UBC Physics 102

Lecture 7

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Outline

Electric potential [Text: Sect. 23-1]

- **Definition:** *electric potential energy,* U
  - Potential energy of a charge q due to presence of external electric field.
  - Like gravitational P.E. (charge $\leftrightarrow$ mass, E-field $\leftrightarrow$ gravity).
- **Definition:** *electric potential,* V
  - Potential energy per unit charge so that

$$U = qV.$$

  - Depends only on external E-field, not test charge q.
  - Analogy: potential, $V \leftrightarrow$ height.

Electric potential, contd

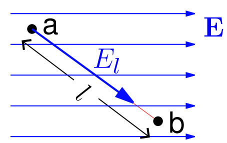
- **Definition:** *electric potential,* V*, contd*
  - Potential is relative because there is no absolute zero (like height).
  - Only differences in V matter.
  - Like height, difference doesn't depend on path taken.
- **Unit: Volt,** V

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

  - Unit of electric potential.
  - Electric potential also called *voltage*.

Relation to electric field [Text: Sect. 23-2, 7]

- **Discussion: Uniform field**
  - Motion through E-field produces change in potential.



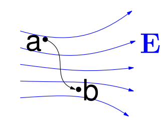
  - If $\mathbf{E}$ uniform and path straight then

$$V_{ba} = V_b - V_a = -E_l l.$$

  - E_l is component of $\mathbf{E}$ parallel to path (a to b).
  - V decreases when travelling along direction of $\mathbf{E}$.

Relation to electric field, contd

- **Interactive Quiz: PRS 07a**
- **Discussion: Non-uniform field**



  - If $\mathbf{E}$ or path not uniform then $V = -E_l l$ meaningless.
  - But $dV = -E_l dl$ must still hold over small enough segment dl so

$$E_l = -\frac{dV}{dl}.$$

Relation to electric field, contd

- **Discussion: Non-uniform field, contd**
  - Gives magnitude of electric field in direction of l.
  - Analogy: $V \leftrightarrow$ height, $E_l \leftrightarrow$ downslope in l-direction.
  - Can use to find electric field vector from potential, eg.

$$\begin{aligned}\mathbf{E} &= E_x\hat{\mathbf{i}} + E_y\hat{\mathbf{j}} + E_z\hat{\mathbf{k}} \\ &= -\frac{dV}{dx}\hat{\mathbf{i}} - \frac{dV}{dy}\hat{\mathbf{j}} - \frac{dV}{dz}\hat{\mathbf{k}}.\end{aligned}$$

- **Interactive Quiz: PRS 07b**

Point charges [Text: Sect. 23-3]

- **Discussion: Coulomb's law**
  - If $V = \frac{kQ}{r} + \text{constant}$ then $E = -\frac{dV}{dr} = \frac{kQ}{r^2}$, Coulomb's law.
  - Convention is to drop constant so potential for a point charge is

$$V = \frac{kQ}{r}.$$

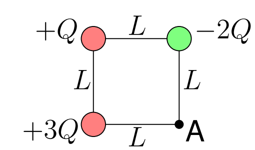
  - So potential is defined as zero far away from Q.

Point charges, contd

- **Discussion: Superposition**
  - If dealing with multiple charges can just add them to get overall potential at some point
    $$V = V_1 + V_2 + \cdots.$$
  - Superposition similar to rule for $\mathbf{E}$ but easier because V a scalar, so don't need to do vector addition.
  - Some cases easier to work with V, others $\mathbf{E}$.

Point charges, contd

- **Example: Pr. 30**



  - Three point charges are arranged at the corners of a square of side L as shown above. What is the potential at the fourth corner (point A)?
- **Solution: Pr. 30**
  - First we need to calculate the potential from each charge, individually.

Point charges, contd

- **Solution: Pr. 30, contd**
  - Starting with the $+3Q$ charge, $V_3 = \frac{3kQ}{L}$.
  - And for the $-2Q$ charge, $V_2 = -\frac{2kQ}{L}$.
  - The $+Q$ charge is at a distance $\sqrt{2}L$ so $V_1 = \frac{kQ}{\sqrt{2}L}$.
  - Superposing these gives the total potential at A,
    $$\begin{aligned} V &= V_1 + V_2 + V_3 \\ &= \left(\frac{1}{\sqrt{2}} - 2 + 3\right)\frac{kQ}{L} \\ &= \left(1 + \frac{1}{\sqrt{2}}\right)\frac{kQ}{L}. \end{aligned}$$
  - Much easier than calculating $\mathbf{E}$ at A!

