lowing us to use his materials. We thank the many professors who administered the CSEM and provided us with data and excellent comments. We also want to thank the many participants of the TYC Physics Workshop Project who provided expert comments at various stages of development of the surveys. We thank Robert Beichner and the other members of the North Carolina State University physics education research group for extensive feedback on a preliminary draft of this article. Finally we thank Bruce Sherwood and Ruth Chabay for allowing us to incorporate into the CSEM questions 3, 4, 5, 31, and 32, which they developed.

Appendix

Conceptual Survey in Electricity and Magnetism (CSEM) (Form H)

(Answer key is the same as Form G)

In any question referring to current, conventional current will be used (where conventional current is the flow of positive charges). In addition, all effects due to the earth's magnetic field will be so small that they will be ignored. Note that the term "particle" is meant to be an object without size or structure.

1. A hollow metal sphere is electrically neutral (no excess charge). A small amount of negative charge is suddenly placed at one point P on this metal sphere. If we check on this excess negative charge a few seconds later we will find one of the following possibilities:
   (a) All of the excess charge remains right around P.
   (b) The excess charge has distributed itself evenly over the outside surface of the sphere.
   (c) The excess charge is evenly distributed over the inside and outside surface.
   (d) Most of the charge is still at point P, but some will have spread over the sphere.
   (e) There will be no excess charge left.

2. A hollow sphere made out of electrically insulating material is electrically neutral (no excess charge). A small amount of negative charge is suddenly placed at one point P on the outside of this sphere. If we check on this excess negative charge a few seconds later we will find one of the following possibilities:
   (a) All of the excess charge remains right around P.
   (b) The excess charge has distributed itself evenly over the outside surface of the sphere.
   (c) The excess charge is evenly distributed over the inside and outside surface.
   (d) Most of the charge is still at point P, but some will have spread over the sphere.
   (e) There will be no excess charge left.

For questions 3 -5:
Two small objects each with a net charge of +Q exert a force of magnitude F on each other.

We replace one of the objects with another whose net charge is +4Q:

3. The original magnitude of the force on the +Q charge was F; what is the magnitude of the force on the +Q now?

   (a) 16F (b) 4F (c) F (d) F/4 (e) other

4. What is the magnitude of the force on the +4Q charge?

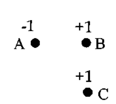
   (a) 16F (b) 4F (c) F (d) F/4 (e) other

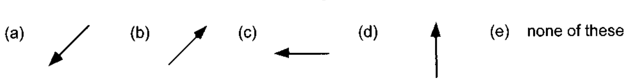
Next we move the +Q and +4Q charges to be 3 times as far apart as they were:

5. Now what is the magnitude of the force on the +4Q?

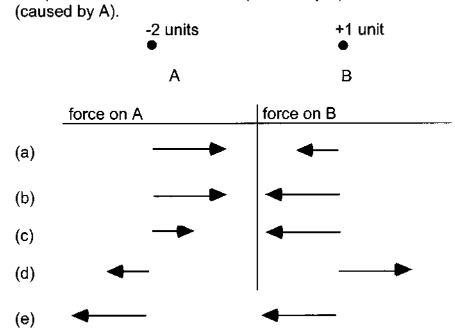
   (a) F/9 (b) F/3 (c) 4F/9 (d) 4F/3 (e) other

6. Which of the arrows is in the direction of the net force on charge B?

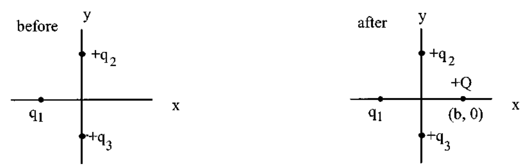




7. The picture below shows a particle (labeled B) which has a net electric charge of +1 unit. Several centimeters to the left is another particle (labeled A) which has a net charge of -2 units. Choose the pair of force vectors (the arrows) that correctly compare the electric force on A (caused by B) with the electric force on B (caused by A).

