Chapter 20: Electric Charge, Force & Field
Thursday September 1st

- Reminders and Brief Review
  - History
  - Charge
- Coulomb's law
  - Example problems
- Electric field
  - The equivalent of Newton's law in electrostatics
  - Electric field lines
  - Example problems
- Electric dipoles (if time)

Reading: pages 328 – 342 in the text book (Ch. 20)

Physics 2049 Reminders

- First LON-CAPA assignment due tonight!!
  - Next LONCAPA due Wed. (opens tonight)
- First Mini-Exam next Thursday (Sep. 8th)
  - Read instructions posted in LONCAPA
- First use of *i*Clicker on Tuesday
  - Make sure to purchase and register
- No labs next week

History Lesson

600BC **Greek philosophers**
First references to magnetism and electric charge

1175-1600 **Alexander Neckem, Petrus Peregrinus, William Gilbert**
References to, and explanation for, the compass

1747 **Benjamin Franklin (and William Watson)**
Discovers that there are two kinds of charge

1780s **Charles Augustine de Coulomb**
Discovers law of forces between charges – birth of electrostatics

1825 **André-Marie Ampère**
Discovers law of forces between currents – birth of magnetostatics

1720 **Hans Christian Oersted**
Discovers that electric currents influence compass needles

1831 **Michael Faraday**
Discovers law of electromagnetic induction – birth of electrodynamics

1873 **James Clerk Maxwell**
Publishes *A Treatise on Electricity and Magnetism*

1887 **Henrich Hertz**
Confirms that light is an electromagnetic wave

1905 **Albert Einstein***
Formulates special theory of relativity

1909 **Robert Millikan***
Measurement of elementary unit of charge

***Nobel prize**

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PHY3101 – next semester

At the end of the 19th century, A. A. Michelson (very famous physicist) stated that *"all of the grand underlying physical principles had been firmly established."*

Then came two revolutions:

- Relativity

  concepts of space and time change at large relative velocities

- Quantum mechanics

  concept of matter changes on small length scales

- Classical laws of mechanics break down in these limits, and much remains to be discovered

What is charge?

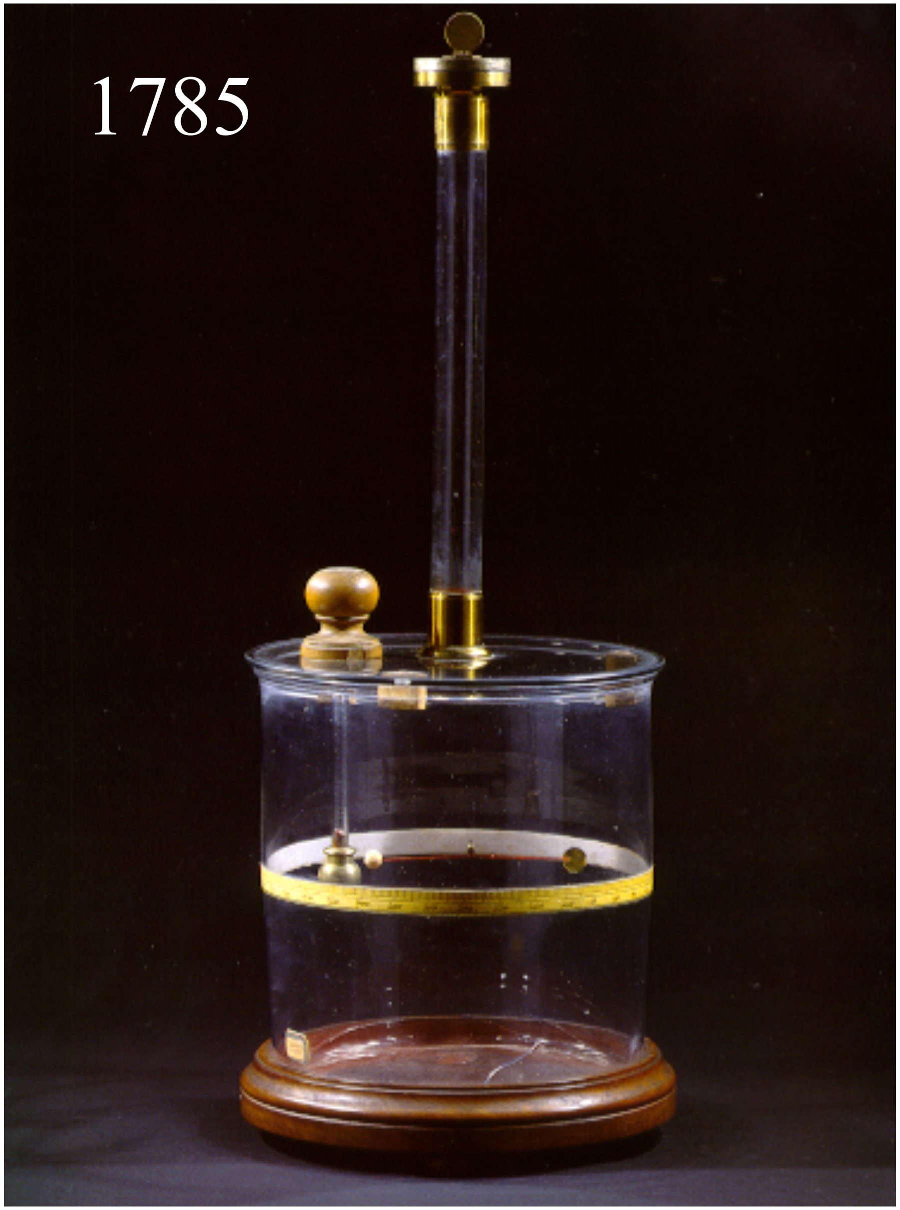
- Charge is measured in Coulombs (C)
  - Fundamental unit.
  - Definition based on forces between current carrying wires (current = Ampères, or C/s), i.e. chapter 26.
- Charge is discrete
  - Thompson discovered the electron in 1896. He found that charge was carried by elementary particles with the same charge to mass ratio.
  - The elementary charge of the electron was not measured until 1909 (Millikan).
  - Both experiments earned Nobel prizes.

