Announcements

1. No class on Monday – MLK holiday
2. Homework assignments HW1 & HW2 due at 11:59 PM on Wednesday, Jan. 19th.
3. Tutorial sessions start Tuesday, Jan. 18th 7-9 PM (?).

   Section B tutorial -- Tuesdays at 5 or 6 PM??
4. Lab sessions start Tuesday, Jan. 18th
5. Comment on extra credit opportunities
6. Today's topics –

   Coulomb's force law

   Electric fields

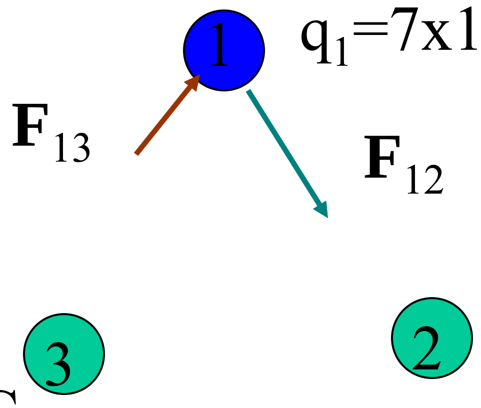
Coulomb's law for 2 charges:

$$\mathbf{F} = k_e \frac{q_1 q_2}{|\mathbf{r}_1 - \mathbf{r}_2|^2} \hat{\mathbf{r}}_{12}$$

k_e: 8.987551787 x 10^9 N · m^2/C^2

Consider 3 charges:

q_1=7x10^{-6}C

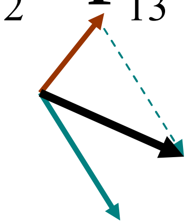


q_2=–4x10^{-6}C

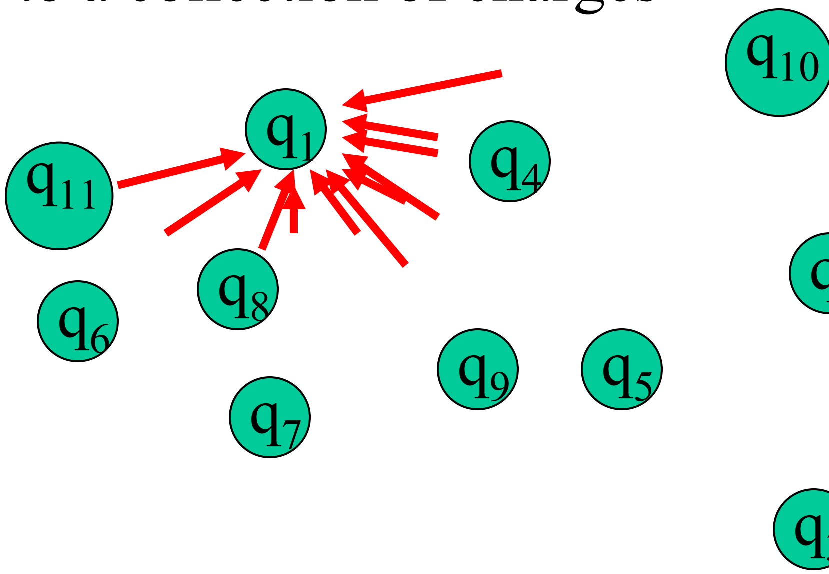
q_3=2x10^{-6}C

Total force on q_1:

$$\mathbf{F}_1 = \mathbf{F}_{12} + \mathbf{F}_{13}$$

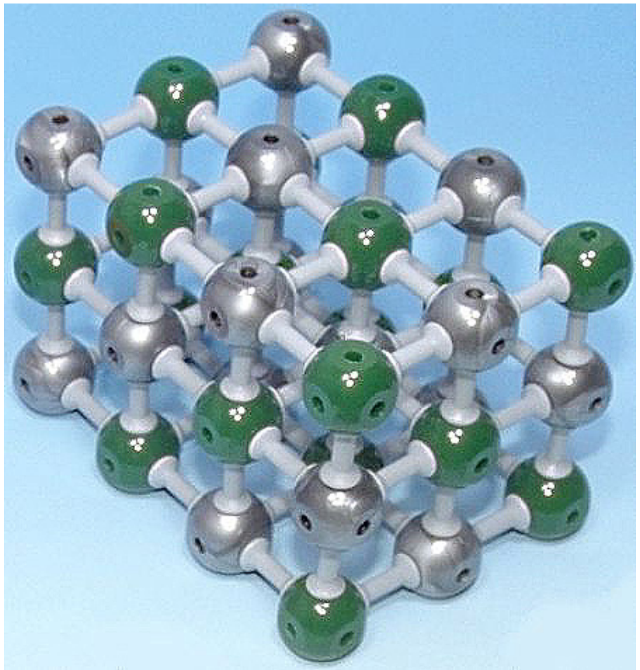


Forces due to a collection of charges



$$\mathbf{F}_1 = k_e \sum_j \frac{q_1 q_j}{|\mathbf{r}_1 - \mathbf{r}_j|^2} \hat{\mathbf{r}}_{1j}$$