Potential energy [Text: Sect. 23-8]

- **Discussion: Energy conservation**
  - Electric potential energy, $U = qV$ so when you move a charge q through a potential V its potential energy changes by
    $$\Delta U = qV.$$
  - To increase potential energy ($\Delta U > 0$) need to do work,
    $$W = \Delta U.$$
  - A *free* particle will convert its potential energy to kinetic, K, ($\Delta U < 0$)
    $$\Delta K = -\Delta U.$$
- **Interactive Quiz: PRS 07c**

Potential energy, contd

- **Example: Pr. 4**
  - An electron acquires 16.4×10^{-16} J of kinetic energy when it is accelerated by an electric field from plate A to plate B. What is the potential difference between the plates, and which plate is at the higher potential?
- **Solution: Pr. 4**
  - Let's turn this around and answer the second question first: which plate is at the higher potential?
  - The electron is free so it reduces its potential energy, $\Delta U < 0$.
  - Since it's a negative charge it goes "up" the potential landscape, $V = \frac{\Delta U}{q}$.
  - So plate B must be at a higher potential.

Potential energy, contd

- **Solution: Pr. 4, contd**
  - Now, what is the potential difference between the plates?
  - The change in potential energy is $\Delta U = -\Delta K = -16.4 \times 10^{-16}$ J.
  - Voltage change from A to B is

$$V_{BA} = \frac{\Delta U}{q} = \frac{-16.4 \times 10^{-16}\ \mathrm{J}}{-1.60 \times 10^{-19}\ \mathrm{C}} = 10,300\ \mathrm{V}.$$

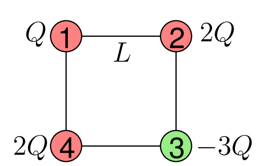
  - So B is at a potential $10,300$ V higher than A.

Potential energy, contd

- **Discussion: Multiple charges**
  - Potential energy of a system of multiple point charges is sum of potential energies between each pair.
  - Use $U = qV$ and $V = \frac{kQ}{r}$ to get energy held between each pair q and Q.
  - Be careful not to double-count.

Potential energy, contd

- **Example: Pr. 70**
  - Four point charges are located at the corners of a square with side L, as shown. What is the total electric potential energy stored in the system?



- **Solution: Pr. 70**
  - There are 6 pairs of charges. For each pair we need to calculate the potential energy stored between them.

Potential energy, contd

- **Solution: Pr. 70, contd**
  - Pairs:

Pair, ij	U_{ij}	Pair, ij	U_{ij}
12	$2\frac{kQ^2}{L}$	23	$-6\frac{kQ^2}{L}$
13	$-\frac{3}{\sqrt{2}}\frac{kQ^2}{L}$	24	$\frac{4}{\sqrt{2}}\frac{kQ^2}{L}$
14	$2\frac{kQ^2}{L}$	34	$-6\frac{kQ^2}{L}$

  - So the total potential energy is

$$U = \sum_{\text{Pairs},ij} U_{ij} = \left(2 - \frac{3}{\sqrt{2}} + 2 - 6 + \frac{4}{\sqrt{2}} - 6\right)\frac{kQ^2}{L}$$
$$= \left(\frac{1}{\sqrt{2}} - 8\right)\frac{kQ^2}{L}. \quad \square$$

Potential energy, contd

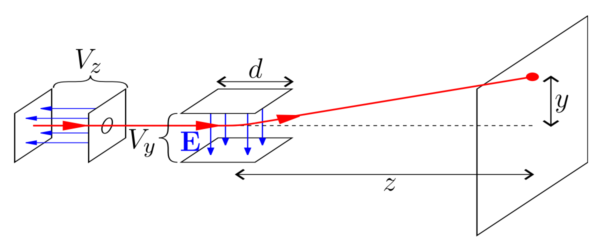
- **Unit: electron Volt,** eV
  - Energy acquired by an electron when it moves through a potential difference of $1\ \text{V}$.

$$1\ \text{eV} = qV = (1.60 \times 10^{-19}\ \text{C})(1\ \text{V}) = 1.60 \times 10^{-19}\ \text{J}.$$

  - More convenient unit than J when dealing with individual particles.

Cathode ray tube [Text: Sect. 23-9]

- **Discussion: Cathode ray tube**



  - When cathode heated up it "boils" off electrons.
  - CRTs use anode, V_z, to accelerate electrons.
  - Voltage V_y applied to plates to deflect electron.
  - Can position precisely where electron will hit screen.
  - Screen glows at point where hit.

End

- **Practice Problems:**
  - Ch. 23: Q. 1, 3, 5, 7, 11, 15, 17, 19.
  - Ch. 23: Pr. 1, 3, 5, 7, 11, 15, 21, 23, 25, 27, 29, 45, 47, 49, 51, 55, 61, 65, 57, 71, 73, 75, 77.
- **Interactive Quiz: Feedback**
- **Tutorial Question: tut07**