Charge on an electron:	$e = 1.6 \times 10^{-19}$ Coulombs
1 Coulomb of charge:	6.24×10^{18} electrons
1 Ampère (= 1 C/s)	6.24×10^{18} electrons/second

Charge is discrete: $q = ne$ $\qquad n = \pm 1, \pm 2, \pm 3, \ldots$

Coulomb's Law

Coulomb's torsional balance



$$F \propto \frac{|q_1||q_2|}{r^2}, \quad \text{or} \quad F = k\frac{|q_1||q_2|}{r^2}$$

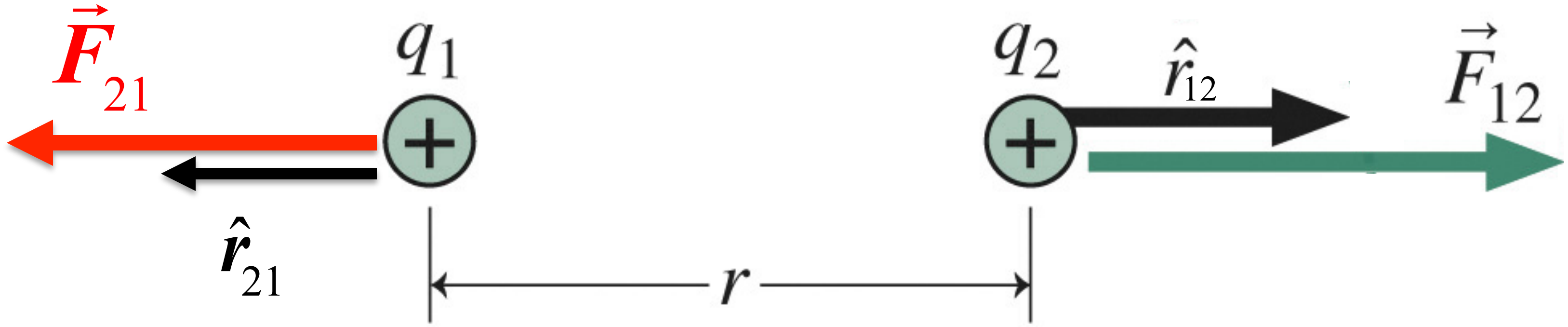
$$k = \frac{1}{4\pi\varepsilon_o} = 8.99 \times 10^9 \ \mathrm{N \cdot m^2 / C^2}$$

$$\varepsilon_o = 8.85418781762 \times 10^{-12} \ \mathrm{C^2/N \cdot m^2}$$

$$\varepsilon_o = \frac{1}{\left(4\pi \times 10^{-7} \ \mathrm{N \cdot s^2 / C^2}\right) \times c^2}$$

c = speed of light in vacuum
= 299792458 m/s

Coulomb's Law in vector notation



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

$$k = \frac{1}{4\pi\varepsilon_o}$$

Newton's 3rd law:

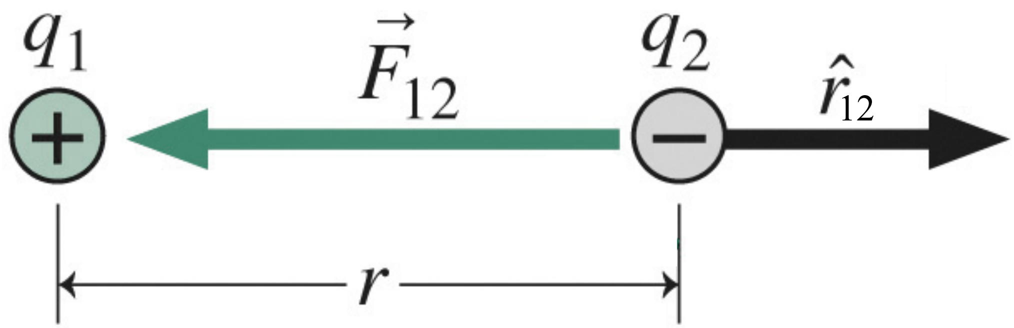
$$\vec{F}_{12} = -\vec{F}_{21}$$

$$\vec{F}_{21} = k\frac{q_1 q_2}{r_{21}^2}\hat{r}_{21}$$

Unit vectors:

$$\hat{r}_{12} = \frac{\vec{r}_{12}}{r} = -\hat{r}_{21}$$

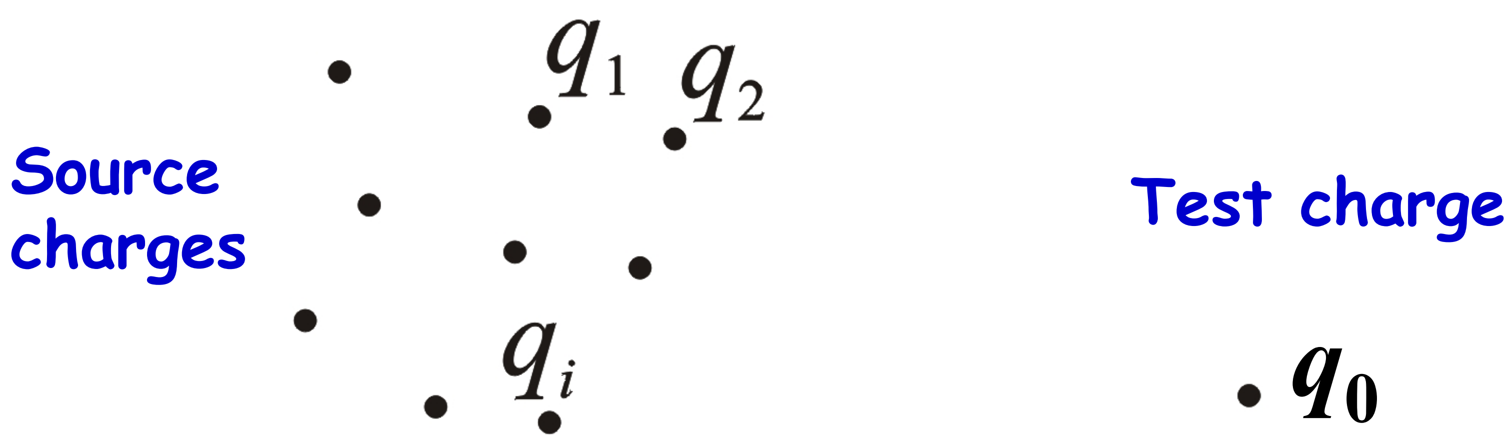
Coulomb's Law in vector notation



$$\vec{\boldsymbol{F}}_{12} = k\frac{q_1 q_2}{r^2}\hat{\boldsymbol{r}}_{12} \qquad k = \frac{1}{4\pi\varepsilon_o}$$

$q_2 < 0,$ so the force is in the opposite direction to $\hat{\boldsymbol{r}}_{12}$

Superposition principle

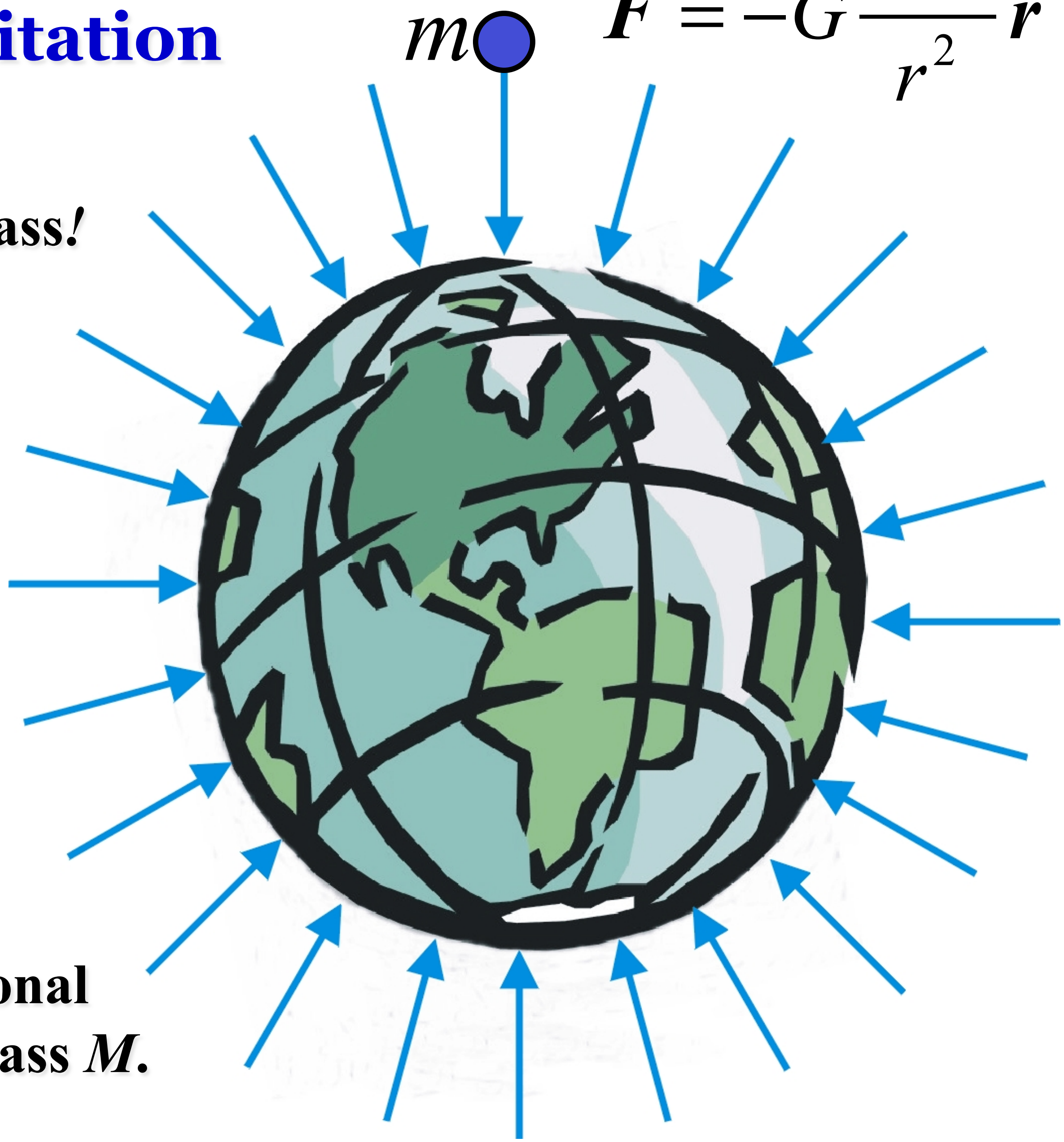


$$\vec{F}_{q_0} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots \vec{F}_i = \sum_i \vec{F}_i$$

- Leads to Maxwell's equations being linear.

