Chapter 21

Electric Fields

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

Day 1 outline

1) Attendance
2) Homework for next Wednesday
   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) Watch my YouTube videos on E-fields.
3) Today:
   Vector sums of coulomb forces (P. 21.13)
   Electric Field basics, point charges.

Notes: Hwk 1 graded (mean = 8.6/10). Checked P. 8, MQ 1-3.
Quiz on Friday on Coulomb’s law and charge.

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

Day 2 outline

1) Homework for next Wednesday
   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 "Questions" 15-26 and compare with online key
   d) Watch YouTube videos on E-fields!
2) Today: Electric Fields
   a) Quiz 1 (~10 minutes)
   b) E-field basics
   c) Calculate E due to discrete (point) charges
   d) Calculate E due to continuous charge distributions
      Line charge
      Ring charge

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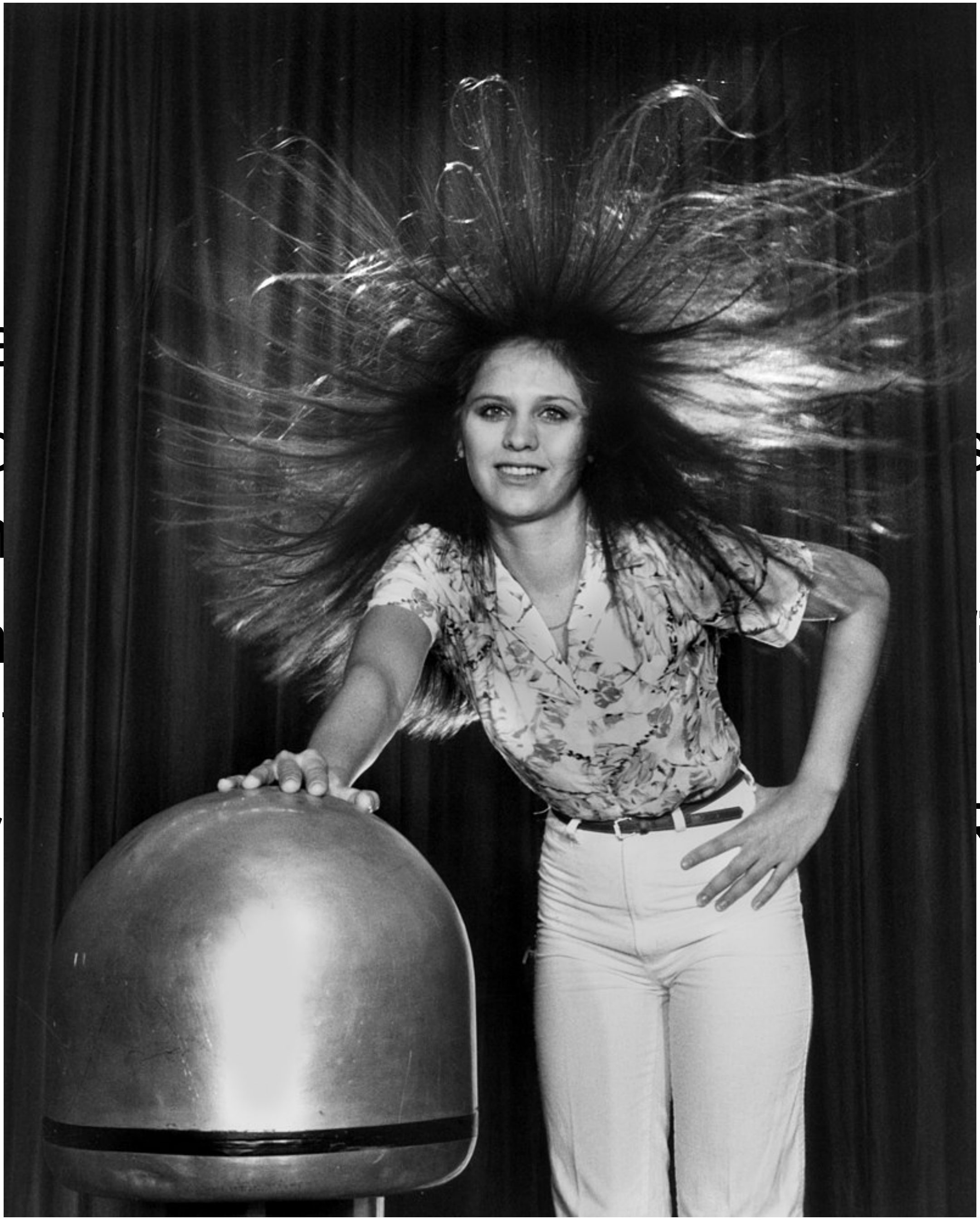
- Invisibl



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 E-field is present and it stores energy!

