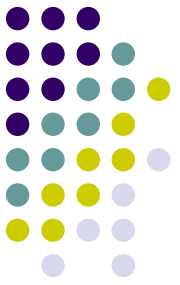
The first homework set looked pretty good!

****Quiz on Wed on Coulomb's law and charge.****



Electric Field – Introduction

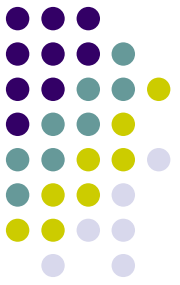
- The electric force is a “field force”
- Field forces act without contact, across a vacuum
 - Light = electromagnetic wave
- Faraday developed the concept of a field while studying electricity
- Similar to gravitational field, $g = GM/R^2$



Electric Field – Definition

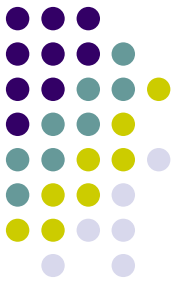
- An **electric field** is said to exist in the region of space around a charged object
 - This charged object is the **source charge**
- When another charged object, the **test charge**, enters this electric field, an electric force acts on it
- Even with NO test charge, an energy is stored in an electric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

Electric Field – Definition, cont



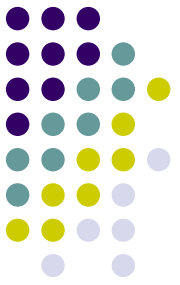
- The electric field vector, \vec{E} , at a point in space is defined as the electric force \vec{F}_{test} acting on a positive test charge, q_{test} placed at that point, divided by the test charge:

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



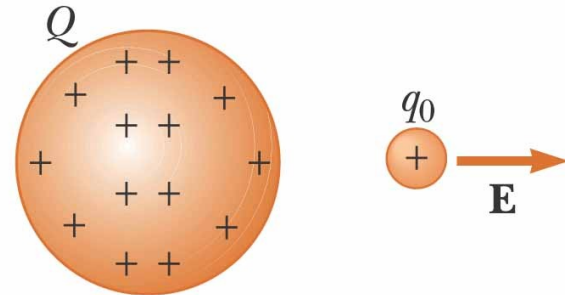
Electric Field, Notes

- \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 \mathbf{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 \mathbf{F} on q_4 due to $q_1 - q_3$. Use $\mathbf{F} = q_4\mathbf{E}$.

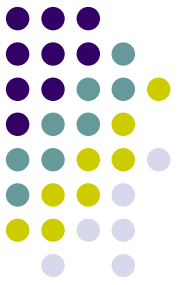


Electric Field Notes, Final

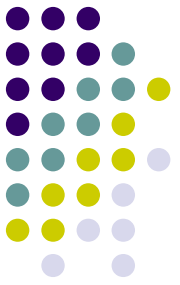
- The direction of \vec{E} is that of the force on a *positive* test charge
- The SI units of \vec{E} are N/C
- \vec{E} points away from positive charges and towards negative
- See PhET “charges-and-fields_en”



Relationship Between F and E



- \vec{E}
 $\vec{F} = q$
 - 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

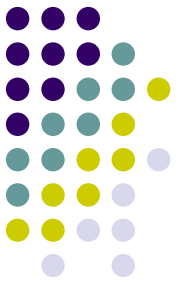
- Remember Coulomb's law, between the point source and test charge, q_o , can be expressed as