Electric fields

Analogy with gravitation



$$\vec{F} = -G\frac{Mm}{r^2}\hat{r}$$

- **Problem:**
  Force depends on test mass!

- **Newton's law:**

$$\vec{F} = m\vec{g} \quad \text{or} \quad \vec{g} = \frac{\vec{F}}{m}$$

$$\vec{g} = -\frac{GM}{r^2}\hat{r}$$

- **Same for all masses.**
- **Represents the gravitational influence (field) of the mass *M*.**

Electric fields

$$\vec{F} = +k\frac{Qq}{r^2}\hat{r}$$

Analogy with gravitation

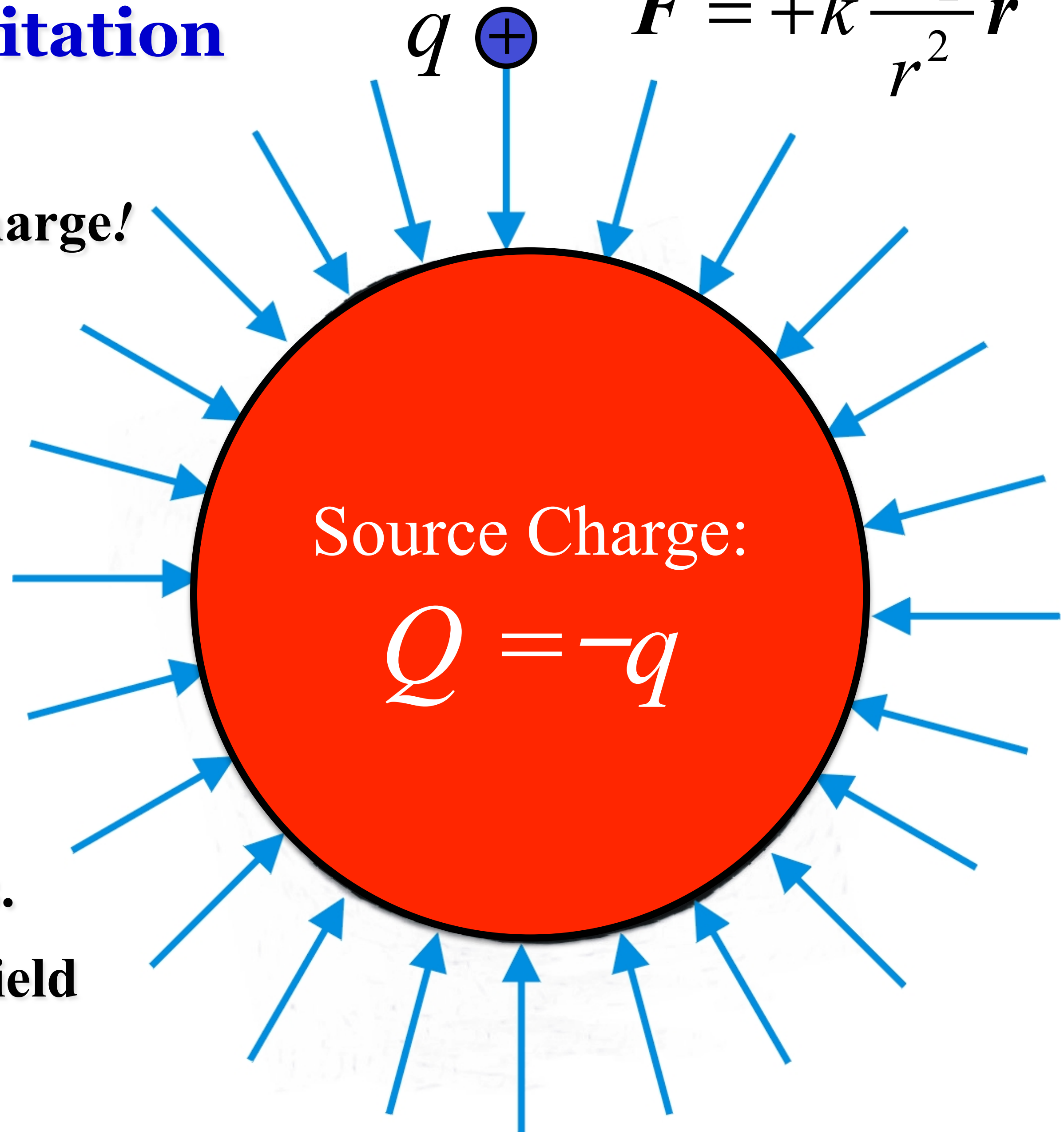
- **Problem:**
  Force depends on test charge!

