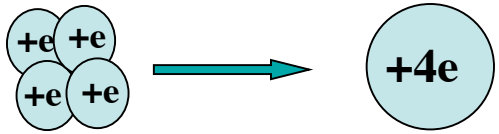
Electric Force



A collection of 4 charges, each with +1e…

…equivalent to "a charge" with +4e

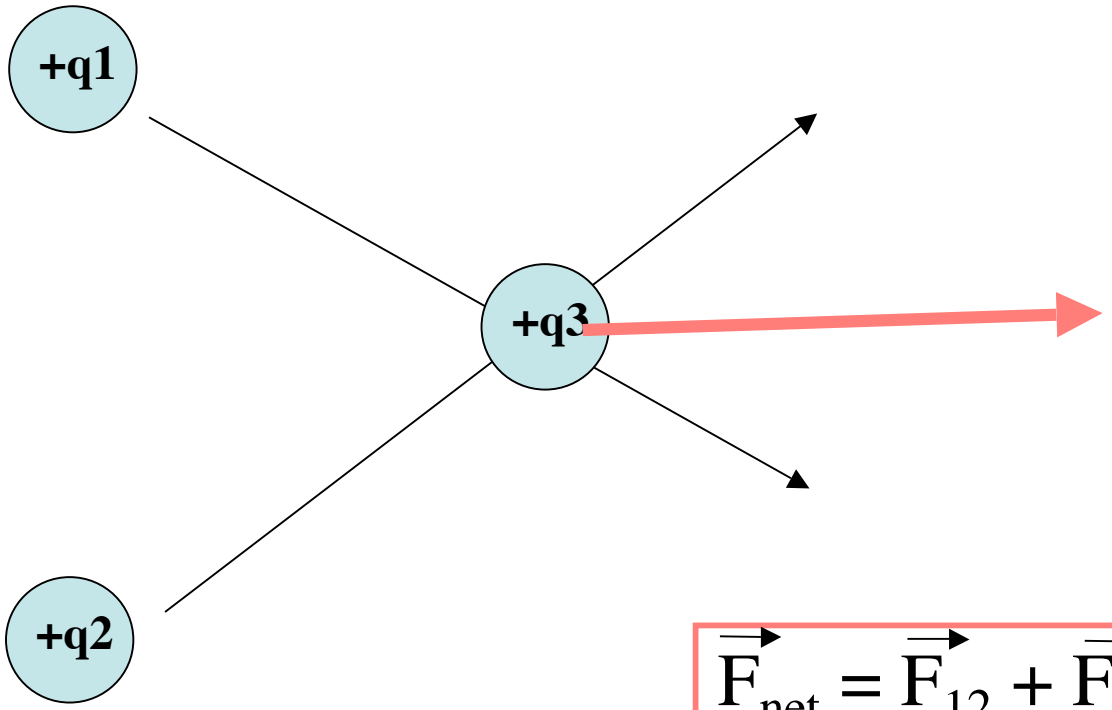
Given two objects with charges q_1 & q_2:

Coulomb's Law: $F_e = \dfrac{k_e\, q_1\, q_2}{r^2}$

Coulomb constant $k_e = 8.9875 \times 10^9\ N\ m^2 / C^2$

Superposition

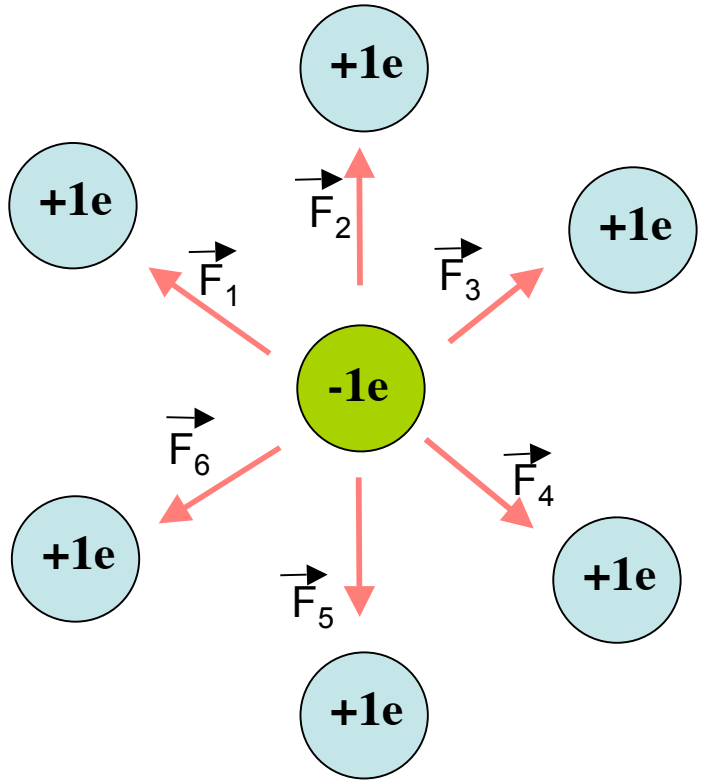
Use superposition (vector addition) to find net force!



$$\vec{F}_{net} = \vec{F}_{12} + \vec{F}_{23}$$

Superposition

Example of superposition: One e^- surrounded by a hexagon of protons, all held fixed: What's the net electrostatic force on the e^-?

