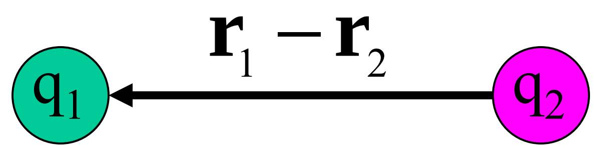
Annoucements

1. Reminder about online quizes – http://www.wfu.edu/~natalie/s05phy114/

2. Topics for today

   Review of Coulomb's law, Gauss's law, and electric fields

   Introduce electrical potential and electrostatic potential energy



Coulomb's law:

$$\mathbf{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{\left|\mathbf{r}_1 - \mathbf{r}_2\right|^2}\hat{\mathbf{r}}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{\left|\mathbf{r}_1 - \mathbf{r}_2\right|^3}\left(\mathbf{r}_1 - \mathbf{r}_2\right)$$

8.99×10^9 N m^2/C^2; $\varepsilon_0 = 8.85 \times 10^{-12}$ C^2/Nm^2

-- force on q_1 due to q_2

Electric field due to q_2:

$$\mathbf{E}(\mathbf{r}_1) = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{\left|\mathbf{r}_1 - \mathbf{r}_2\right|^2}\hat{\mathbf{r}}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{\left|\mathbf{r}_1 - \mathbf{r}_2\right|^3}\left(\mathbf{r}_1 - \mathbf{r}_2\right) = \mathbf{F}_{12} / q_1$$

Electric field due to several charges q_i:

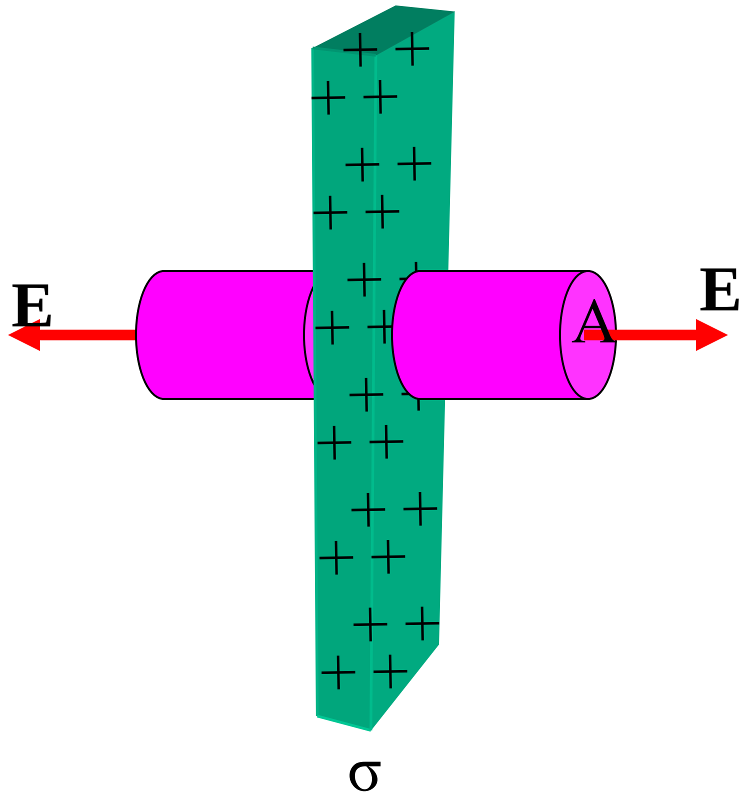
$$\mathbf{E}(\mathbf{r}) = \sum_i \frac{1}{4\pi\varepsilon_0} \frac{q_i}{|\mathbf{r}-\mathbf{r}_i|^2} \hat{\mathbf{r}}_{1i}$$

Gauss's law:

$$\oint \mathbf{E}\cdot d\mathbf{A} = q_{en}/\varepsilon_0$$

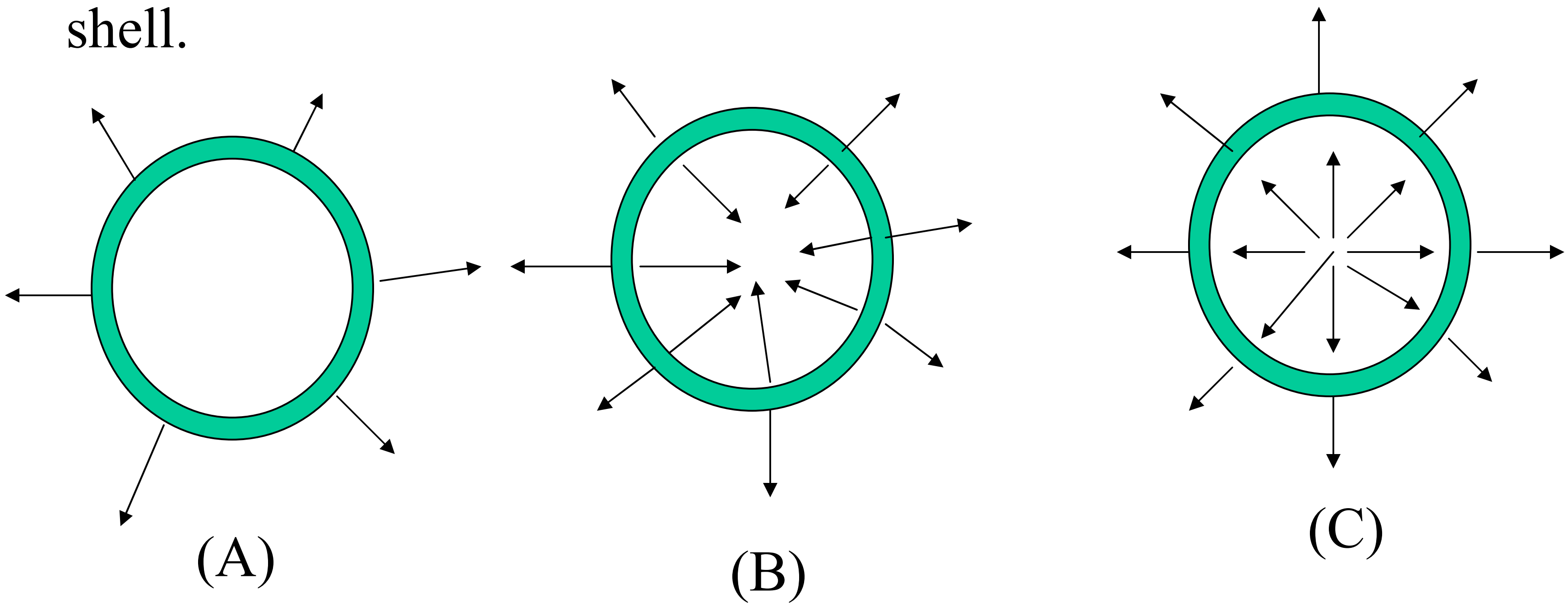
$$2EA = \sigma A/\varepsilon_0$$

$$E = \frac{\sigma}{2\varepsilon_0}$$



Peer instruction question

Suppose you have a uniformly charged spherical shell. Which of these diagrams correctly represent the field lines for this system? For this purpose, assume that the only charge in the system is a uniform positive charge represented by the green shell.

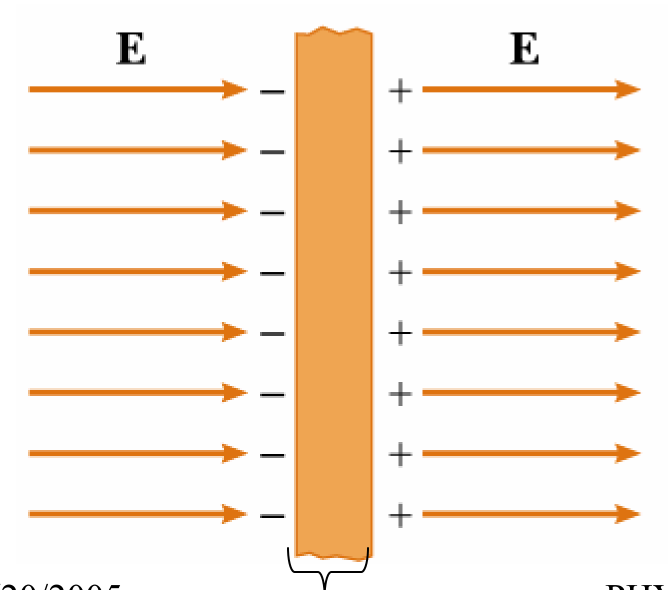


Response of materials to electrical fields

Solids: In metals, electrons are mobile and move within metal until there are no net forces acting on them. Excess charges migrate to the surfaces. In insulators, charges are constrained by atomic and molecular forces to move only a small amount.

