Chapter 3 Electric Potential Energy

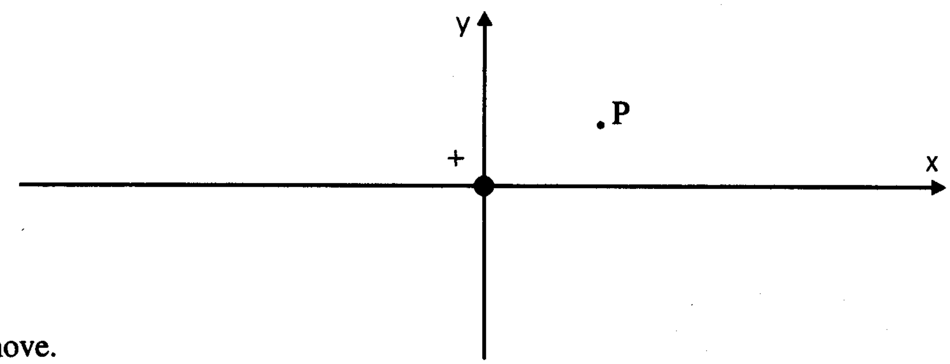
In-Class Questions

Prerequisite Concepts:

- **Positive and negative charge; Coulomb's law**
- **Definition of electric field**
- **Electric field of a parallel plate capacitor**
- **Kinetic energy and mechanical potential energy**
- **Definition of work; work/energy relationship**
- **Conservative forces/conservation of total energy**
- **Electrical force is conservative**

[Note: All gravitational forces may be ignored in this chapter]

1. *(Questions #1–6 refer to this figure.)* This figure shows a positive charge that is ***fixed in position*** at the origin. Suppose a positive charge q is placed at position P, and then released so that it (the charge q) is free to move. What will happen to this charge q?



   A. It will not move.
   B. It will move closer to the origin.
   C. It will move farther away from the origin.
   D. It will start moving closer to the origin, but then will reverse direction and start moving back out again.
   E. It will start moving away from the origin, but then will reverse direction and start moving back in again.

2. As the charge q moves, what will happen to the magnitude of the electrical force acting on it?
   A. The force will remain constant.
   B. The force will increase in magnitude.
   C. The force will decrease in magnitude, but never quite reach zero.
   D. The force will decrease in magnitude, and at a certain point will reach zero.
   E. The force will begin to decrease in magnitude, but then will start to increase again.

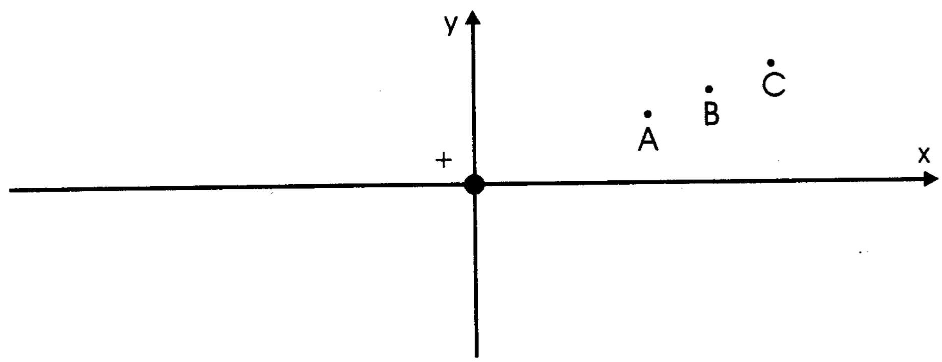
3. As the charge q moves, what will happen to its acceleration?
   - A. The acceleration will remain constant.
   - B. The acceleration will increase in magnitude.
   - C. The acceleration will decrease in magnitude, but never quite reach zero.
   - D. The acceleration will decrease in magnitude, but at a certain point will reach zero.
   - E. The acceleration will begin to decrease in magnitude, but then will start to increase again.

4. As the charge q moves, what will happen to its speed?
   - A. Its speed will remain constant.
   - B. Its speed will always increase.
   - C. Its speed will increase for a while, and then remain constant.
   - D. Its speed will increase for a while and then will start to decrease, but never quite reach zero.
   - E. Its speed will increase for a while, and then will start to decrease until it comes to rest.

5. As the charge q moves, what will happen to its kinetic energy?
   - A. Its kinetic energy will remain constant.
   - B. Its kinetic energy will always increase.
   - C. Its kinetic energy will increase for a while, and then remain constant.
   - D. Its kinetic energy will increase for a while and then will start to decrease, but will never quite reach zero.
   - E. Its kinetic energy will continuously decrease, until at some definite point it reaches zero.
   - F. Its kinetic energy will continuously decrease, but will never quite reach zero.

6. As the charge q moves, what will happen to its electric potential energy?
   - A. Its electric potential energy will remain constant.
   - B. Its electric potential energy will always increase.
   - C. Its electric potential energy will increase for a while, and then remain constant.
   - D. Its electric potential energy will increase for a while and then will start to decrease, but will never quite reach a constant minimum value.
   - E. Its electric potential energy will continuously decrease, until at some definite point it reaches a constant minimum value.
   - F. Its electric potential energy will continuously decrease, but will never quite reach a constant minimum value.

7. *(Questions #7–10 refer to this figure.)* In this figure (as in the previous one) a positive charge is fixed in position at the origin. Suppose a positive charge q is held at rest at position A, and then released and allowed to move freely. It passes through position B, and then moves on toward position C. Which of the following statements about charge q is true?



A. Its kinetic energy is the same at B and A, and its electric potential energy is the same at B and A.
B. Its kinetic energy is larger at B than at A, and its electric potential energy is larger at B than at A.
C. Its kinetic energy is smaller at B than at A, and its electric potential energy is smaller at B than at A.
D. Its kinetic energy is larger at B than at A, but its electric potential energy is smaller at B than at A.
E. Its kinetic energy is smaller at B than at A, but its electric potential energy is higher at B than at A.