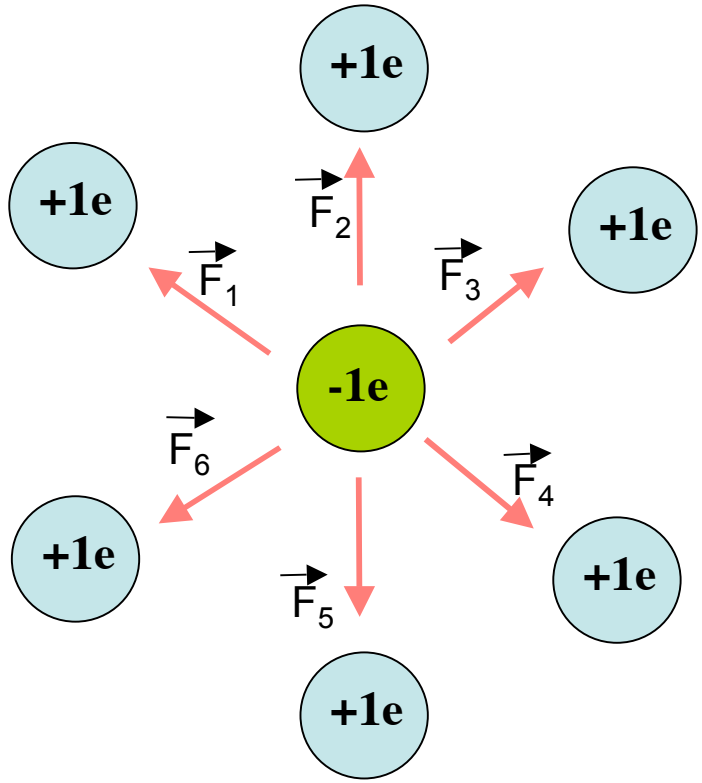


Superposition

Example of superposition: One e^- surrounded by a hexagon of protons, all held fixed: What's the net electrostatic force on the e^-?

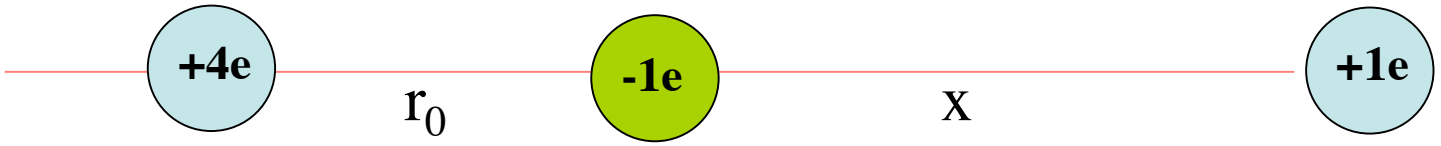
$$\vec{F}_1 + \vec{F}_4 = 0$$
$$\vec{F}_2 + \vec{F}_5 = 0$$
$$\vec{F}_3 + \vec{F}_6 = 0$$

Total $\vec{F} = 0$!



Superposition

You have two charges (+4e and -1e) in a line, separated by distance r_0. Where along the line is the net force on a charge of +1e zero?



$$|\vec{F}_{13}| = |\vec{F}_{23}|$$

$$\left| \frac{k_e(q_1)(q_3)}{(r_0 + x)^2} \right| = \left| \frac{k_e(q_2)(q_3)}{x^2} \right|$$

$$\left| \frac{k_e(+4e)(+1e)}{(r_0 + x)^2} \right| = \left| \frac{k_e(-1e)(+1e)}{x^2} \right|$$

$$4x^2 = (r_0 + x)^2$$

$$2x = (r_0 + x)$$

$$\boxed{x = r_0}$$

Electric vs. Gravitational Forces

Consider a hydrogen atom: One proton, one electron, r = 5.3×10^{-11} m

$$F_e = \frac{k_e q_1 q_2}{r^2} = \frac{8.99\times10^{9}\,Nm^2/C^2\,(1.6\times10^{-19}\,C)^2}{(5.3\times10^{-11}\,m)^2}$$

$$= 8.2\times10^{-8}\,N$$

$$F_g = \frac{G m_1 m_2}{r^2} = \frac{6.67\times10^{-11}\,Nm^2/kg^2\,(1.67\times10^{-27}\,kg)(9.11\times10^{-31}\,kg)}{(5.3\times10^{-11}\,m)^2}$$

$$= 3.6\times10^{-47}\,N$$

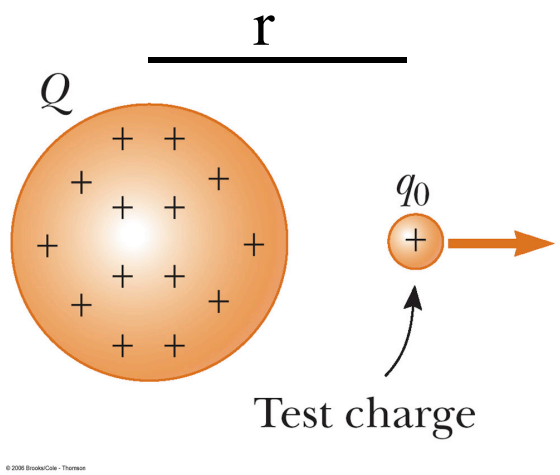
Both forces are prop. to $1/r^2$, but gravity is **much** weaker!