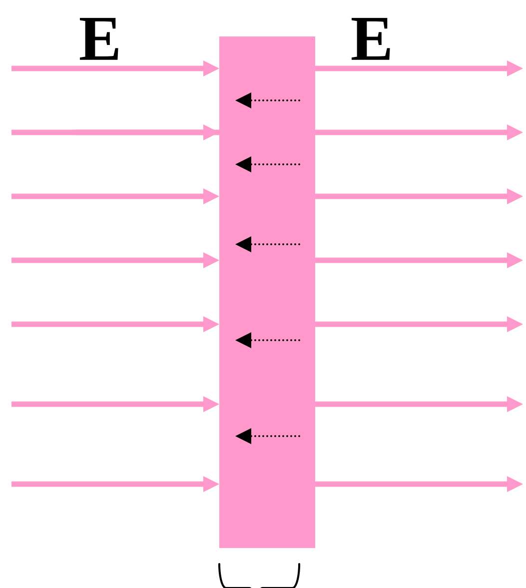
Examples:

Neutral non-grounded metal



$E'=0$

Neutral insulating sheet

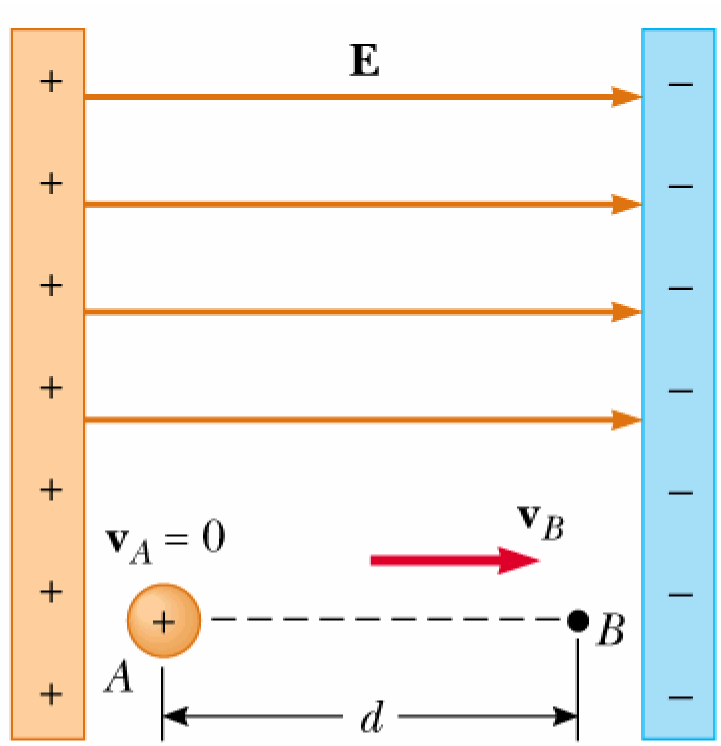


$E'<E$

Work and electrostatic potential energy

$$W = \int_A^B \mathbf{F} \cdot d\mathbf{r} = q\int_A^B \mathbf{E} \cdot d\mathbf{r} = K_B - K_A = U_A - U_B$$

Because electrostatic forces are conservative.



Example:

A proton (q=1.6x10^{-19}C) moves a distance d = 0.1m in the direction of a uniform electric field **E**=8000N/C.

What is its change in kinetic energy?

K_B-K_A=qEd=1.28x10^{-16} J =U_A-U_B

Online Quiz for Lecture 4
Electrical potential -- Jan. 21, 2005

1. An electron is accelerated through a uniform potential difference of 1 Volt. How much kinetic energy does it gain?

   (a) 1 J
   (b) 1.6×10^{-19} J
   (c) 9.1×10^{-31} J
   (d) Not enough information is given to answer the question.

2. A proton is accelerated through a uniform potential difference of 1 Volt. How much kinetic energy does it gain?

   (a) 1 J
   (b) 1.6×10^{-19} J
   (c) 1.7×10^{-27} J
   (d) Not enough information is given to answer the question.