Peer instruction question

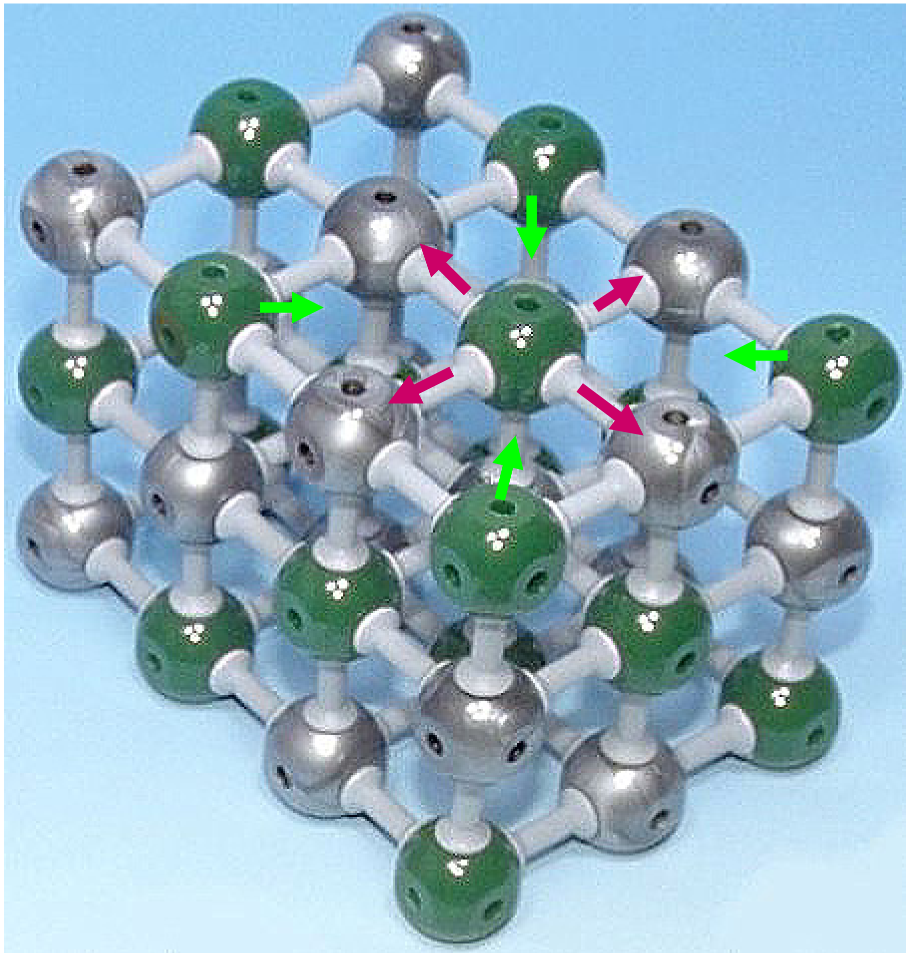


The picture on the right shows a model of a NaCl crystal (table salt). The Green balls represent Na^{+} ions and the Grey balls represent Cl^{-} ions. Which of these statements is true?

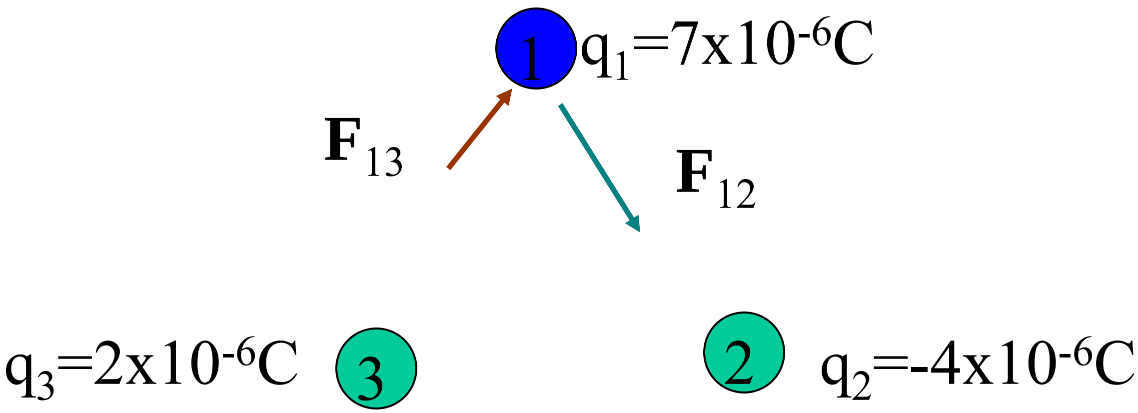
(A) The net electrostatic forces in this crystal are attractive.

(B) The net electrostatic forces in this crystal are repulsive.

(C) The stability of this crystal can be explained completely in terms of electrostatic forces.



