

# Phys102 Lecture 6

# Electric Potential

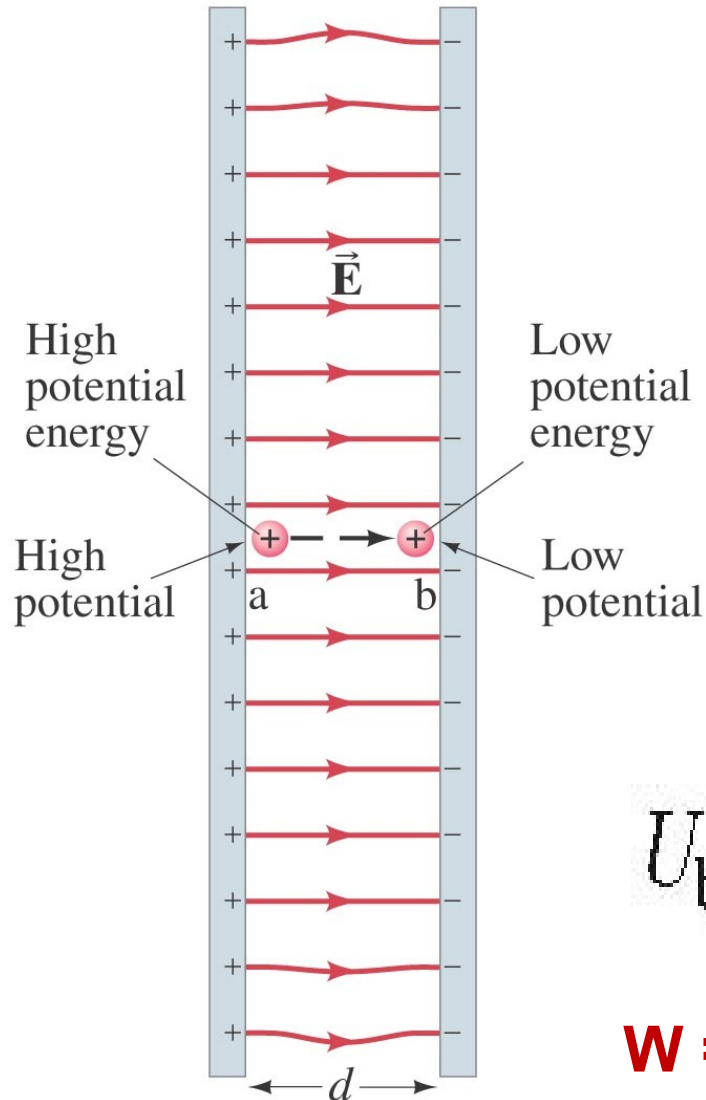
## Key Points

- Electric Potential Energy and Potential Difference
- Relation between Electric Potential and Electric Field
- Electric Potential Due to Point Charges
- Equipotential Surfaces
- Electric Dipole Potential

## References

17-1,2,3,4,5,6,+.

# Electrostatic Potential Energy and Potential Difference



The electrostatic force is conservative – potential energy can be defined.

Change in electric potential energy is negative of work done by electric force:

$$U_b - U_a = -W = -qEd.$$

**W = work by electric field from a to b**

# Electrostatic Potential Energy and Potential Difference

**Electric potential is defined as potential energy per unit charge:**

$$V_a = \frac{U_a}{q}.$$

**Unit of electric potential: the volt (V):**

$$1 \text{ V} = 1 \text{ J/C}.$$

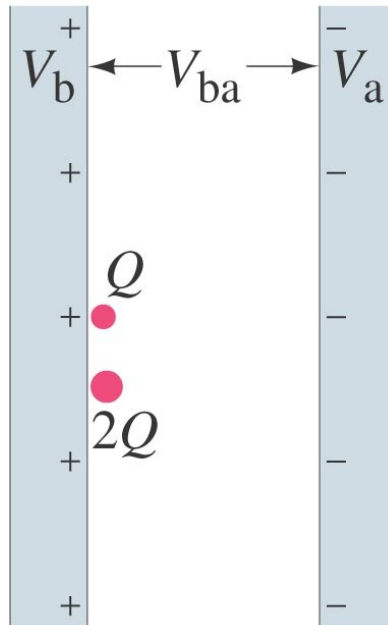
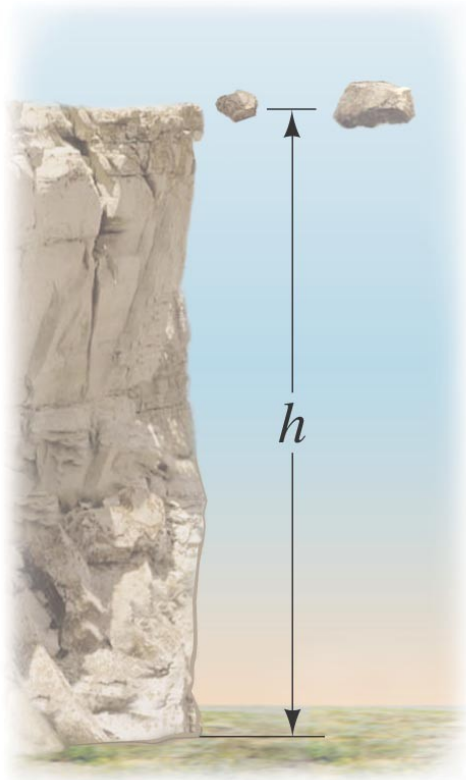
# Electrostatic Potential Energy and Potential Difference

**Only changes in potential can be measured, allowing free assignment of  $V = 0$ :**

$$V_{ba} = \Delta V = V_b - V_a = \frac{U_b - U_a}{q} = -\frac{W_{ba}}{q}.$$

# Electrostatic Potential Energy and Potential Difference

**Analogy between gravitational and electrical potential energy:**



**Sign of charges:**

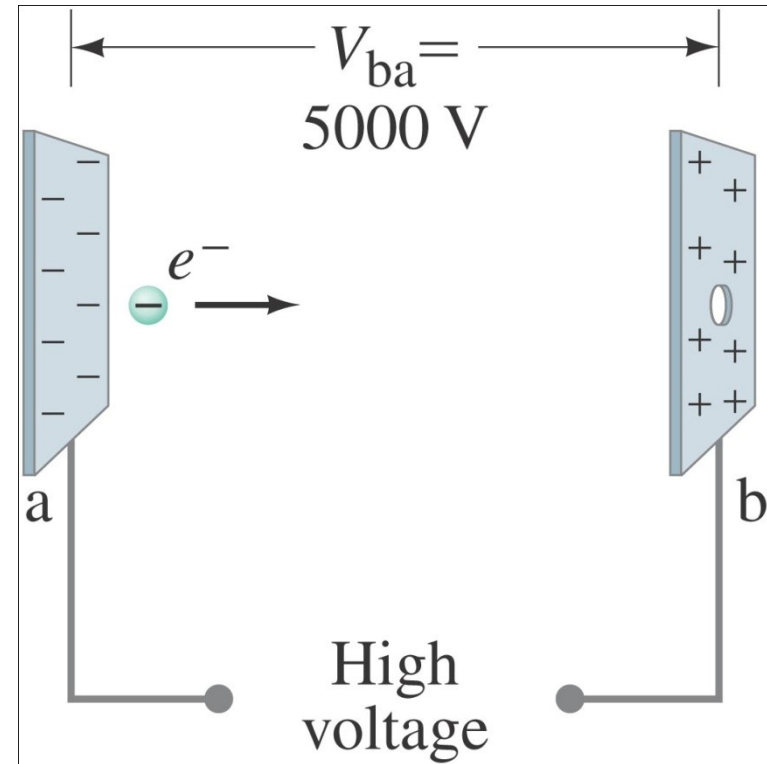
**When a positive charge is moved from lower potential to higher potential, its potential energy increases.**

**When a negative charge moves from lower potential to higher potential, its potential energy decrease.**

## Example: Electron in CRT.

Suppose an electron in a cathode ray tube is accelerated from rest through a potential difference  $V_b - V_a = V_{ba} = +5000 \text{ V}$ .