8. This question again refers to the situation in Question #7. In comparing the energy of the charge q at positions C and B, which of the following statements is true?

A. Its kinetic energy is the same at C and B, and its electric potential energy is the same at C and B.
B. Its kinetic energy is larger at C than at B, and its electric potential energy is larger at C than at B.
C. Its kinetic energy is smaller at C than at B, and its electric potential energy is smaller at C than at B.
D. Its kinetic energy is larger at C than at B, but its electric potential energy is smaller at C than at B.
E. Its kinetic energy is smaller at C than at B, but its electric potential energy is higher at C than at B.

9. Again consider the setup shown in Question #7. Suppose now that a positively charged particle is shot from a gun that is located far away from the positive charge at the origin, but which is aimed directly at it. After leaving the gun the particle heads toward the origin, passing first through position C, then position B, and then position A. In comparing its energy at positions C and B, which of the following statements is true?

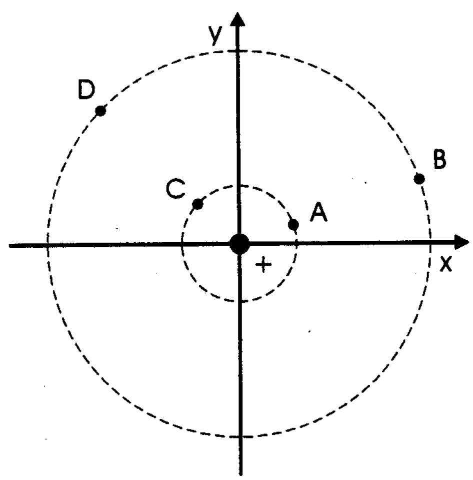
   A. Its kinetic energy and electric potential energy are both the same at C and B.
   B. Its kinetic energy and electric potential energy are both larger at C than at B.
   C. Its kinetic energy and electric potential energy are both smaller at C than at B.
   D. Its kinetic energy is larger at C than at B, but its electric potential energy is smaller at C than at B.
   E. Its kinetic energy is smaller at C than at B, but its electric potential energy is higher at C than at B.

10. Consider the situation described in #9. Let us call the ***magnitude*** of the change in kinetic energy $|\Delta KE|$, and the ***magnitude*** of the change in electric potential energy $|\Delta PE|$. Which of these is true about the energy of the particle shot from the gun, as it travels from position C to position B?

   A. $|\Delta KE| = |\Delta PE|$
   B. $|\Delta KE| > |\Delta PE|$
   C. $|\Delta KE| < |\Delta PE|$
   D. Not enough information to answer.

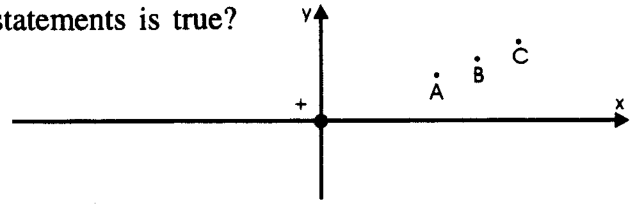
11. In this figure (as in the two previous ones), a positive charge is fixed in position at the origin. The dotted lines are circles centered at the origin. Suppose a positive charge q is placed at rest at position A on the inner circle, and then allowed to move freely until it passes position B on the outer circle. Its kinetic energy at that point is KE_B, and its electric potential energy is PE_B. Suppose now that the charge q is placed instead at rest at position C on the inner circle, and allowed to move freely. As it passes position D on the outer circle, its kinetic energy at that point is KE_D, and its electric potential energy is PE_D. Which of the following statements is true?

   A. $KE_B = KE_D$, and $PE_B = PE_D$
   B. $KE_B = KE_D$, and $PE_B > PE_D$
   C. $KE_B = KE_D$, and $PE_B < PE_D$
   D. $KE_B > KE_D$, and $PE_B < PE_D$
   E. $KE_B < KE_D$, and $PE_B > PE_D$
   F. Not enough information to answer this question.



It can be shown that the electric potential energy of a charge q in the neighborhood of another charge Q depends only on the values of q and Q, and on the distance between the two charges. Use this fact to help answer Questions #12–14 below.

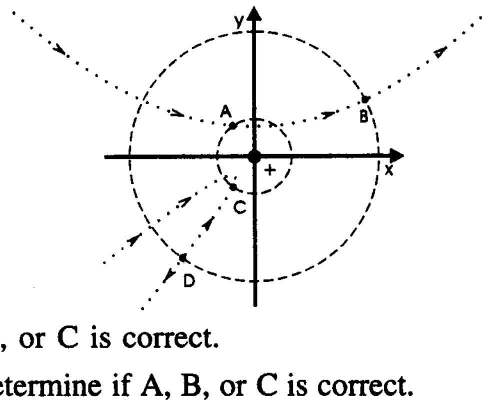
12. As in Questions #9 and #10, a positively charged particle is shot from a gun toward the origin, so that it travels on a path that takes it first through position C, and then through position B. First, the particle is shot from the gun at a "slow" speed, and the change in its potential energy between points C and B is ΔPE_{slow}. Then, the same particle is shot from the gun at a "fast" speed, and the change in its potential energy between points C and B is ΔPE_{fast}. Which of the following statements is true?



   A. $\Delta PE_{fast} > \Delta PE_{slow}$
   B. $\Delta PE_{fast} = \Delta PE_{slow}$
   C. $\Delta PE_{fast} < \Delta PE_{slow}$
   D. Need to know the actual speeds of the particle to determine if ΔPE_{fast} is larger than ΔPE_{slow}.

13. With regard to the particle discussed in problem #12, which of these statements regarding its change in *kinetic* energy is true?
   A. $\Delta KE_{fast} > \Delta KE_{slow}$
   B. $\Delta KE_{fast} = \Delta KE_{slow}$
   C. $\Delta KE_{fast} < \Delta KE_{slow}$
   D. Need to know the actual speeds of the particle to determine if ΔKE_{fast} is larger than ΔKE_{slow}.