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:

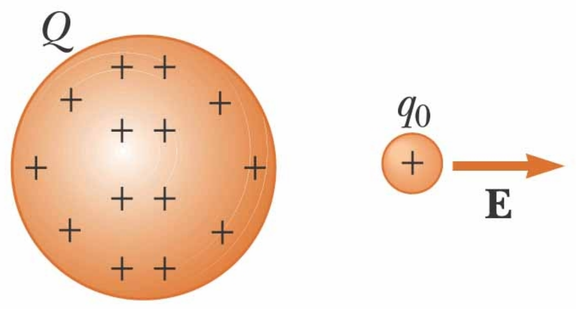
$$\vec{E} \equiv \frac{\vec{F}_{test}}{q_{test}}$$

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 $\mathbf{E}$.
- 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

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

- $\vec{F} = q\vec{E}$
  - Valid when q is point charge, but E can be from extended charge.
  - 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

PHYS 2321: Physics 2
Week 3 on Electric Fields & Charge Distributions

Day 1 outline

1) Homework for Wednesday
   - 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 "Questions" 15-26 and compare with online key
   - d) Watch YouTube videos on E-fields!
2) Today: Electric Fields
   - a) Return Quiz 1 (~10 minutes)
   - b) Calculate E due to discrete (point) charges
   - c) Calculate E due to continuous charge distributions
     Line charge
     Ring charge

Electric Field, Vector Form

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

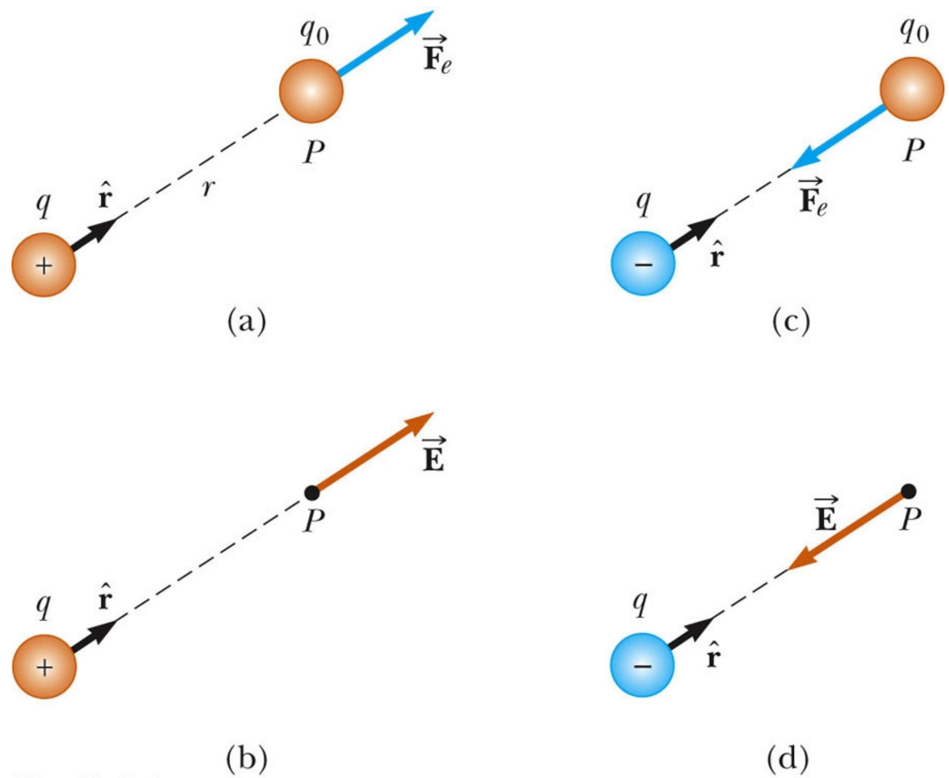
$$\vec{F}_e = k_e \frac{q q_o}{r^2} \hat{r}$$