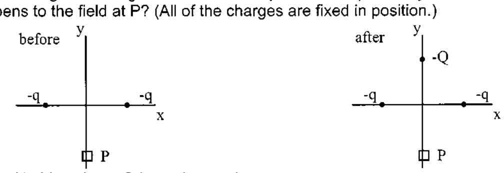


8. In the figure below, positive charges q_2 and q_3 exert on charge q_1 a net electric force that points along the +x axis. If a positive charge Q is added at (b,0), what now will happen to the force on q_1? (All charges are fixed at their locations.)



   (a) No change in the size of the net force since Q is on the x-axis.
   (b) The size of the net force will change but not the direction.
   (c) The net force will decrease and the direction may change because of the interaction between Q and the positive charges q_2 and q_3.
   (d) The net force will increase and the direction may change because of the interaction between Q and the positive charges q_2 and q_3.
   (e) Cannot determine without knowing the magnitude of q_1 and/or Q.

9. In the figure below, the electric field at point P is directed upward along the y-axis. If a negative charge -Q is added at a point on the positive y-axis, what happens to the field at P? (All of the charges are fixed in position.)



   (a) Nothing since -Q is on the y-axis.
   (b) Strength will increase because -Q is negative.
   (c) Strength will decrease and direction may change because of the interactions between -Q and the two negative q's.
   (d) Strength will increase and direction may change because of the interactions between -Q and the two negative q's.
   (e) Cannot determine without knowing the forces -Q exerts on the two negative q's.

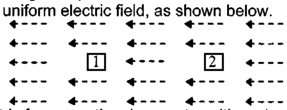
FOR QUESTIONS 10-11

A positive charge is placed at rest at the center of a region of space in which there is a uniform, three-dimensional electric field. (A uniform field is one whose strength and direction are the same at all points within the *region*.)

10. When the positive charge is released from rest in the uniform electric field, what will its subsequent motion be?
    (a) It will move at a constant speed.
    (b) It will move at a constant velocity.
    (c) It will move at a constant acceleration.
    (d) It will move with a linearly changing acceleration.
    (e) It will remain at rest in its initial position.

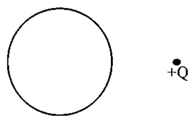
11. What happens to the electric potential energy of the positive charge, after the charge is released from rest in the uniform electric field?
    (a) It will remain constant because the electric field is uniform.
    (b) It will remain constant because the charge remains at rest.
    (c) It will increase because the charge will move in the direction of the electric field.
    (d) It will decrease because the charge will move in the opposite direction of the electric field.
    (e) It will decrease because the charge will move in the direction of the electric field.

12. A positive charge might be placed at one of two different locations in a region where there is a uniform electric field, as shown below.



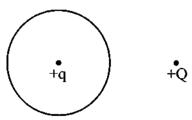
How do the electric forces on the charge at positions 1 and 2 compare?
(a) Force on the charge is greater at 1.
(b) Force on the charge is greater at 2.
(c) Force at both positions is zero.
(d) Force at both positions is the same but not zero.
(e) Force at both positions has the same magnitude but is in opposite directions.

13. The figure below shows a hollow conducting metal sphere which was given initially an evenly distributed positive (+) charge on its surface. Then a positive charge +Q was brought up near the sphere as shown. What is the direction of the electric field at the center of the sphere after the positive charge +Q is brought up near the sphere?



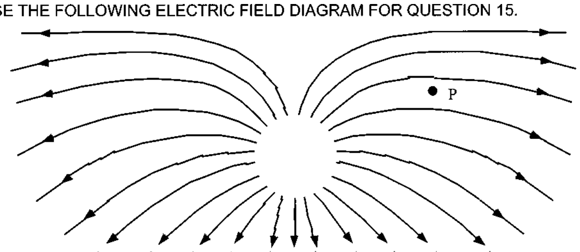
(a) Left
(b) Right
(c) Up
(d) Down
(e) Zero field

14. The figure below shows an electric charge q located at the center of a hollow uncharged conducting metal sphere. Outside the sphere is a second charge Q. Both charges are positive. Choose the description below that describes the net electrical forces on each charge in this situation.