14. In this figure, a positive charge is again fixed in position at the origin. Another positive charge q comes in along a trajectory that carries it through positions A and B, as shown. The change in its kinetic energy as it moves between these points is ΔKE_{AB}. An ***identical*** charge q comes in along a different trajectory, which carries it through positions C and D as shown. The change in its kinetic energy as it moves between these two points is ΔKE_{CD}. Which of the following statements is true?



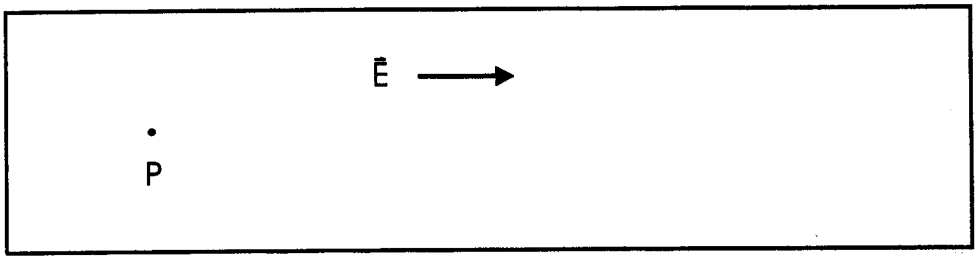
   A. $\Delta KE_{AB} = \Delta KE_{CD}$
   B. $\Delta KE_{AB} > \Delta KE_{CD}$
   C. $\Delta KE_{AB} < \Delta KE_{CD}$
   D. Need to know the magnitude of q to determine if A, B, or C is correct.
   E. Need to know the velocity and mass of the particle to determine if A, B, or C is correct.
   F. Need to know the magnitude of q, and the velocity and mass of the particle to determine if A, B, or C is correct.

In-Class Exercises

Questions #1–15 all refer to Figure 1 shown below.

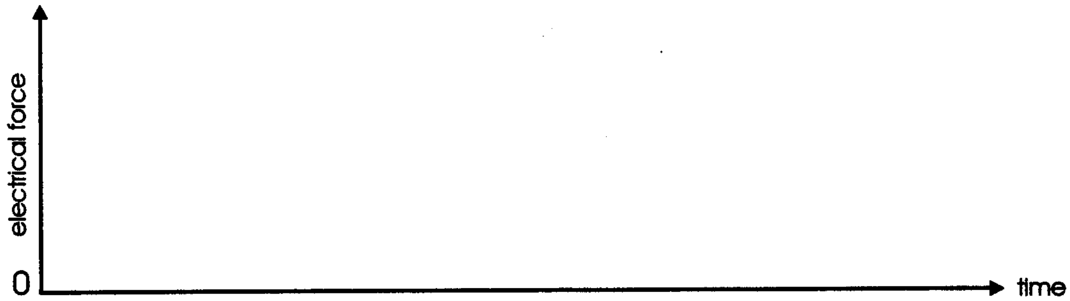
In Figure 1, a region of space is shown where the electric field ***everywhere has the same magnitude and direction***. The direction of the electric field is indicated by the arrow.

Fig. 1

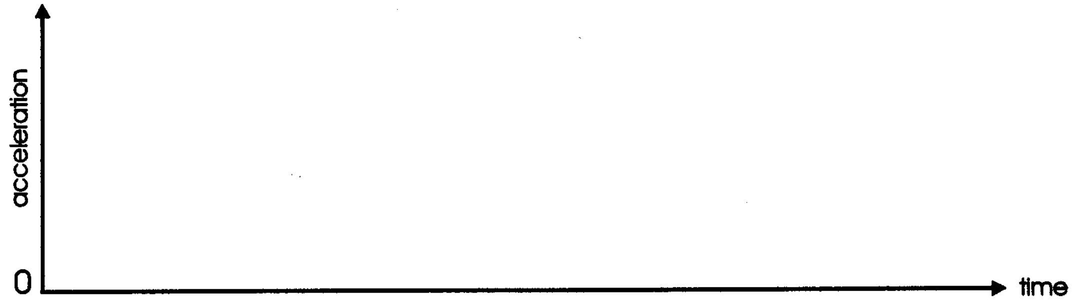


1. Suppose that a positive charge q is placed at position P, and then is released so that it (the charge q) is free to move. Draw a dotted line representing the path along which this particle will travel in the region shown.

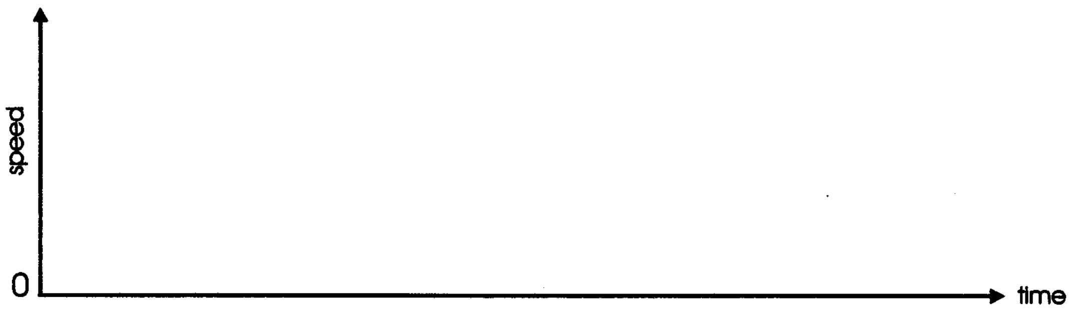
2. In the space below, sketch a graph of the magnitude of the electrical force acting on the particle q as a function of time, during the period that the particle is moving through the region.



3. In the space below, sketch a graph of the particle's acceleration as a function of time, during the period that the particle is moving through the region.



4. In the space below, sketch a graph of the particle's speed as a function of time, during the period that the particle is moving through the region.