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

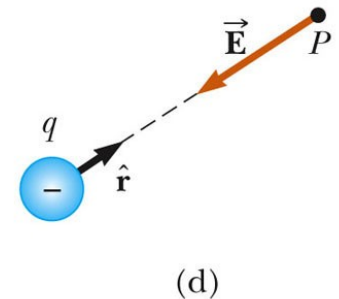
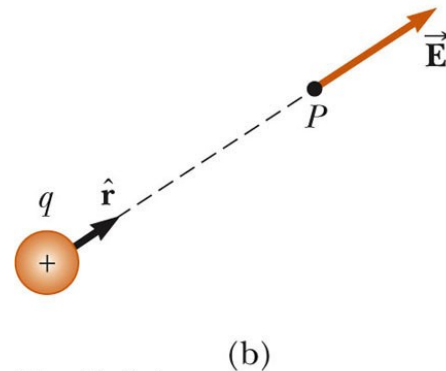
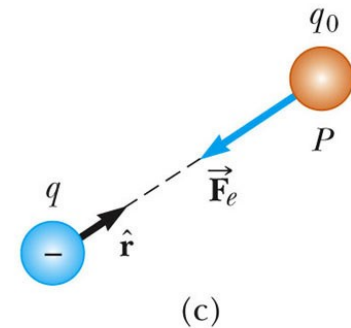
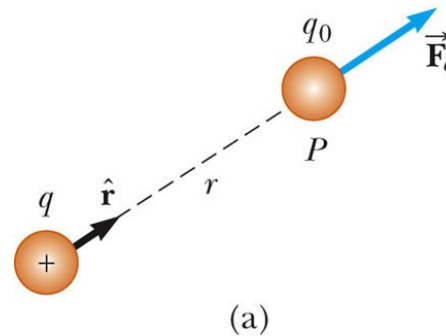
- Then, the electric field due to a point charge will be

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

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



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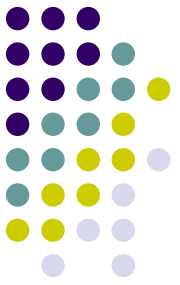
**PLAY
ACTIVE FIGURE**

Superposition with Electric Fields



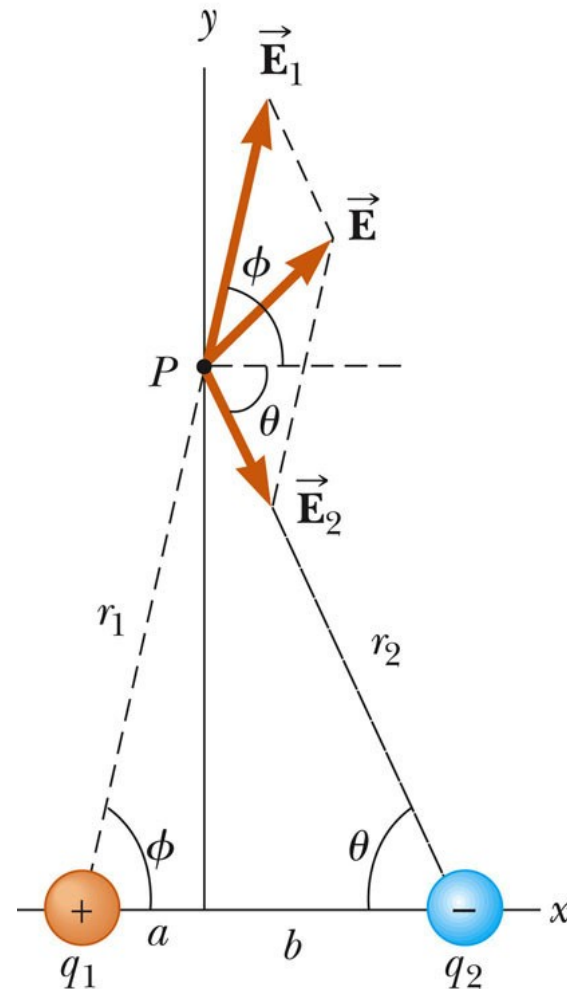
- At any point P , the total electric field due to a group of source charges equals the vector sum of the electric fields of all the charges

