Chapter 13: The Electric Field

- The Coulomb or electric force between two charged point particles

$$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{r} = \vec{F}_e$$

- q (or Q) is the electric charge. Related to the "electric energy" in or upon an object. A fundamental attribute of an object (like mass)

- Electric charge can have any magnitude; can be positive, negative, or zero (neutral)

- Modern convention: electrons have a negative charge, protons have a positive charge
- Objects with total charge of the same sign repel each other (opposite signs - attract)
- Conservation of charge: for an isolated (closed) system, the total charge remains constant. Charge can be transferred between objects within a system. Charge is neither created or destroyed.
- Coulomb constant (exactly):

$$k_e = \frac{1}{4\pi\epsilon_0} = 8.98755179 \times 10^9\ \mathrm{Nm}^2/\mathrm{C}^2$$

- Permittivity of free space (exactly):

$$\epsilon_0 = 8.854187817 \times 10^{-12}\ \mathrm{C}^2/(\mathrm{Nm}^2)$$

- Fundamental constants: accepted values available at: http://physics.nist.gov/cuu/Constants/index.html
- Unit of charge: Coulomb

$$1\ e = 1.6021766208(98) \times 10^{-19}\mathrm{C}$$

- where 1 e is the charge on a proton
- -e is the charge on an electron

Fields

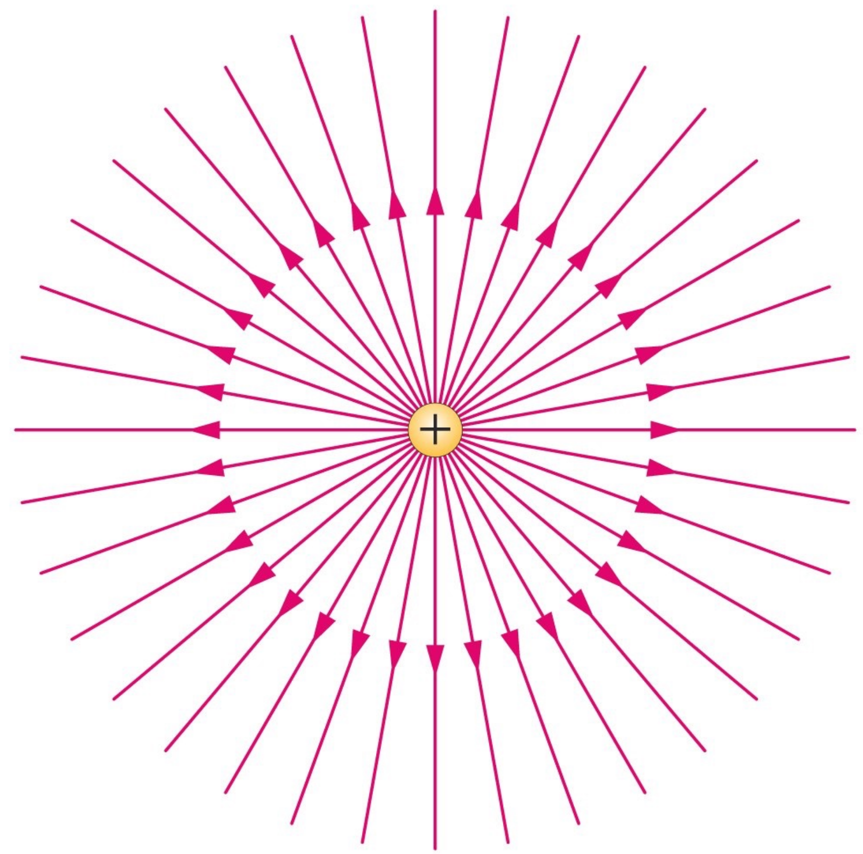
- The electric force (and the gravitational force) are action-at-a-distance forces - no “contact” between objects
- Useful to define a new concept called the <u>field</u>
- The temperature in this room can be given as a function of coordinates - T(x,y,z) - call this the “temperature field”
- Likewise we can define a “pressure field” P(x,y,z)
- However, T and P are scalars, so these are <u>scalar fields</u>