3. Which particle would have a larger speed after the acceleration?

   (a) electron
   (b) proton

Electrostatic potential

$V = U/q$

Note:

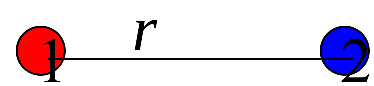
$$U(\mathbf{r}) = -\int_{\mathbf{r}_{ref}}^{\mathbf{r}} \mathbf{F}\cdot d\mathbf{r}$$

$$V(\mathbf{r}) = -\int_{\mathbf{r}_{ref}}^{\mathbf{r}} E\cdot d\mathbf{r}$$

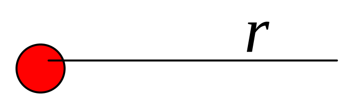
Volt=J/C

N/C

For a point charge, a convenient choice is $r_{ref}=\infty$.



$$U(r) = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$



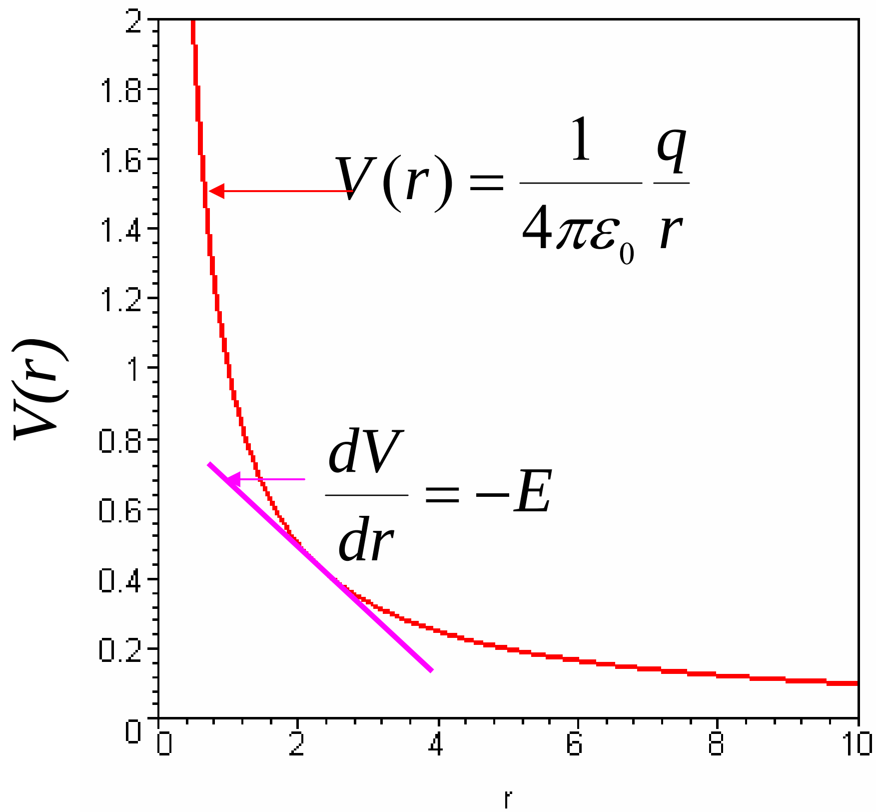
$$V(r) = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

Some details:

$$U(r) = -\frac{1}{4\pi\varepsilon_0}\int_{\infty}^{r}\frac{q_1 q_2}{r'^2}dr' = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}\bigg|_{\infty}^{r} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}\bigg|$$

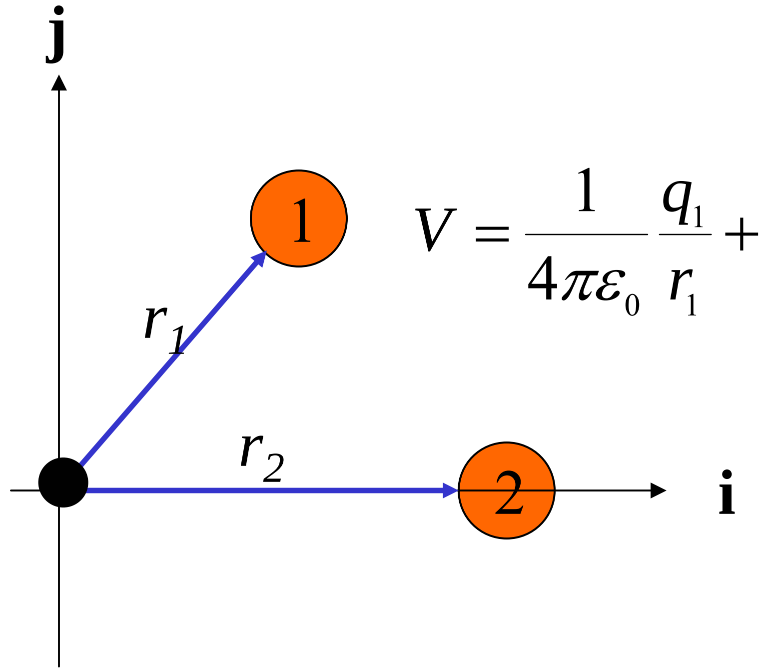
$$V(r) = -\frac{1}{4\pi\varepsilon_0}\int_{\infty}^{r}\frac{q}{r'^2}dr' = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}\bigg|_{\infty}^{r} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}\bigg|$$

