Electrostatics

Course- PHY 2105 / PHY 105

Lecture 19

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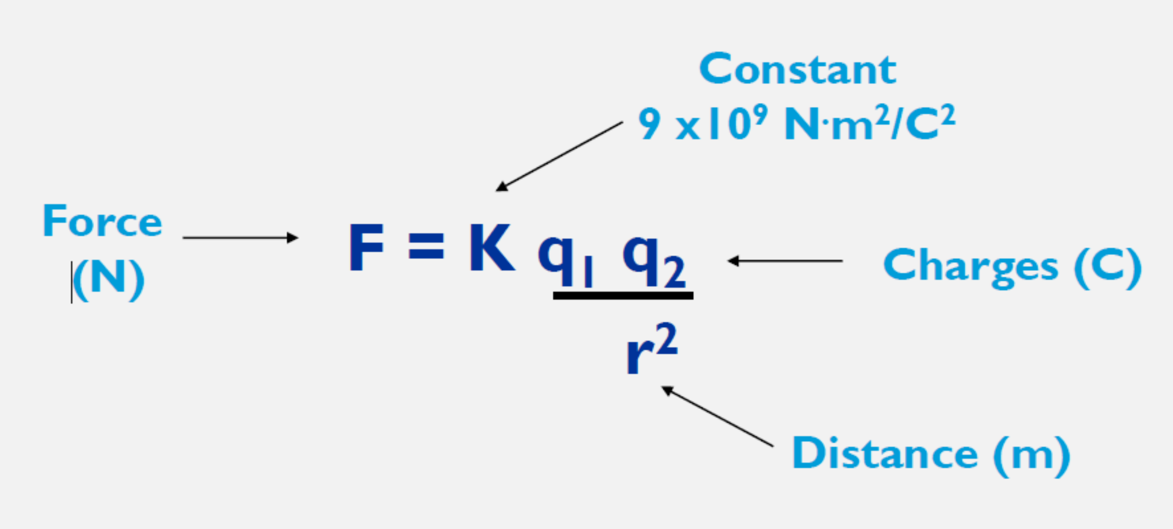
Coulomb’s Law

The electrostatic force between two charged object is directly proportional to the product of the amount of charges and inversely proportional to the square of the distance between them



$$k = \frac{1}{4\pi\varepsilon_0}$$

- *Experimental law*
- *Valid for point charges only*
- *Obeys Inverse Square Law*
- *Valid for only charges at rest*

$$Electrostatic\ constant, k = 9 \times 10^9\ \frac{Nm^2}{C^2}$$

$$Permittivity\ constant, \varepsilon_0 = 8.854 \times 10^{-12}\ \frac{C^2}{Nm^2}$$

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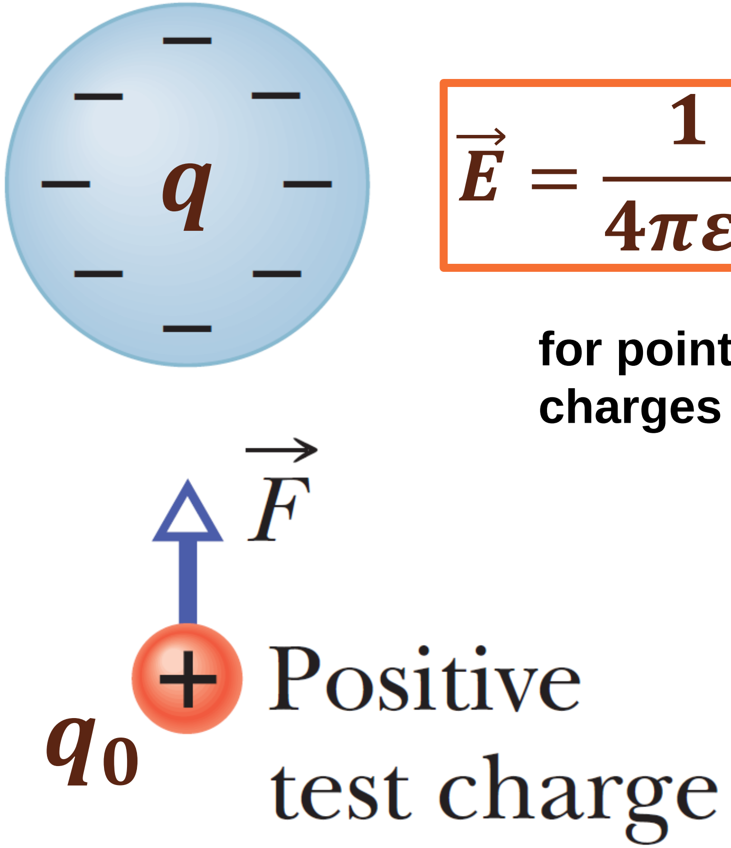
Electric Field