Another way to consider the three charge system:



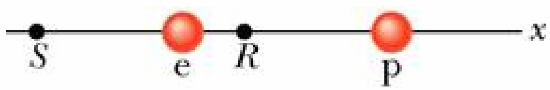
$$\mathbf{F}_1 = k_e \frac{q_1 q_2}{|\mathbf{r}_1 - \mathbf{r}_2|^2}\hat{\mathbf{r}}_{12} + k_e \frac{q_1 q_3}{|\mathbf{r}_1 - \mathbf{r}_3|^2}\hat{\mathbf{r}}_{13}$$

$$= q_1\left(k_e \frac{q_2}{|\mathbf{r}_1 - \mathbf{r}_2|^2}\hat{\mathbf{r}}_{12} + k_e \frac{q_3}{|\mathbf{r}_1 - \mathbf{r}_3|^2}\hat{\mathbf{r}}_{13}\right) \equiv q_1\mathbf{E}(\mathbf{r}_1)$$

$$\mathbf{E}(\mathbf{r}_1) \equiv \mathbf{F}_1 / q_1 = k_e \frac{q_2}{|\mathbf{r}_1 - \mathbf{r}_2|^2}\hat{\mathbf{r}}_{12} + k_e \frac{q_3}{|\mathbf{r}_1 - \mathbf{r}_3|^2}\hat{\mathbf{r}}_{13}$$

Electric field == force on q_1 if it were +1 Coulomb

Online Quiz for Lecture 2
Electric field due to charged particles -- Jan. 14, 2005



For each of these questions choose one of the following answers:

(a) left (b) right (c) up (d) down

The figure here shows a proton p and an electron e on an x axis.

1. What is the direction of the electric field due to the electron at point S? (right)
2. What is the direction of the electric field due to the electron at point R? (left)
3. What is the direction of the *net* electric field at point S? (right)
4. What is the direction of the *net* electric field at point R? (left)

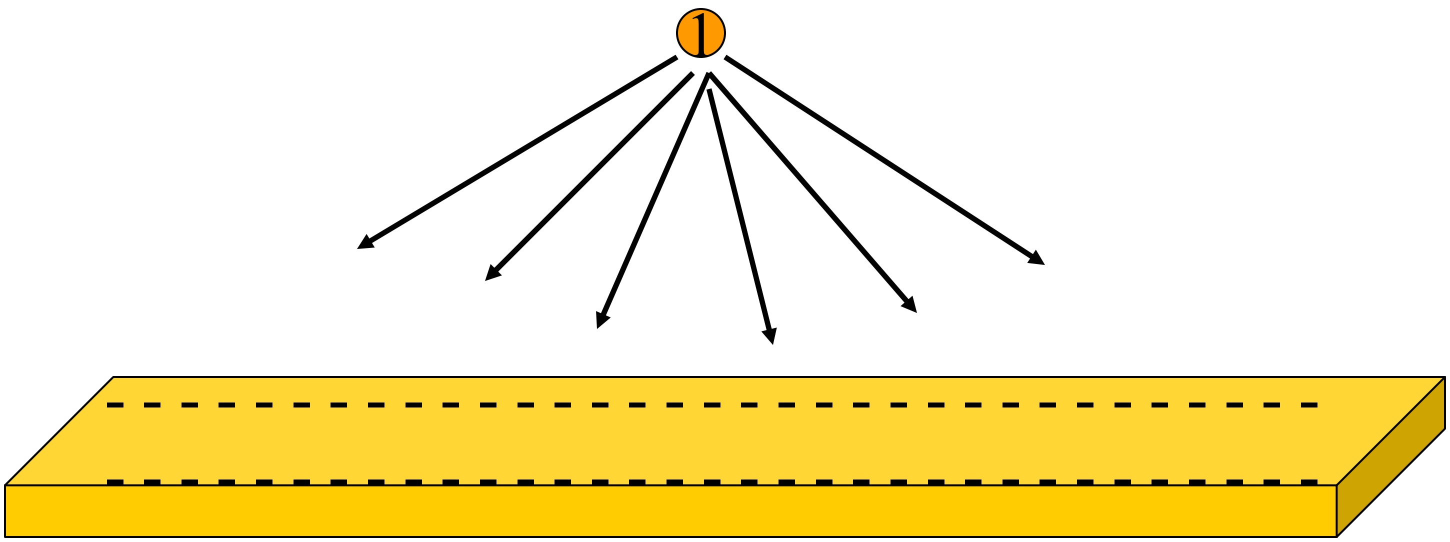
Why (when) the concept of an electric field is useful –

In general,

$$\mathbf{E}(\mathbf{r}_1) = \sum_i k_e \frac{q_i}{|\mathbf{r}_1 - \mathbf{r}_i|^2} \hat{\mathbf{r}}_{1i}$$

➔The force on a charge q_1 placed at $\mathbf{r}_1$ is then $\mathbf{F}_1 = q_1\mathbf{E}(\mathbf{r}_1)$.