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

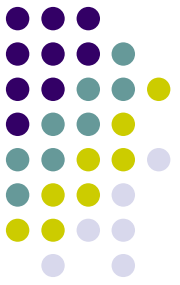


Superposition Example

- 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

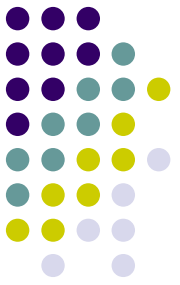


Electric Field – Continuous Charge Distribution

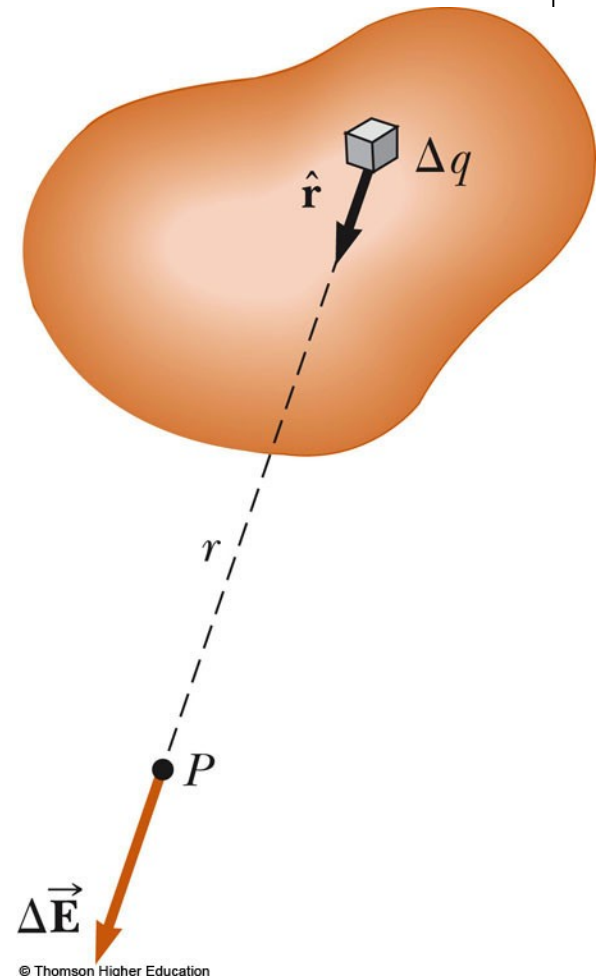


- The distances between charges in a group of charges may be much smaller than the distance between the group and a point of interest
- In this situation, the system of charges can be modeled as continuous
- The system of closely spaced charges is equivalent to a total charge that is continuously distributed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

- a) Read Ch. 21 sec. 5-10(11), Ch. 24 Sec. 1
- b) Ch. 21 Probs.
- c) Try Questions 15-26 and compare to Moodle key
- d) Try practice quizzes
- d) Watch YouTube videos on E-fields.

2) Today: E-fields due to CCDs

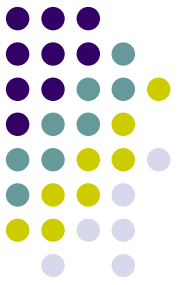
- a) line charge
- b) ring of charge

3) Quiz on charge and Coulomb's Law

Notes:

First home work almost graded.

Electric Field – Continuous Charge Distribution, equations



- For the individual charge elements

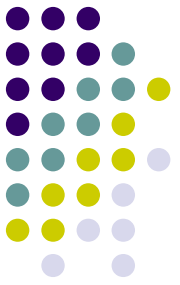
$$\Delta \vec{E} = k_e \frac{\Delta q}{r^2} \hat{r}$$

- Because the charge distribution is continuous

$$\sum_i \frac{\Delta q_i}{r_i^2} \hat{r}_i = k_e \int \frac{dq}{r^2} \hat{r}$$

Correction:

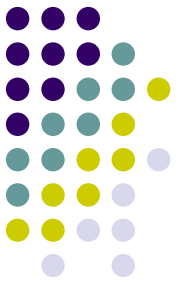
$$\sum_i \frac{\Delta q_i}{r_i^2} \hat{r}_i = k_e \int \frac{dq}{r^2} \hat{r}$$



