Tutorial 5

Electric Potential

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Lecture Outline

- **Chapter 24**, D Halliday, R Resnick, and J Walker, "Fundamentals of Physics" 9th Edition, Wiley (2005).

- Electric Potential
  - Conservative force and potential energy
  - Potential energy and potential
  - Potential due to different charge distribution
  - Field and potential (versus force and potential energy)
  - Conductors

$$\boxed{\begin{array}{l} \mathbf{F} = q\,\mathbf{E} \\ U = q\,V \end{array}}$$

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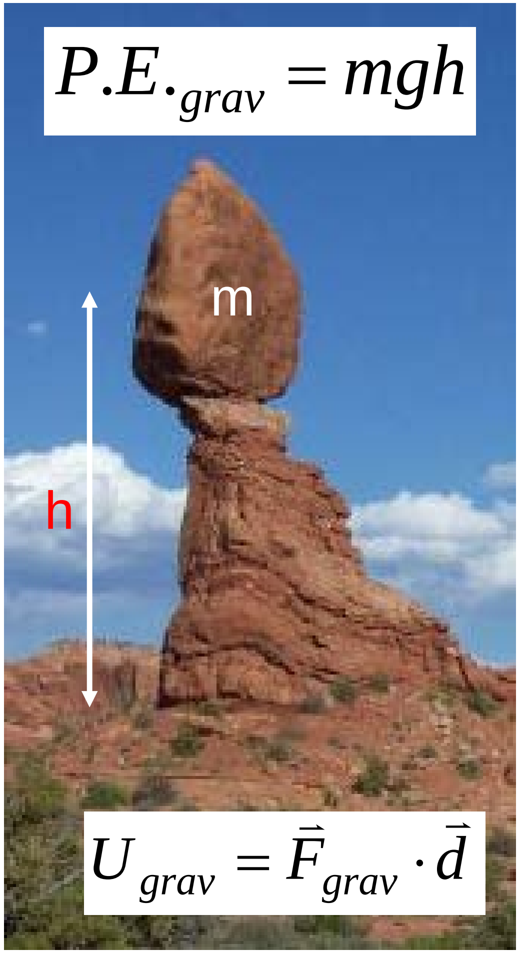
Lecture 05 Review

- Potential energy is defined as the stored energy of potential.
- The potential energy of a system of objects in a conservative force field is defined by the positions of the objects. By rearranging their positions, one can adjust the amount of the stored energy in the physical system.
- Potential energy is represented by the symbol U.



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Lecture 05 Review

- Potential energy has the same SI unit *J* Joule as Work Done *W*
- One very important concept regarding potential energy is to account for how the work gets done.
- The easy way to determine this concept is by comparing the potential energy stored in the system before and after the adjustment or rearrangement.
- Case 1: moving the rock from d=0 to d=h

$$U_{gain/loss} = U_{after} - U_{before}$$

$$\Delta U = U_{d=h} - U_{d=0} = mgh - 0 = mgh = \boxed{W_{you} = -W_{system}}$$

<u>You contributed work</u> (energy) into the system.

- Case 2: dropping the rock from d=h to d=0

$$\Delta U = U_{d=0} - U_{d=h} = 0 - mgh = -mgh = \boxed{-W_{you} = W_{system}}$$

<u>The system did the work</u> and released the energy.

Lecture 05 Review

- We learnt the differences between conservative and non-conservative forces.
- The conservative forces are path independence. All the Electromagnetic forces, as well as gravitational force, considered in this course are conservative forces.

a) The work done by a conservative force on a particle moving between two points does not depend on the path taken by the particle.

b) The net work done by a conservative force on a particle moving around every closed path is zero.

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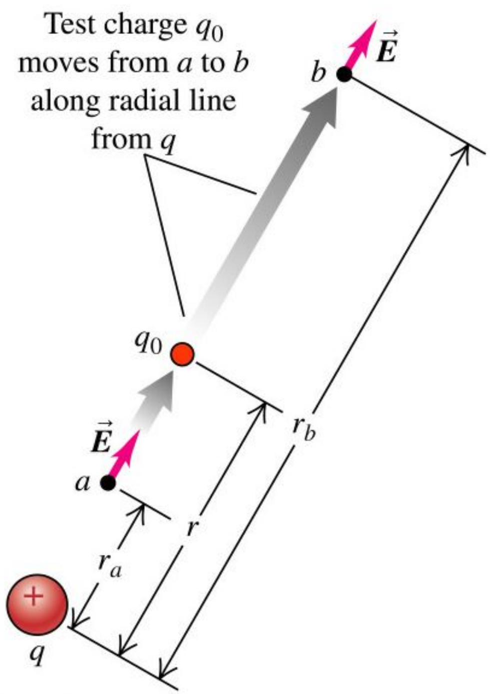
Lecture 05 Review