- **Definition:**

$$\vec{F} = q\vec{E} \quad \text{or} \quad \vec{E} = \frac{\vec{F}}{q}$$

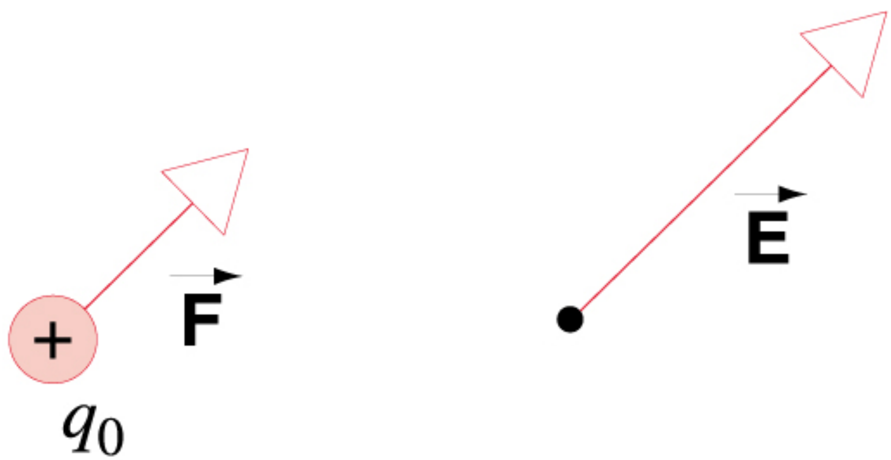
$$\vec{E} = +k\frac{Q}{r^2}\hat{r}$$

- **Same for all test charges.**
- **Represents the electric field due to the charge *Q*.**



Electric fields

Newton's law for electrostatics:



$$\vec{F} = q_0 \vec{E}$$

There's really no need for the "test charge"

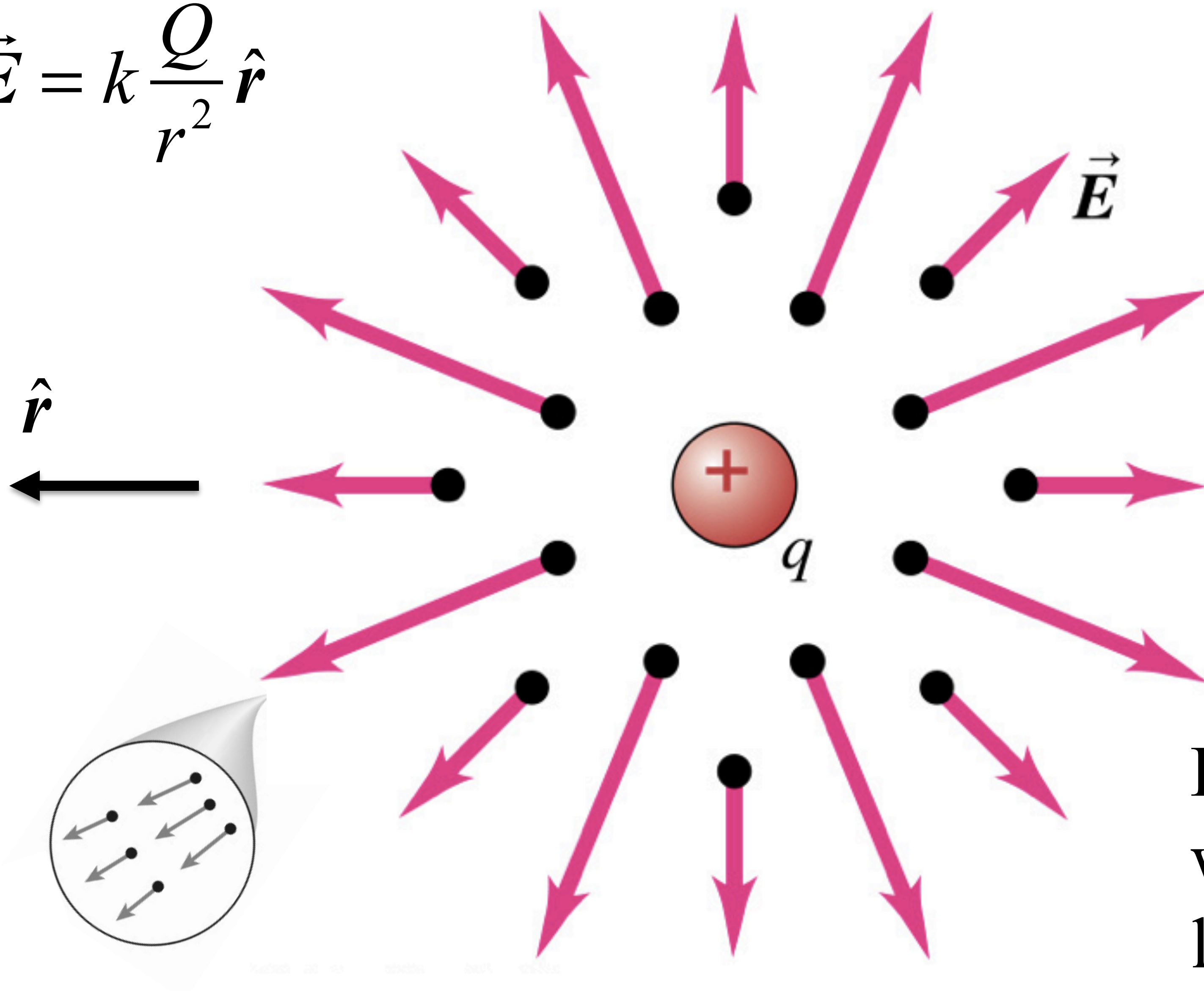
$$\vec{F} = q\vec{E}$$

This is the force on a charge q in an electric field $\vec{E}$

Units for E are N/C in this chapter
(later we shall use volts per meter)

