I. Review of work

A. Suppose an object moves under the influence of a force. Sketch arrows showing the relative directions of the force and displacement when the work done by the force is:
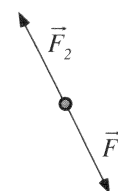
Positive	Negative	Zero

B. An object travels from point A to point B while two constant forces, $\vec{F_1}$ and $\vec{F_2}$, of equal magnitude are exerted on it.

1. Is the total work done on the object by $\vec{F_1}$ *positive, negative,* or *zero?*

   • Point B

2. Is the total work done on the object by $\vec{F_2}$ *positive, negative,* or *zero?*

   $\vec{F_2}$

3. Is the net work done on the object *positive, negative,* or *zero?* Explain.
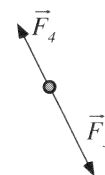
   $\vec{F_1}$

   Point A •

4. Is the speed of the object at point B *greater than, less than,* or *equal to* the speed of the object at point A? Explain how you can tell.

C. An object travels from point A to point B while two constant forces, $\vec{F_3}$ and $\vec{F_4}$, of *unequal* magnitude are exerted on it as shown.

1. Is the total work done on the object by $\vec{F_3}$ *positive, negative,* or *zero?*

   • Point B

2. Is the total work done on the object by $\vec{F_4}$ *positive, negative,* or *zero?*

   $\vec{F_4}$

3. Is the net work done on the object *positive, negative,* or *zero?* Explain.

   $\vec{F_3}$

   Point A •

4. Is the speed of the object at point B *greater than, less than,* or *equal to* the speed of the object at point A? Explain how you can tell.

D. State the work-energy theorem in your own words. Are your answers in part B consistent with this theorem? Explain.

Are your answers in part C consistent with the work-energy theorem? Explain.

II. Work and electric fields

The diagram at right shows a top view of a positively charged rod. Points W, X, Y, and Z lie in a plane near the center of the rod. Points W and Y are equidistant from the rod, as are points X and Z.
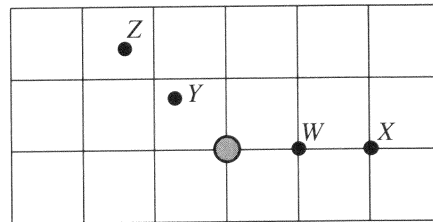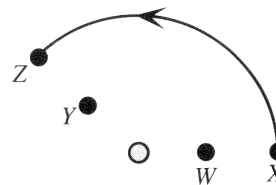
A. Draw electric field vectors at points W, X, Y, and Z.

B. A particle with charge $+q_o$ travels along a straight line path from point W to point X.

Is the work done *by the electric field* on the particle *positive, negative,* or *zero?* Explain using a sketch that shows the electric force on the particle and the displacement of the particle.
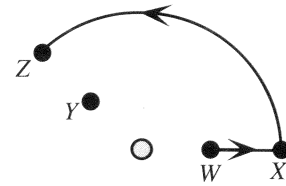
Compare the work done by the electric field when the particle travels from point W to point X to that done when the particle travels from point X to point W.

C. The particle travels from point X to point Z along the circular arc shown.

1. Is the work done *by the electric field* on the particle *positive, negative,* or *zero?* Explain. (*Hint:* Sketch the direction of the force on the particle and the direction of the displacement for several short intervals during the motion.)

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2. Compare the work done by the electric field when the particle travels from point W to point X to that done when the particle travels from point W to point Z along the path shown. Explain.

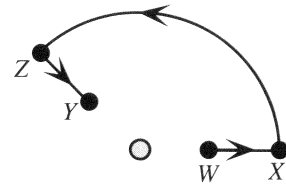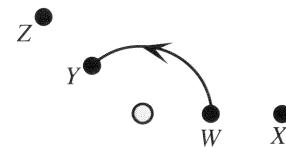D. Suppose the particle travels from point W to point Y along the path *WXZY* as shown.

1. Compare the work done by the electric field when the particle travels from point W to point X to that done when the particle travels from point Z to point Y. Explain.

What is the total work done on the particle by the electric field as it moves along the path *WXZY?*

2. Suppose the particle travels from W to Y along the arc shown. Is the work done on the particle by the electric field *positive, negative,* or *zero?* Explain using force and displacement vectors.

3. Suppose the particle travels along the straight path *WY*. Is the work done on the particle by the electric field *positive, negative,* or *zero?* Explain using force and displacement vectors. (*Hint:* Compare the work done along the first half of the path to the work done along the second half.)
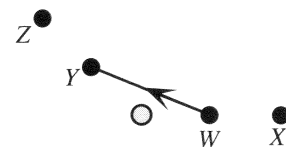
E. Compare the work done as the particle travels from point W to point Y along the three different paths in part D.

It is often said that the work done by a static electric field is *path independent*. Explain how your results in part D are consistent with this statement.

III. Electric potential difference

A. Suppose the charge of the particle in section II is increased from $+q_o$ to $+1.7q_o$.

1. Is the work done by the electric field as the particle travels from W to X *greater than, less than*, or *equal to* the work done by the electric field on the original particle? Explain.

2. How is the quantity *the work divided by the charge* affected by this change?

The *electric potential difference* ΔV_{WX} between two points W and X is defined to be:

$$\Delta V_{WX} = -\frac{W_{elec}}{q}$$

where W_{elec} is the work done by the field as a charge q travels from point W to point X.

3. Does this quantity depend on the *magnitude* of the charge of the particle that is used to measure it? Explain.

4. Does this quantity depend on the *sign* of the charge of the particle that is used to measure it? Explain.

B. Shown at right are four points near a positively
    charged rod. Points *W* and *Y* are equidistant from the
    rod, as are points *X* and *Z*. A charged particle with
    mass $m_o = 3 \times 10^{-8}$ kg is released from rest at point *W*
    and later is observed to pass point *X*.
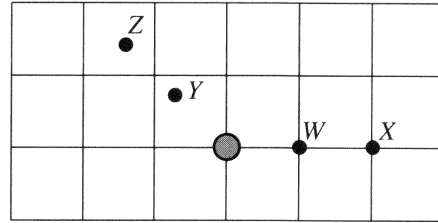
    1. Is the particle positively or negatively charged?
        Explain.

    2. Suppose that the magnitude of the charge on the particle is 2×10^{-6} C and that the speed
        of the particle is 40 m/s as it passes point *X*.

        a. Find the change in kinetic energy of the particle as it travels from point *W* to point *X*.

        b. Find the work done on the particle by the electric field between point *W* and point *X*.
            (*Hint:* See part D of section I.)

        c. Find the electric potential difference between point *W* and point *X*.

        d. If the same particle were released from point *Y*, would its speed as it passes point *Z*
            be *greater than*, *less than*, or *equal to* 40 m/s? Explain.

    3. Suppose that a second particle with the same mass as the first but nine times the charge
        (*i.e.*, 18×10^{-6} C) were released from rest at point W.

        a. Would the electric potential difference between points *W* and *X* change? If so, how,
            if not, why not?

        b. Would the speed of the second particle as it passes point *X* be *greater than*, *less than*,
            or *equal to* the speed of the first particle as it passed point *X?* Explain.

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4. A particle with mass $m_o = 3 \times 10^{-8}$ kg is launched toward the rod from point Z and turns around at point Y.

   a. If the particle has charge $q_o = 2 \times 10^{-6}$ C, with what speed should it be launched? Explain.

   b. If instead the particle has charge $9q_o$ (*i.e.*, 18×10^{-6} C) with what speed should it be launched? Explain.

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