Electric Field due to a point charge

E-field exerts a force on other point charges

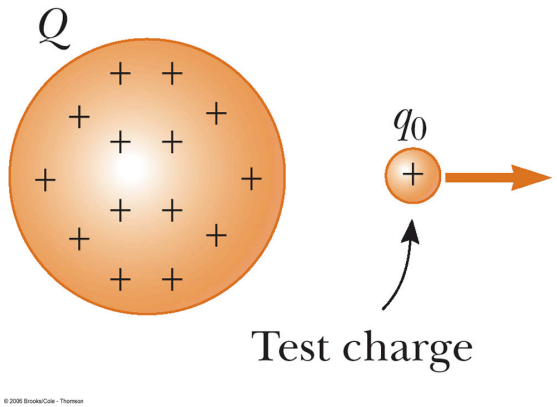
$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{\frac{k_e Q q_0}{r^2}}{q_0}$$

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



$\vec{E}$ is a vector quantity

Magnitude & direction vary with position--but depend on object w/ charge Q setting up the field



The electric field depends on Q, not q_0. It also depends on r.

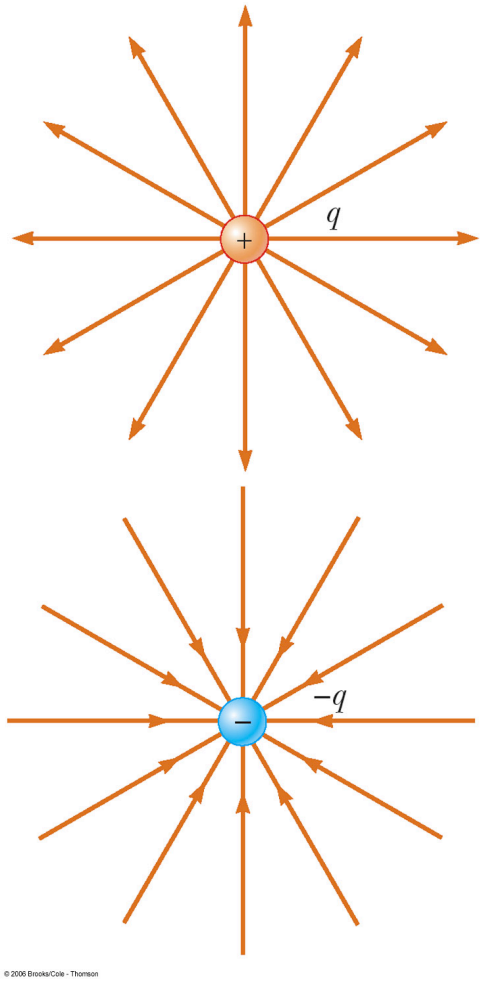
If you replace q_0 with $-q_0$ or $2q_0$, the strength & magnitude of the E-field at that point in space remain the same

The electrostatic FORCE, however, depends on Q AND q_0 as well as r.