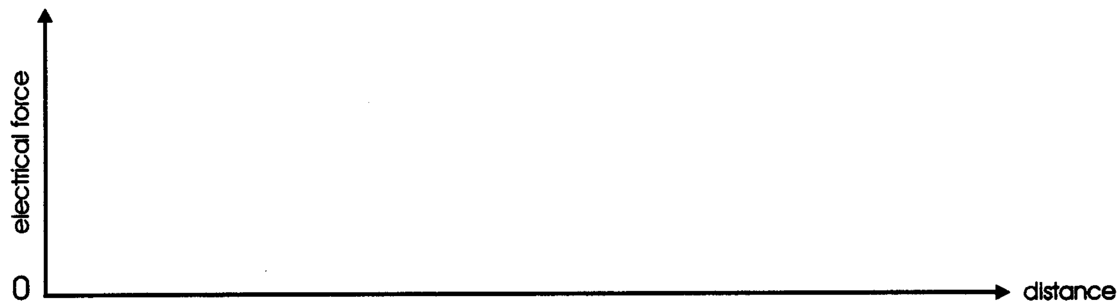


5. Along the path you have indicated in Figure 1, draw a number of arrows which indicate the velocity vectors of the particle q at different times. Indicate the speed of the particle at any given time by the length of the arrow.

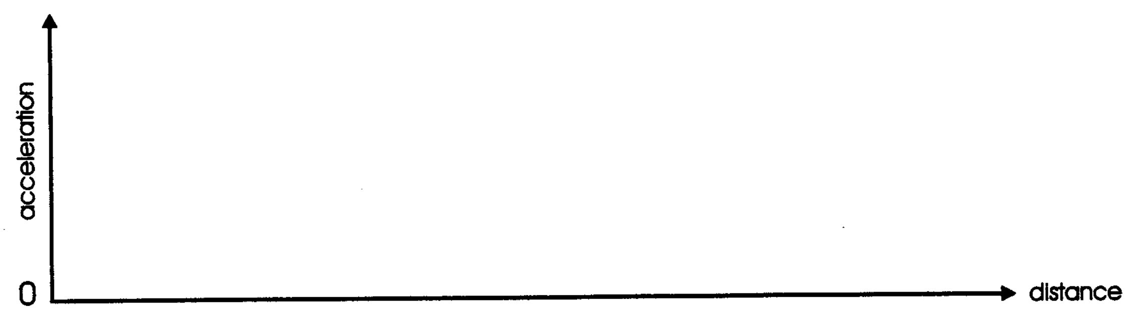
6. As the particle moves through the region, will its kinetic energy increase, decrease, or remain the same? Explain your answer.

7. As the particle moves through the region, will its electric potential energy increase, decrease, or remain the same? Explain your answer.

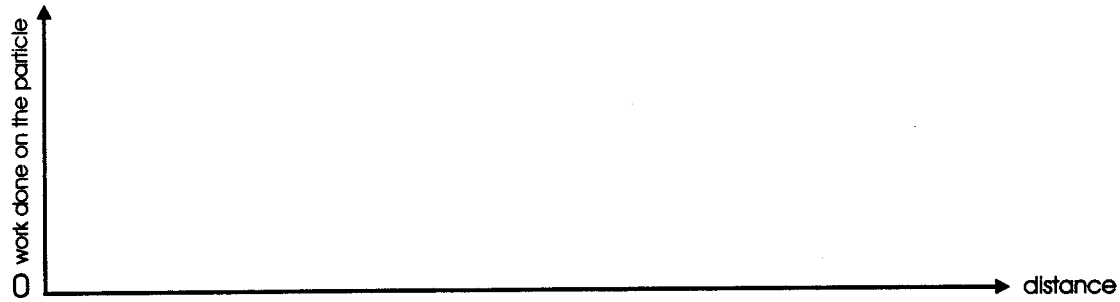
8. In the space below, sketch a graph of the magnitude of electrical force acting on the particle q as a function of *distance* traveled, during the period that the particle is moving through the region.



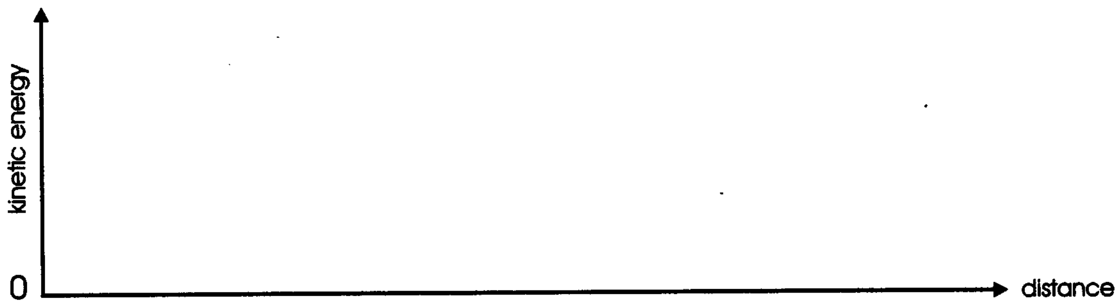
9. In the space below, sketch a graph of the particle's acceleration as a function of *distance* traveled, during the period that the particle is moving through the region.



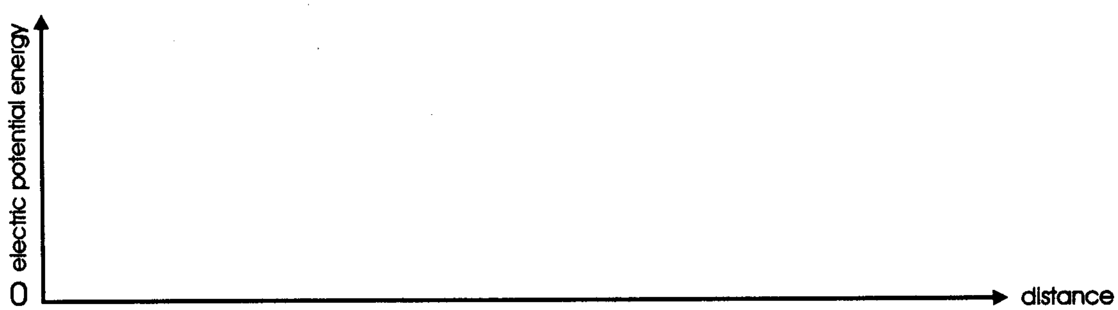
10. In the space below, sketch a graph of the work done ***on*** the particle by the electrical force, as a function of distance traveled, during the period that the particle is moving through the region.