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

A charge has an effect on its surroundings. The area where it has an effect is generally called an *Electric field.* If any other charge enters that area, it feels an electrostatic Coulomb force.



$$\boxed{\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\,\hat{r}}$$

for point test charges only

The electric force on a charged body is exerted by the electric field created by *other* charged bodies.

Electric Potential & Potential Energy

Relationship between work and potential energy:

$$W_{a\to b} = U_a - U_b = -(U_b - U_a) = -\Delta U$$

The electric potential *V* at a point *P* in the electric field of a charged object is

$$V = \frac{-W_\infty}{q_0} = \frac{U}{q_0}$$

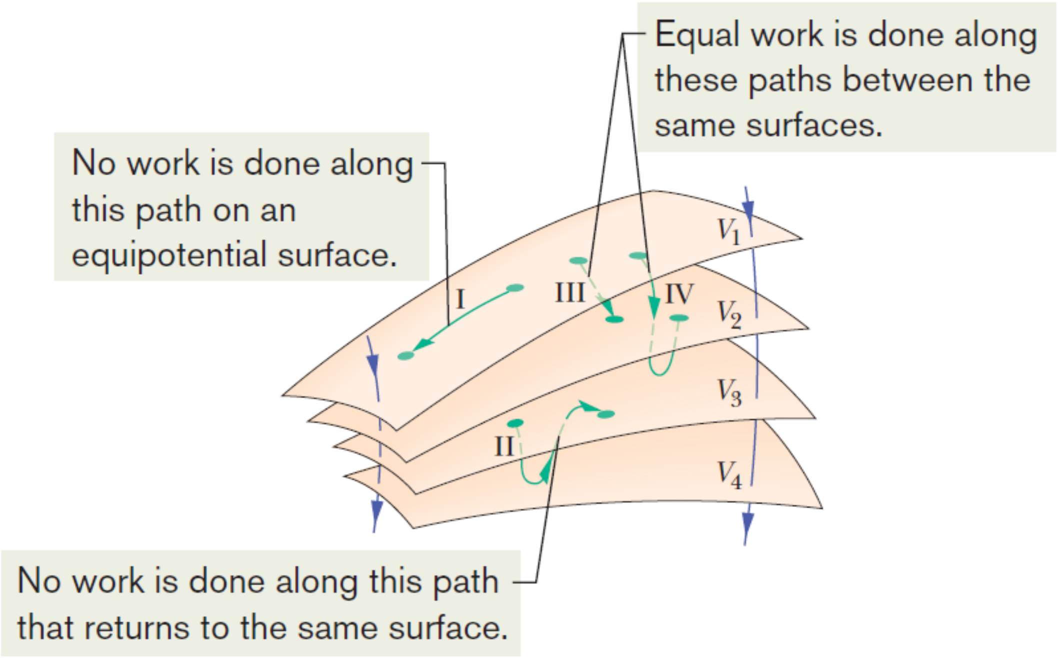
where is the work that would be done by the electric force on a positive test charge *q*0 were it brought from an infinite distance to *P*, and *U* is the electric potential energy that would then be stored in the test charge–object system

Change in electric potential: $\Delta V = V_f - V_i$

Change in system potential energy: $\Delta U = q\Delta V = q\left(V_f - V_i\right)$