- Then, the 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



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

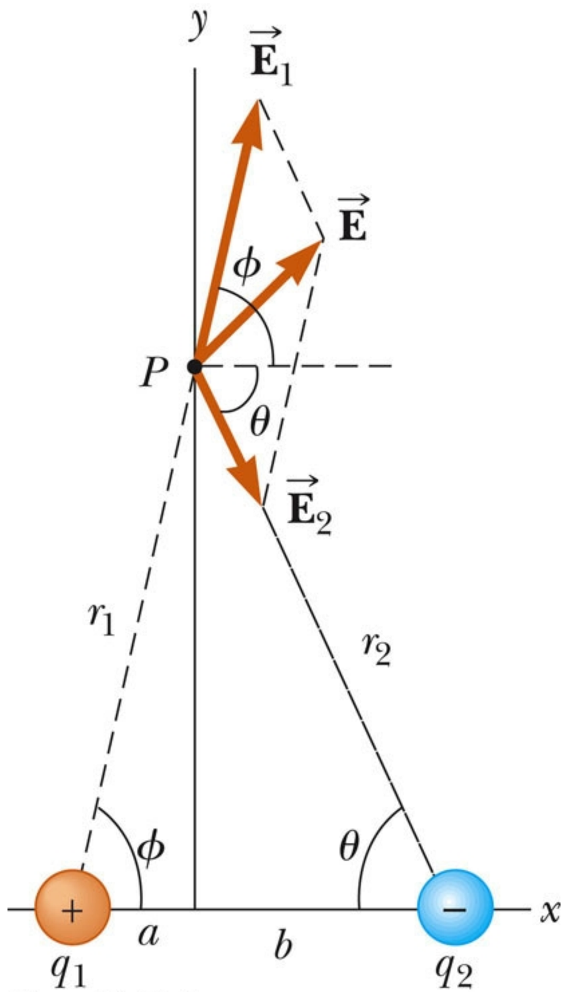
$$\vec{E}_{net} = \frac{\vec{F}_{net}}{q_o} = \frac{1}{q_0} \sum_{i=1}^{N} \vec{F}_i$$

Or

$$\vec{E}_{net} = \sum_{i=1}^{N} \vec{E}_i = \vec{E}_1 + \vec{E}_2 + \ldots + \vec{E}_N$$

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

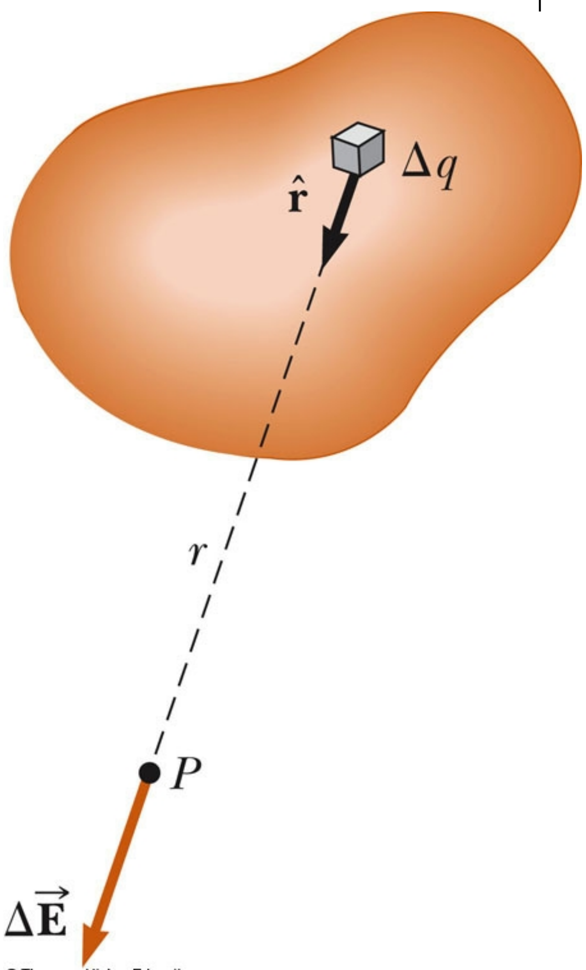


Electric Field – Continuous Charge Distribution

- 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



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, the sum becomes an integral over all charge:

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

Charge Densities

- **Volume charge density**: when a charge is distributed evenly throughout a volume
  - $\rho \equiv Q / V$ with units C/m^3 … so dq = ρdV
- **Surface charge density**: when a charge is distributed evenly over a surface area
  - $\sigma \equiv Q / A$ with units C/m^2 … so $dq = \sigma dA$
- **Linear charge density**: when a charge is distributed along a line (or arc)
  - $\lambda \equiv Q / \ell$ with units C/m … so $dq = \lambda dl$

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: $dq = \lambda \, d\ell$

PHYS 2321: Physics 2

Week 3 -- Electric Fields & Charge Distributions

Day 2 outline

1) Homework for Wednesday (today by 3 pm)
   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 *Careful if you have an e-book!*
   c) See online key for "Questions" 15-26.
   d) Watch YouTube videos on E-fields!
   e) Next: Ch. 22 P. 1,2,5,6,9,10,13,17,19,20,35 + MisCQs
2) Today: Electric Fields
   a) Calculate E due to continuous charge distributions
      Line charge, Arc charge, ring charge, disk charge,
      Infinite plane charge.
   b) field lines (see YouTube)
   c) motion of charges in E-fields

Note: Physics Tutor on 2nd floor Library on Thurs 7-9 pm.
Next quiz: Monday (on E-fields).

Finding E due to continuous charge distributions

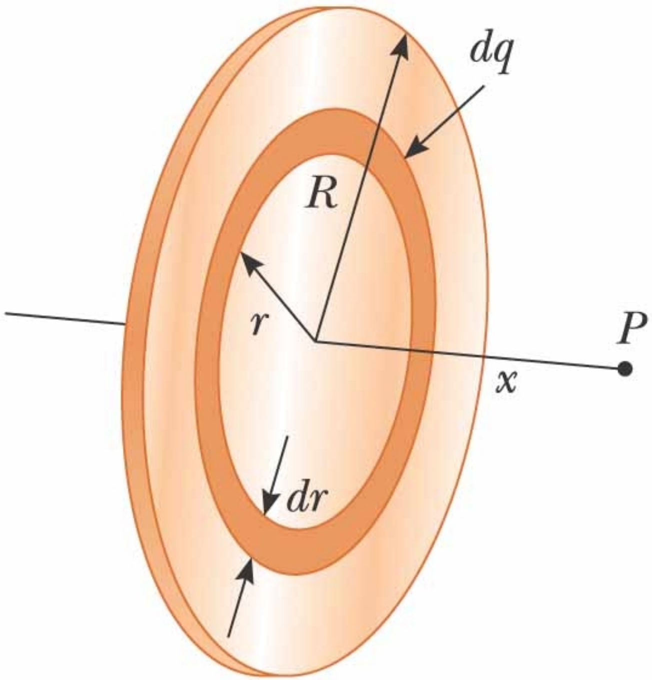
$$E = k_e \int \frac{dq}{r^2} \hat{r}$$

1) Substitute dq= λ dx, or σ dA, ρ dV, λ dy, λr dθ, etc.
2) Substitute r = x or y, if needed, to match dq.
3) Substitute $\hat{r}$ = $\hat{i}$ or $\hat{j}$
4) Choose limits of integral to match dq and geometry
5) Use symmetry to simplify
   Ex) Perhaps Ex=0 or Ey=0 so one integral is not needed
6) Place constants outside the integral
7) Integrate to find $E_x = \int dE_x$ and/or $E_y = \int dE_y$
8) Combine into vector expression

$$\vec{E} = E_x \hat{i} + E_y \hat{j} \quad \text{or} \quad \vec{E} = E_r \hat{r}$$