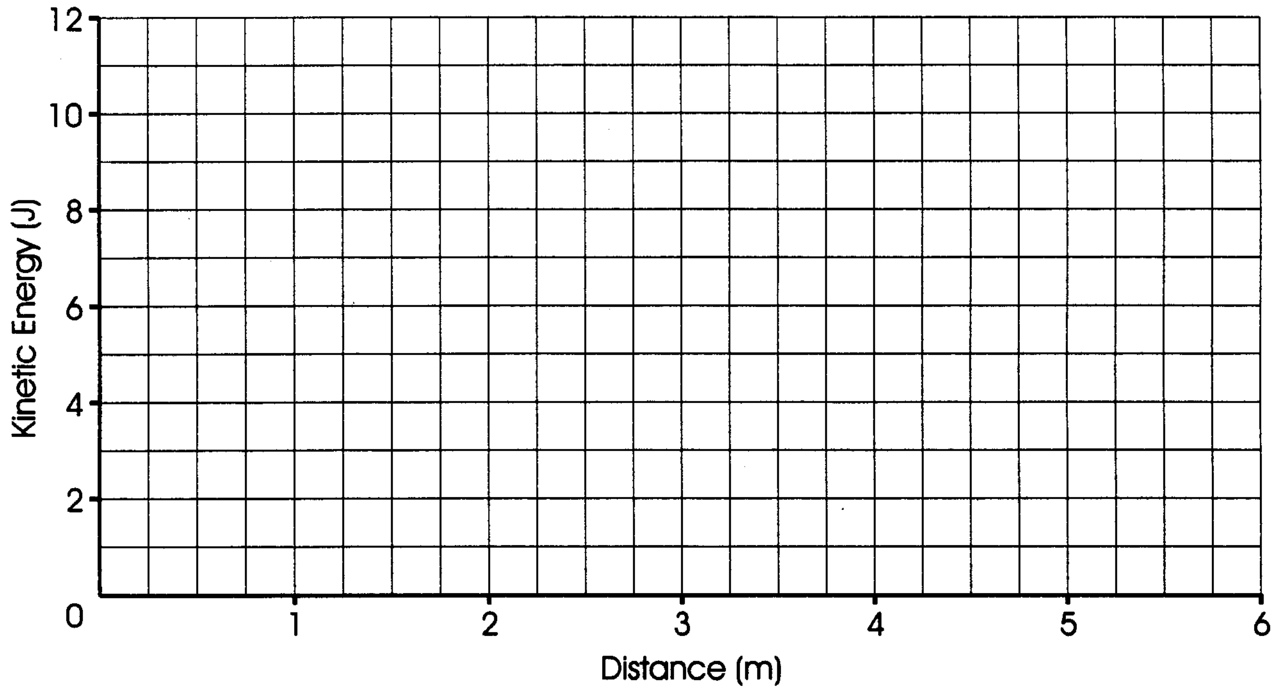
11. In the space below, sketch a graph of the particle's kinetic energy as a function of distance traveled, during the period that the particle is moving through the region.



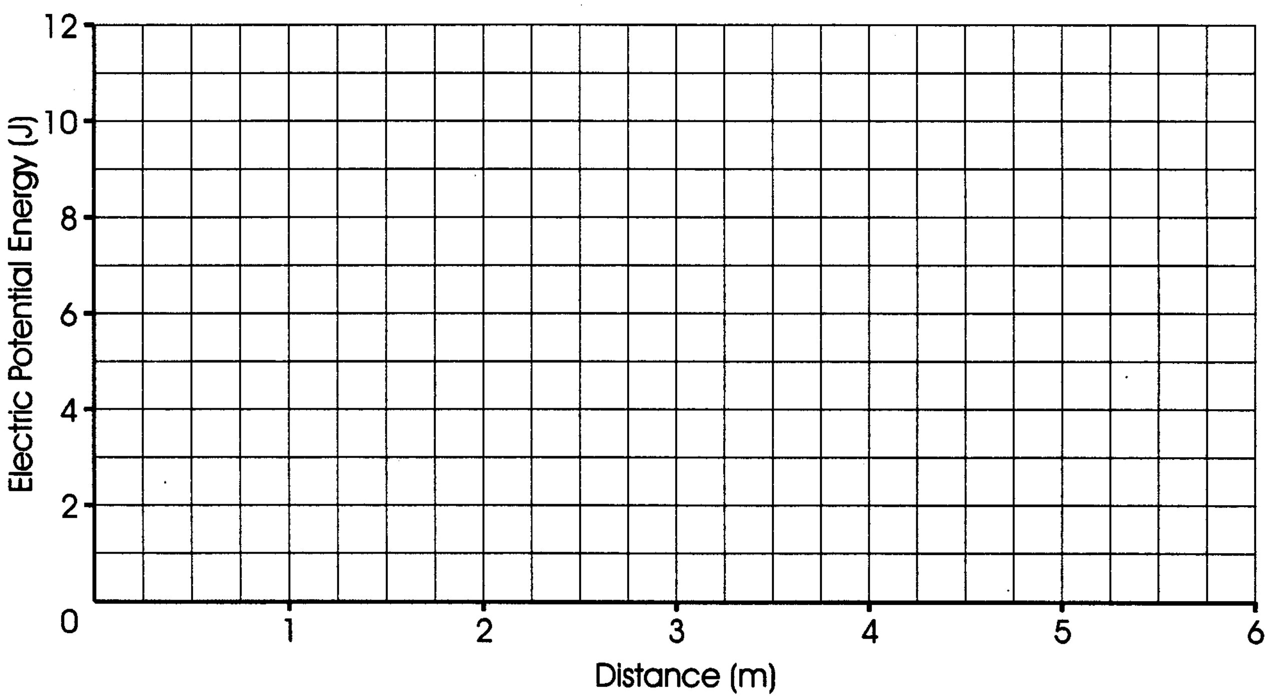
12. In the space below, sketch a graph of the particle's electric potential energy as a function of distance traveled, during the period that the particle is moving through the region. *Assume that the minimum value attained is equal to zero.*



13. Suppose the length of the region is 5 meters. Assume that the particle starts from rest on the left side (distance = 0 m), and that the kinetic energy of the particle when it reaches the other end of the region is 10 joules. In the space below, draw a graph of the particle's kinetic energy as a function of distance traveled, during the period that the particle is moving through the region.