- From the expression of the potential energy of the two point charges system, we observe that the resulting potential energy can be expressed as the difference between the values of a function at the locations of the two points.



$$W_{a\to b} = \frac{qq_0}{4\pi\varepsilon_0}\left(\frac{1}{r_a} - \frac{1}{r_b}\right) = \frac{qq_0}{4\pi\varepsilon_0 r_a} - \frac{qq_0}{4\pi\varepsilon_0 r_b}$$

We define this function to be the potential energy

$$U(r) = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r}$$

$$W_{a\to b} = U(r_a) - U(r_b)$$

$$\Delta U = U(r_b) - U(r_a) = -W_{a\to b}$$

$r = \infty$ $\qquad U(r) = 0$

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Lecture 05 Review

- We also introduced the term Electric Potential which is represented by the symbol V.
- Electric Potential (V) is closely related to Electric Potential Energy (U), however there are some important differences:
  - V is defined as the potential energy *per unit charge* $V = U/q$.
  - Unlike the electric potential energy U where a minimum of two charges are needed to define its value, a single charge can create an electric potential distribution.

$$V = \frac{Electric\ Potential\ Energy}{Unit\ Charge} = \frac{U}{q}$$

$$\Delta V = V_f - V_i = \frac{U_f}{q} - \frac{U_i}{q} = \frac{\Delta U}{q}.$$

$$= -\frac{W}{q} \quad \text{(potential difference defined).}$$

$$V = -\frac{W_\infty}{q} \quad \text{(potential defined)}$$

  - Here W_∞ is the work done by the electric field on a charged particle as that particle moves in from infinity to point f.

Lecture 05 Review

- The electric potential is characterized by the electric field created by the electric field distribution.
- The potential difference $V_f - V_i$ between any two points *i* and *f* in an electric field is equal to the negative of the line integral from *i* to *f*: $V = -\int_i^f \vec{E} \cdot ds$.
- The SI unit of the electric potential is V Volt.
- This unit of volt allows us to adopt a more conventional unit for the electric field, E, which was expressed in Newton per Coulomb in Lecture 4.

P.E. (J) = Electric Potential (V) x Charge (C)

$$1\ \mathrm{N/C} = \left(1\frac{\mathrm{N}}{\mathrm{C}}\right)\left(\frac{1\ \mathrm{V\cdot C}}{1\ \mathrm{J}}\right)\left(\frac{1\ \mathrm{J}}{1\ \mathrm{N\cdot m}}\right)$$
$$= 1\ \mathrm{V/m}.$$

Work (J) = Force (N) x Displacement (m)

- We define electron-volt (eV) as the energy equal to the work required to move a single elementary charge e, such as that of the electron or the proton, through a potential difference of exactly one volt.

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Lecture 05 Review

- Electric potential is a scalar field, or a scalar function that is defined in space V(x,y,z).
- From V(x,y,z), we can identify surfaces that have the same V values, we call these equipotential surfaces.
- There are two important properties about equipotential surfaces:
  - The electric field is perpendicular to these surfaces;
  - A test charge moving along the equipotential surface does not result in any work done.
- Finally, we can determine the positive or negative work done on a charge moving between the different potential surfaces from the product of the charge and the potential difference

$$-W = \Delta U = q\Delta V$$

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Halliday/Resnick/Walker
Fundamentals of Physics 8th edition

Classroom Response System Questions

Chapter 24 Electric Potential

Interactive Lecture Questions

PHY 1202

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24.2.1. Two electrons are separated by a distance R. If the distance between the charges is increased to $2R$, what happens to the total electric potential energy of the system?

a) The total electric potential energy of the system would increase to four times its initial value.

b) The total electric potential energy of the system would increase to two times its initial value.

c) The total electric potential energy of the system would remain the same.

d) The total electric potential energy of the system would decrease to one half its initial value.

e) The total electric potential energy of the system would decrease to one fourth its initial value.

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$$U(r) = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r}$$

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24.2.2. The electric potential energy for two positive charges of magnitude q and separated by a distance r is U_1. What will the electric potential energy be if one of the charges is completely removed and replaced by a negative charge of the same magnitude?

a) $U_2 = 2U_1$

b) $U_2 = U_1$

c) $U_2 = -U_1$

d) $U_2 = -2\,U_1$

e) There is no way to determine this without knowing the value of q.

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$$U(r) = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r}$$

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24.2.3. Why is an electrostatic force considered a conservative force?

a) Charged particles do not experience friction, which is a non-conservative force.

b) The energy required to move a charged particle around a closed path is equal to zero joules.

c) The work required to move a charged particle from one point to another does not depend upon the path taken.

d) Answers (a) and (b) are both correct.

e) Answers (b) and (c) are both correct.