- Forces are vectors, so a field related to a vector is a vector field
- The electric and gravitational force are two body constructs - not really convenient
- Remove one of the objects from the problem, by dividing the force by q_0 (or m) of the object to remove ($q_2=q$, $q_1=q_0$)
- This gives for the electric force, the electric field:

$$\vec{E} = k_e \frac{q}{r^2}\hat{r} = \frac{\vec{F}_e}{q_0}$$

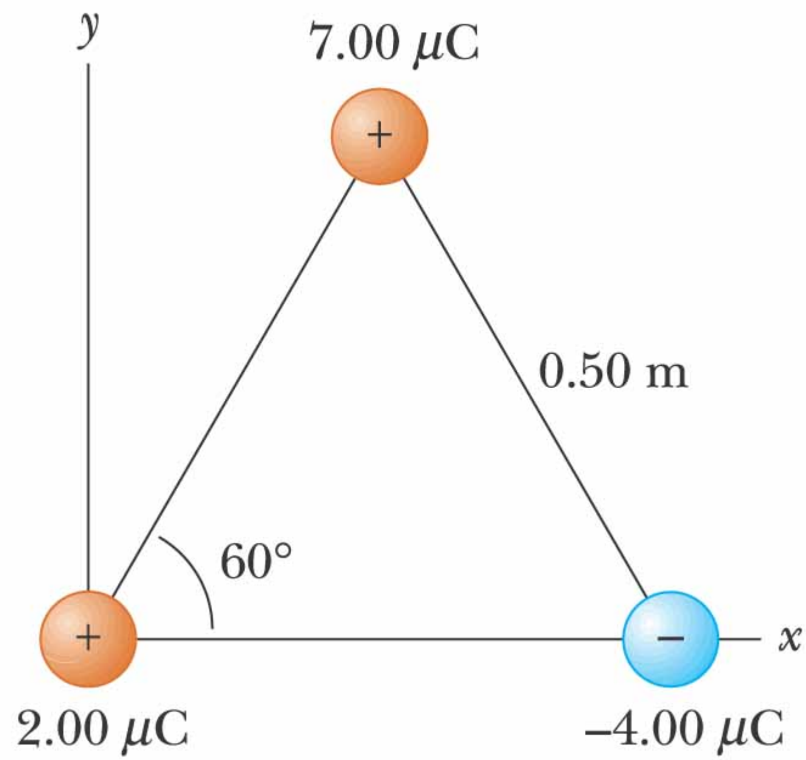
Electric Field Lines

- Field lines of a positive point charge

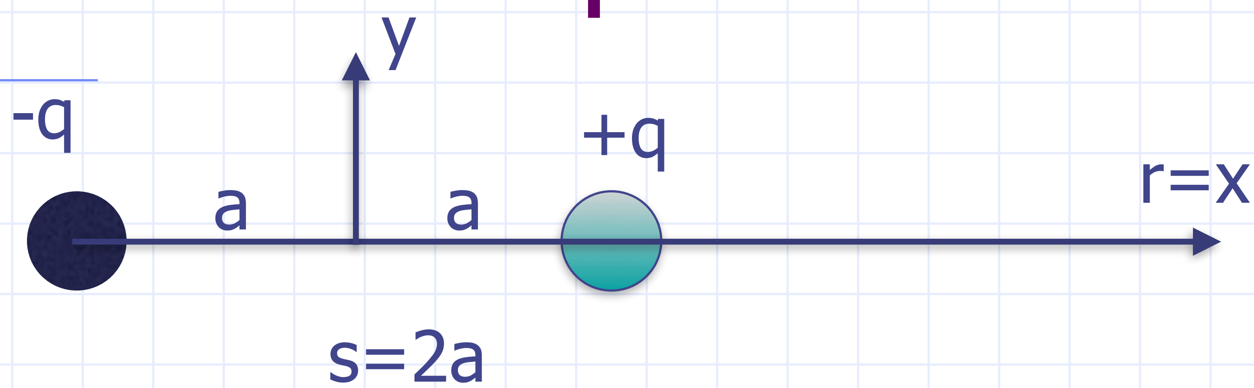


Example Problem

- Three point charges are at the corners of an equilateral triangle as shown. Calculate the electric field at the position of the 2.00 μC charge due to the other two charges.