- (a) What is the change in electric potential energy of the electron?
- (b) What is the speed of the electron ( $m = 9.1 \times 10^{-31} \text{ kg}$ ) as a result of this acceleration?



# Relation between Electric Potential and Electric Field

**The simplest case is a uniform field:**

**When charge  $q$  moves from  $a$  to  $b$ , the change in potential energy is:**

$$U_b - U_a = -\vec{F} \cdot \vec{d} = -q\vec{E} \cdot \vec{d}$$

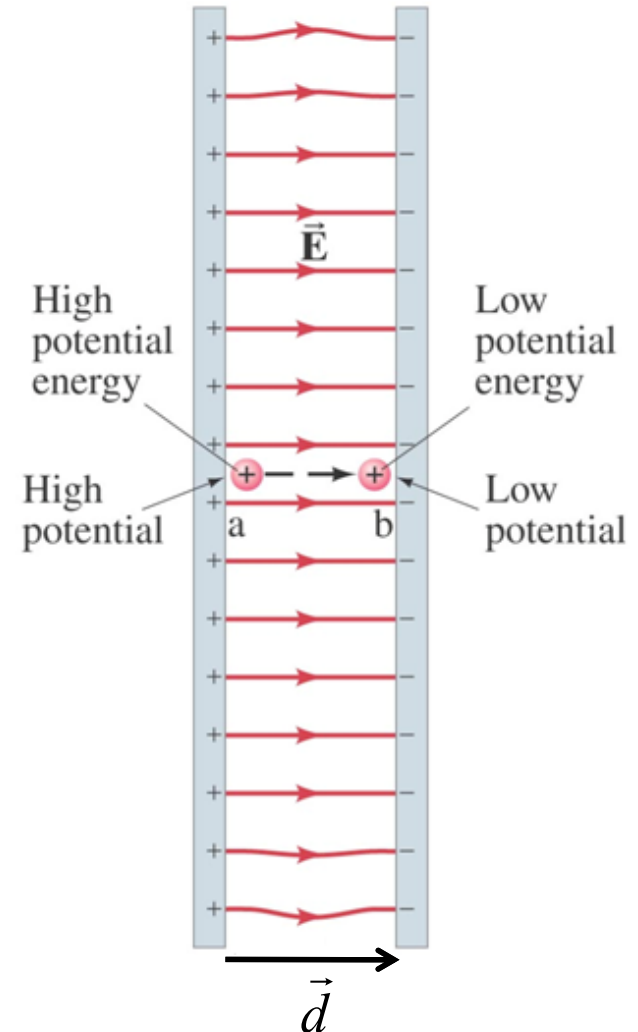
**The change in electric potential is:**

$$V_b - V_a = -\vec{E} \cdot \vec{d} = -Ed$$

**Note  $V_a > V_b$ . In general, the direction of electric field is from higher potential to lower potential.**

**The electric field will drive a positive charge to move from higher potential to lower potential; and a negative charge from lower potential to higher potential.**