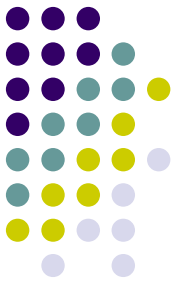
Charge Densities

- **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



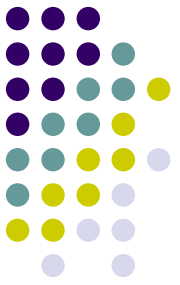
- If the charge is nonuniformly distributed over a volume, surface, or line, the amount of charge, dq , is given by
 - For the volume: $dq = \rho \, dV$
 - For the surface: $dq = \sigma \, dA$
 - For the length element: $dq = \lambda \, d\ell$



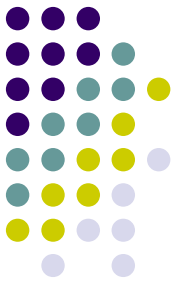
Problem-Solving Strategy

- *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



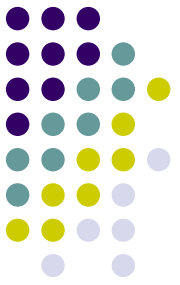
Day 3 outline

- 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.

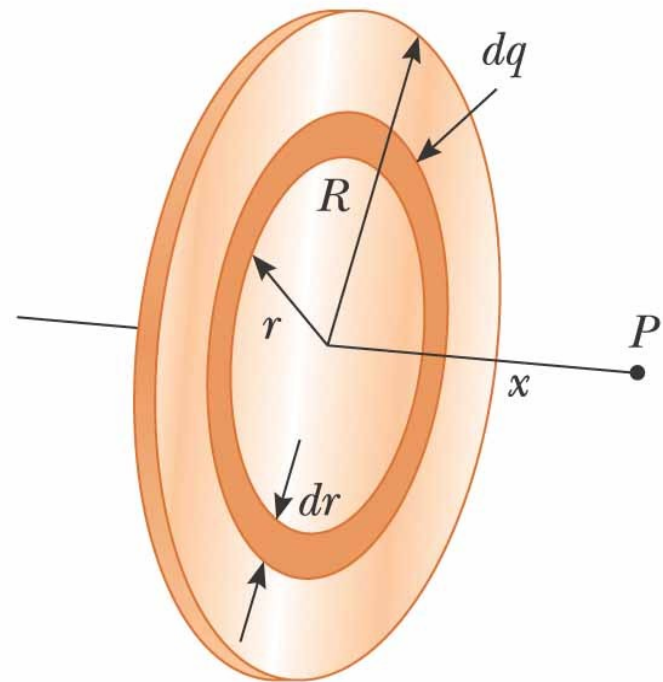
See me in SA 111 if you want to get your quiz.

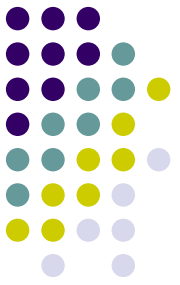
Make homework 2 legible. Original and wrong is better than copied.



Example – Charged Disk

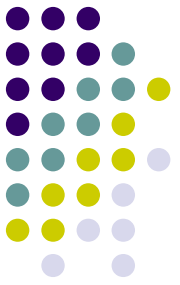
- The ring has a radius R and a uniform charge density σ
- Choose dq as a ring of radius r
- The ring has a surface area $2\pi r dr$





