PHY 114 A General Physics II
11 AM-12:15 PM TR Olin 101

Plan for Lecture 4:

1. Introduction to the electric potential

2. Relationship between the electric potential and the electric field

Announcements:

No.	Lecture Date	Topic	Text Sections	Problem Assignments	Assignment Due Date
1	01/19/2012	Coulomb's law	23.1-23.4	23.6,23.8a,23.13	01/24/2012
2	01/24/2012	Electric field	23.4-23.7	23.22,23.20,23.61a	01/26/2012
3	01/26/2012	Gauss's Law	24.1-24.3	24.22a,24.23,24.40	01/31/2012
4	01/31/2012	Electric potential	25.1-25.4	25.12,25.23,25.34,25.01	02/02/2012
5	02/02/2012	Electric potential	25.5-25.8	(Review for exam)	
	02/07/2012	Exam			

i-clicker question

Would you attend a review session for next Tuesday's exam on

A. Monday afternoon at 4 PM
B. Monday evening at 5 PM
C. Sunday afternoon at 3 PM
D. Sunday evening at 5 PM
E. None of these

i-clicker registration problems:

- Campbell, Thane
- Dearmon, Jake
- Klebous, Sandy
- Samsel, David
- Story, William

Consider a neutral (electrically isolated) metal sheet:

What happens when you bring a point charge +Q close to the sheet?

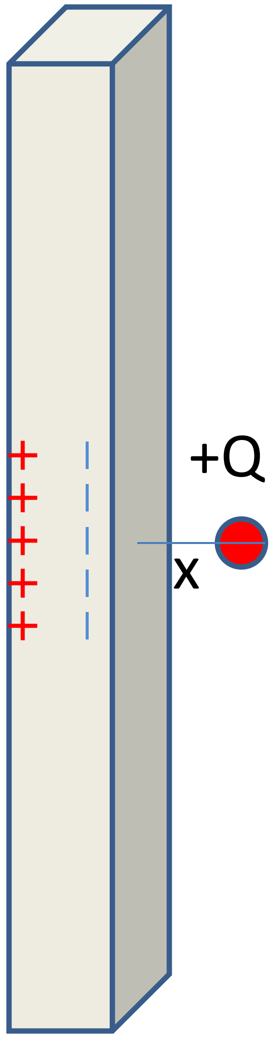
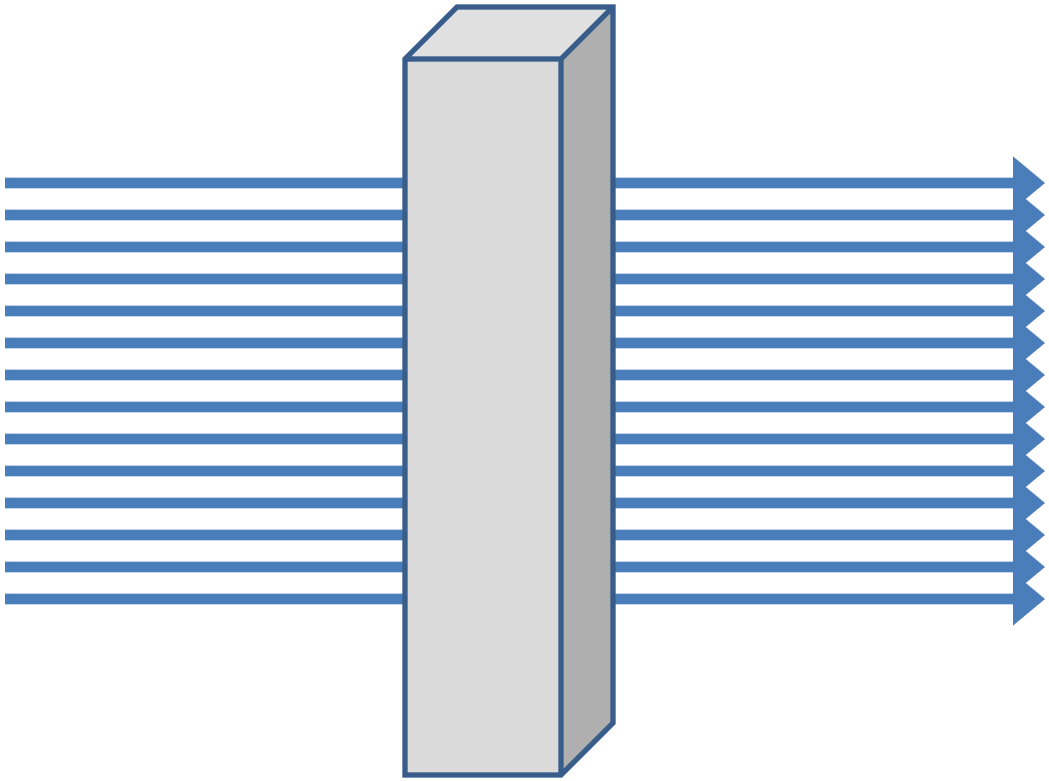