Example:

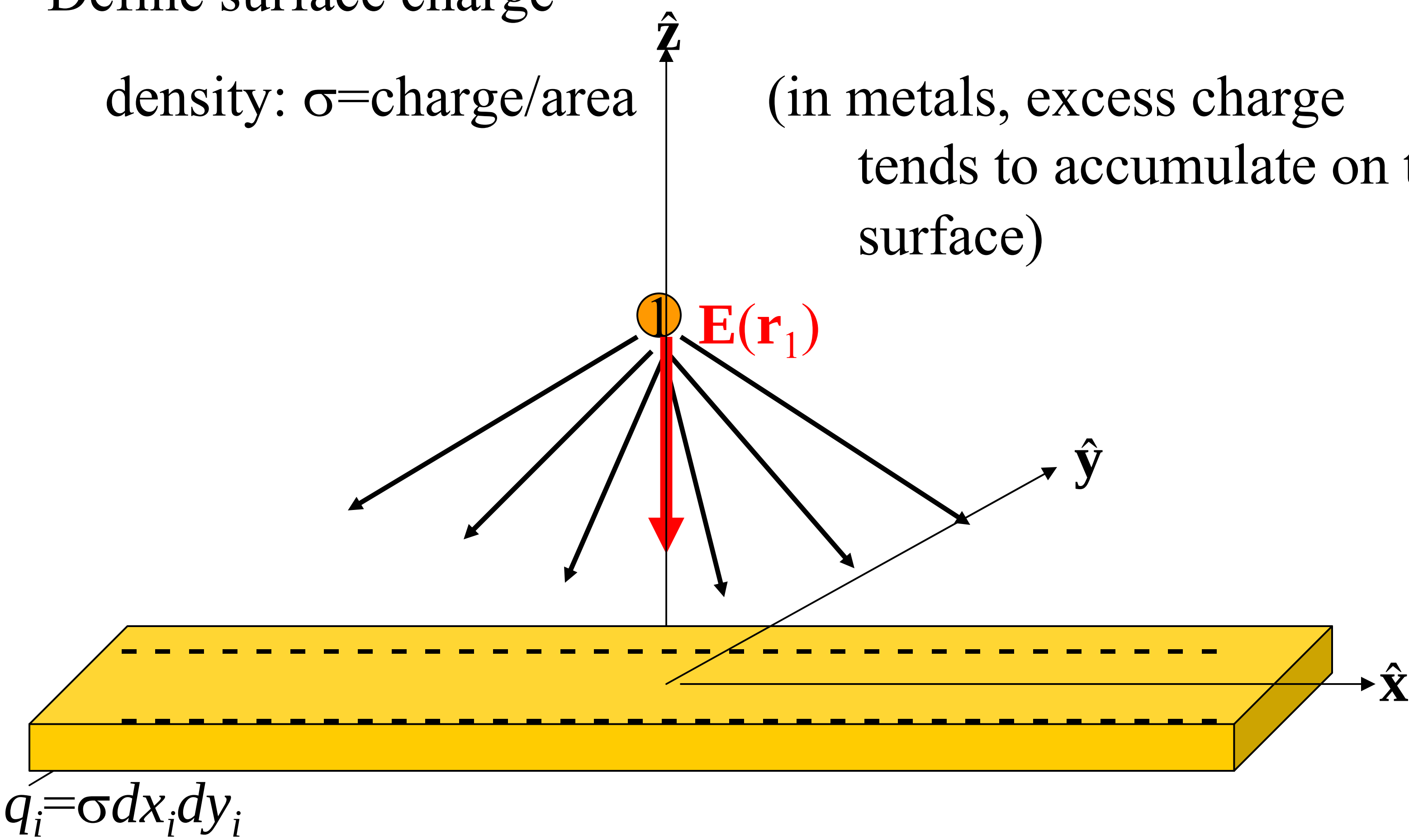


Calculation of the net electric field for a distribution of surface charge:

Define surface charge

density: σ=charge/area

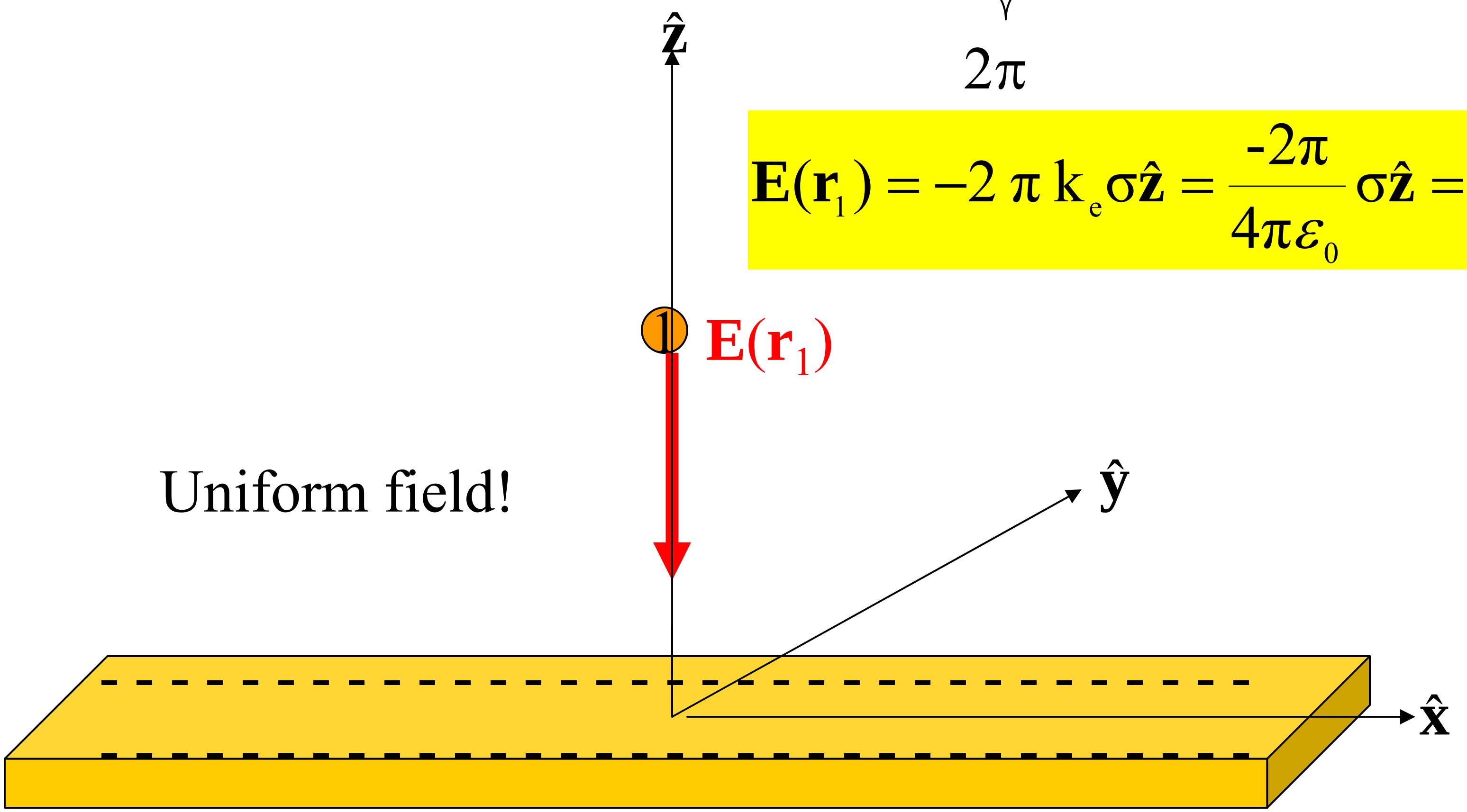
(in metals, excess charge tends to accumulate on the surface)



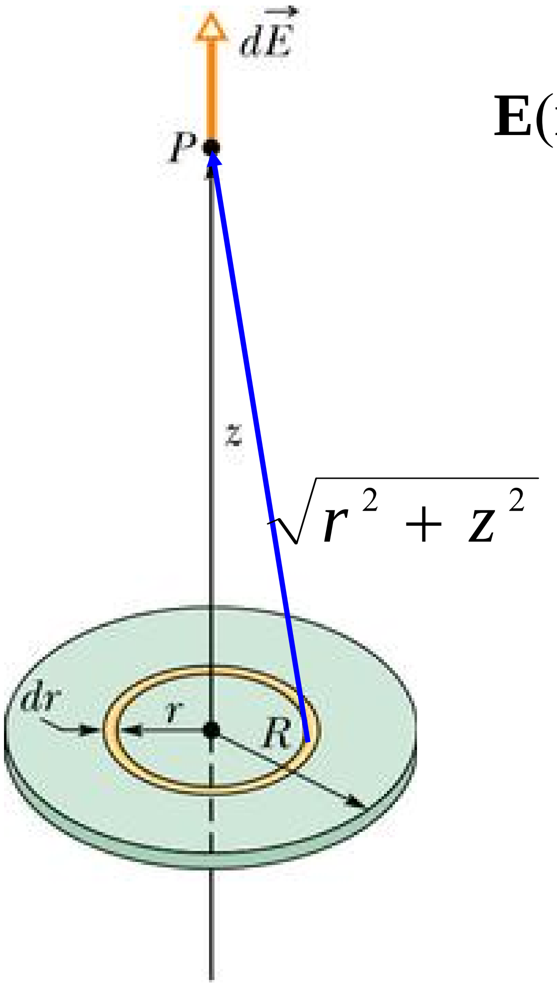
Some details:

$$\mathbf{E}(\mathbf{r}_1) = \sum_i k_e \frac{q_i}{|\mathbf{r}_1 - \mathbf{r}_i|^2}\hat{\mathbf{r}}_{1i} = -k_e \sigma \hat{\mathbf{z}} \underbrace{\int_{-\infty}^{\infty} \frac{z\,dx_i\,dy_i}{\left(z^2 + x_i^2 + y_i^2\right)^{3/2}}}_{2\pi}$$

$$\mathbf{E}(\mathbf{r}_1) = -2\,\pi\,\mathrm{k_e}\sigma\hat{\mathbf{z}} = \frac{-2\pi}{4\pi\varepsilon_0}\sigma\hat{\mathbf{z}} = \frac{-\sigma}{2\varepsilon_0}\hat{\mathbf{z}}$$