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*πr dr*

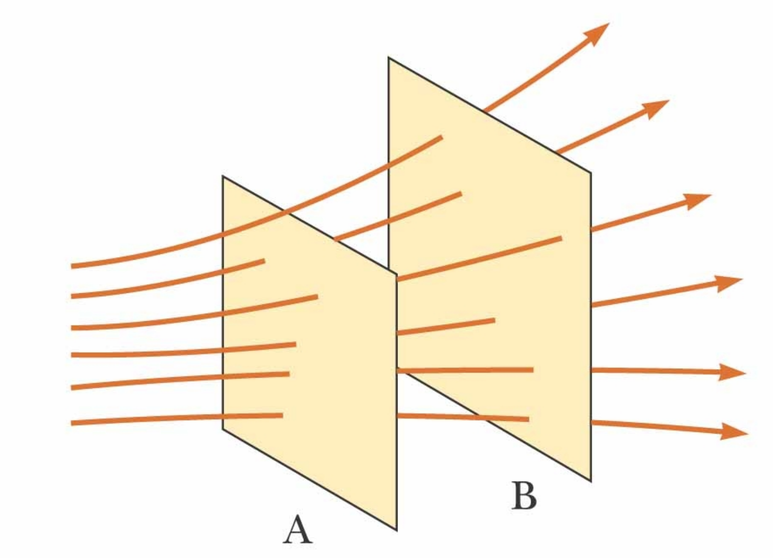


Electric Field Lines

- 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

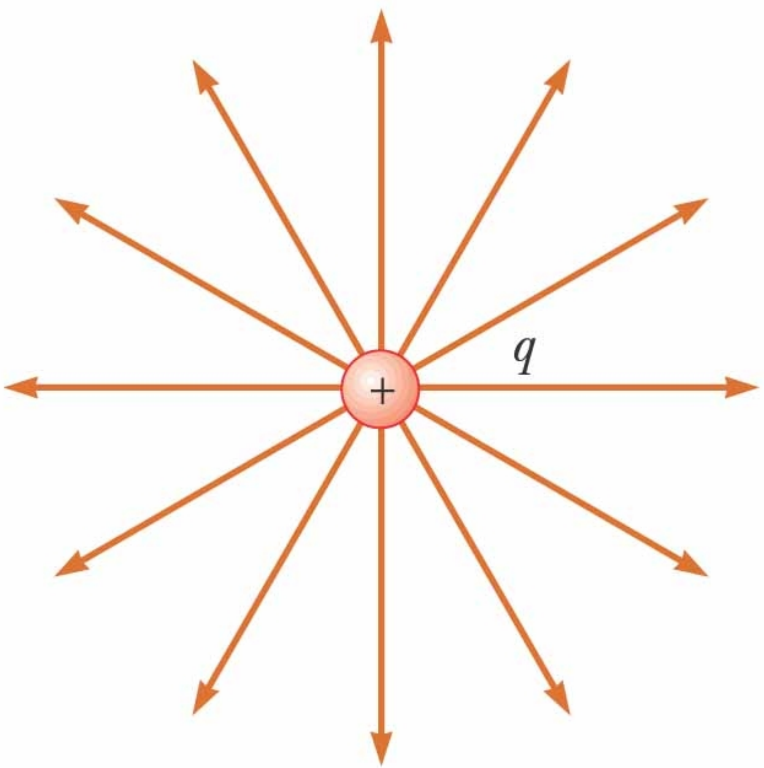
Electric Field Lines, General

- 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

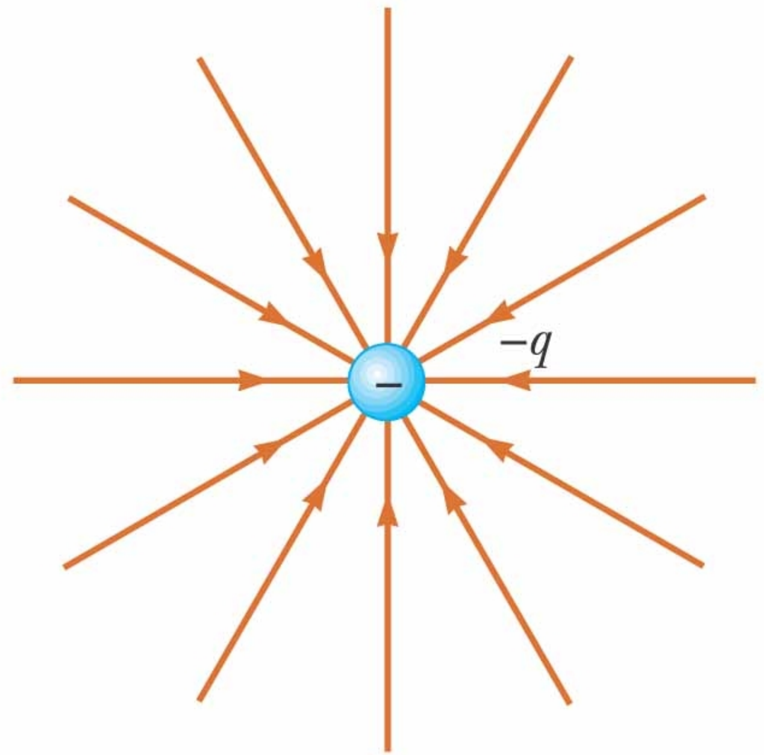
- The field lines radiate outward in all directions
  - In three dimensions, the distribution is spherical
- The lines are directed away from the source charge
  - A positive test charge would be repelled away from the positive source charge