(a) Both charges experience the same net force directed away from each other.
(b) No net force is experienced by either charge.
(c) There is no force on Q but a net force on q.
(d) There is no force on q but a net force on Q.
(e) Both charges experience a net force but they are different from each other.

USE THE FOLLOWING ELECTRIC FIELD DIAGRAM FOR QUESTION 15.



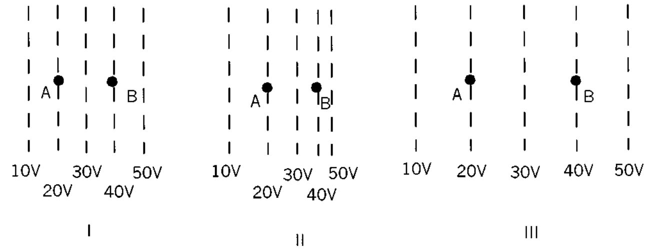
15. What is the direction of the electric force on a negative charge at point P in the diagram above?

(a) ← (b) ↙ (c) → (d) ↗ (e) the force is zero

16. An electron is placed at a position on the x-axis where the electric potential is + 10 V. Which idea below best describes the future motion of the electron?
(a) The electron will move left (-x) since it is negatively charged.
(b) The electron will move right (+x) since it is negatively charged.
(c) The electron will move left (-x) since the potential is positive.
(d) The electron will move right (+x) since the potential is positive.
(e) The motion cannot be predicted with the information given.

FOR QUESTIONS 17-19

In the figures below, the dotted lines show the equipotential lines of electric fields. (A charge moving along a line of equal potential would have a constant electric potential energy.) A charged object is moved directly from point A to point B. The charge on the object is +1 μC.

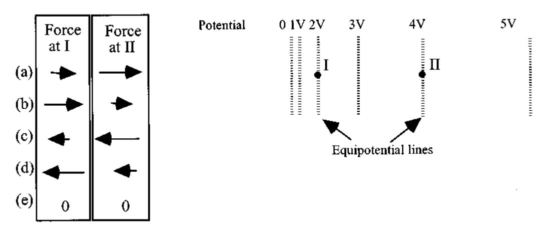


17. How does the amount of work needed to move this charge compare for these three cases?
(a) Most work required in I.
(b) Most work required in II.
(c) Most work required in III.
(d) I and II require the same amount of work but less than III.
(e) All three would require the same amount of work.

18. How does the magnitude of the electric field at B compare for these three cases?
(a) I > III > II
(b) I > II > III
(c) III > I > II
(d) II > I > III
(e) I = II = III

19. For case III what is the direction of the electric force exerted by the field on the + 1 μC charged object when at A and when at B?
(a) left at A and left at B
(b) right at A and right at B
(c) left at A and right at B
(d) right at A and left at B
(e) no electric force at either.

20. A positively-charged proton is first placed at rest at position I and then later at position II in a region whose electric potential (voltage) is described by the equipotential lines. Which set of arrows on the left below best describes the relative magnitudes and directions of the electric force exerted on the proton when at position I or II?

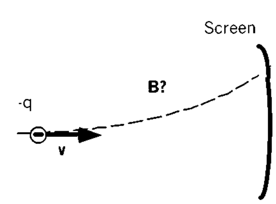


21. What happens to a positive charge that is placed at rest in a uniform magnetic field? (A uniform field is one whose strength and direction are the same at all points.)

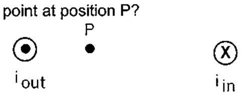
(a) It moves with a constant velocity since the force has a constant magnitude.
(b) It moves with a constant acceleration since the force has a constant magnitude.
(c) It moves in a circle at a constant speed since the force is always perpendicular to the velocity.
(d) It accelerates in a circle since the force is always perpendicular to the velocity.
(e) It remains at rest since the force and the initial velocity are zero.

22. An electron moves horizontally toward a screen. The electron moves along the path that is shown because of a magnetic force caused by a magnetic field. In what direction does that magnetic field point?