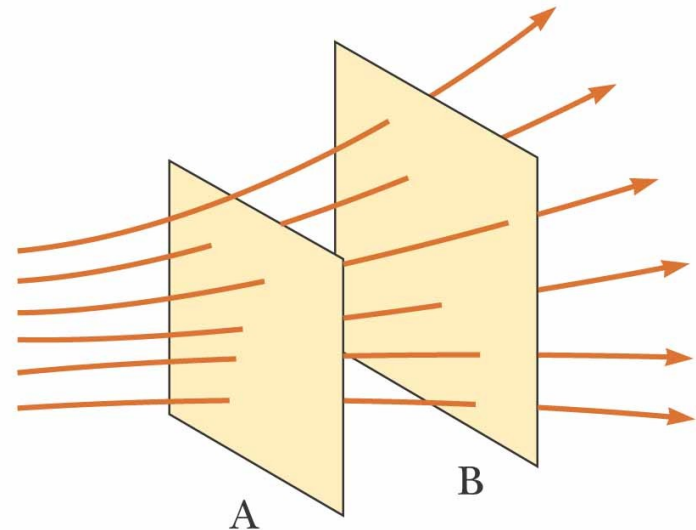
Electric Field Lines

- Field lines give us a means of representing the electric field pictorially
- The electric field vector \mathbf{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

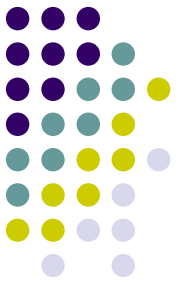


Electric Field Lines, General

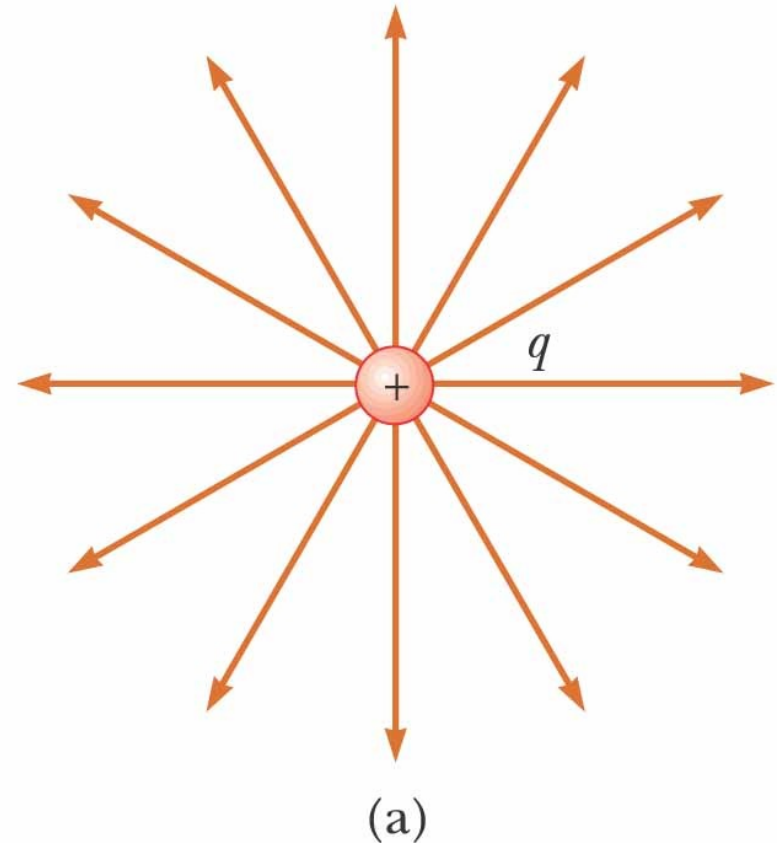
- The density of lines through surface A is greater than through surface B
- The magnitude of the electric field is greater on surface A than B
- The lines at different locations point in different directions
 - This indicates the field is nonuniform