$$V_{ba} = V_b - V_a = -\vec{E} \cdot \vec{d}_{a \rightarrow b}$$



# Relation between Electric Potential and Electric Field

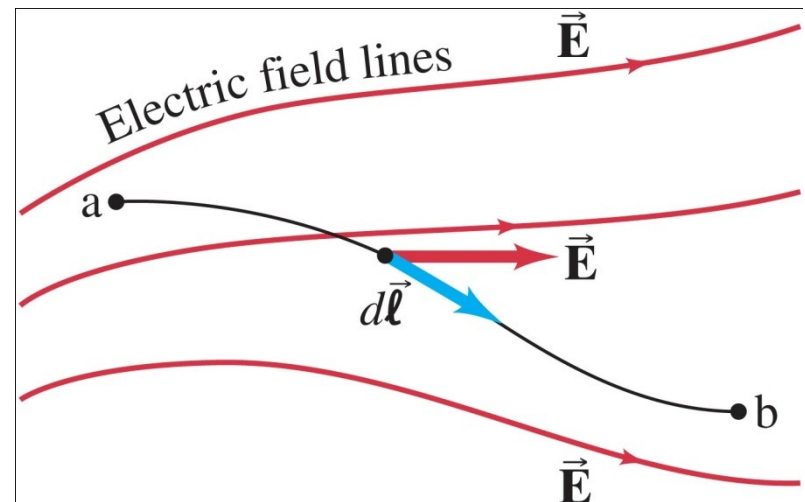
The general relationship between a conservative force and potential energy:

$$U_b - U_a = - \int_a^b \vec{\mathbf{F}} \cdot d\vec{\ell}.$$

- **Work by electric force**

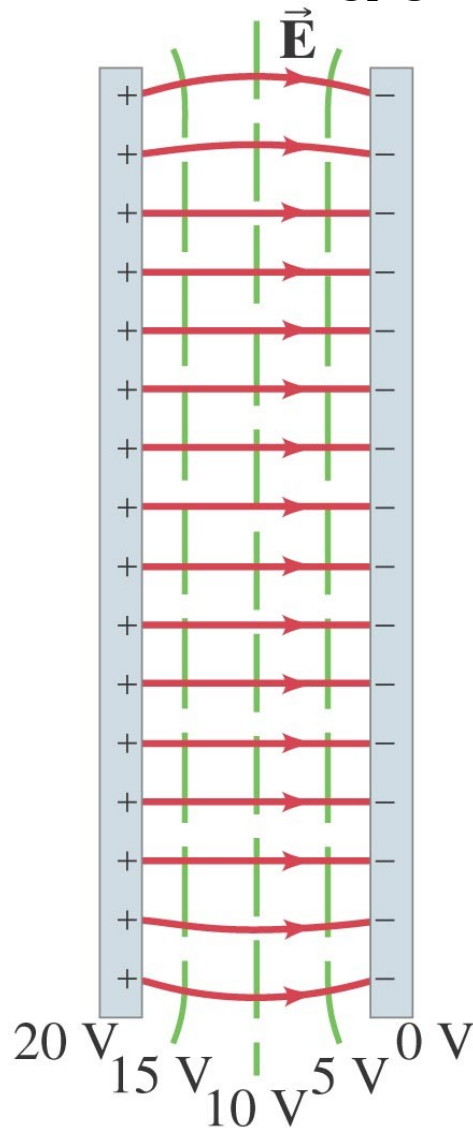
Substituting the potential difference and the electric field:

$$V_{ba} = V_b - V_a = - \int_a^b \vec{\mathbf{E}} \cdot d\vec{\ell}. = - \sum_{a \text{ to } b} \vec{E} \cdot \Delta \vec{l}$$





# Equipotential Surfaces



**An equipotential surface/line is surface/line over which the potential is constant.**

**Electric field lines are perpendicular to equipotential surfaces.**

**The surface of a conductor is an equipotential surface.**

**A conductor is an equipotential body.**

# Electric Potential Due to Point Charges

To find the electric potential due to a point charge, we integrate the field along a field line:

$$V_b - V_a = - \int_{r_a}^{r_b} \vec{E} \cdot d\vec{\ell} = - \frac{Q}{4\pi\epsilon_0} \int_{r_a}^{r_b} \frac{1}{r^2} dr = \frac{1}{4\pi\epsilon_0} \left( \frac{Q}{r_b} - \frac{Q}{r_a} \right).$$