(a) Toward the top of the page
(b) Toward the bottom of the page
(c) Into the page
(d) Out of the page
(e) The magnetic field is in the direction of the curved path.

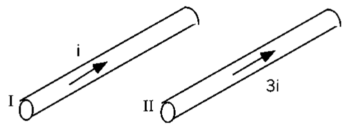


23. Wire 1 has a large current i flowing out of the page (⊙), as shown in the diagram. Wire 2 has a large current i flowing into the page (⊗). In what direction does the magnetic field point at position P?



(a) ↑ (b) ← (c) → (d) ↓ (e) none of the above.

24. Two parallel wires I and II that are near each other carry currents i and 3i both in the same direction. Compare the forces that the two wires exert on each other.



(a) Wire I exerts a stronger force on wire II than II exerts on I.
(b) Wire II exerts a stronger force on wire I than I exerts on II.
(c) The wires exert equal magnitude attractive forces on each other.
(d) The wires exert equal magnitude repulsive forces on each other.
(e) The wires exert no forces on each other.

25. The figures below represent positively charged particles moving in the same uniform magnetic field. The field is directed from left to right. All of the particles have the same charge and the same speed v. Rank these situations according to the magnitudes of the force exerted by the field on the moving charge, from greatest to least.

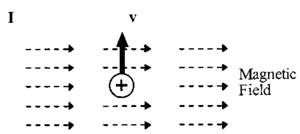
(a) I = II = III

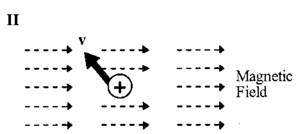
(b) III > I > II

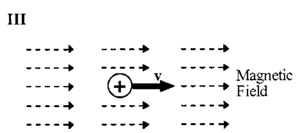
(c) II > I > III

(d) I > II > III

(e) III > II > I

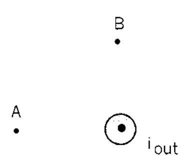




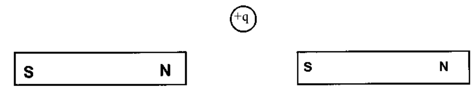


26. The diagram shows a wire with a large electric current i (⊙) coming out of the paper. In what direction would the magnetic field be at positions A and B?

	A	B
(a)	↓	←
(b)	→	↓
(c)	↑	→
(d)	←	↑
(e)	None of these	



27. A positively-charged particle (+q) is at rest in the plane between two fixed bar magnets, as shown. The magnet on the left is three times as strong as the magnet on the right. Which choice below best represents the resultant **MAGNETIC** force exerted by the magnets on the charge?



(a) → (b) ↙ (c) ← (d) ↘ (e) Zero

28. Two identical loops of wire carry identical currents i. The loops are located as shown in the diagram. Which arrow best represents the direction of the magnetic field at the point P midway between the loops?

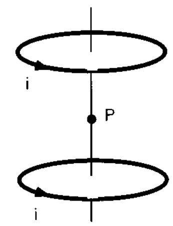
(a) ↓

(b) →

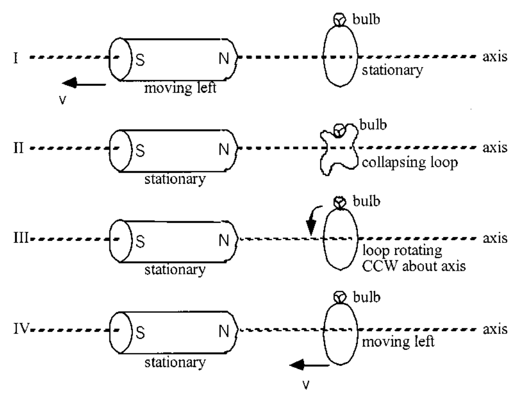
(c) ↑

(d) ←

(e) Zero



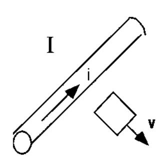
The five separate figures below involve a cylindrical magnet and a tiny light bulb connected to the ends of a loop of copper wire. These figures are to be used in the following question. The plane of the wire loop is perpendicular to the reference axis. The states of motion of the magnet and of the loop of wire are indicated in the diagram. Speed will be represented by v and CCW represents counter clockwise.