Electric fields

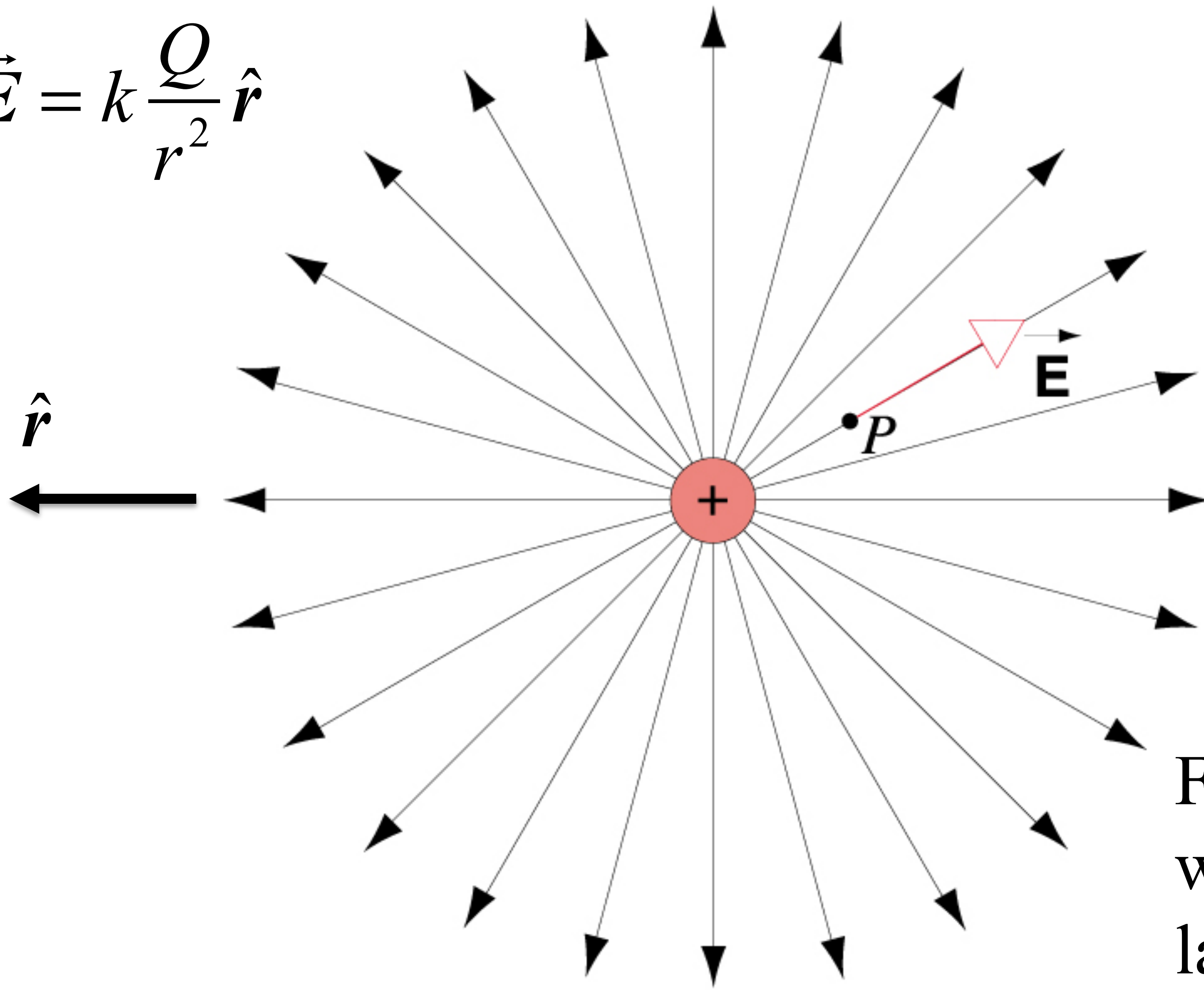
$$\vec{E} = k\frac{Q}{r^2}\hat{r}$$



Field gets weaker at larger distances

Electric field lines

$$\vec{E} = k\frac{Q}{r^2}\hat{r}$$