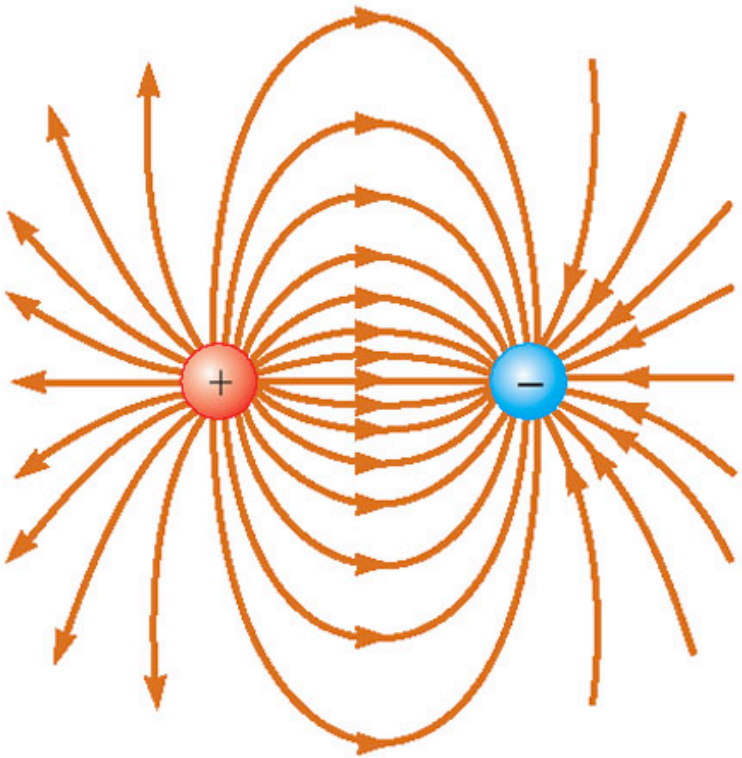
15.5: Electric Field Lines

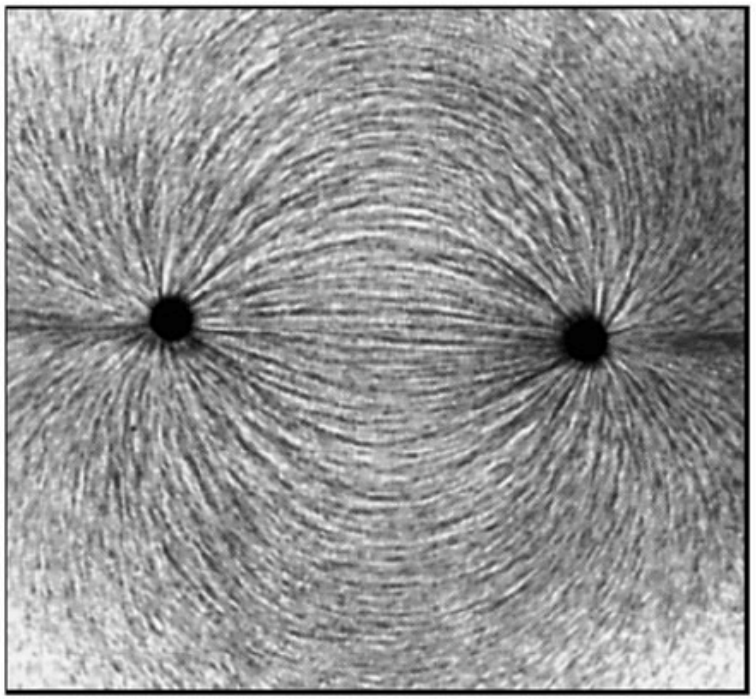
Field lines are a way of visualizing strength and direction of E-field at a given point in space