(a)

Electric Field Lines, Negative Point Charge

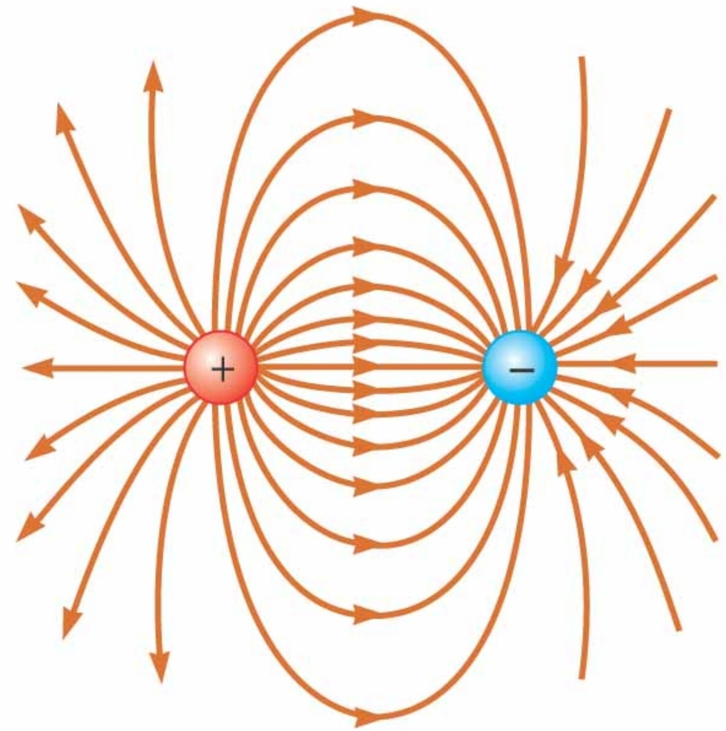
- The field lines radiate inward in all directions
- The lines are directed toward the source charge
  - A positive test charge would be attracted toward the negative source charge



(b)

Electric Field Lines – Dipole

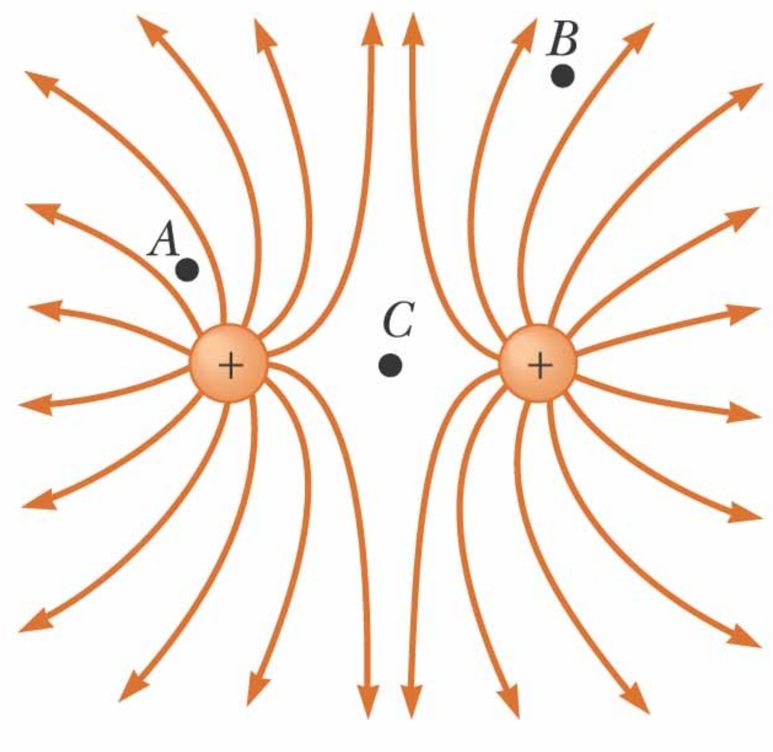
- The charges are equal and opposite
- The number of field lines leaving the positive charge equals the number of lines terminating on the negative charge