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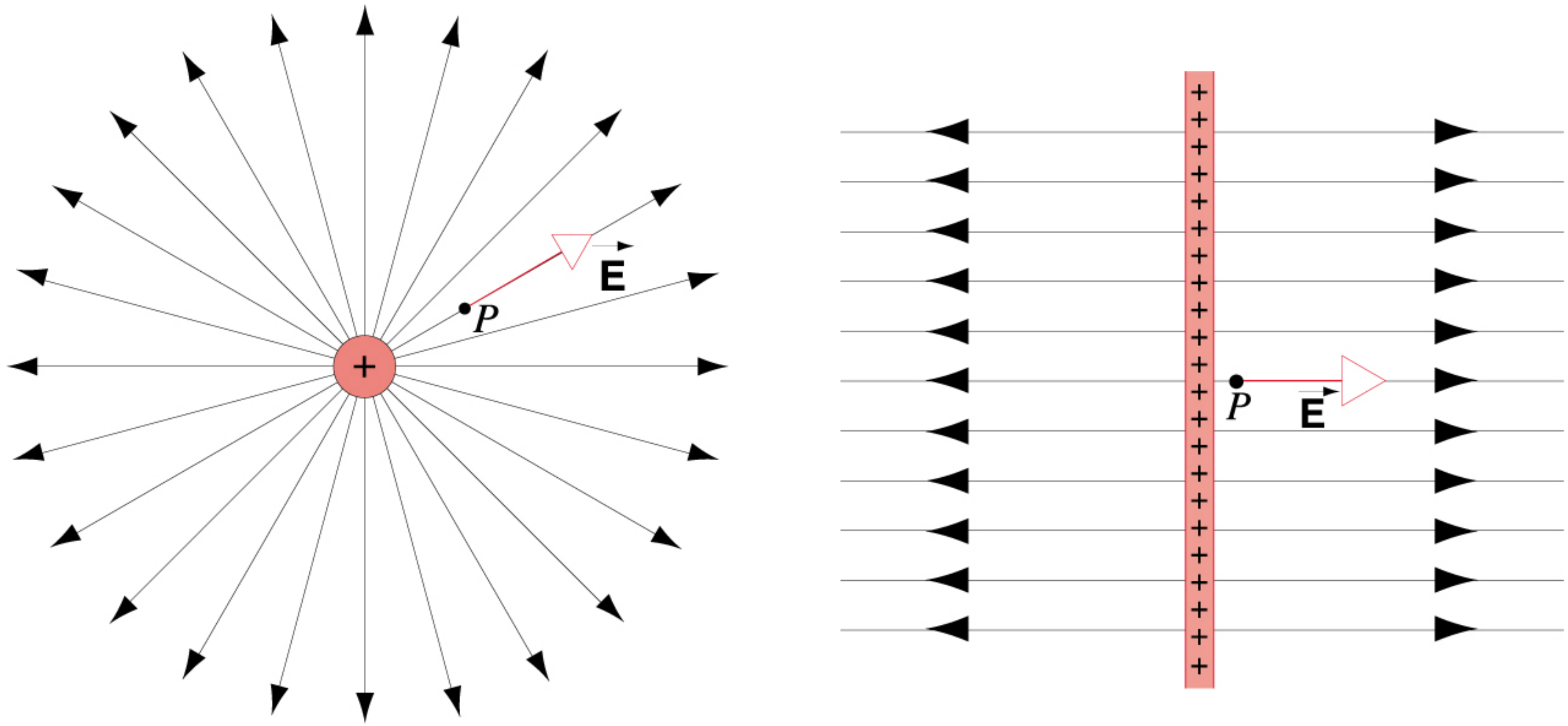
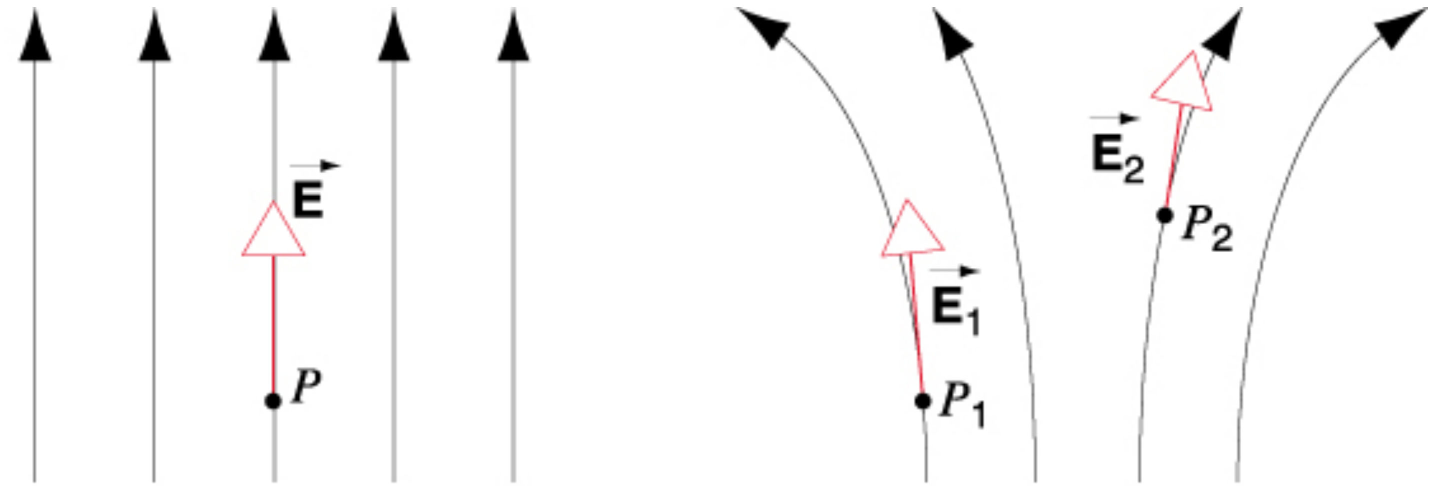
Electric field lines