The Electric Dipole

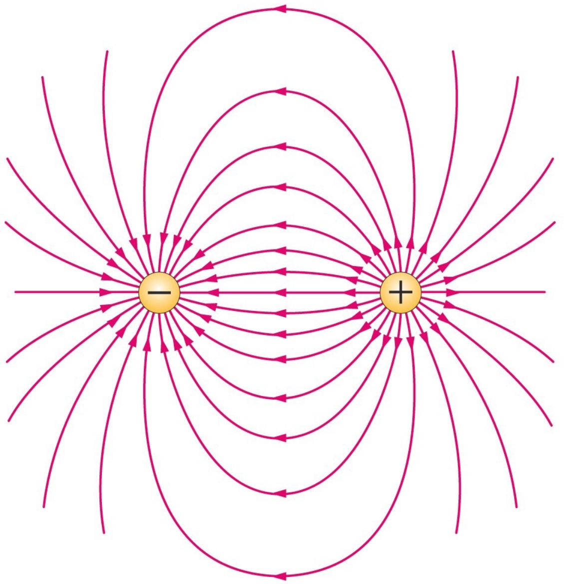


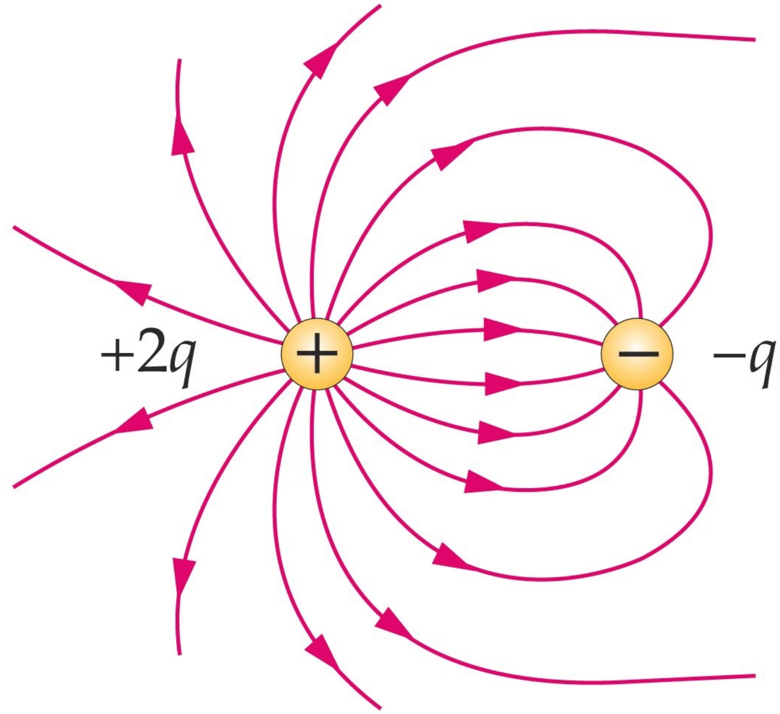
Example Problem

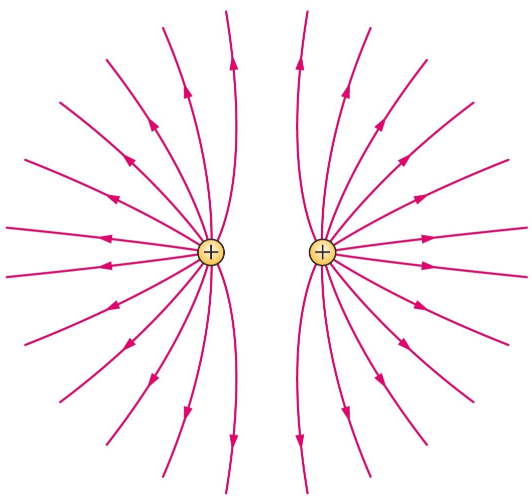
- For the electric dipole, show that the electric field at a distant point on the +x axis is