Density of field lines prop. to magnitude of E



Electric Field Lines

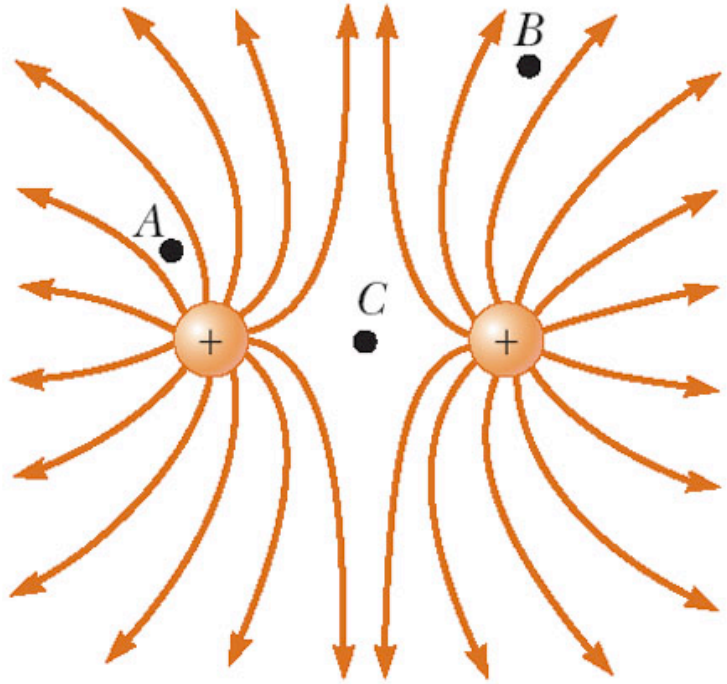


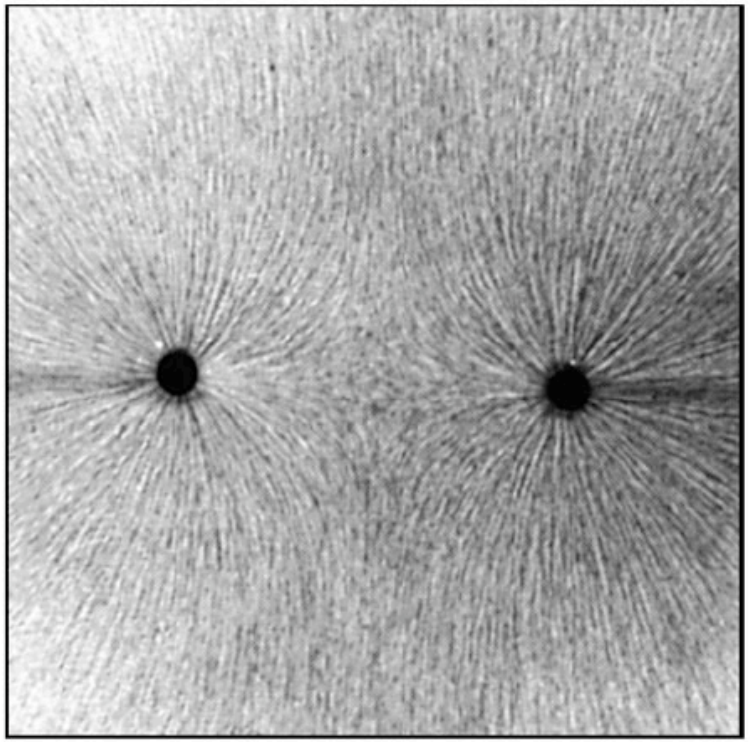


An Electric Dipole

Electric Field Lines

Two positive charges





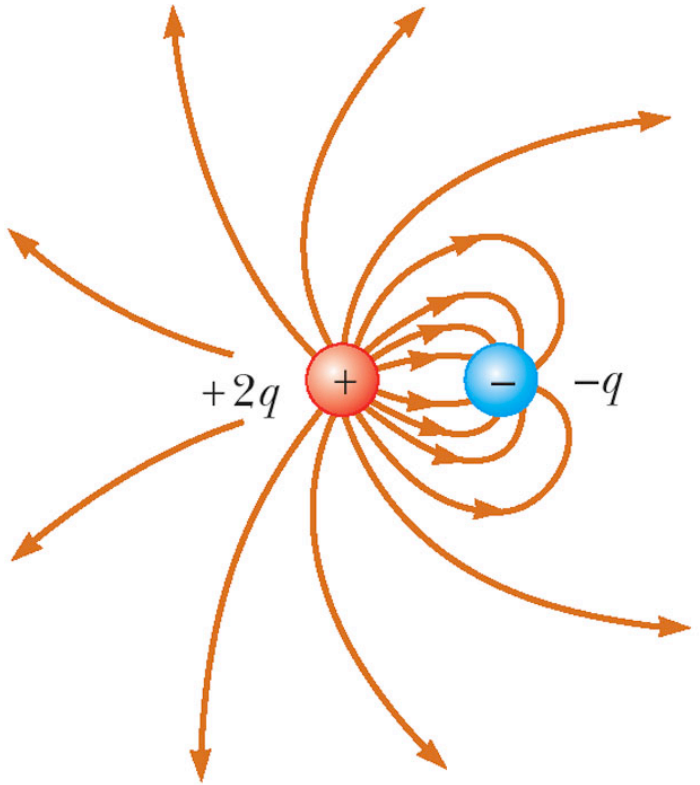
Electric Field Lines

Field lines begin on + charges and terminate on – charges

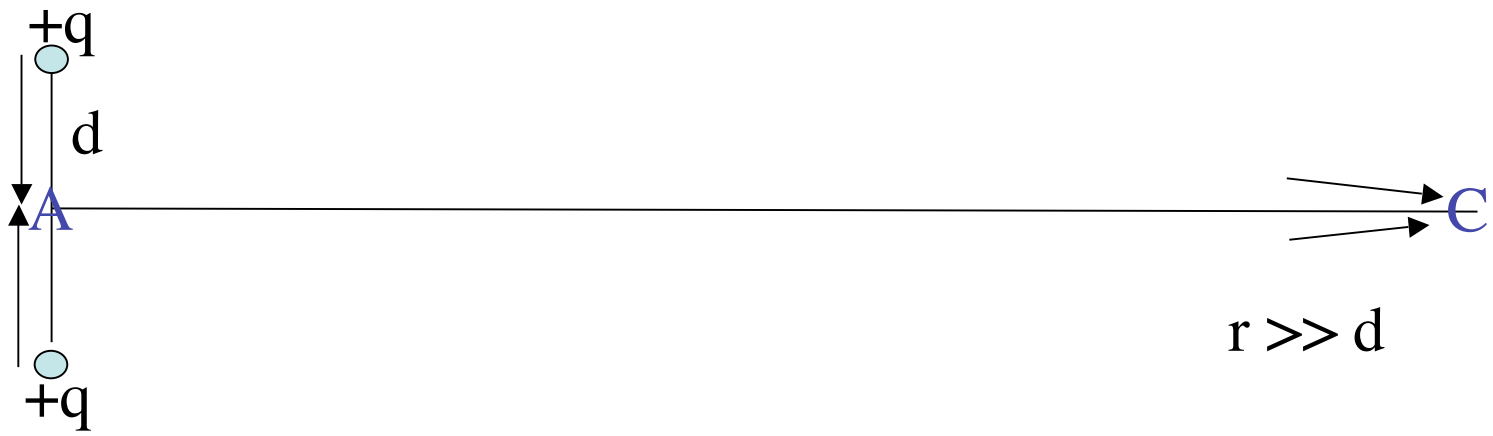
If there's excess +(–) charge, some lines will end(begin) at infinity

Number of lines beginning/ terminating at a point charge is prop. to amount of charge