14. For the particle described in #13, suppose that its ***total*** energy is 10 joules. In the space below, draw a graph of the particle's electric potential energy as a function of distance traveled, during the period that the particle is moving through the region.



15. Fill in the following chart, indicating the amount of increase (+) or decrease (–) of kinetic, potential, and total energy as the particle described in #13 and #14 moves through the region.

As the positive charge travels from:	**its kinetic energy increases (+) or decreases (–) by this amount:**	**its potential energy increases (+) or decreases (–) by this amount:**	**its total energy increases (+) or decreases (–) by this amount:**
0 m to 1 m			
1 m to 2 m			
2 m to 3 m			
3 m to 4 m			
4 m to 5 m			

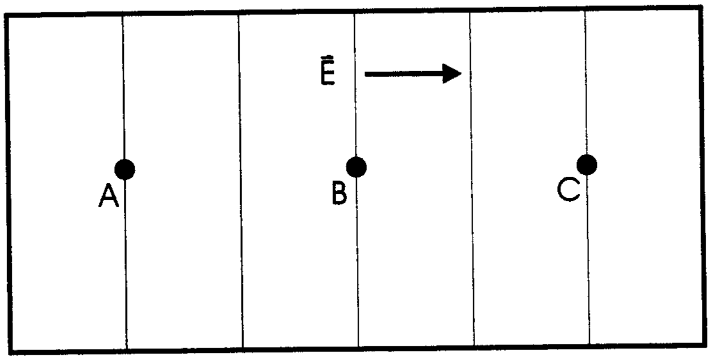
The magnitude of the electric potential energy (EPE) of a charged particle in a uniform electric field may be expressed as a mathematical equation involving *d*, the distance of the particle from the point where the value of its EPE = 0. The equation also contains a constant; let "C" represent this contant.

A. Find the equation for EPE in terms of *d* and the constant C.

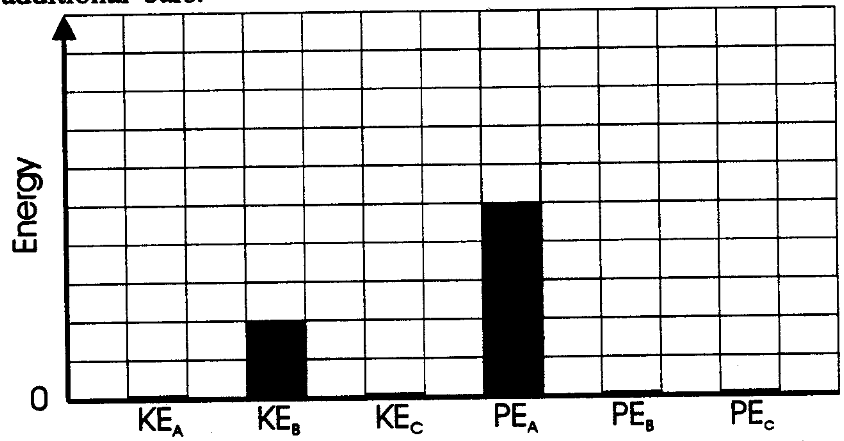
B. Find an expression for the constant C in terms of E (the magnitude of the electric field), and q (the magnitude of the charge).

In Figure 2, the same region of space is shown as in Figure 1. (A grid is shown in order to measure distances.)

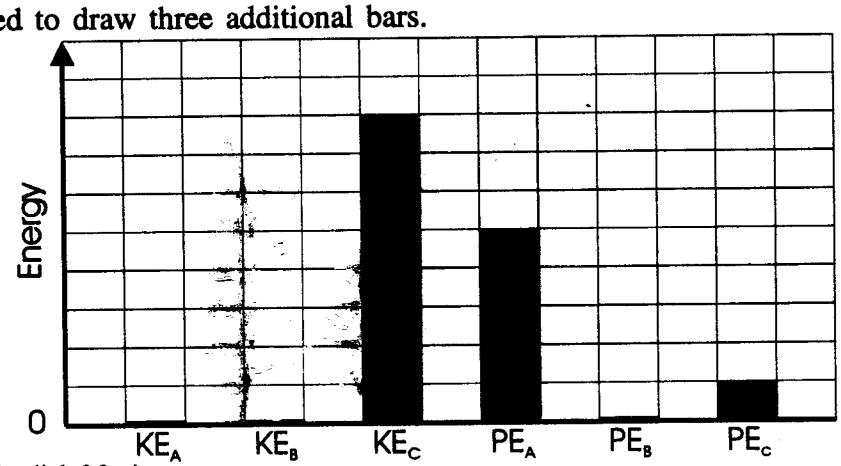
Fig. 2



16. A positive charge q is held at rest at position A, and then released and allowed to move freely. It passes through position B, and then moves on toward position C.
On the grid below, complete the bar graph to show the kinetic energy (KE) of the particle at A, B, and C, and the electric potential energy (PE) of the particle at A, B, and C. The kinetic energy at B (KE_B) and the electric potential energy at A (PE_A) are already shown; you need to draw four additional bars.