Electrostatic potential of a point charge continued --



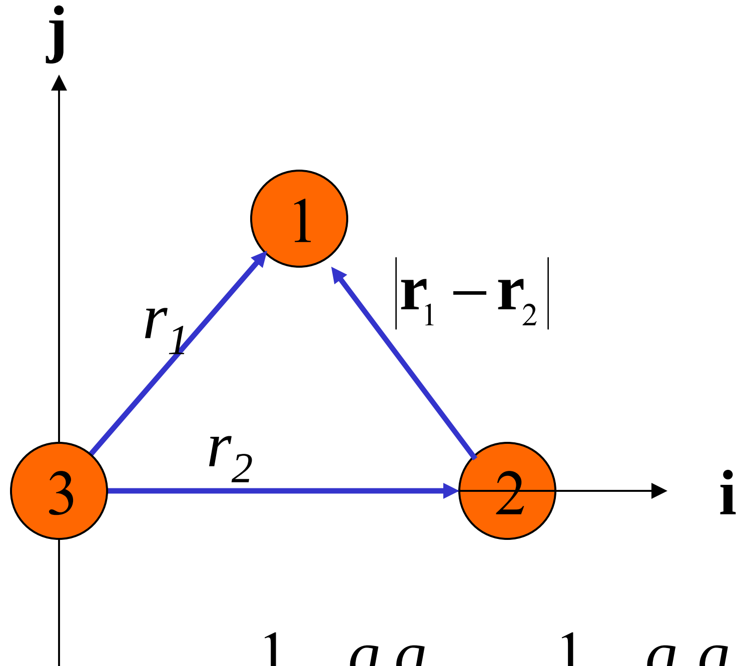
$$\mathbf{E}(r) = -\nabla V(r) = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{\mathbf{r}}$$

Electrostatic potential due to 2 point charges



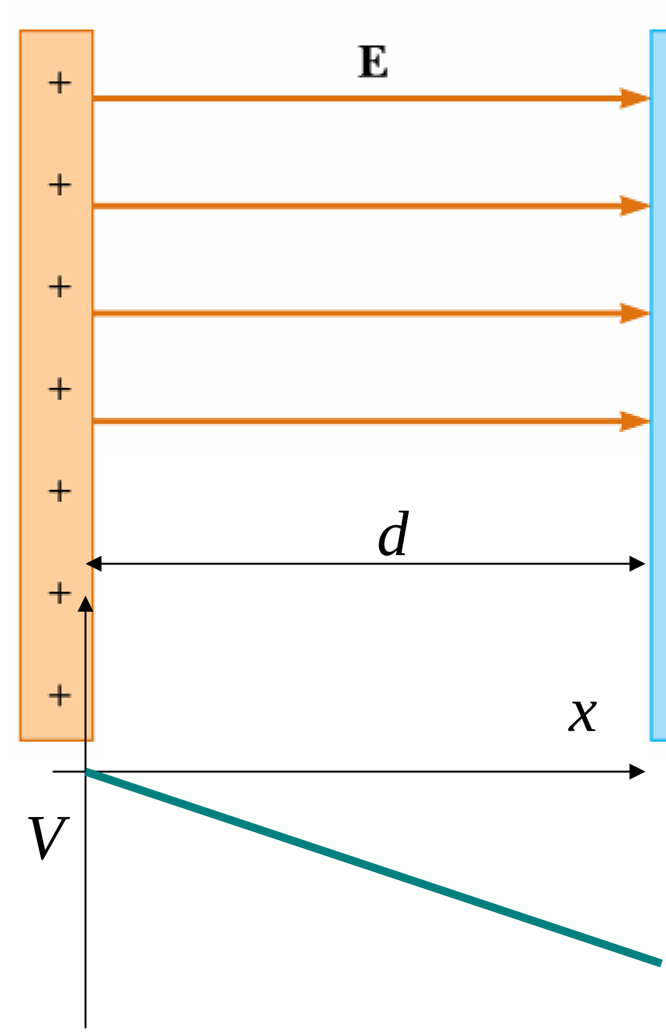
$$V = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1} + \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2}$$