Field lines may not cross each other



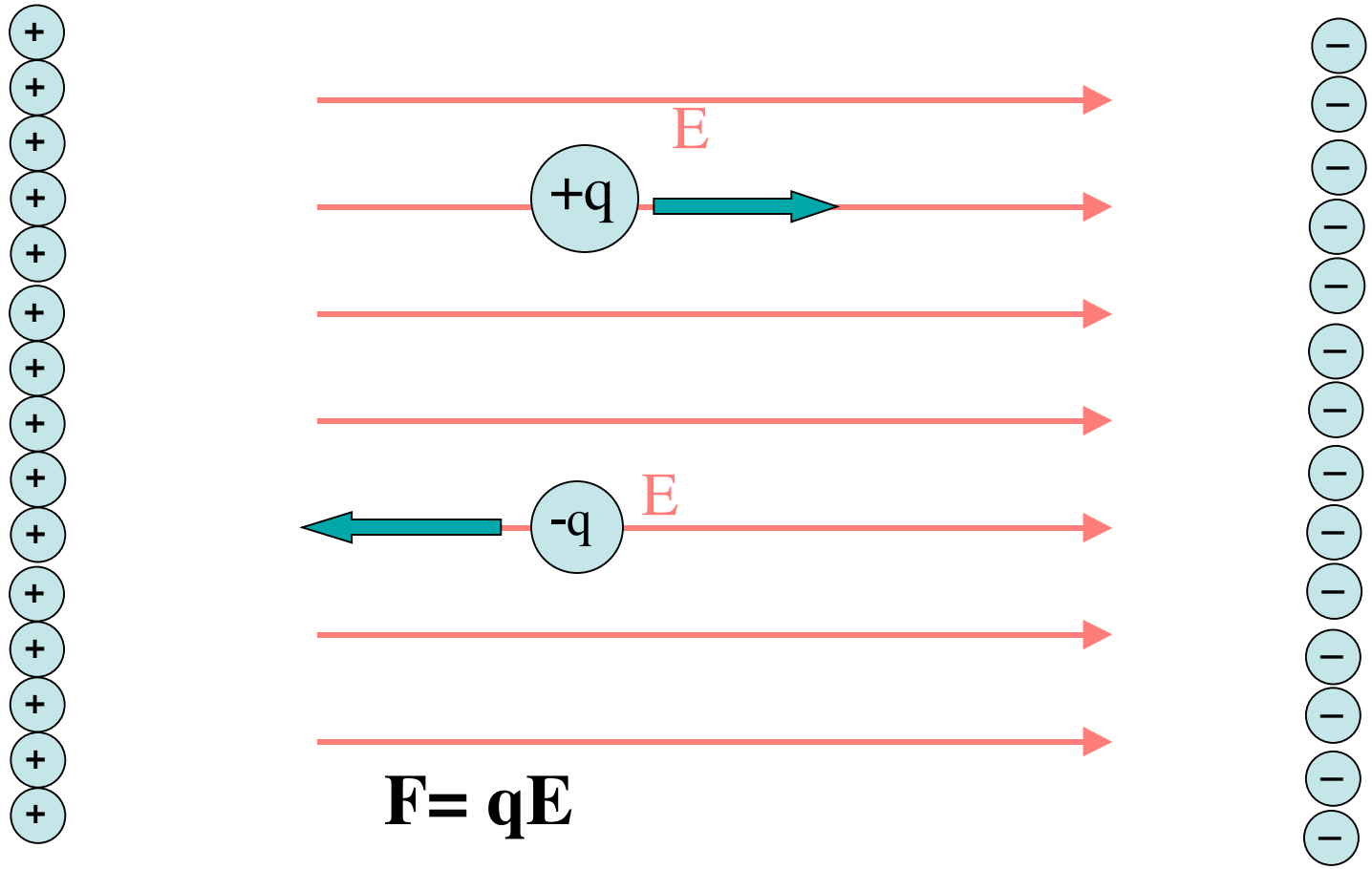
E-field due to 2 + Charges



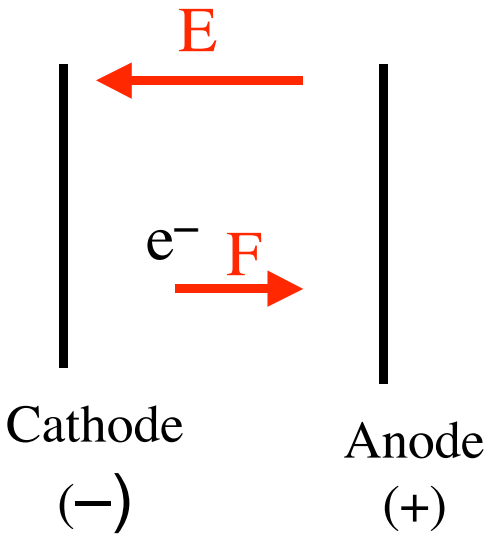
$\vec{E}$ at point A is zero because the force vectors cancel out. At point C, the distribution looks like a point charge +2q