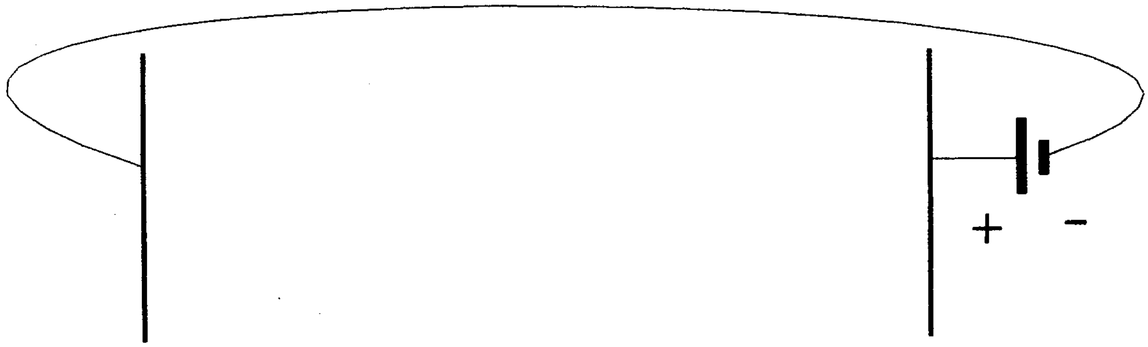
17. Suppose a positively charged particle is shot from a gun that is located on the right side of the region, but is pointed toward the left side. After leaving the gun the particle heads toward the left side, passing first through position C, then position B, and then position A. On the grid below, complete the bar graph to show the kinetic energy (KE) of the particle at A, B, and C, and the electric potential energy (PE) of the particle at A, B, and C. The kinetic energy at C (KE_C) and the electric potential energy at C (PE_C) *and* at A (PE_A) are already shown; you need to draw three additional bars.



Homework Exercises

In Figure 1, two parallel metal plates are connected to the terminals of a battery as shown. A positively charged particle (charge = +q) is held at rest on the right-hand plate, and then released and allowed to move freely. When it strikes the left-hand plate, its kinetic energy is 5 joules, and its total energy is 5 joules.

Fig. 1



1. Choose a starting position for this particle, and indicate it with a red dot. In red ink or pencil, draw a series of dots representing the position of this particle when its electric potential energy is 0 joules, 1 joule, 2 joules, 3 joules, 4 joules, and 5 joules. Label each dot (in red) with the appropriate potential energy.

2. Repeat #1, but choose a starting position for the particle that is at a different point on the right-hand plate.

3. Repeat #1, but choose a starting position for the particle that is at a different position on the right-hand plate from that used in #1 and #2.

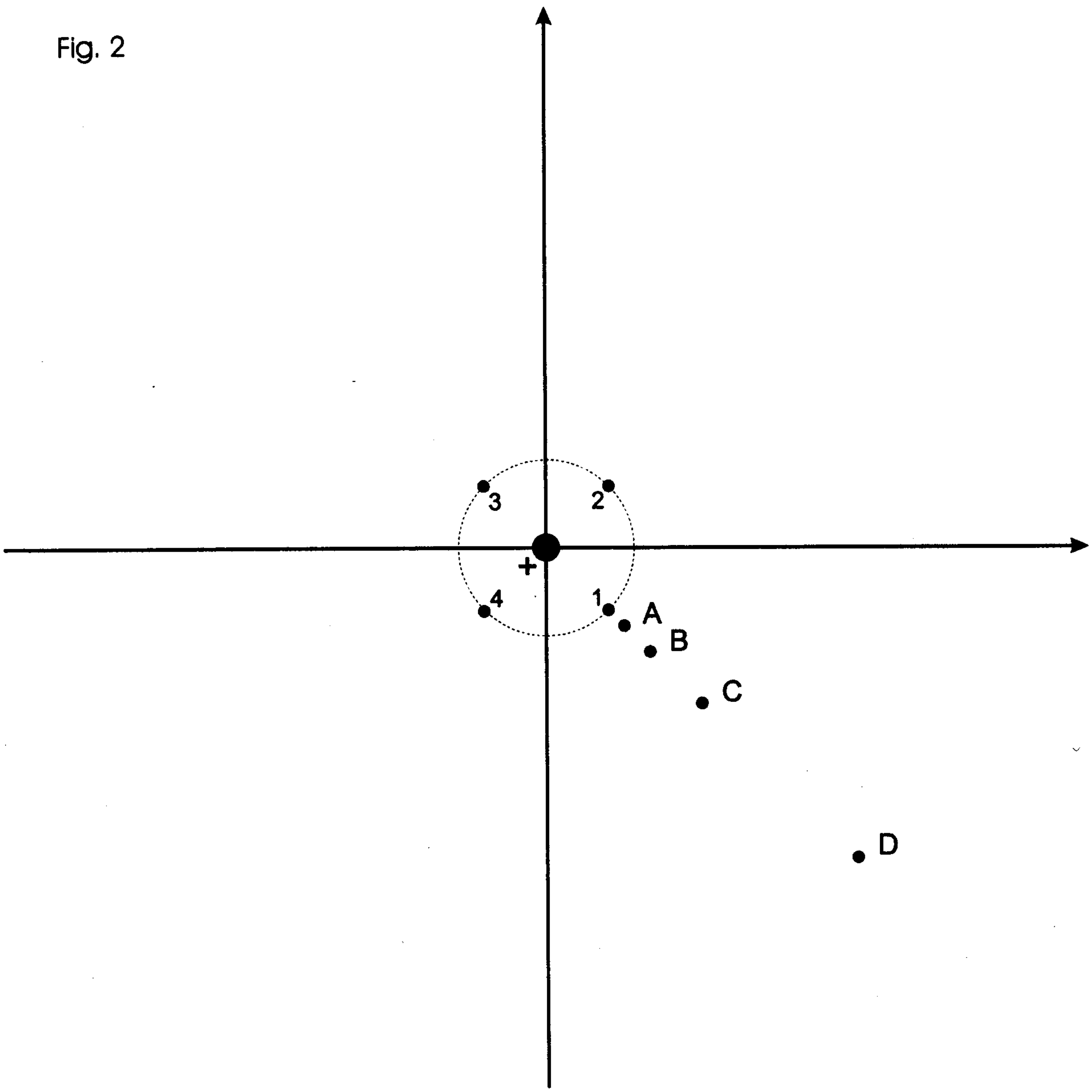
4. Suppose now that you repeated this process for many different starting positions of the particle, all located on the right-hand plate. In blue ink or pencil, draw four separate dashed lines connecting the locations of all of the resulting 1-joule points, the 2-joule points, the 3-joule points, and the 4-joule points.