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24.3.1. Which one of the following statements best explains why it is possible to define an *electrostatic potential* in a region of space that contains an electrostatic field?

a) The work required to bring two charges together is independent of the path taken.

b) A positive charge will gain kinetic energy as it approaches a negative charge.

c) Like charges repel one another and unlike charges attract one another.

d) Work must be done to bring two positive charges closer together.

e) A negative charge will gain kinetic energy as it moves away from another negative charge.

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24.3.2. A positive charge is located at the origin. What is the direction of the electric potential of the positive charge?

a) radially outward from the origin

b) radially inward from the origin

c) toward the positive x, y, and z directions

d) toward the negative x, y, and z directions

e) There is no direction since the electric potential is a scalar quantity.

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24.3.2. A positive charge is located at the origin. What is the direction of the electric potential of the positive charge?

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c) toward the positive *x*, *y*, and *z* directions

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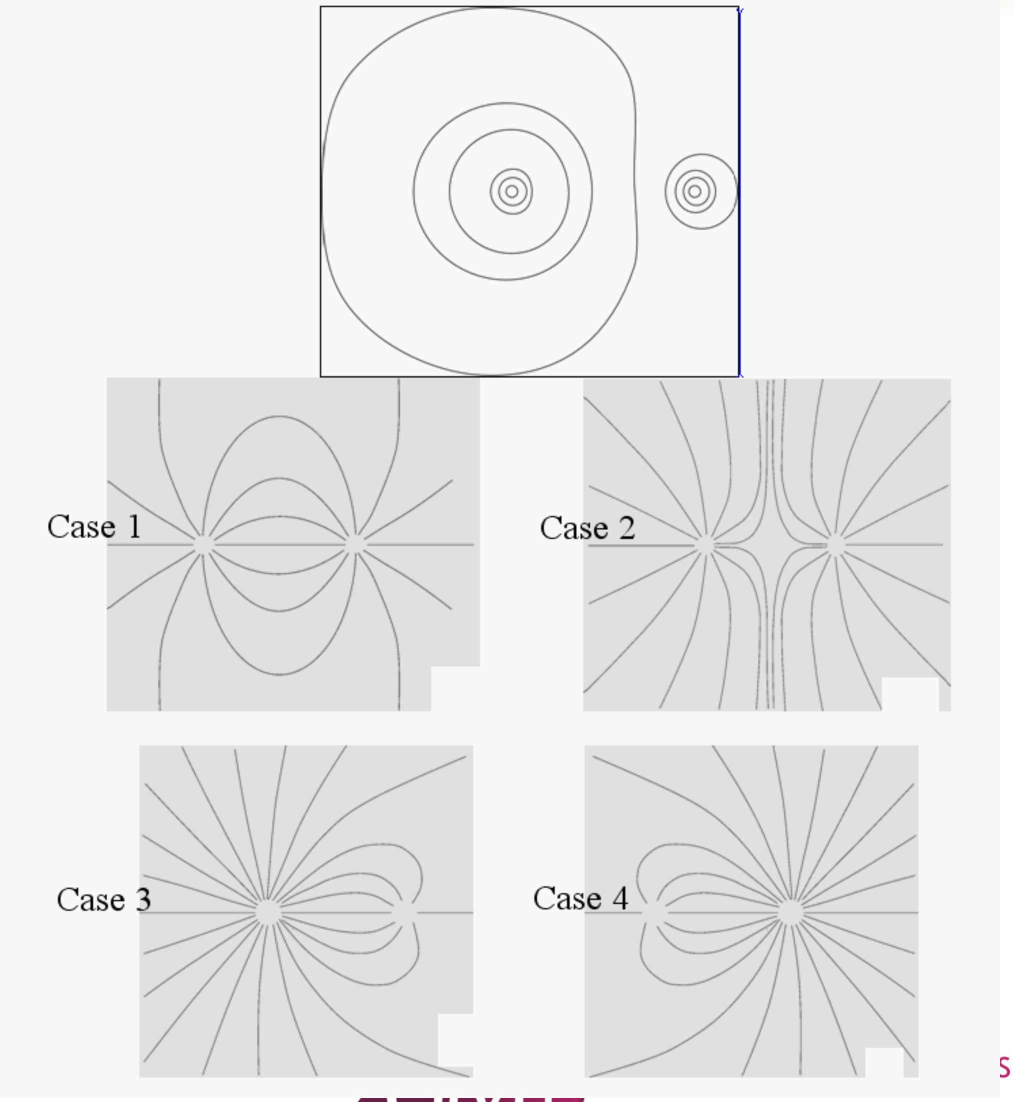
24.4.4. Consider the equipotential lines shown in the box. The labeled cases indicate electric field line drawings. Which of these cases best matches the equipotential lines shown?



a) 1

b) 2

c) 3

d) 4

e) None of these cases match the equipotential lines shown.