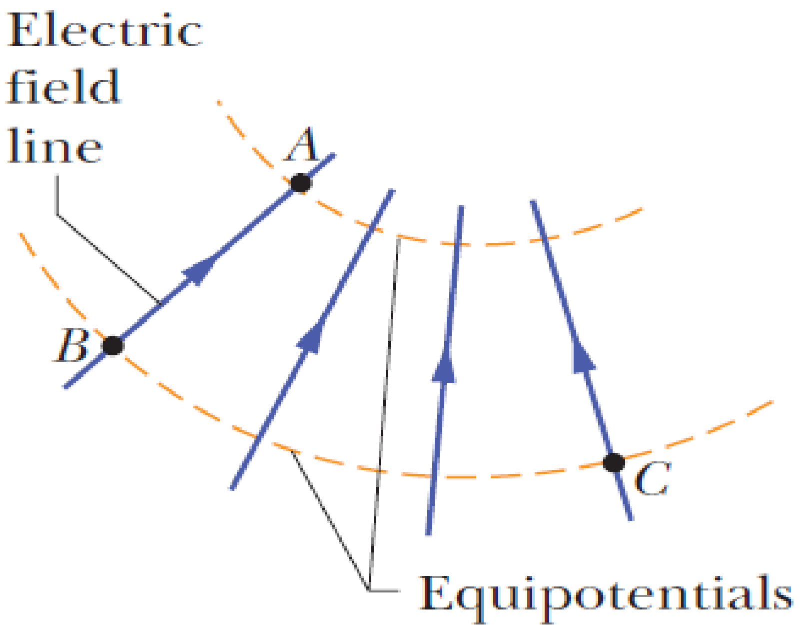
Equipotential Surfaces

An **equipotential surface is** an imaginary surface or a real, physical surface where no net work *W* is done on a charged particle by an electric field when the particle moves between two points *i* and *f* on the same equipotential surface



Example 19.1

When two electron moves from A to B along an electric field line in below figure, the electric field does 3.94×10^{-19} J of work on it. What are the electric potential differences (i) $V_B - V_A$, (ii) $V_C - V_A$, and (iii) $V_C - V_B$?



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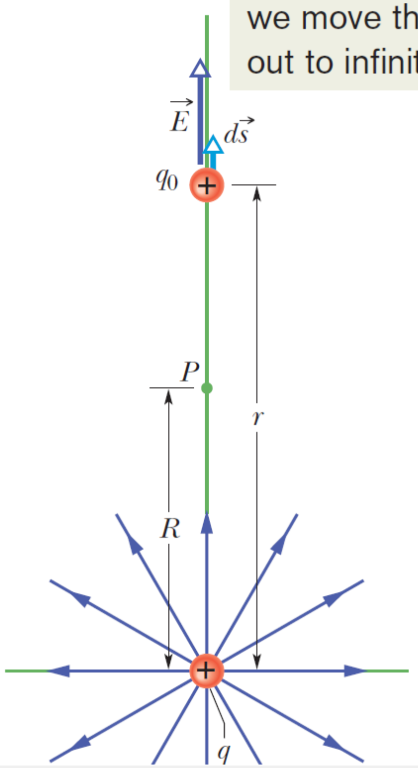
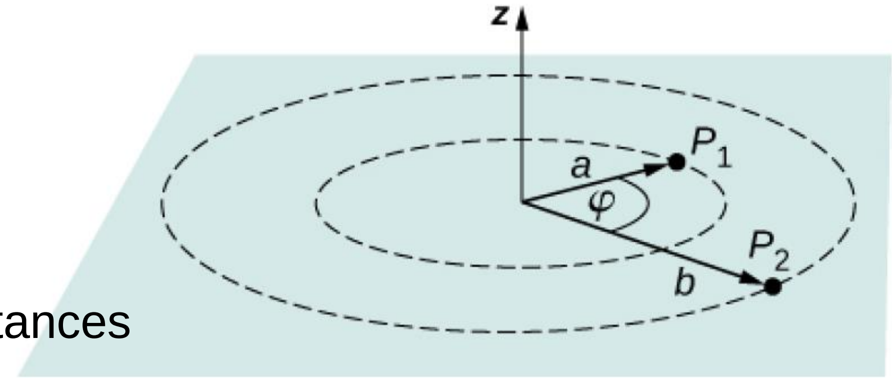
Potential Due to a Charged Particle

To find the potential of the charged particle, we move this test charge out to infinity.



$$V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$$

$$V = \sum_{i=1}^{n} V_i = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i} \quad (n \text{ charged particles}).$$