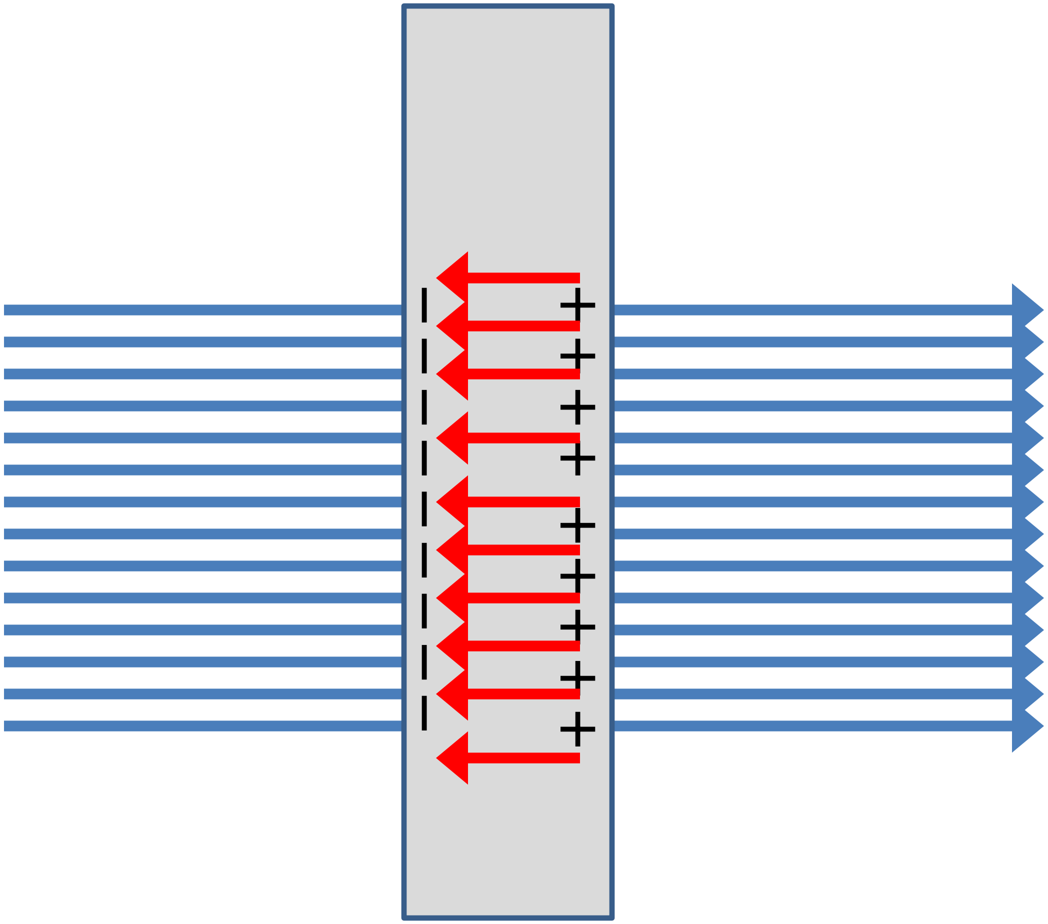
Image charge effect due to metal sheet

$$\mathbf{F} = -\frac{k_e Q^2}{(2x)^2}\hat{\mathbf{x}}$$

Somewhat related question from homework:

Suppose an electrically neutral sheet of metal is placed in a uniform electric field. What is the resultant charge distribution on the surface of the sheet?



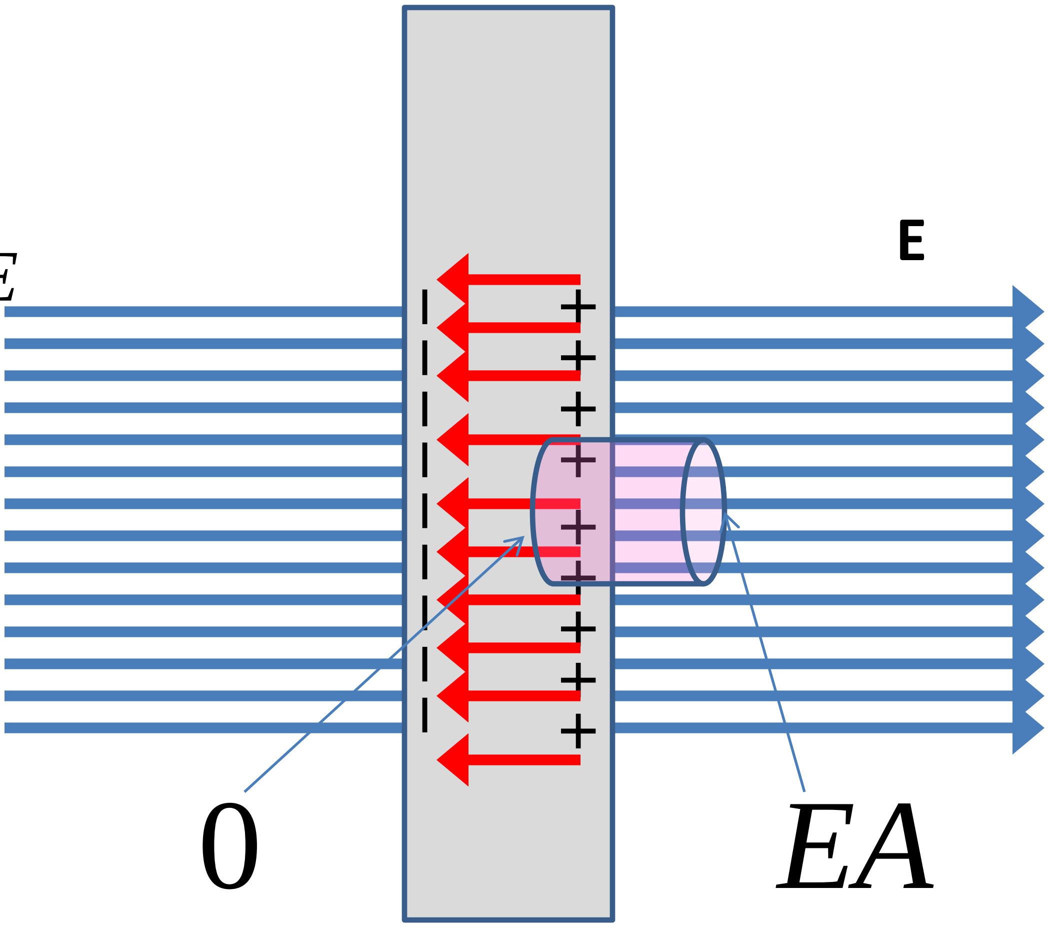


Electric field inside an electric isolated, neutral ideal metal = 0.

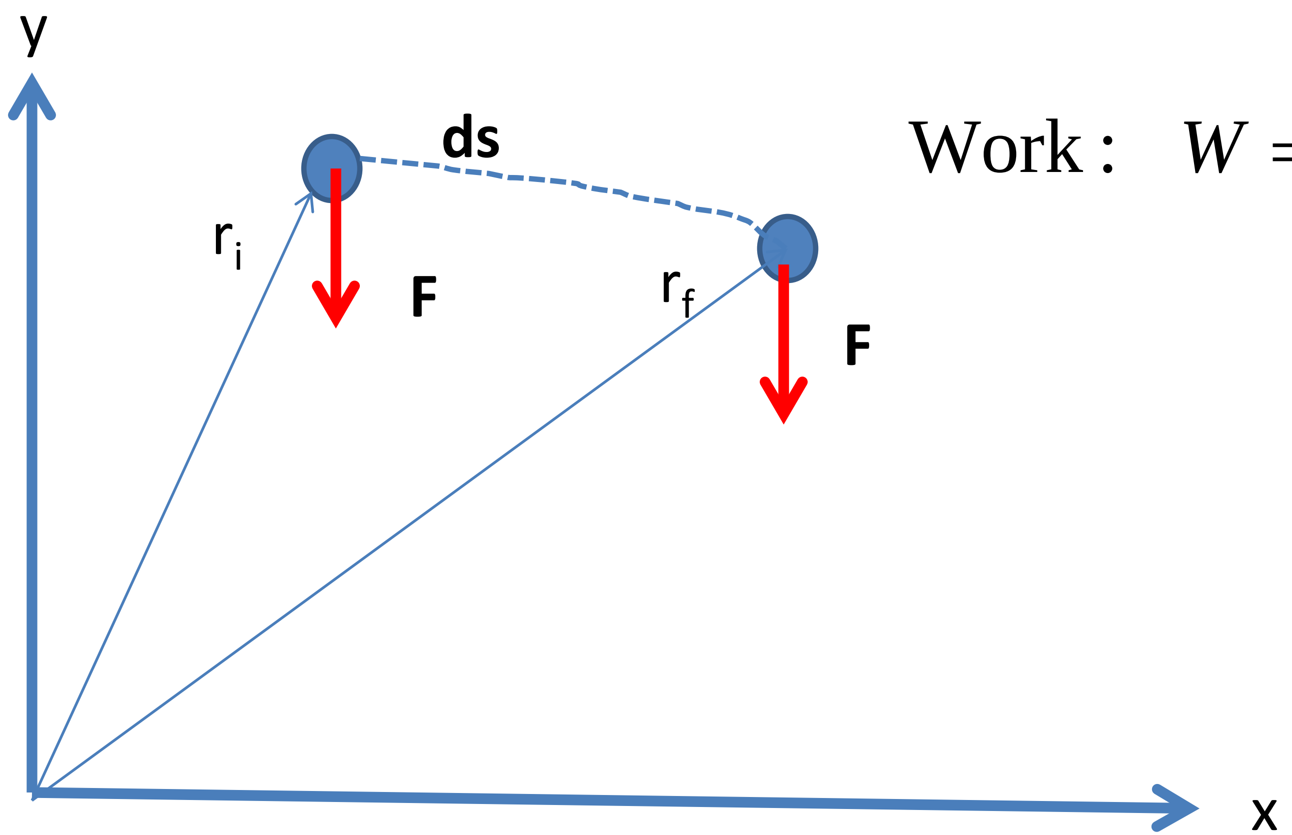
Gauss's Law for cylinder:

$$0 + EA = \frac{Q_{in}}{\varepsilon_0}$$

$$\frac{Q_{in}}{A} = \sigma = \varepsilon_0 E$$



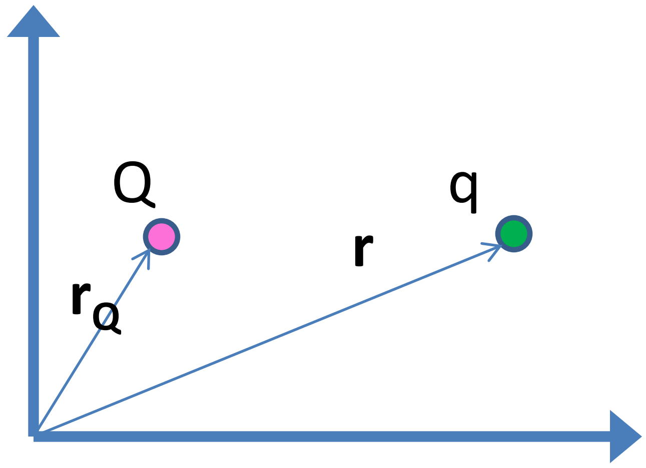
Review of work and potential energy



$$\text{Work}: \quad W = \int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F} \cdot d\mathbf{s}$$

$$\text{For conservative } \mathbf{F}: \quad W = \int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F} \cdot d\mathbf{s} = -\left(U_f - U_i\right)$$

Application of work principles to Coulomb's law force



$$\mathbf{F}(\mathbf{r}) = \frac{k_e q Q}{|\mathbf{r}-\mathbf{r}_Q|^2} \frac{\mathbf{r}-\mathbf{r}_Q}{|\mathbf{r}-\mathbf{r}_Q|}$$

$$W = \int_{\mathbf{r}_{ref}\to\infty}^{\mathbf{r}} \mathbf{F}(\mathbf{r}')\cdot d\mathbf{r}' = -\frac{k_e q Q}{|\mathbf{r}-\mathbf{r}_Q|} = -\left(U(\mathbf{r}) - U_\infty\right)$$

Potential energy due to Coulomb's law with charges q and Q:

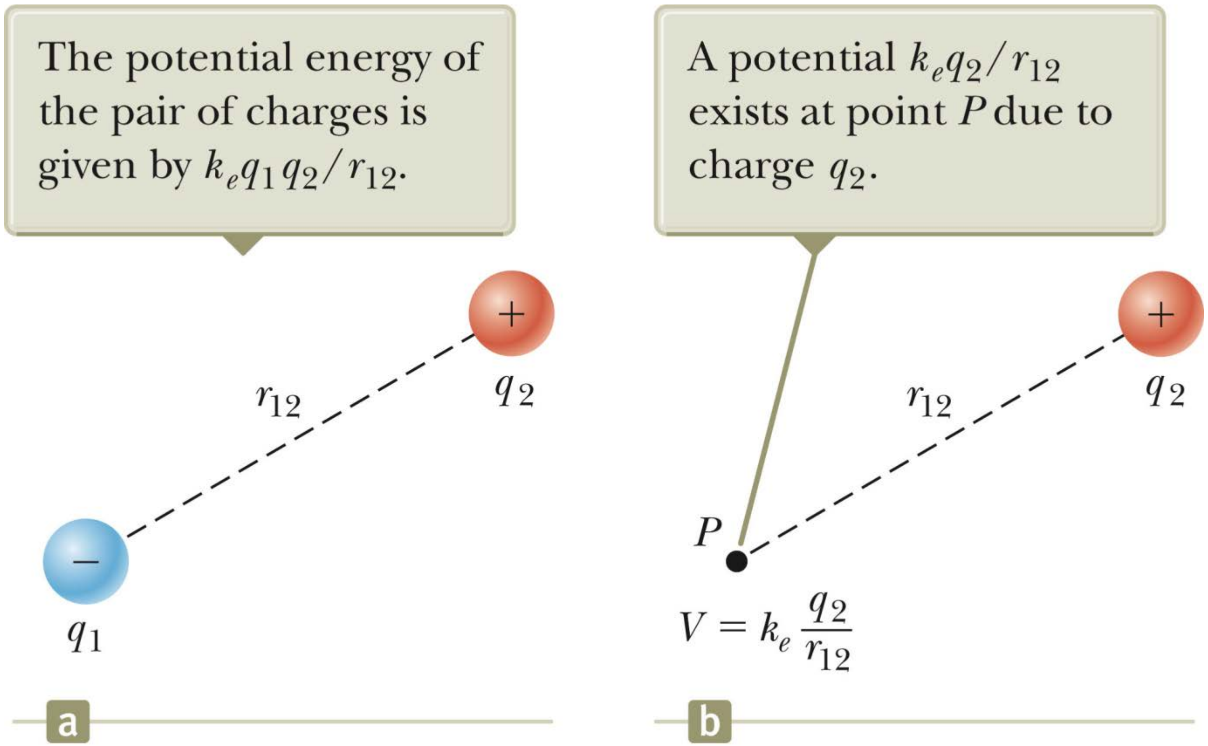
$$U(\mathbf{r}) = \frac{k_e q Q}{|\mathbf{r} - \mathbf{r}_Q|} \qquad \text{(joules)}$$