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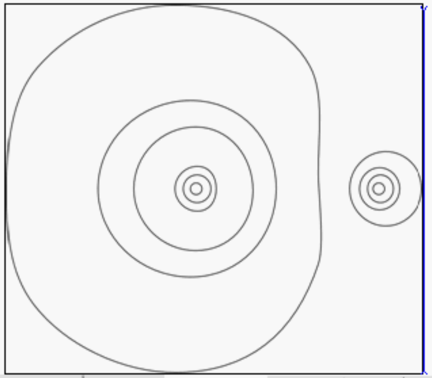

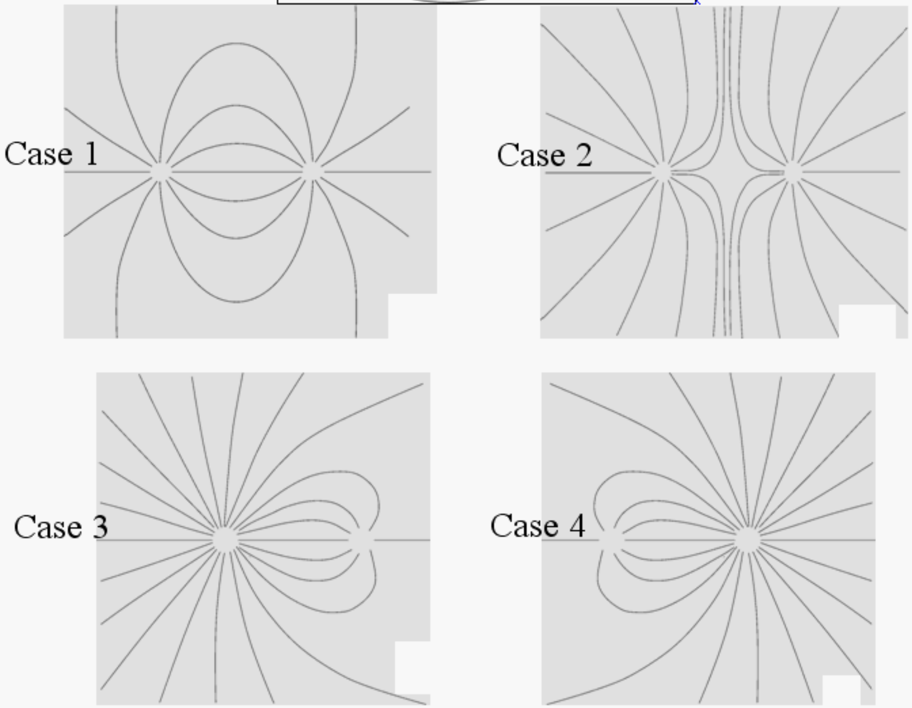

a) 1

b) 2

c) 3

d) 4

e) None of these cases match the equipotential lines shown.

24.7.2. Two point charges lie along the x axis. One charge, located at the origin, has a magnitude $+2q$. The other charge of unknown magnitude and sign is located at $x = 5$ units. If the electric potential at $x = 4$ units is equal to zero volts, what is the magnitude and sign of the second point charge?

a) $-q/2$

b) $-q/4$

c) $-2q$

d) $+q/2$

e) $+2q$

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24.7.2. Two point charges lie along the *x* axis. One charge, located at the origin, has a magnitude $+2q$. The other charge of unknown magnitude and sign is located at $x = 5$ units. If the electric potential at $x = 4$ units is equal to zero volts, what is the magnitude and sign of the second point charge?

a) $-q/2$

b) $-q/4$

c) $-2q$

d) $+q/2$

e) $+2q$

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

2q/4+x/1=0

X=-q/2

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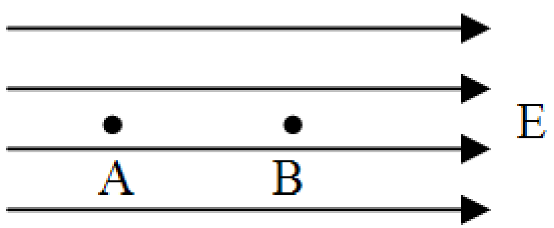
24.7.3. A proton is moved from point B to point A in an electric field as shown. As a result of its movement, its potential increases to *V*. If three protons are moved from point B to A, how much will the electric potential of the protons increase?



a) $V/9$

b) $V/3$

c) V

d) $3V$

e) $9V$

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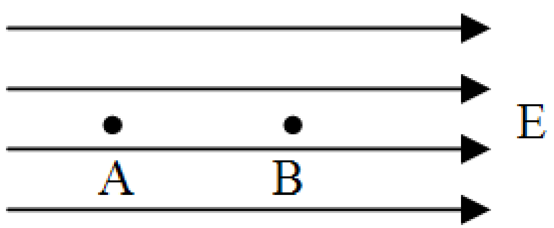

a) $V/9$

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