Another example – a disk with uniform positive charge on its surface



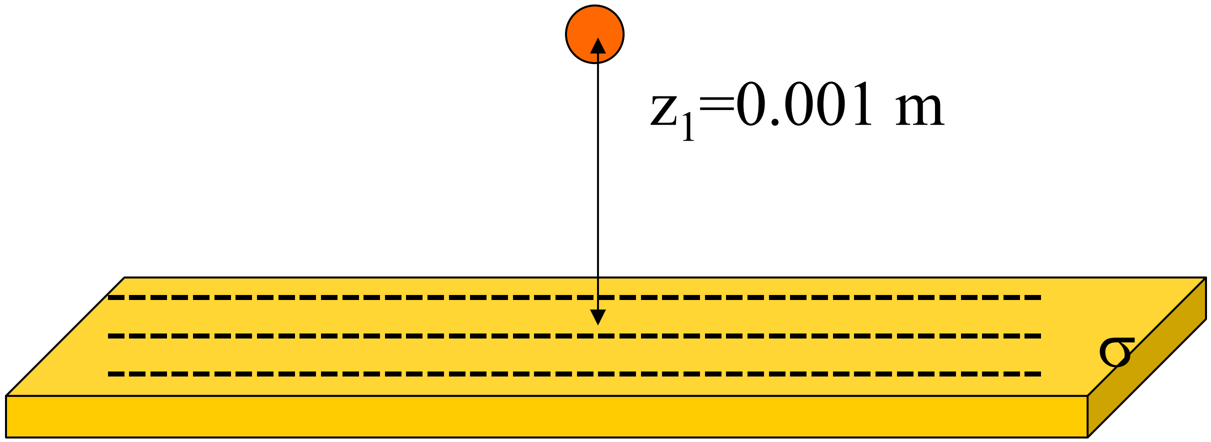
$$\mathbf{E}(\mathbf{r}_1) = \sum_i \frac{1}{4\pi\varepsilon_0} \frac{q_i}{|\mathbf{r}_1 - \mathbf{r}_i|^2} \hat{\mathbf{r}}_{1i} = \frac{1}{4\pi\varepsilon_0} \sigma \hat{\mathbf{z}} \int_0^\infty \frac{z\, 2\pi r dr}{\left(z^2 + r^2\right)^{3/2}}$$

$$= \frac{2\pi\sigma}{4\pi\varepsilon_0} \hat{\mathbf{z}} \left[-\frac{z}{\left(z^2 + r^2\right)^{1/2}} \right]_0^R$$

$$= \frac{\sigma}{2\varepsilon_0} \hat{\mathbf{z}} \left[1 - \frac{z}{\left(z^2 + R^2\right)^{1/2}} \right]$$

Example: Suppose $\sigma = -8.85\text{x}10^{-9}$ C/m^2

$$\mathbf{E}(\mathbf{r}_1) = 2\pi k_e \sigma\, \hat{\mathbf{z}} \;\; = -500 \text{ N/C } \hat{\mathbf{z}}$$



Question:

Suppose an ion of q=$1.6\text{x}10^{-19}$C and m=$3\text{x}10^{-27}$ kg is initial at rest at z_1=0.001 m. What will be its kinetic energy at z_1=0 m?

(A) $2.94\text{x}10^{-29}$ J (B) $8\text{x}10^{-20}$J (C) 0.5 J (D) 500 J

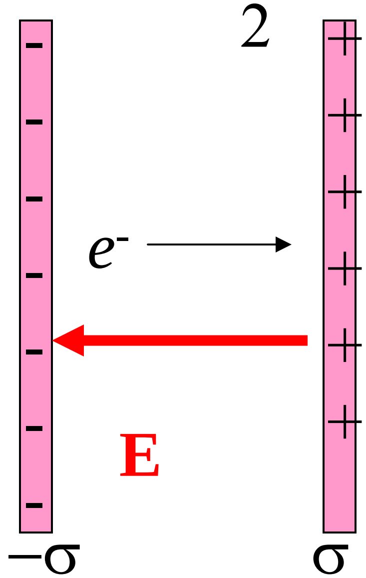
New unit of energy: "electron volt":

$$1 \text{ eV} = 1.60217733 \times 10^{-19} \text{ J}$$

$$8 \times 10^{-20} \text{ J} = 0.5 \text{ eV}$$

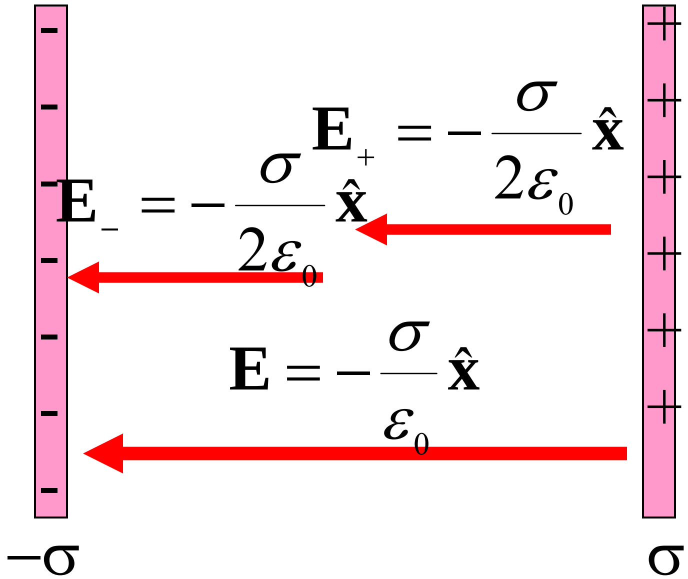
Velocity of electron (mass m=9.1×10^{-31}kg) with $K = 8 \times 10^{-20}$ J :