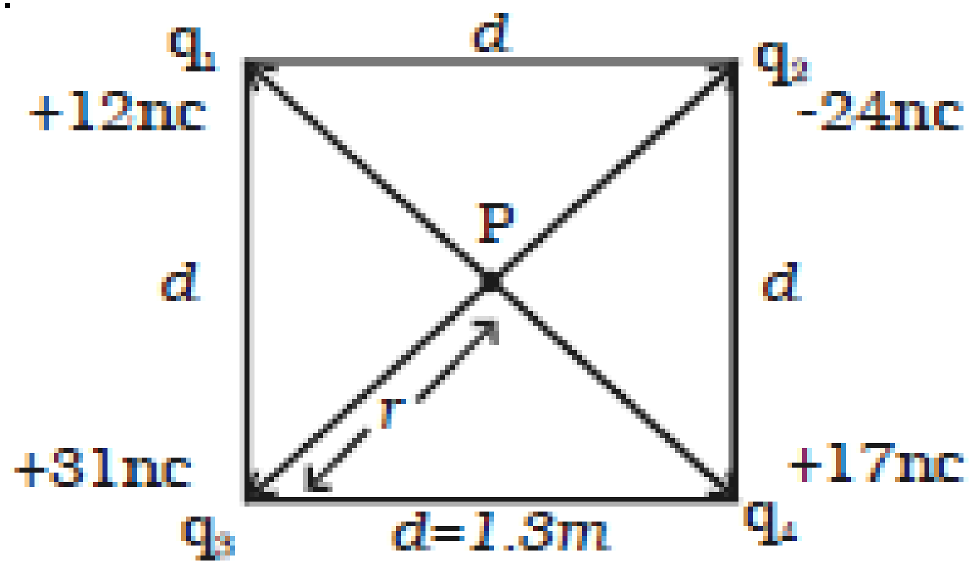


Potential at points of finite distances

$$\Delta V = -\int_a^b \frac{kq}{r^2}dr = kq\left[\frac{1}{a} - \frac{1}{b}\right]$$

Example 19.2

Calculate the electric potential at a point P, located at the centre of the square of point charges shown in the figure.



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Example 19.3

(a) An electron is to be accelerated from 3x10^6 m/s to 8x10^6 m/s. Through what potential difference must the electron pass to accomplish this?

(b) (b) Through what potential difference must the electron pass if it is to be slowed from 8x10^6 m/s to a halt?

(a) EXECUTE: $K_1 + qV_1 = K_2 + qV_2$, $q(V_2 - V_1) = K_1 - K_2$; $q = -1.602 \times 10^{-19}$ C.

$K_1 = \frac{1}{2} m_e v_1^2 = 4.099 \times 10^{-18}$ J; $K_2 = \frac{1}{2} m_e v_2^2 = 2.915 \times 10^{-17}$ J. $\Delta V = V_2 - V_1 = \dfrac{K_1 - K_2}{q} = 156$ V.

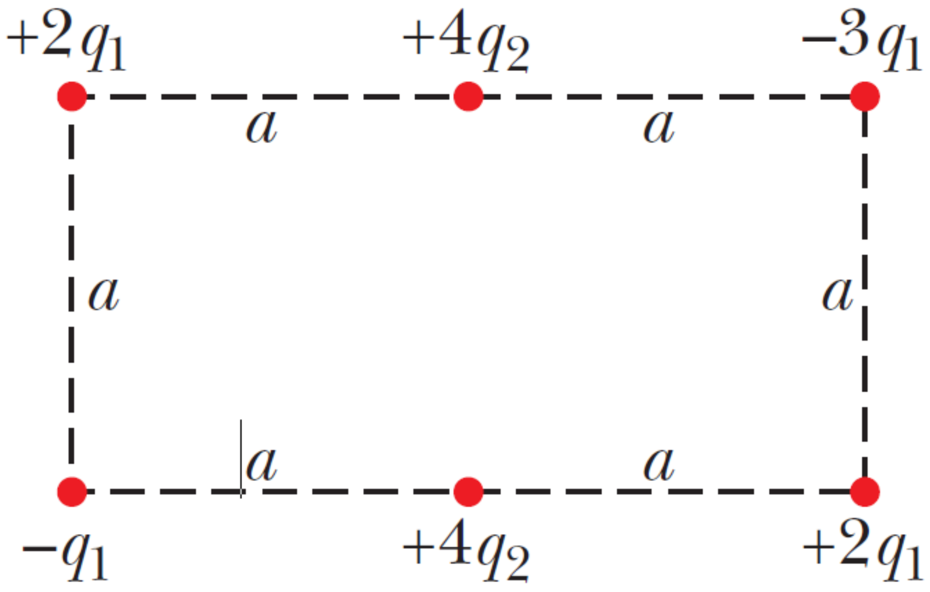
EVALUATE: The electron gains kinetic energy when it moves to higher potential.