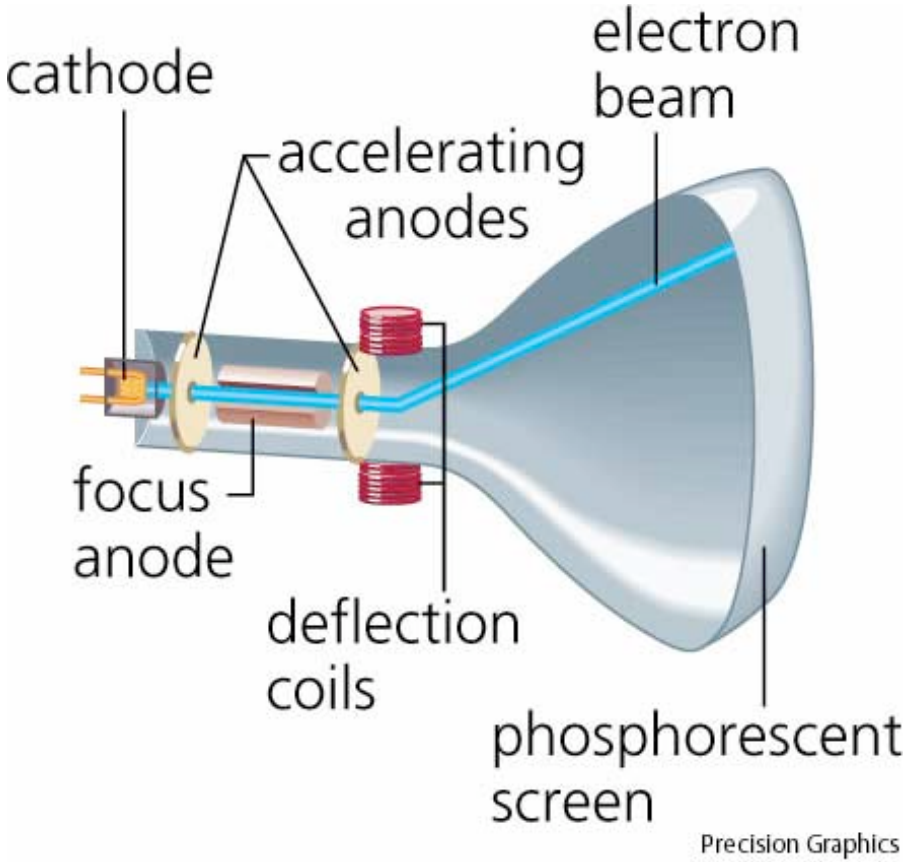
E-field exerts force on a charge

Consider an array of + charges and an array of – charges:



Cathode Ray Tube

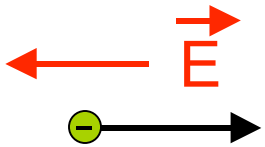




http://building.pbworks.com

Accelerating electrons in a constant E-field

A single electron is accelerated from rest in a constant electric field of 1000 N/C through a distance of 3 cm. Find the electric force on the electron, and calculate its final velocity (m_e = 9.1x10^{-31} kg)



$F = qE = (1.6\text{x}10^{-19}\ \text{C})(1000\text{N/C})$
$= 1.6\text{x}10^{-16}\ \text{N}$

$F = qE = m_e a$

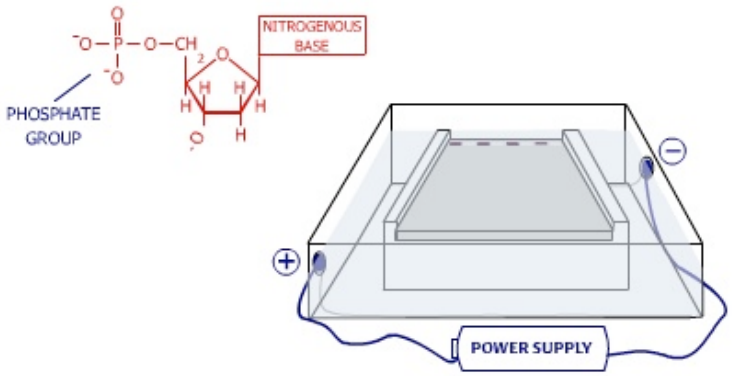
$$v^2 = v_0^2 + 2ad$$
$$\rightarrow v = \sqrt{2ad} = \sqrt{2(F/m_e)d} = \sqrt{2(qE/m_e)d}$$

$$v = \sqrt{\frac{2(1.6\times10^{-19}C)(1000N/C)0.03m}{9.1\times10^{-31}kg}}$$
$$v = 3.2 \times 10^6\ \text{m/s}$$