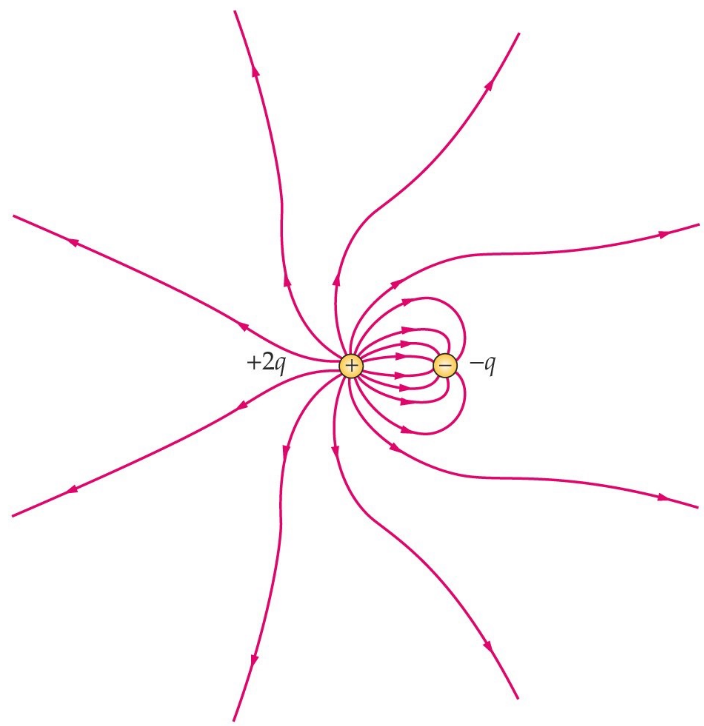
$$E_x \approx 4k_e q \frac{a}{x^3}$$

Two point charges

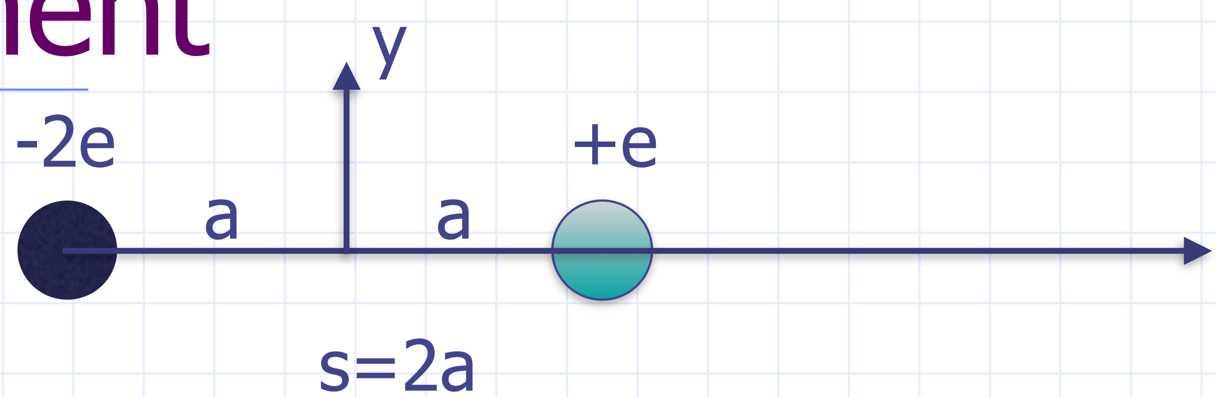








Electron’s Electric Dipole Moment



- If the electron’s “charge” was distributed non-spherically symmetric, it would have an electric dipole moment
- As of 2011 $p=1.05\times10^{-27}$ e cm (90% confidence upper limit)
- Used YbF molecule

Surprising upper limit on the electron's electric dipole moment

A new null result challenges favored expansions of particle theory's standard model.

For decades, experimenters have been using atomic and molecular beams to measure the electric dipole moment (EDM) of the electron. As yet they've found no clear signal—just increasingly stringent upper limits. Those modest tabletop searches are addressing an issue crucial to particle physics, a discipline whose usual search tools are gargantuan. It's been argued that such EDM searches are the fastest and cheapest route to the discovery of new physics beyond the standard model of particle theory.

The electron can have a nonvanishing EDM only if nature violates symmetry under time reversal (T) and under the combined operations of charge conjugation (C), which replaces particles by their antiparticles, and parity inversion what's predicted by leading attempts to progress beyond the manifestly incomplete standard model and, in particular, to explain the cosmological imbalance of matter and antimatter. The range of those new-physics predictions is now accessible by molecular-beam searches.

An EDM implies some spatial separation of charges. But the electron, unlike the hadrons, is taken to be a dimensionless point particle. Its EDM is attributed to the surrounding cloud of virtual particles it continually emits and reabsorbs. And the proposed new physics predicts heavy new particles whose interactions strongly violate CP symmetry.

The electron's EDM vector $\mathbf{d}_e$ must be coaxial with its intrinsic spin. A nonvanishing EDM would manifest itself electric field $\mathbf{E}_{\text{eff}}$. Three years ago Edward Hinds's team at Imperial College London used an ytterbium fluoride beam[1] to set an upper limit of 10^{-27} e·cm on the magnitude of d_e (see PHYSICS TODAY, August 2011, page 12). The sign of d_e indicates whether the electron's EDM is parallel (+) or antiparallel (−) to its intrinsic spin.

The 2011 limit already bit significantly into the parameter space of promising supersymmetric extensions of the standard model. But now, such "SUSY" models and a wide class of alternatives are even more hard-pressed by a new null result reported by the ACME collaboration.[2] The team is headed by John Doyle and Gerald Gabrielse at Harvard University and David DeMille at Yale. With a cryogenic thorium oxide beam setup at Harvard, they have reduced the Hinds team's upper limit by a further order of magnitude.

Physics Today (April 2014)

- Best measurement today is $<1.0\text{x}10^{-29}$ e cm (as of 2018) - using ThO
- Standard Model predicts 10^{-40} e cm
- For proton ($p<5.4\text{x}10^{-24}$ e cm, $R=0.878\text{x}10^{-15}$ m)

Example Problem

- Review problem. In the Bohr theory of the hydrogen atom, an electron moves in a circular orbit about a proton, where the radius of the orbit is 0.529×10^{-10} m. (a) Find the electric force between the two. (b) If this causes the centripetal acceleration of the electron, what is the speed of the electron?

Example Problem

- What are the magnitude and direction of the electric field that will balance the weight of (a) an electron and (b) a proton?