Electric Field Lines, Positive Point Charge



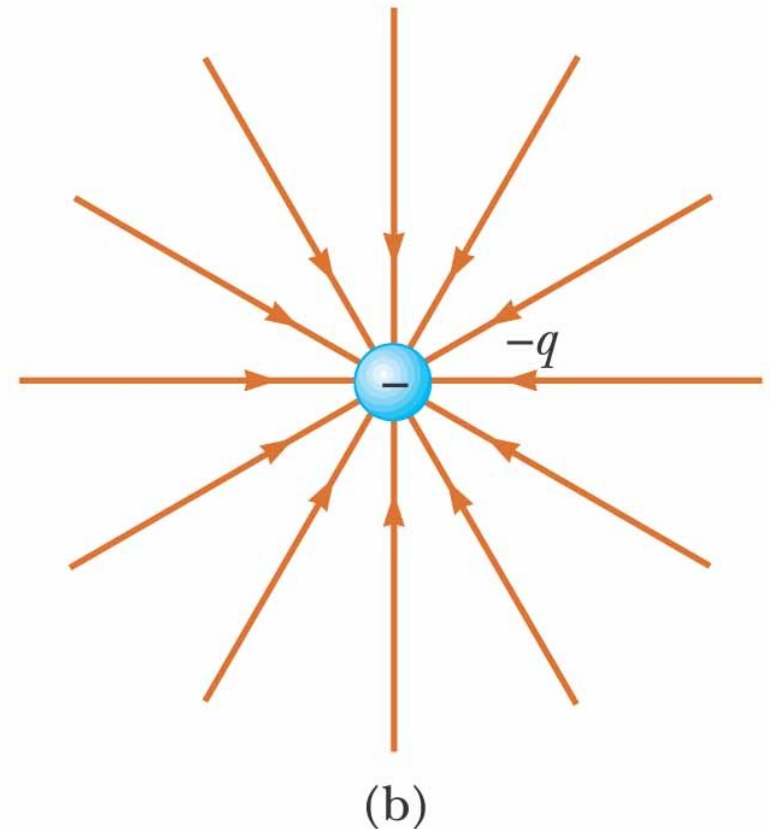
- The field lines radiate outward in all directions
 - In three dimensions, the distribution is spherical
- The lines are directed away from the source charge
 - A positive test charge would be repelled away from the positive source charge

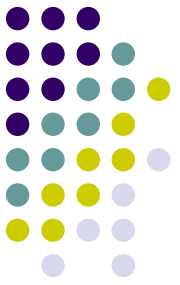


Electric Field Lines, Negative Point Charge



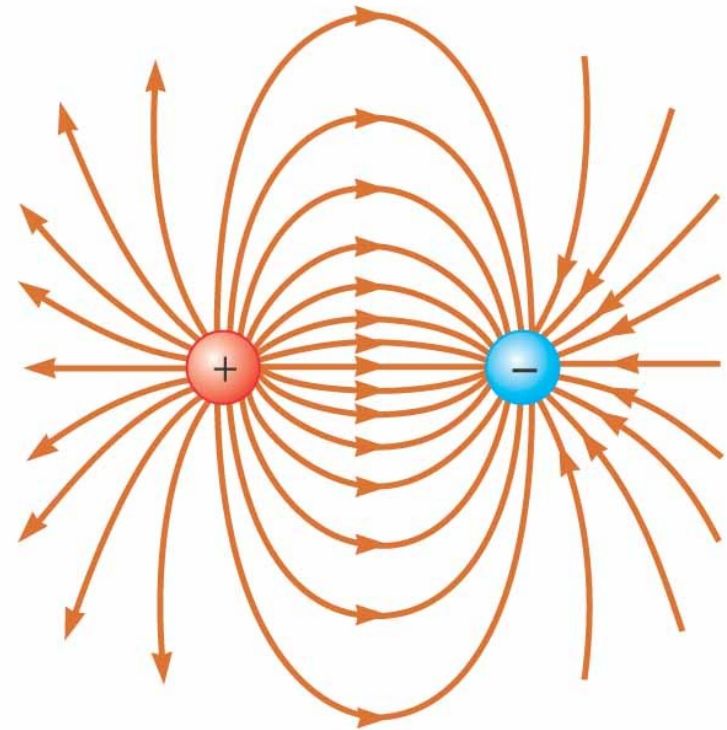
- The field lines radiate inward in all directions
- The lines are directed toward the source charge
 - A positive test charge would be attracted toward the negative source charge