We often set the potential to zero at  $r = \infty$ . Then the potential at a can be determined by letting b approach infinity:

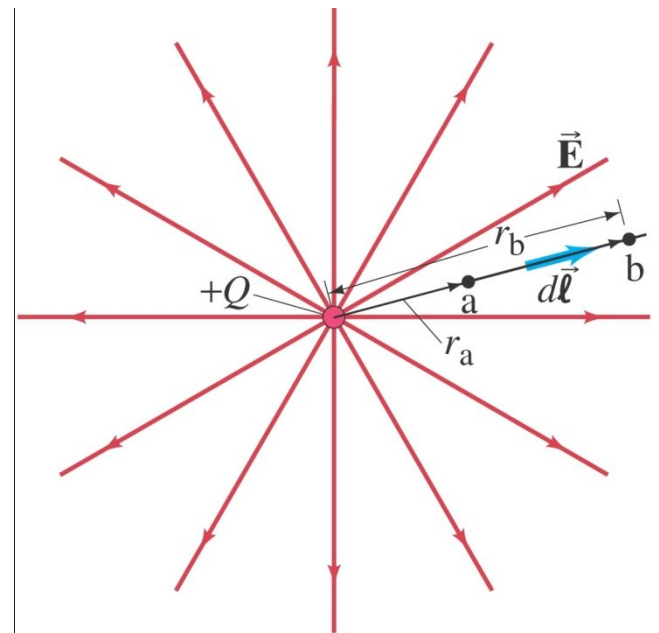
$$0 - V_a = \frac{1}{4\pi\epsilon_0} \left( 0 - \frac{Q}{r_a} \right)$$

$$V_a = \frac{1}{4\pi\epsilon_0} \frac{Q}{r_a}$$

Therefore, in general, the potential due to a point charge is:

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

Assuming the potential at infinity is zero.

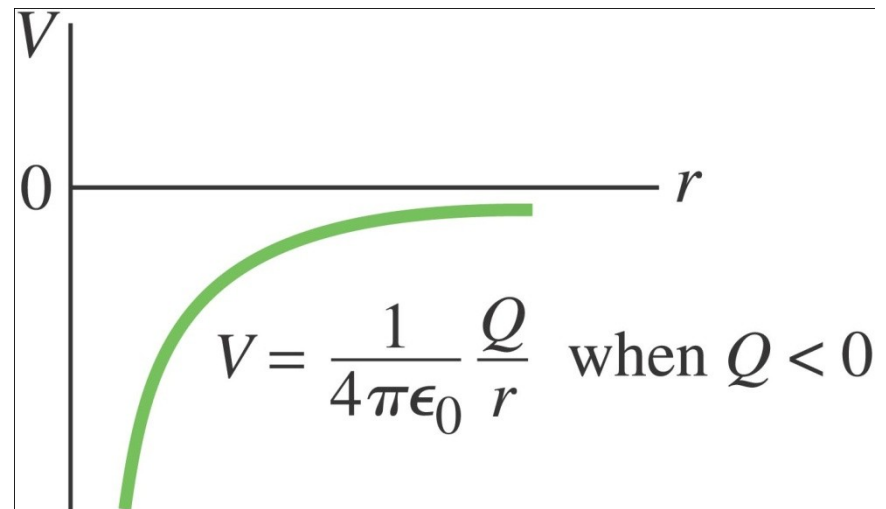
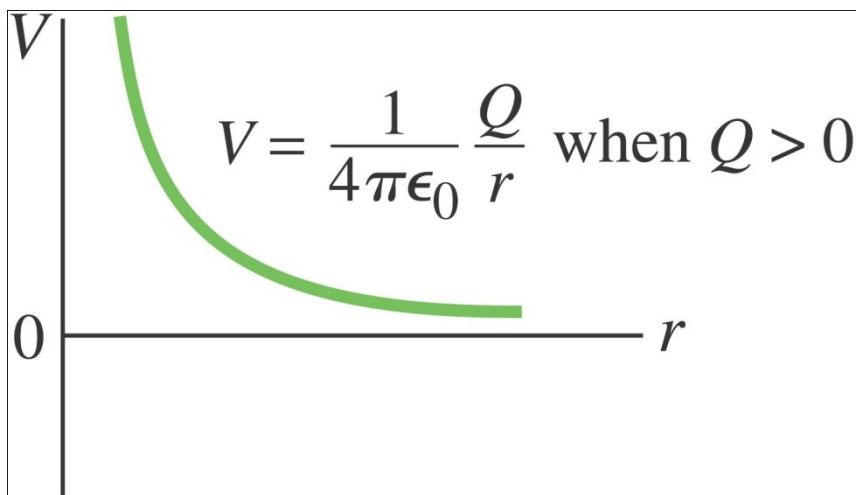