(a)

Electric Field Lines – Like Charges

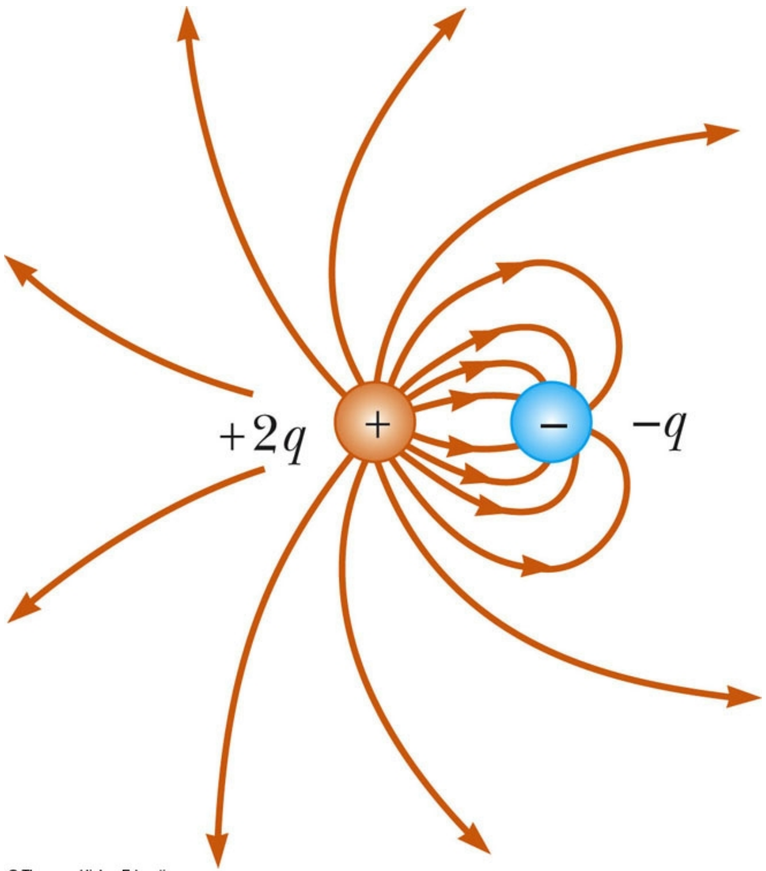
- The charges are equal and positive
- The same number of lines leave each charge since they are equal in magnitude
- At a great distance, the field is approximately equal to that of a single charge of $2q$



(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

* See my 9 rules on my YouTube video.

Motion of Charged Particles

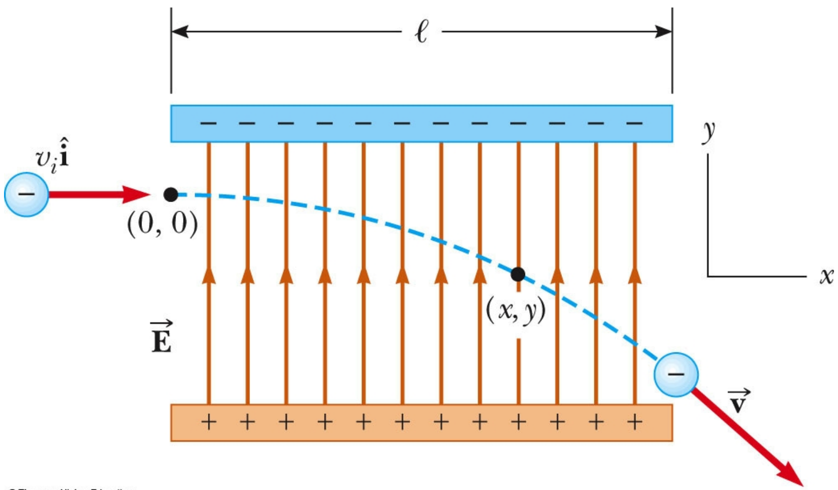
- When a charged particle is placed in an electric field, it experiences an electrical force
- If this is the only force on the particle, it must be the net force
- The net force will cause the particle to accelerate according to Newton's second law

Motion of Particles, cont

- When only Coulomb force exists, $\mathbf{F}=q\mathbf{E} = m\mathbf{a}$.
- If **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.
- If the acceleration is constant, the kinematic equations for uniform acceleration 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