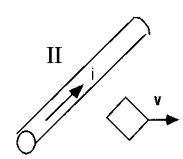


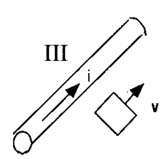
29. In which of the above figures will the light bulb be glowing?

(a) I, III, IV (b) I, IV (c) I, II, IV (d) IV (e) None of these

30. A very long straight wire carries a large steady current i. Rectangular metal loops, in the same plane as the wire, move with velocity **v** in the directions shown. Which loop will have an induced current?







(a) only I and II

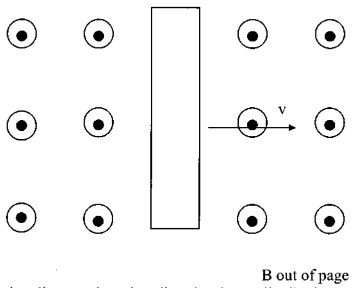
(b) only I and III

(c) only II and III

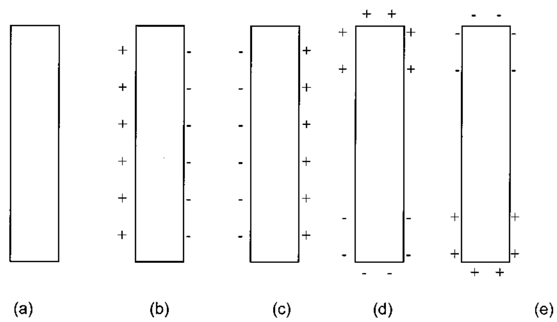
(d) all of the above.

(e) none of the above.

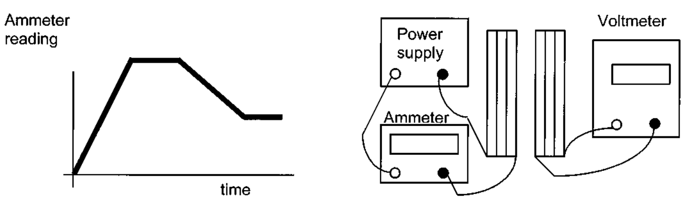
31. A neutral metal bar is moving at constant velocity v to the right through a region where there is a uniform magnetic field pointing out of the page. The magnetic field is produced by some large coils which are not shown on the diagram.



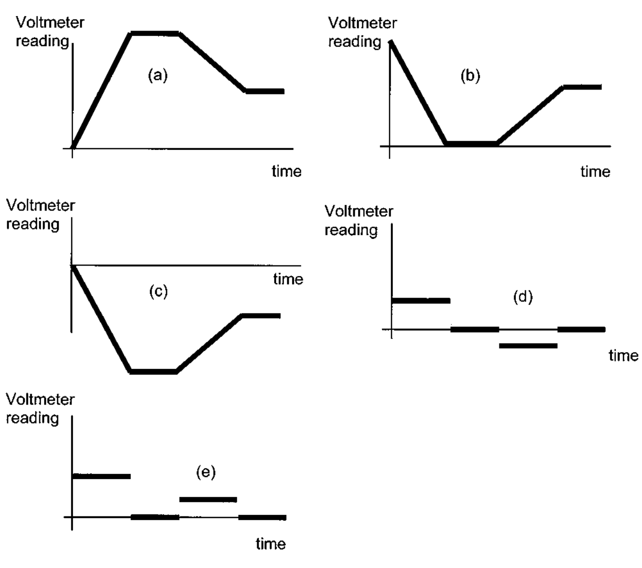
Which one of the following diagrams best describes the charge distribution on the surface of the metal bar?



32. A variable power supply is connected to a coil and an ammeter, and the time dependence of the ammeter reading is shown. A nearby coil is connected to a voltmeter.



Which of the following graphs correctly shows the time dependence of the voltmeter reading?



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