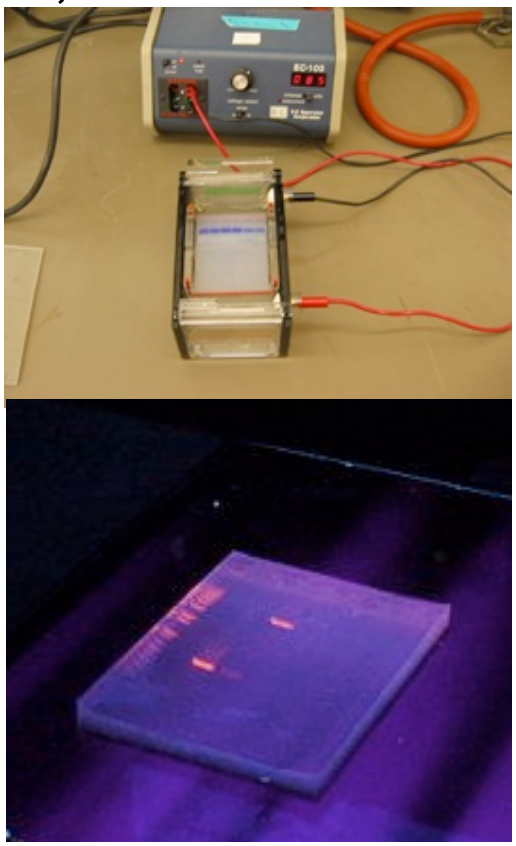
Application: Electrophoresis

Separation of DNA segments (q ~ –1000 e due to O^-'s in phosphate backbone of DNA chain) in an E-field ~ 1000 N/C.

Moves through pores in gel towards anode; smaller segments travel further

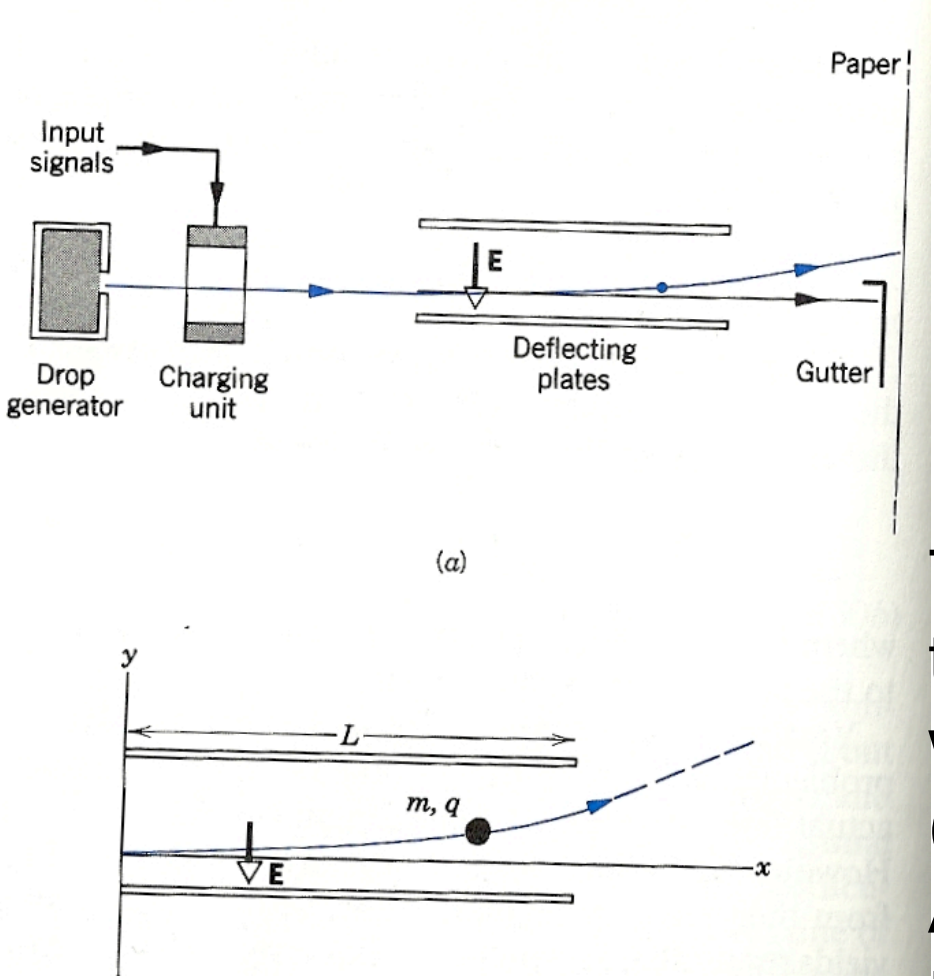


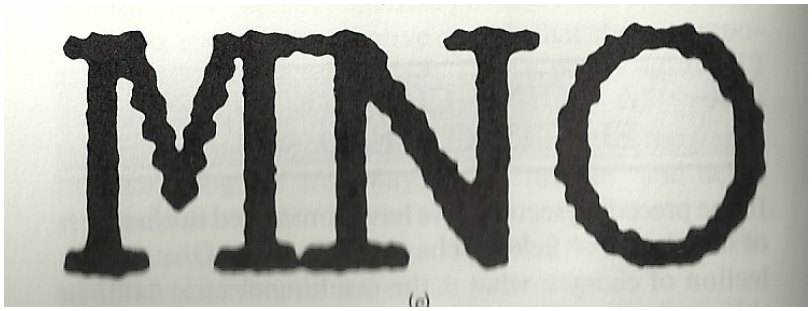
Source: http://dnalc.org



http://web.mit.edu/7.02/virtual_lab/RDM/RDM1virtuallab.html

Application: Ink-jet printers





Tiny drop of ink is shot through charging unit, where a negative charge (typ. ~ –1000e) is applied. An E-field is then applied to deflect the drop through the proper angle.