$$K = \frac{1}{2} m v^2; \qquad v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2 \cdot 8 \times 10^{-20}}{9.1 \times 10^{-31}}} = 1.3 \times 10^5 \text{ m/s}$$



$$\mathbf{E} = -4\pi k_e \sigma \, \hat{\mathbf{x}}$$

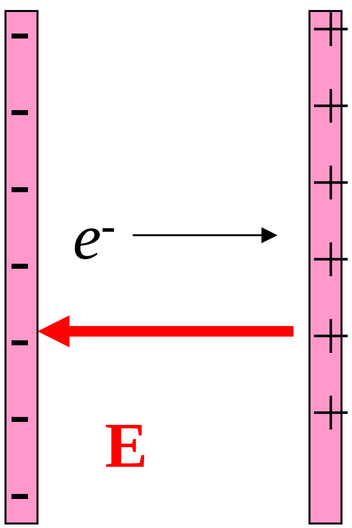
Two charged plates:



$$\mathbf{E}_{+} = -\frac{\sigma}{2\varepsilon_0}\hat{\mathbf{x}}$$

$$\mathbf{E}_{-} = -\frac{\sigma}{2\varepsilon_0}\hat{\mathbf{x}}$$

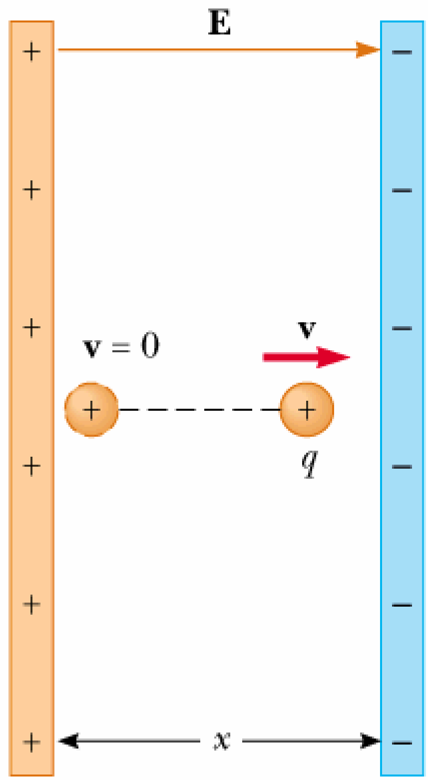
$$\mathbf{E} = -\frac{\sigma}{\varepsilon_0}\hat{\mathbf{x}}$$



Acceleration of an electron between two charged plates:

$$\mathbf{F} = e^{-}\mathbf{E} = \frac{e^{-}\sigma}{\varepsilon_0}\hat{\mathbf{x}}$$

Serway, Physics for Scientists and Engineers, 5/e
Figure 23.24



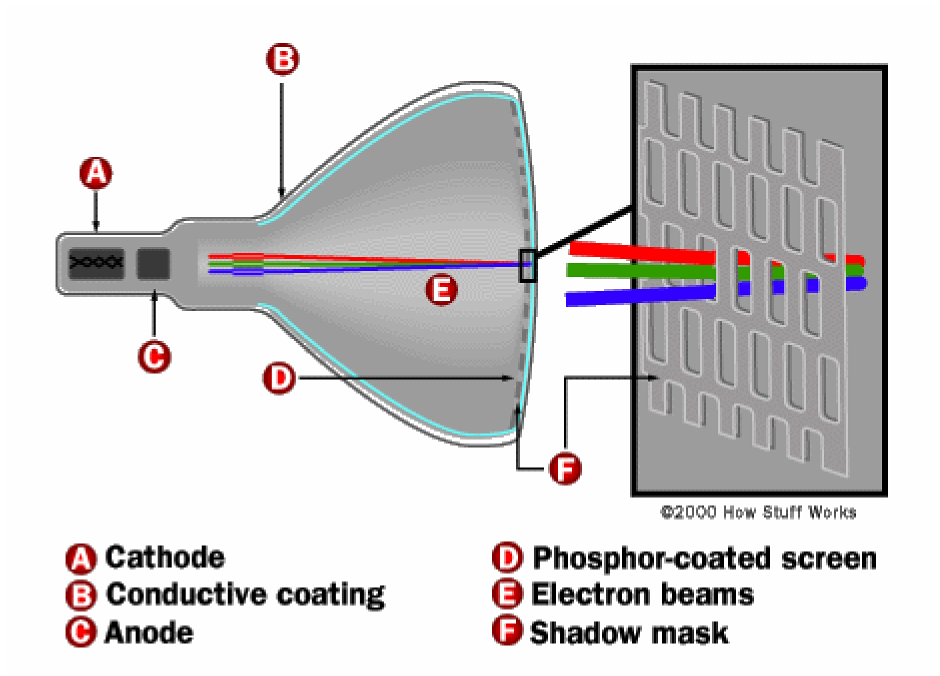
$$\mathbf{F} = q\mathbf{E} = m\,\mathbf{a}$$