Electric potential due to charge Q:

$$V(\mathbf{r}) = \frac{k_e Q}{|\mathbf{r} - \mathbf{r}_Q|} \qquad \text{(joules/C} \equiv \text{Volt)}$$

Electric potential due to many charges Q_i:

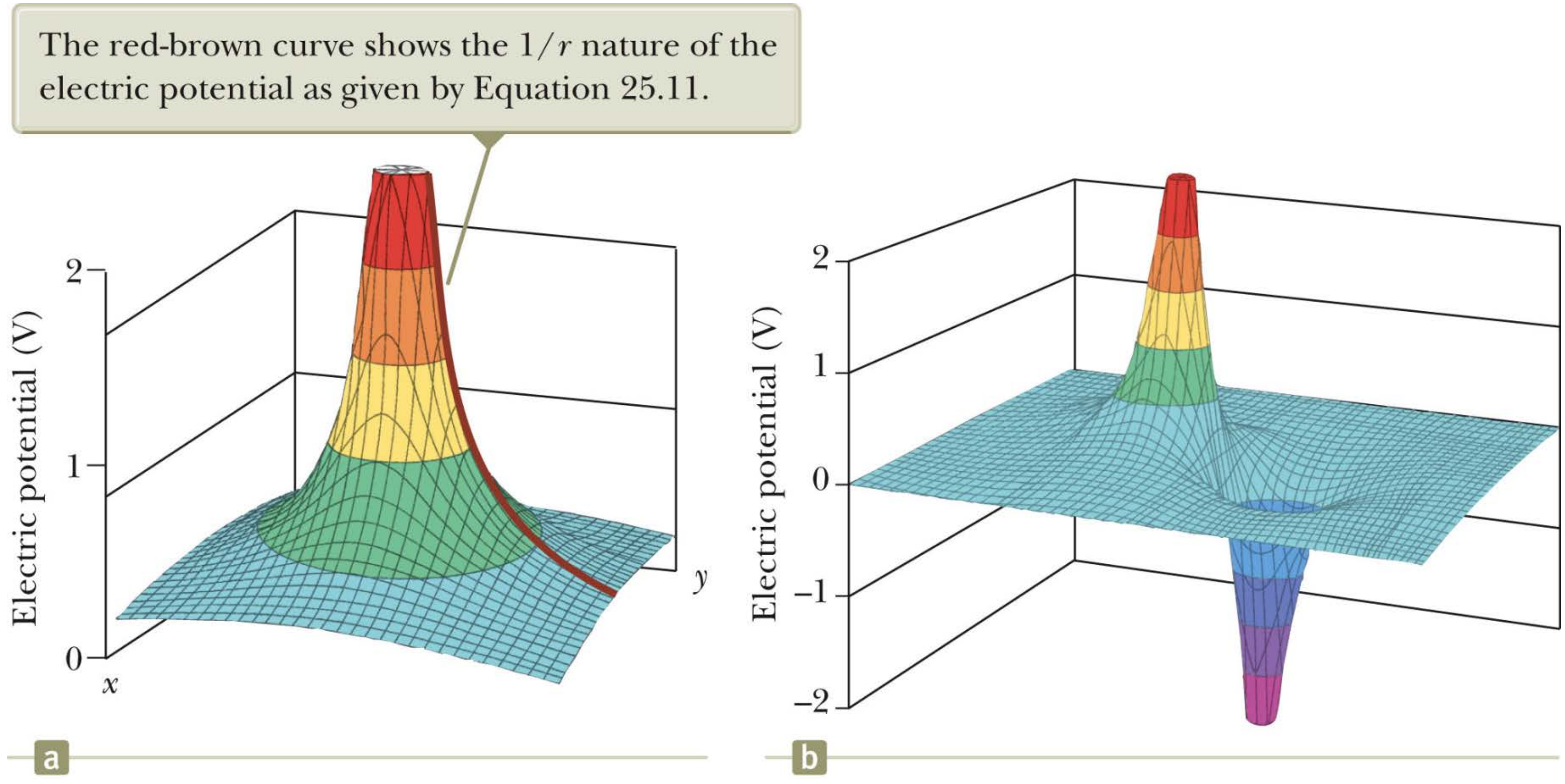
$$V(\mathbf{r}) = \sum_i \frac{k_e Q_i}{|\mathbf{r} - \mathbf{r}_{Q_i}|}$$


The potential energy of the pair of charges is given by $k_e q_1 q_2 / r_{12}$.
A potential $k_e q_2 / r_{12}$ exists at point P due to charge q_2.
+
r_{12}
q_2
−
q_1
+
r_{12}
q_2
P
$V = k_e \frac{q_2}{r_{12}}$
a
b

Examples of spatial distribution of electric potential

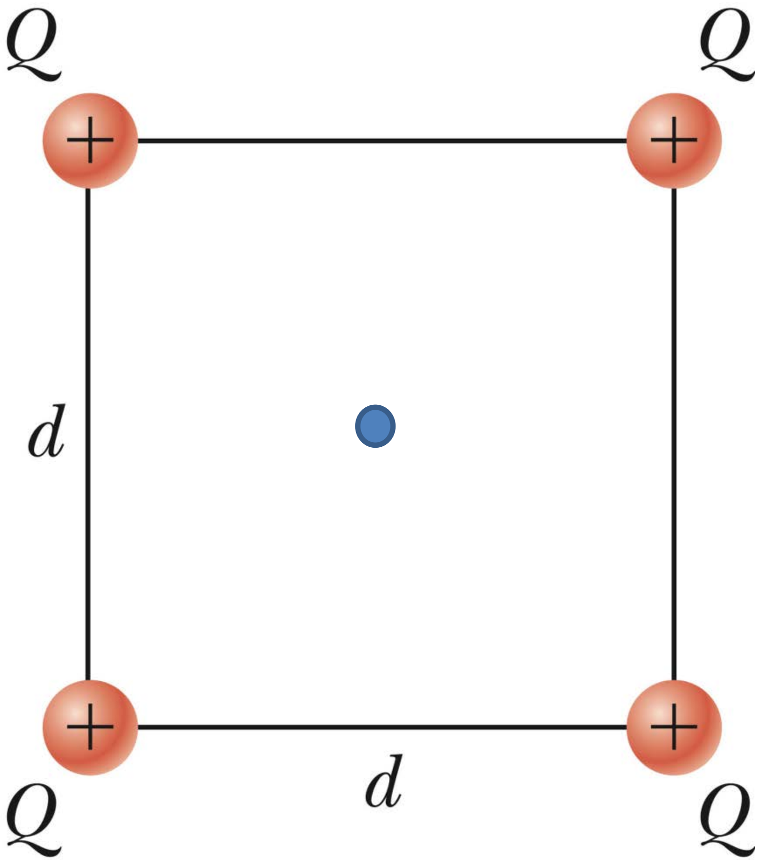
$$V(x,y) = \frac{k_e Q}{\sqrt{x^2 + y^2}}$$

$$V(x,y) = \frac{k_e Q}{\sqrt{(x+a)^2 + (y+a)^2}} + \frac{-k_e Q}{\sqrt{(x-a)^2 + (y-a)^2}}$$



i-clicker exercise:

Choose the expression which corresponds to the value of the electrostatic potential at the center of the square in the diagram.