Electrostatic energy to assemble 3 point charges



$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_3}{r_1} + \frac{1}{4\pi\varepsilon_0}\frac{q_2 q_3}{r_2} + \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{|\mathbf{r}_1 - \mathbf{r}_2|}$$

Electrostatic potential between two parallel plates



$V(d)=-Ed=-\sigma\, d/\varepsilon_0$

Example:

If $V = 1$ Volt
and $d = 0.01$ m

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

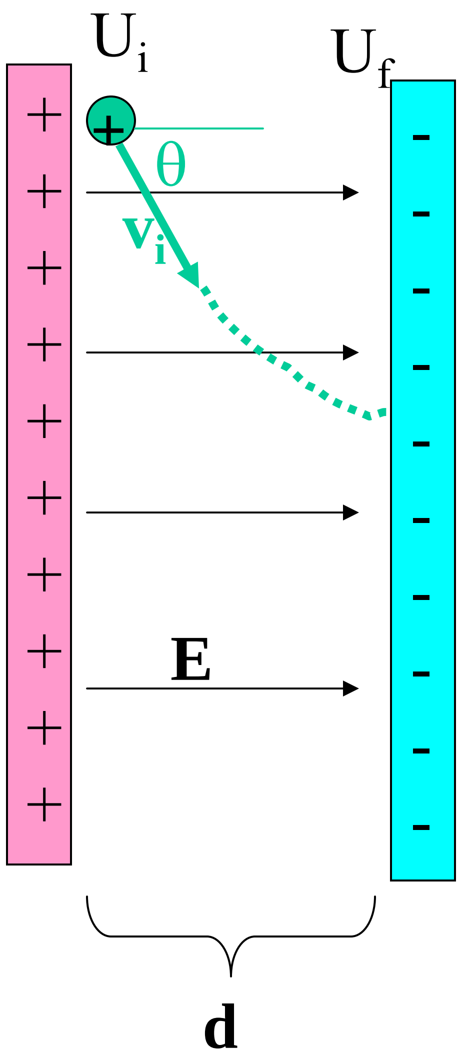
Energy units

1 eV = 1.602177×10^{-19} J

= magnitude of the potential energy of an electron or proton in a 1V electrostatic potential

speed of 1eV proton: 1.4×10^{4} m/s

electron: 5.9×10^{5} m/s



$$K_f + U_f = K_i + U_i$$

$$K_f - K_i = U_i - U_f = -q\Delta V = qEd$$

Suppose a proton has an initial kinetic energy of $K_i = 10^{-19}$ J. What is its final kinetic energy after passing through a uniform electric field E=10 N/C over a distance d=0.2 m?

$K_f = K_i + qEd = 4.2\text{x}10^{-19}$J.

3. [HRW6 25.P.020.] In Fig. 25-39, point *P* is at the center of the rectangle. With *V* = 0 at infinity, what is the net electric potential in terms of *q/d* at *P* due to the six charged particles?

_____ *q/d*

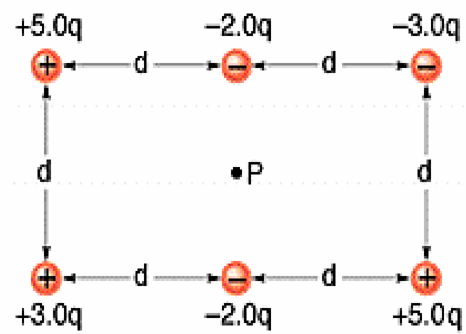


Figure 25-39.

4. [HRW6 25.P.037.] Derive an expression in terms of q^2/a for the work required to set up the four-charge configuration of Fig. 25-50, assuming the charges are initially infinitely far apart.

[ ] q^2/a

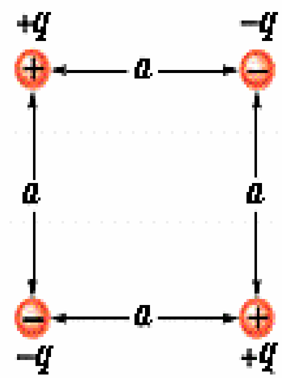


Figure 25-50.