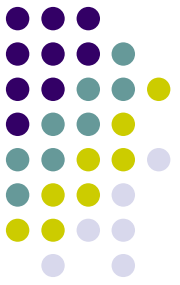
Electric Field Lines – Dipole

- 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

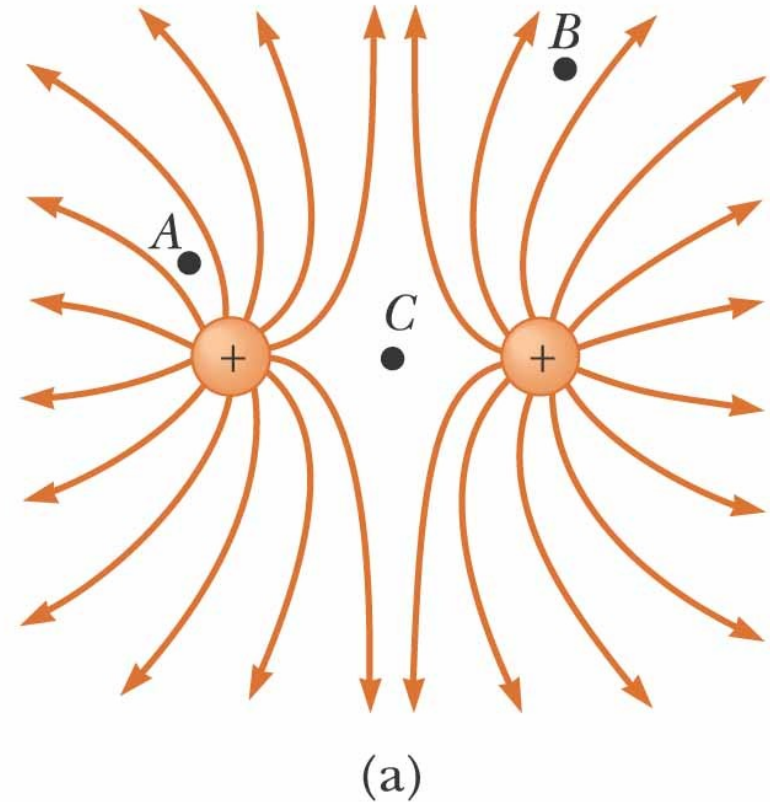


(a)

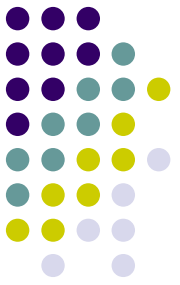
Electric Field Lines – Like Charges



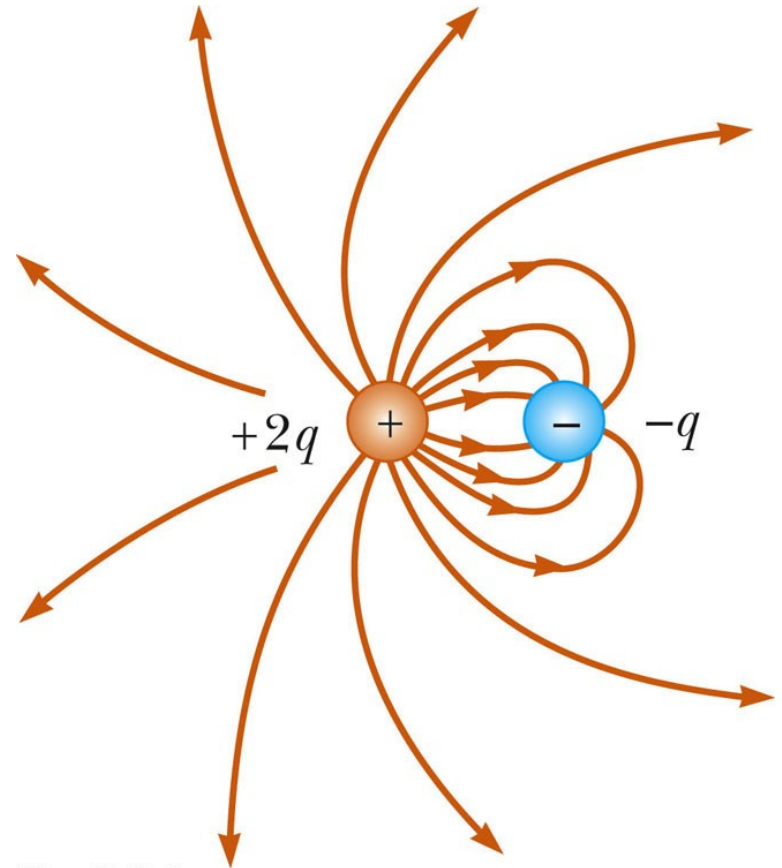
- The charges are equal and positive
- The same number of lines leave each charge since they are equal in magnitude
- At a great distance, the field is approximately equal to that of a single charge of $2q$