# Electric Potential Due to Point Charges

Setting the potential to zero at  $r = \infty$  gives the general form of the potential due to a point charge:

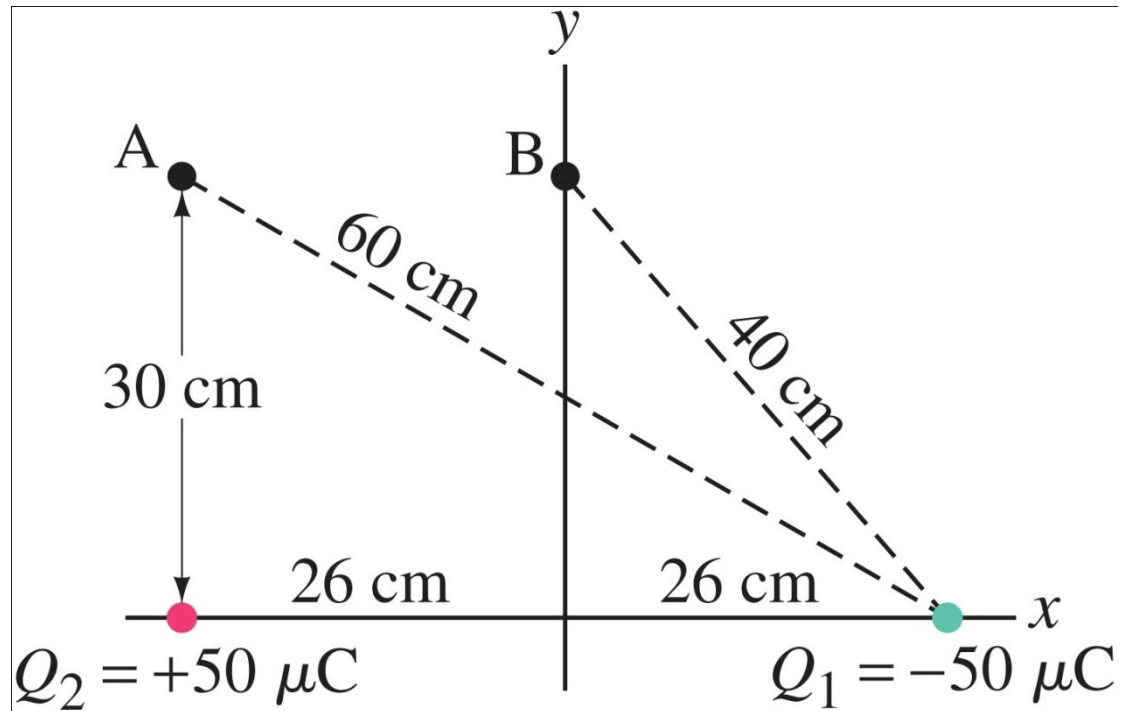
$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}.$$

$$\left[ \begin{array}{l} \text{single point charge;} \\ V = 0 \text{ at } r = \infty \end{array} \right]$$