A. 0

B. $\frac{4k_eQ}{d}$

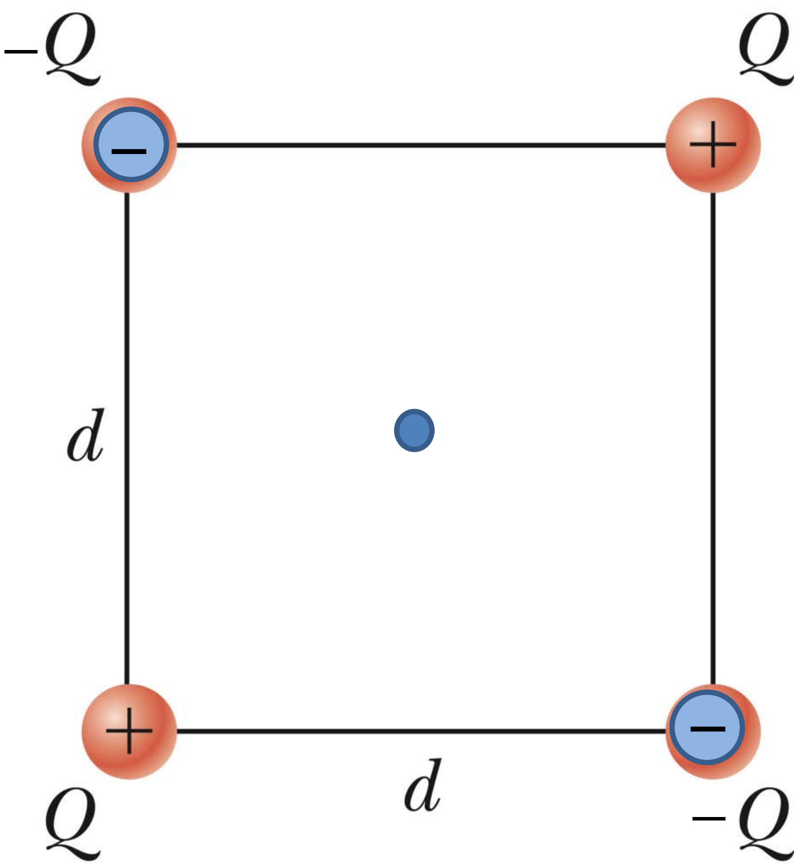
C. $\frac{8k_eQ}{d}$

D. $\frac{\sqrt{32}k_eQ}{d}$

E. None of these.

i-clicker exercise:

Choose the expression which corresponds to the value of the electrostatic potential at the center of the square in the diagram.



A. 0

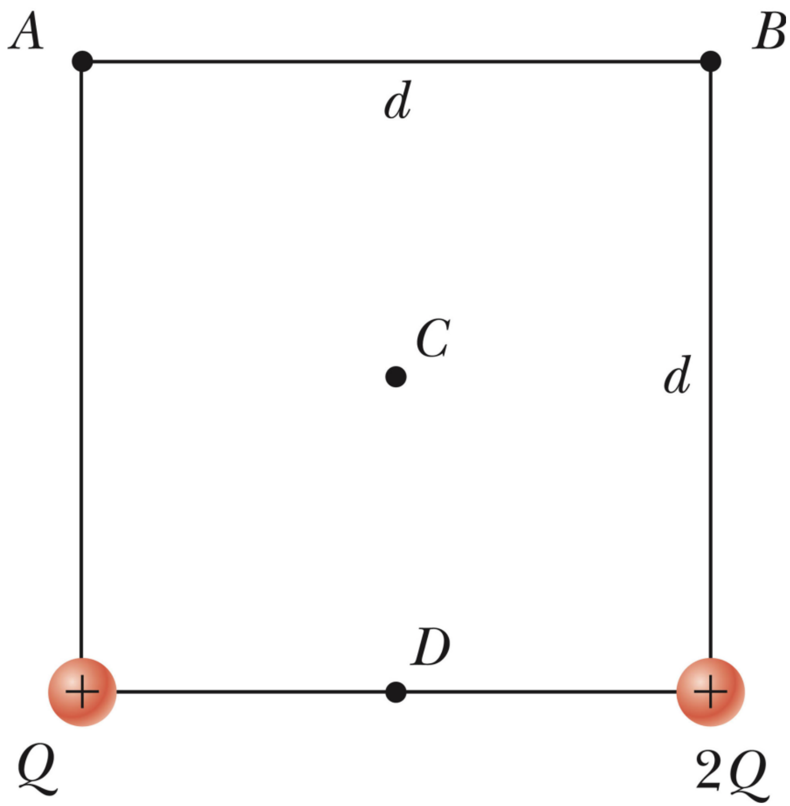
B. $\dfrac{4k_eQ}{d}$

C. $\dfrac{8k_eQ}{d}$

D. $\dfrac{\sqrt{32}k_eQ}{d}$

E. None of these.

Calculation of the electrostatic potential at points A,B,C,D:



$$V_A = \frac{k_e Q}{d} + \frac{2k_e Q}{\sqrt{2}d}$$

$$V_B = \frac{2k_e Q}{d} + \frac{k_e Q}{\sqrt{2}d}$$

$$V_C = \frac{k_e Q}{d/\sqrt{2}} + \frac{2k_e Q}{d/\sqrt{2}} = \frac{3\sqrt{2}k_e Q}{d}$$

$$V_D = \frac{k_e Q}{d/2} + \frac{2k_e Q}{d/2} = \frac{6k_e Q}{d}$$

Relationships between electric potential and electric field:

E has units N/C

V has units J/C=Volt

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

$$\mathbf{E}(\mathbf{r}) = -\nabla V(\mathbf{r}) = -\hat{\mathbf{i}}\frac{\partial V(\mathbf{r})}{\partial x} - \hat{\mathbf{j}}\frac{\partial V(\mathbf{r})}{\partial y} - \hat{\mathbf{k}}\frac{\partial V(\mathbf{r})}{\partial z}$$