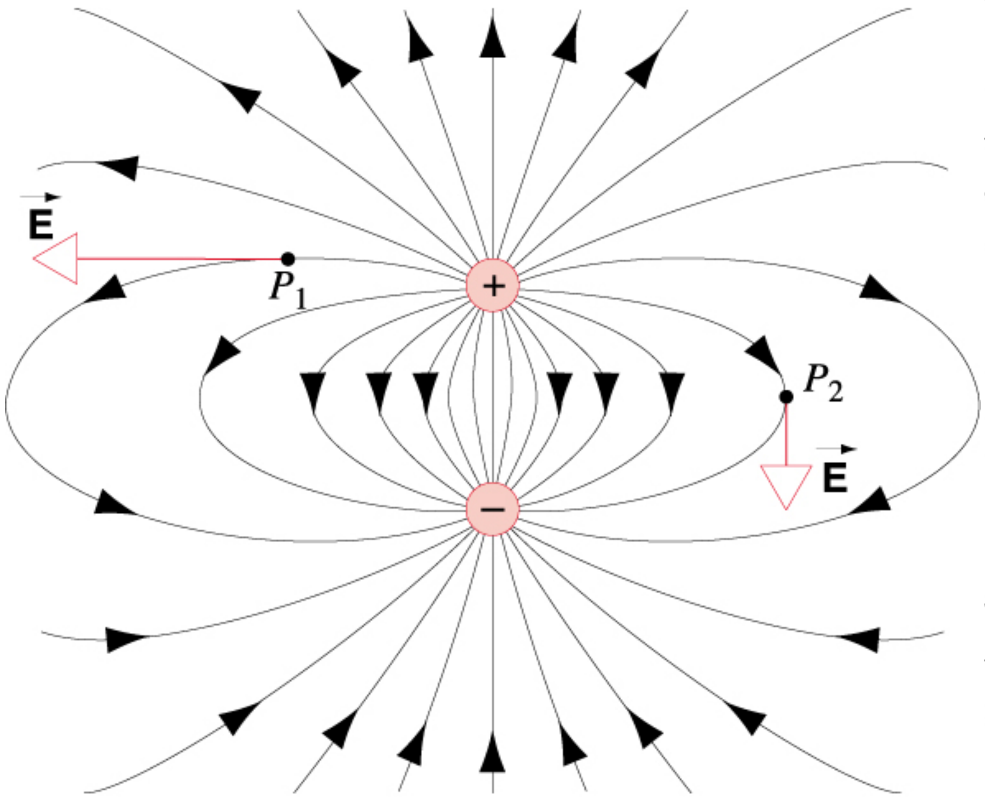
- Electric field lines start on positive charges and end on negative charges (can also start/end at infinity).
- The symmetry of the problem dictates the directions in which field lines radiate from charges.

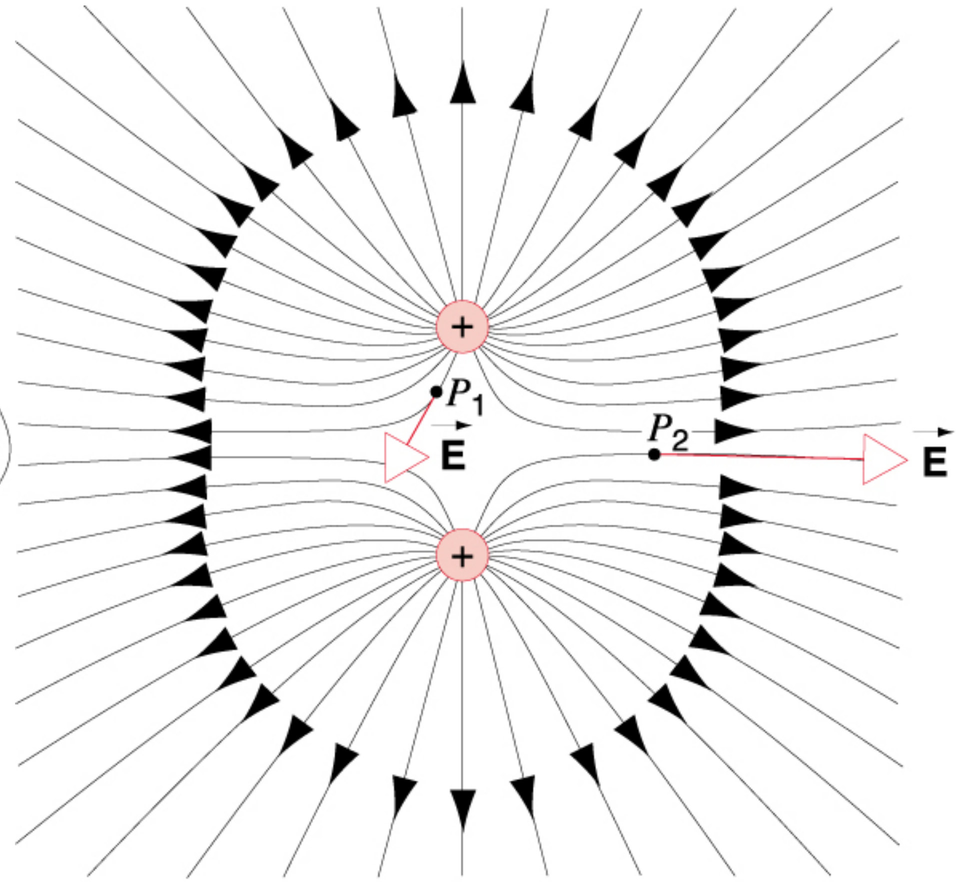
Electric field lines



- The tangent to an electric field line at a point in space gives the direction of the electric field at that point.
- The magnitude of the electric field at any point is proportional to the number of field lines per unit cross-sectional area perpendicular to the lines (tightness of their spacing).
- Plus charges experience a force parallel to the field lines; negative charges in the opposite direction.

Electric field lines





- The number of field lines radiating from a charge is proportional to the charge.
- Field lines cannot cross (why?)