(b) EXECUTE: Now $K_1 = 2.915 \times 10^{-17}$ J, $K_2 = 0$. $V_2 - V_1 = \dfrac{K_1 - K_2}{q} = -182$ V.

EVALUATE: The electron loses kinetic energy when it moves to lower potential.

Example 19.4

Figure below shows a rectangular array of charged particles fixed in place, with distance *a*= 39.0 cm and the charges shown as integer multiples of q_1=3.40 pC and q_2 =6.00 pC. With *V*=0 at infinity, what is the net electric potential at the rectangle's center?



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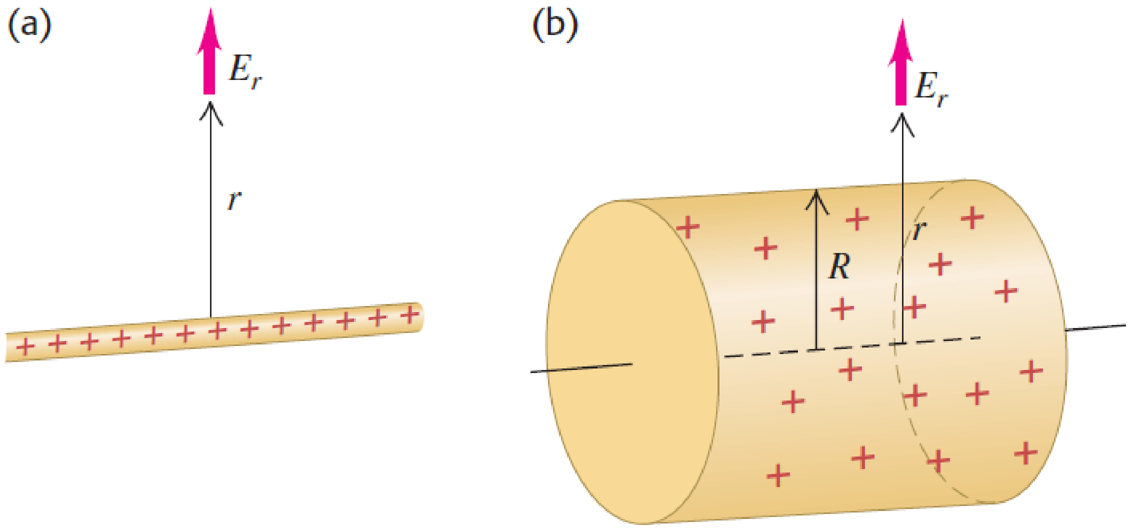
Example 19.5

A neutral water molecule in its vapor state has an electric dipole moment of magnitude 15 × 10-30 Cm. If the molecule is placed in an electric field of 7.5 ×104 N/C, what maximum torque can the field exert on it?

Potential due to an infinite line charge



$$V_a - V_b = \int_a^b \vec{E} \cdot d\vec{l} = \int_a^b E_r\,dr = \frac{\lambda}{2\pi\epsilon_0}\int_{r_a}^{r_b}\frac{dr}{r} = \frac{\lambda}{2\pi\epsilon_0}\ln\frac{r_b}{r_a}$$

Potential Gradient

At each point, the potential gradient points in the direction in which *V increases* most rapidly with a change in position. Hence at each point the direction of is the direction in which *V decreases* most rapidly and is always perpendicular to the equipotential surface through the point. Moving in the direction of the electric field means moving in the direction of decreasing potential

$$V_a - V_b = \int_b^a dV = -\int_a^b dV$$

$$V_a - V_b = \int_a^b \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{l}}$$

$$E_r = -\frac{\partial V}{\partial r}$$

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