Electric Field Lines, Unequal Charges



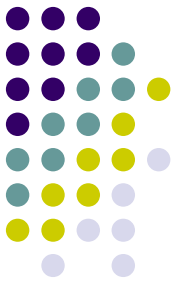
- The positive charge is twice the magnitude of the negative charge
- Two lines leave the positive charge for each line that terminates on the negative charge
- At a great distance, the field would be approximately the same as that due to a single charge of $+q$
- Use the active figure to vary the charges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



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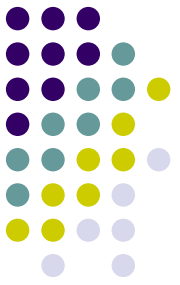
**PLAY
ACTIVE FIGURE**

Electric Field Lines – Rules for Drawing*



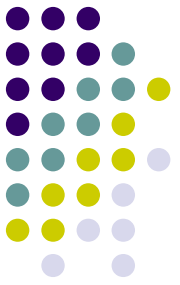
- The lines must begin on a positive charge and terminate on a negative charge
 - In the case of an excess of one type of charge, some lines will begin or end infinitely far away
- The number of lines drawn leaving a positive charge or approaching a negative charge is proportional to the magnitude of 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

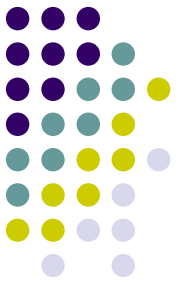
- When a charged particle is placed in an electric field, it experiences an electrical force
- If this is the only force on the particle, it must be the net force
- The net force will cause the particle to accelerate according to Newton's second law



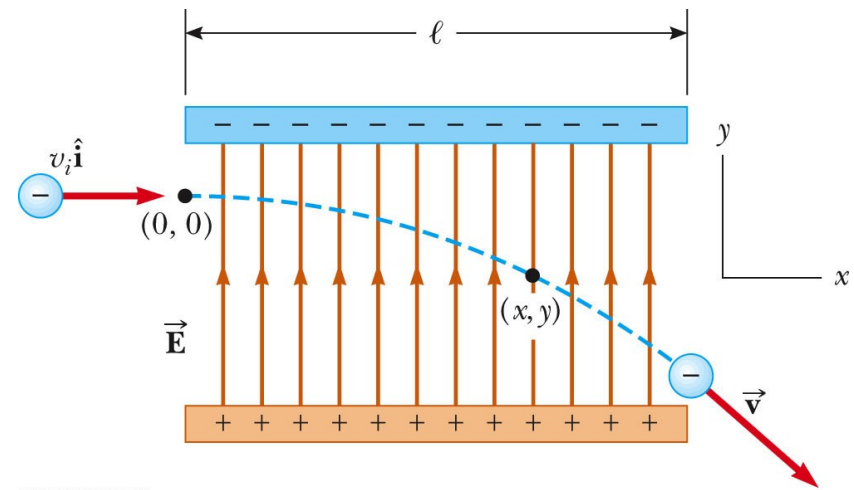
Motion of Particles, cont

- When only Coulomb force exists, $\mathbf{F} = q\mathbf{E} = m\mathbf{a}$
- If \mathbf{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



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

**PLAY
ACTIVE FIGURE**