### Example: Potential above two charges.

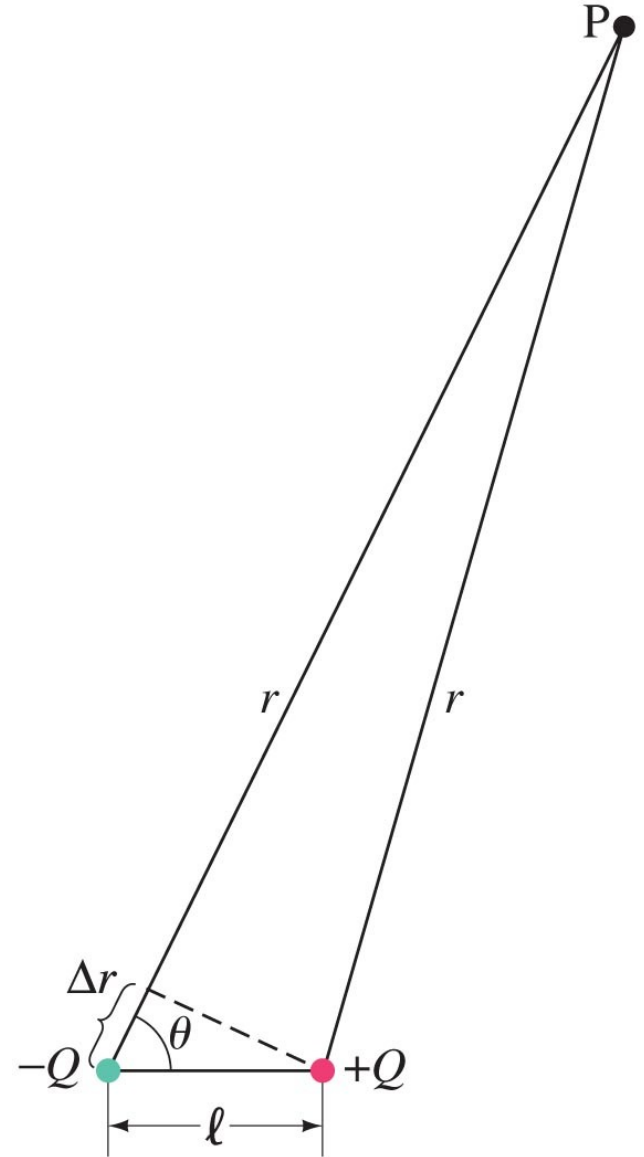
Calculate the electric potential (a) at point A in the figure due to the two charges shown, and (b) at point B.



# Electric Dipole Potential

The potential due to an electric dipole is just the sum of the potentials due to each charge, and can be calculated exactly. For distances large compared to the charge separation:

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q\ell \cos \theta}{r^2} = \frac{1}{4\pi\epsilon_0} \frac{p \cos \theta}{r^2}.$$



# Electrostatic Potential Energy; the Electron Volt

The potential energy of a charge in an electric potential is  $U = qV$ . To find the electric potential energy of two charges, imagine bringing each in from infinitely far away. The first one takes no work, as there is no field. To bring in the second one, we must do work due to the field of the first one; this means the potential energy of the pair is:

$$U = Q_2 V = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r_{12}}.$$

# Electrostatic Potential Energy; the Electron Volt

**One electron volt (eV) is the energy gained by an electron moving through a potential difference of one volt:**

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J.}$$

**The electron volt is often a much more convenient unit than the joule for measuring the energy of individual particles.**

# Electrostatic Potential Energy; the Electron Volt

**Example: Disassembling a hydrogen atom.**

**Calculate the work needed to “disassemble” a hydrogen atom. Assume that the proton and electron are initially separated by a distance equal to the “average” radius of the hydrogen atom in its ground state,  $0.529 \times 10^{-10}$  m, and that they end up an infinite distance apart from each other.**