5. Suppose a particle with ***negative*** charge –q is held at rest on the left-hand plate, then released and allowed to move freely. Assume that the total energy of this particle is also 5 joules. Choose a starting position for this particle, and indicate it with a blue dot. In blue ink or pencil, draw a series of dots indicating the positions where the electric potential energy of this particle equals 0 joules, 1 joule, 2 joules, 3 joules, 4 joules, and 5 joules. Label each dot (in blue) with the appropriate potential energy.

6. Suppose a positive charge q sits at rest on the left-hand plate, and you want to move it from its initial position to a new position, where you will hold it motionless. How much net energy will you have to provide to move it:
   to the right-hand plate?__________to a point exactly midway between the plates?__________
   Note: The total energy of this charged particle will not necessarily be 5 joules.

In Figure 2, a positive charge is fixed in place at the origin as shown. A positively charged particle is held at rest at position #1, and then released and allowed to move freely. The dots labeled A, B, C, and D indicate the points where this particle has kinetic energy of 1 joule, 2 joules, 3 joules, and 4 joules respectively.

Fig. 2



7. Assume that the initial value of the total energy of this particle (at point #1) is 5 joules. What is the electric potential energy of this particle at points

   #1: ________

   A: ________

   B: ________

   C: ________

   D: ________

8. As the particle continues to move farther and farther away from the origin — as it moves infinitely far away — its electric potential energy closely approaches one particular value. What is this value?________

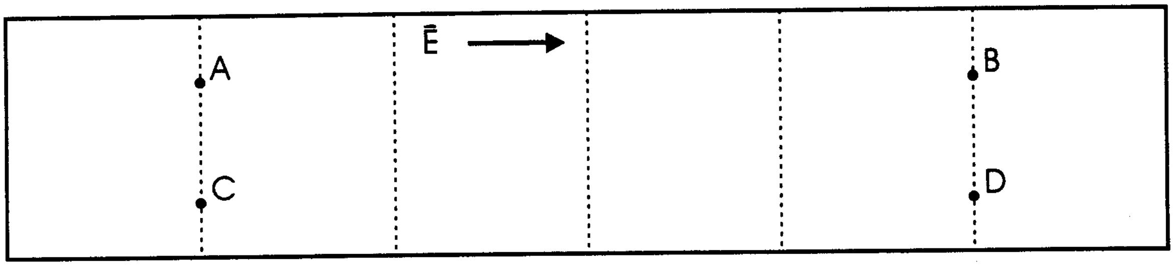
9. Now assume the same particle is held at rest at position #2, and then released and allowed to move freely. Draw a series of dots indicating its position when its electric potential energy is 1 joule, 2 joules, 3 joules, and 4 joules. Label the dots with the appropriate values.

10. Repeat #9, first assuming starting position #3, and then #4.

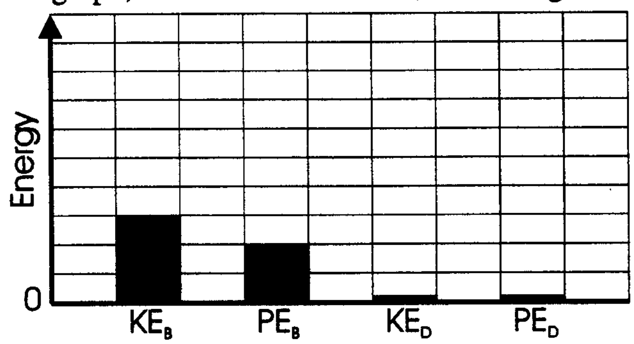
11. Suppose now that you repeated this process for many different starting positions of the particle, all located on the circle on which points #1–4 are located. In blue ink or pencil, draw four separate dashed lines connecting the locations of all of the resulting 1-joule points, the 2-joule points, the 3-joule points, and the 4-joule points.

12. Suppose you hold this particle at rest at position C, and then move it in to position A, at which point it is held at rest again. How much net energy must be supplied to carry out this transfer of position?________
    Note: In this case, the total energy of the particle will not necessarily be 5 joules.

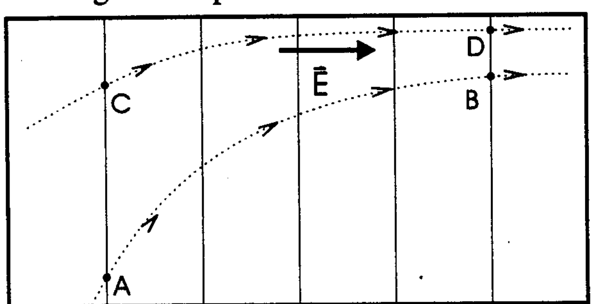
In this figure, a region of space is shown where the electric field everywhere has the same magnitude and direction. The direction of the electric field is indicated by the arrow.



13. Suppose a positive charge is placed at rest at position A, and then allowed to move freely until it passes position B. The bar graph below indicates its kinetic and potential energy at position B.
    Now suppose that the particle is placed at rest at position C, and allowed to move freely until it passes position D. On the same graph, draw two more bars, indicating the kinetic and potential energy at position D.



In this figure, the same region of space is shown as that in Exercise #13.



14. A positive charge is shot from a gun ***outside*** the region, and it travels along a trajectory that carries it first through position A, and then through position B. The bar graph indicates its kinetic energy at positions A and B.
    Now, the same charge is shot from another gun outside the region, this time following the trajectory shown that carries it first through position C, and then through position D. The bar graph below indicates the magnitude of KE_C. On the same graph, draw a bar indicating the kinetic energy of the particle at position D.