Aside -- connection to Gauss's Law

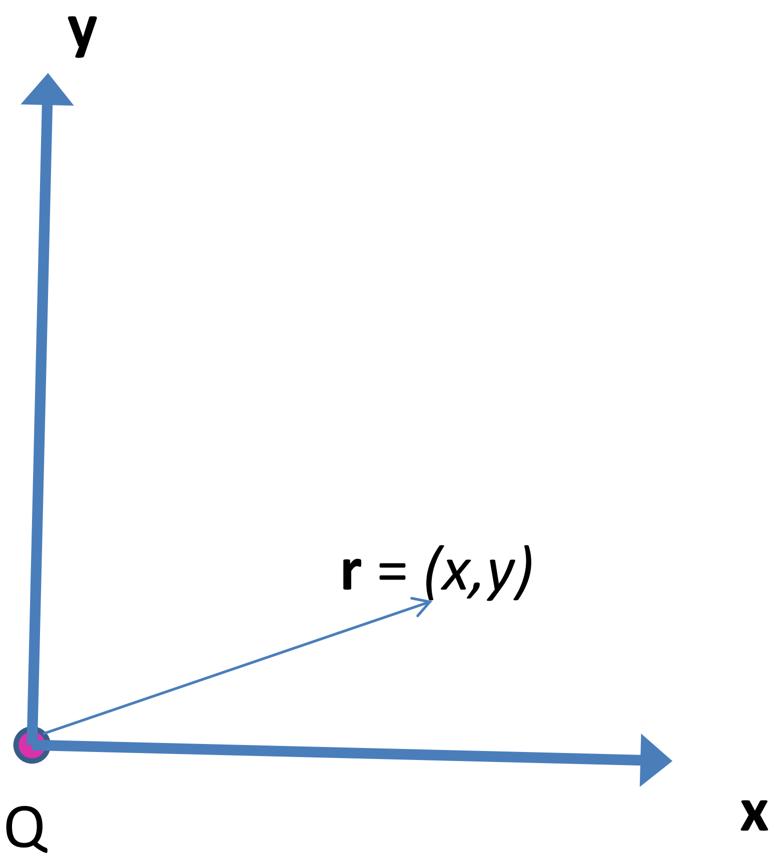
$$\nabla \cdot \mathbf{E} = \frac{\rho(\mathbf{r})}{\varepsilon_0}$$

$$\mathbf{E}(\mathbf{r}) = -\nabla V(\mathbf{r}) \Rightarrow \nabla^2 V(\mathbf{r}) = -\frac{\rho(\mathbf{r})}{\varepsilon_0}$$

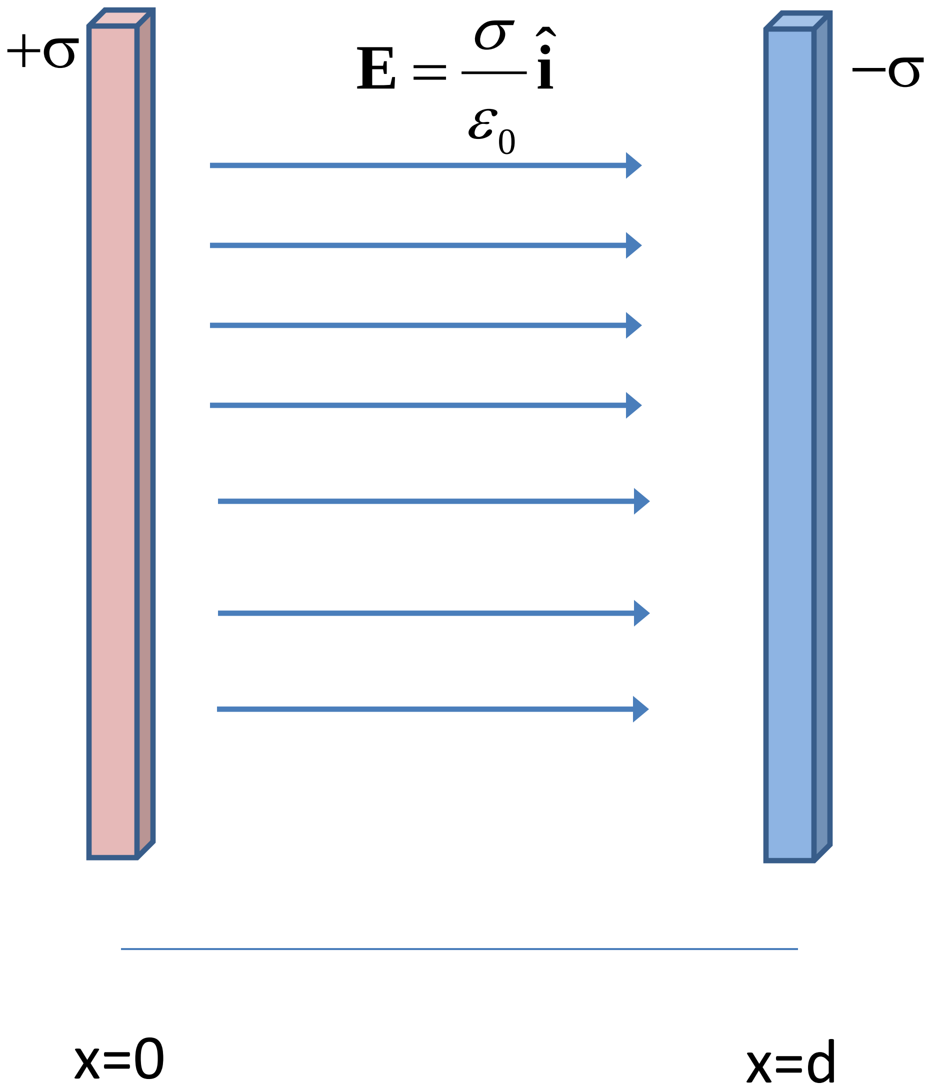
$$V(\mathbf{r}) = \frac{k_e Q}{\sqrt{x^2 + y^2}}$$

$$\mathbf{E}(\mathbf{r}) = -\nabla V(\mathbf{r}) = -\hat{\mathbf{i}}\frac{\partial V(\mathbf{r})}{\partial x} - \hat{\mathbf{j}}\frac{\partial V(\mathbf{r})}{\partial y}$$

$$= \hat{\mathbf{i}}\frac{k_e Q x}{\left(x^2 + y^2\right)^{3/2}} + \hat{\mathbf{j}}\frac{k_e Q y}{\left(x^2 + y^2\right)^{3/2}}$$



Electric potential for constant electric field:



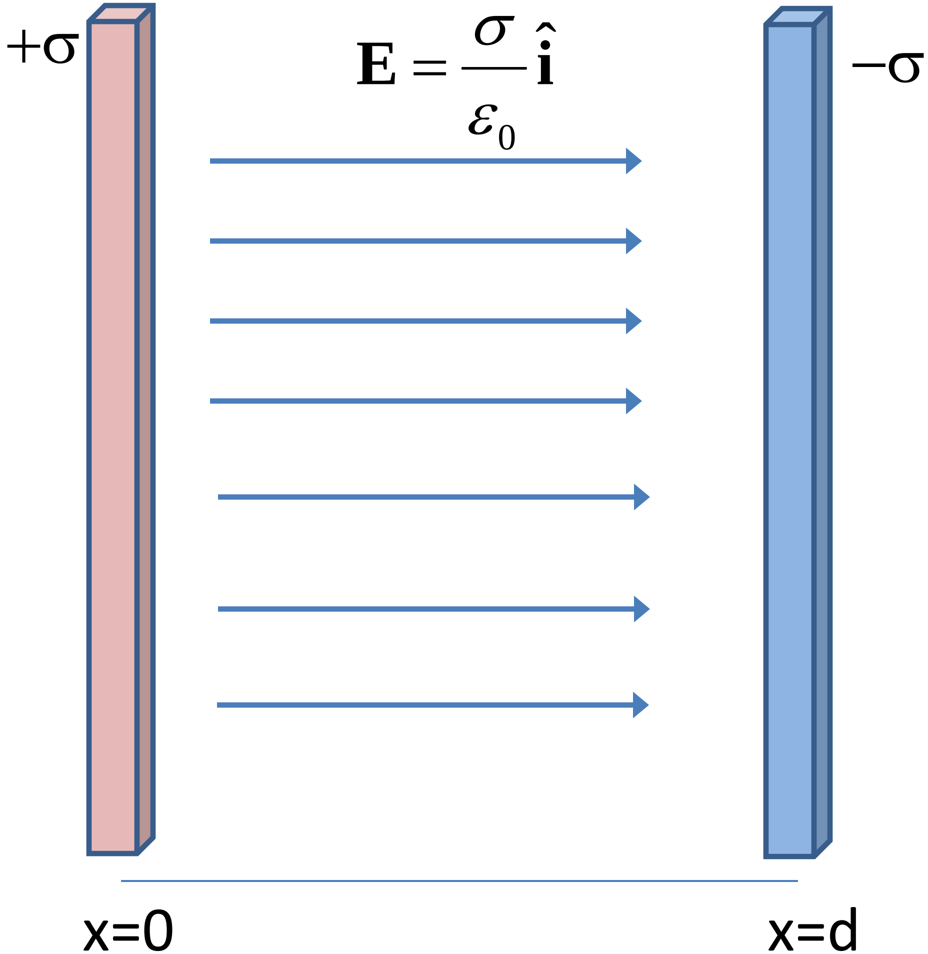
$$\mathbf{E} = \frac{\sigma}{\varepsilon_0}\hat{\mathbf{i}}$$

$$V = -\int_{x_{ref}}^{x} \mathbf{E} \cdot d\mathbf{s}$$

$$= -\int_{0}^{x} \frac{\sigma}{\varepsilon_0} dx'$$

$$= -\frac{\sigma}{\varepsilon_0} x \quad \text{for } 0 \le x \le d$$

Electric potential for constant electric field:



$$V = -\int_{x_{ref}}^{x} \mathbf{E} \cdot d\mathbf{s}$$

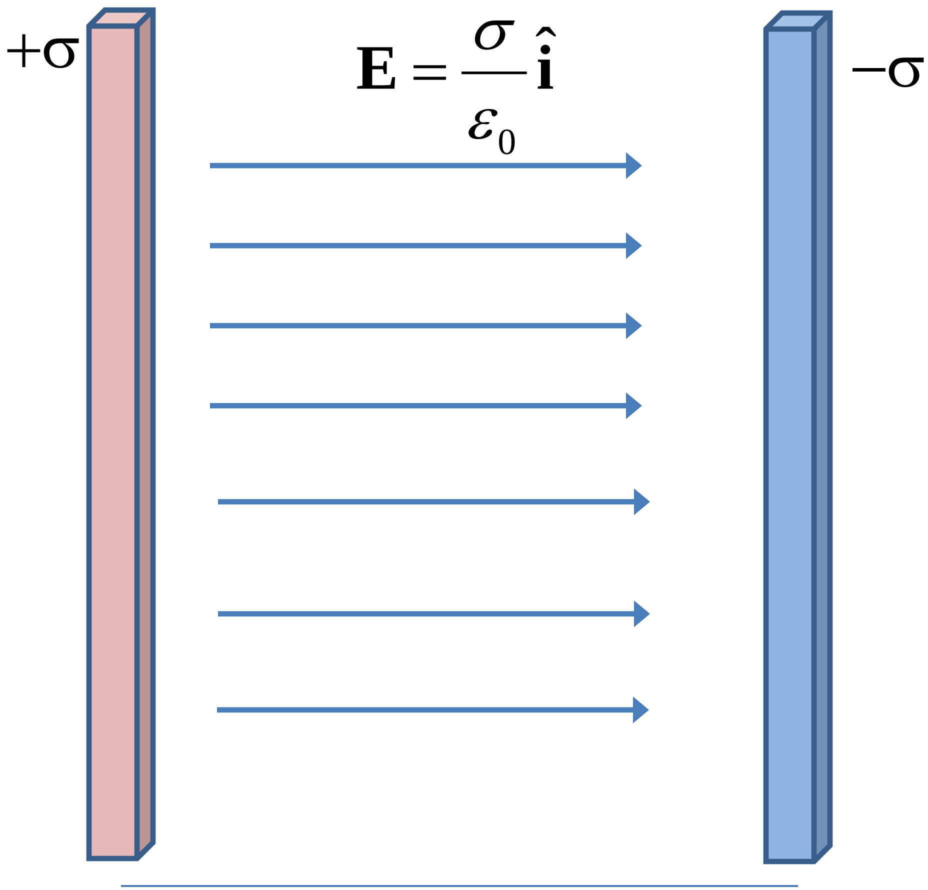
$$= -\int_0^x \frac{\sigma}{\varepsilon_0} dx'$$

$$= -\frac{\sigma}{\varepsilon_0} x \quad \text{for } 0 \le x \le d$$

$$V_i = 0$$

$$V_f = -\frac{\sigma d}{\varepsilon_0}$$

Electric potential for constant electric field:



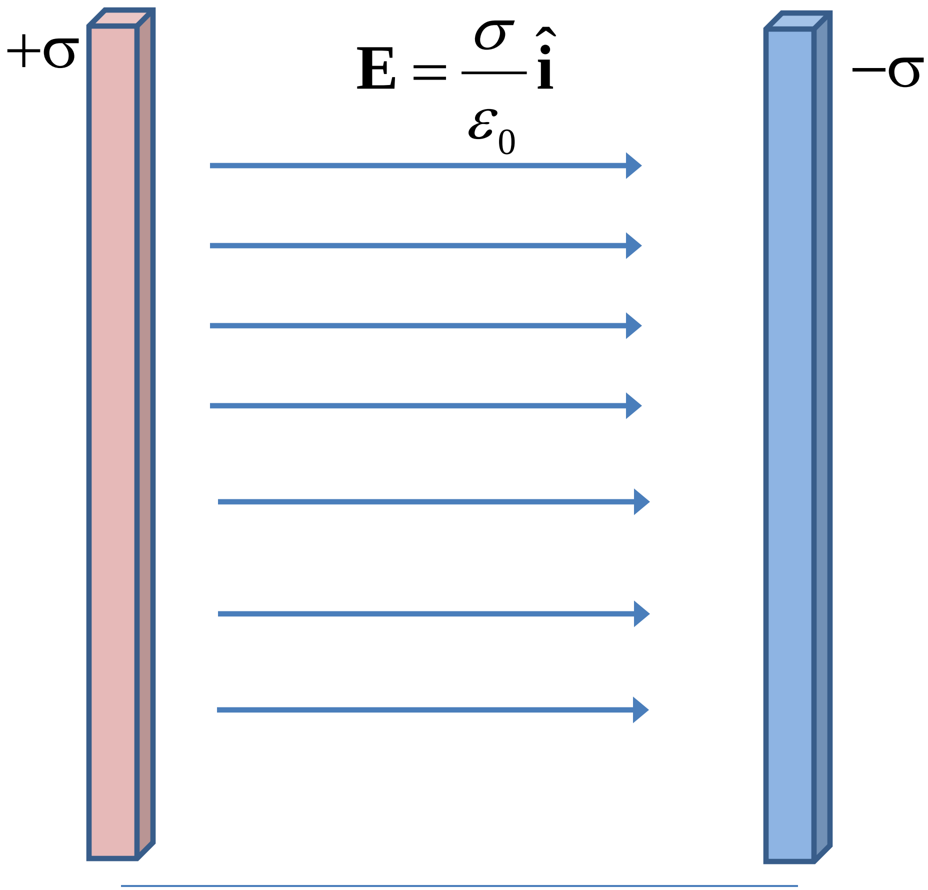
x=0 x=d

$$V_i = 0 \qquad V_f = -\frac{\sigma d}{\varepsilon_0}$$

Suppose a proton having charge e=1.6x10^{-19} C is initially at rest at x=0, what is its final kinetic energy at x=d?

A. 0
B. $-e\sigma d/\varepsilon_0$
C. $+e\sigma d/\varepsilon_0$
D. $2e\sigma d/\varepsilon_0$

Electric potential for constant electric field:



$$\mathbf{E} = \frac{\sigma}{\varepsilon_0}\hat{\mathbf{i}}$$

x=0 x=d

$$V_i = 0 \qquad V_f = -\frac{\sigma d}{\varepsilon_0}$$

Suppose a proton is initially at rest at x=0, what is its final kinetic energy at x=d?

$$K_i + U_i = K_f + U_f$$

$$K_f = K_i + U_i - U_f$$

$$K_f = -U_f = eV_f = \frac{e\sigma d}{\varepsilon_0}$$

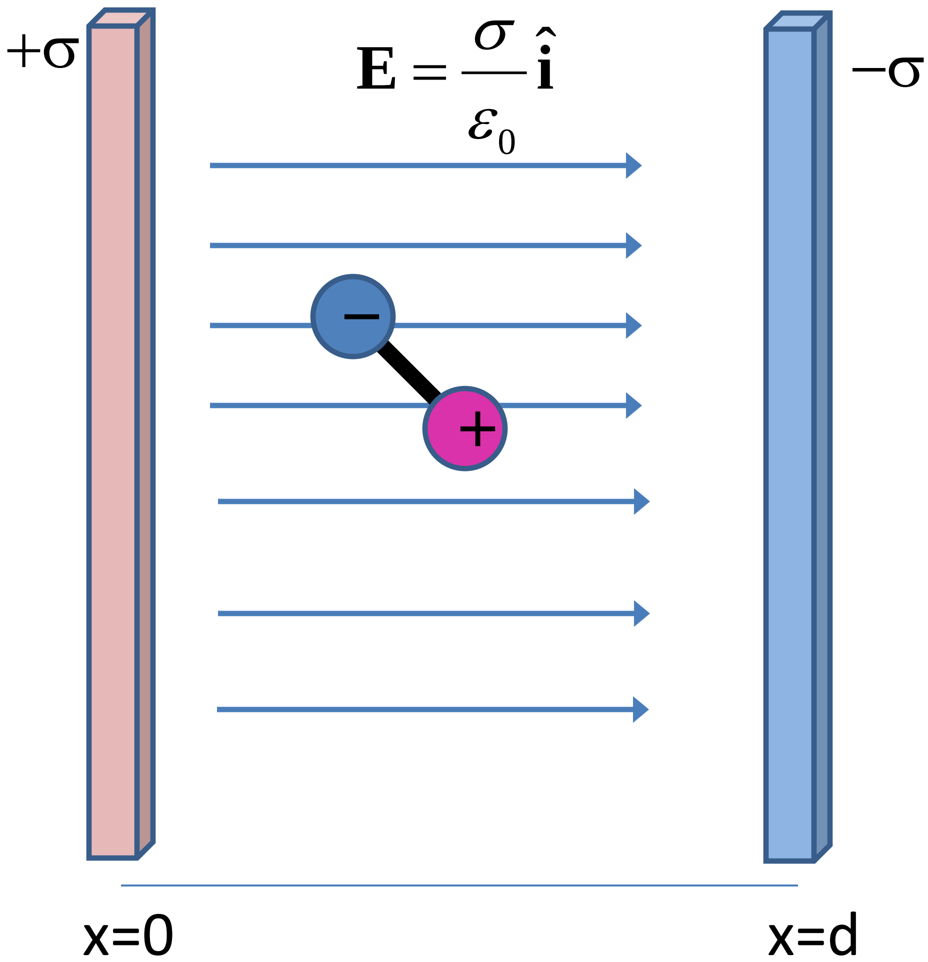
Uses for accelerated charges:

- In an X-ray machine, electrons are accelerated before hitting a Cu or Mo target that produce X-ray radiation.

  Note: An electron accelerated through a potential difference of 10V will have
  K_f = 10eV = 1.6 x 10^{-18} J v_f = 2 x 10^6 m/s

- Electron beam microscopy (almost atomic resolution)
- Accelerated electrons moving in a circle generate synchrotron radiation

Electric potential for constant electric field:



$$\mathbf{E} = \frac{\sigma}{\varepsilon_0}\hat{\mathbf{i}}$$

$$V_i = 0 \qquad V_f = -\frac{\sigma d}{\varepsilon_0}$$

Suppose a molecule with positive and negative parts is placed in the field E as show.

A. It will move to the right
B. It will move to the left
C. It will not move
D. It will rotate