$$\mathbf{a} = q\mathbf{E}/m$$

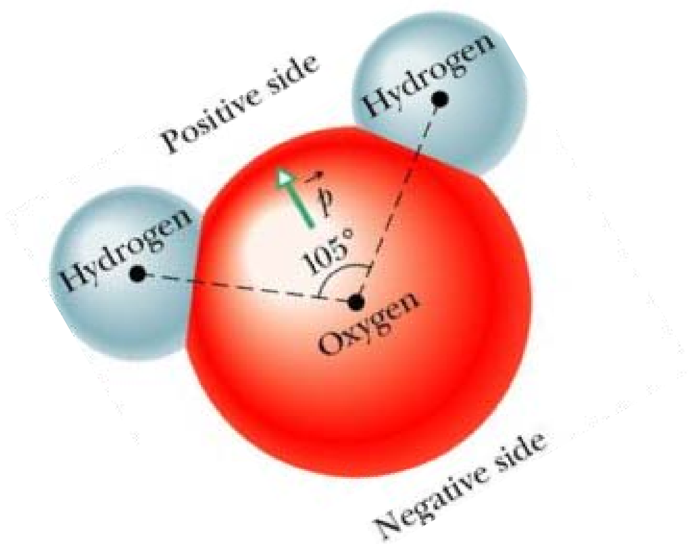
Harcourt, Inc.

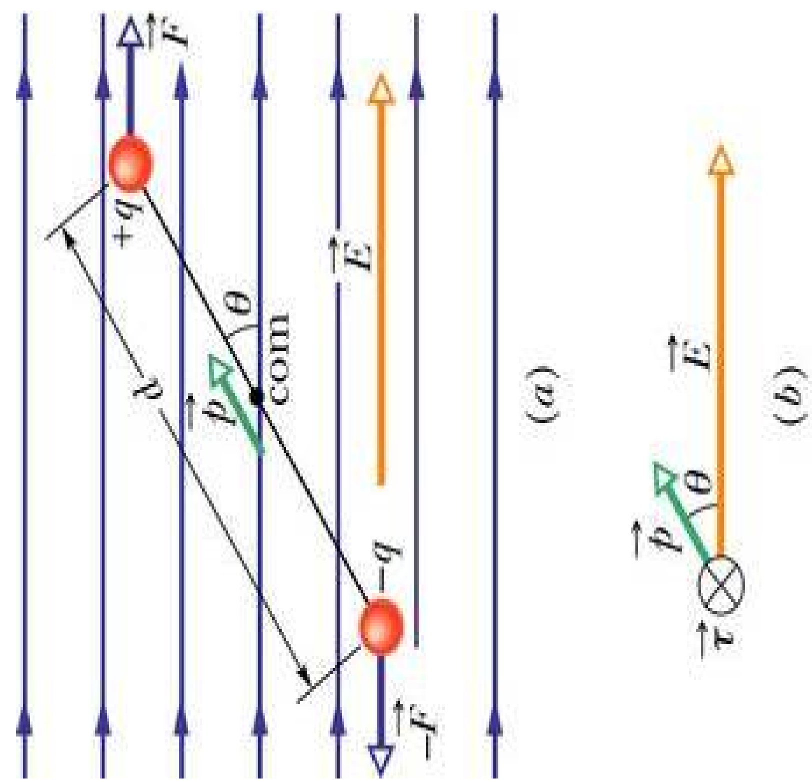
Cathode ray tube (CRT)

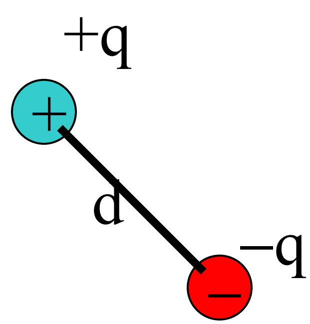
Ref: http://www.howstuffworks.com/



Electric dipole moments







Dipole moment: $p = qd$ (Cm)

2. [HRW6 23.P.010.]

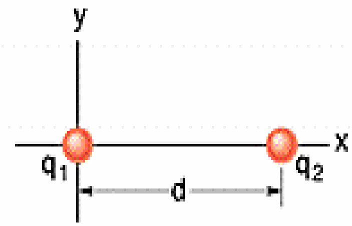


Figure 23-30.

(a) In Fig. 23-30, two point charges q_1 = -9q and q_2 = +4q are separated by distance d. Locate the point (measured from the origin at q_1) at which the electric field due to the two charges is zero.

x = [ ] d

(b) Sketch the electric field lines qualitatively. (Do this on paper. Your instructor may ask you to turn in the sketch.)