Name: ________________________

Class: ________________________

Due Date: ________________________

D.2 Electric and Magnetic Fields

Understandings

- The direction of forces between the two types of electric charge.
- Coulomb's law as given by $F = k\frac{q_1 q_2}{r^2}$ for charged bodies treated as point charges where $k = \frac{1}{4\pi\varepsilon_0}$.
- The conservation of electric charge.
- Millikan's experiment as evidence for quantization of electric charge.
- The electric charge can be transferred between bodies using friction, electrostatic induction, and by contact, including the role of grounding (earthing).
- The electric field strength as given by $E = \frac{F}{q}$.
- Electric field lines.
- The relationship between field line density and field strength.
- The uniform electric field strength between parallel plates as given by $E = \frac{V}{d}$.
- Magnetic field lines.

Equations

$F = k\frac{q_1 q_2}{r^2}$ where $k = \frac{1}{4\pi\varepsilon_0}$

$E = \frac{F}{q}$

$E = \frac{V}{d}$

Additional HL Understandings

- The electric potential energy E_p in terms of work done to assemble the system from infinite separation.
- The electric potential energy for a system of two charged bodies as given by $E_\mathrm{p} = k\frac{q_1 q_2}{r}$.
- The electric potential is a scalar quantity with zero defined at infinity.
- The electric potential V_e at a point is the work done per unit charge to bring a test charge from infinity to that point as given by $V_\mathrm{e} = \frac{kQ}{r}$.
- The electric field strength E as the electric potential gradient as given by $E = -\frac{\Delta V_\mathrm{e}}{\Delta r}$.
- The work done in moving a charge q in an electric field as given by $W = q\Delta V_\mathrm{e}$.
- Equipotential surfaces for electric fields.
- The relationship between equipotential surfaces and electric field lines.

Additional HL Equations

$E_\mathrm{p} = k\frac{q_1 q_2}{r}$

$V_\mathrm{e} = \frac{kQ}{r}$

$E = -\frac{\Delta V_\mathrm{e}}{\Delta r}$

$W = q\Delta V_\mathrm{e}$

If you are interested in learning more about electricity and magnetism then please read the book *Electricity and Magnetism* by Edward M. Purcell and David J. Morin.

Important! *Electric potential* and *electric potential energy* are not the same! Compare the definitions, equations, and units!

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Part 1: Use your favorite sources to answer the following questions

1. C: What is *charge q*? Units?

2. C: What is the difference between an *electrical conductor* and an *electrical insulator*? Give two examples of each.

3. C: Two charged objects with the same charge will ______ each other while two charged objects with the opposite charge will ______ each other.

4. C: State the charge, in Coulombs, of each particle:

   a. Neutron
   b. Proton
   c. Electron

5. C: There is a metal sphere which has a net positive charge.

   a. Is there any negative charge in it?

   b. Where does the extra positive charge go?

6. C: State the *law of conservation of charge.*

7. E: A pith ball has a surplus of 4.20×10^{15} electrons. What will be the net charge on this ball in Coulombs?

8. E: A pith ball has a shortage of 1.85×10^{17} electrons. What is the net charge on this ball in Coulombs?

9. E: How many electrons will be contained in a net charge of 1,250 μC?

10. E: A pith ball, which has a residual charge of -36 μC, is brought into contact with a second, identical pith ball which is initially neutral, allowing charge to flow between them. These two balls are then separated.

    a. What will be the final residual charge on each pith ball?

    b. How many extra electrons will be present on each ball after they have been separated?

11. E: A pith ball, which has a residual charge of +54 μC, is brought in contact with a second identical pith ball which has an initial residual charge of -38 μC. What will be the final residual charge on each pith ball after they have been separated?

12. E: A pith ball, which has a residual charge of +66 μC, is brought in contact with a second pith ball which has an initial residual charge of -33 μC and which has twice the surface area of the first pith ball. What will be the final residual charge on each pith ball after they have been separated?

13. C: Define and give the units of each variable in *Coulomb's Law* $\vec{F}_{\text{electric}} = k\frac{q_1 q_2}{r^2}$. What is the minimum number of objects required to use *Coulomb's law*?

14.C: Define relative permittivity ε_{r}.

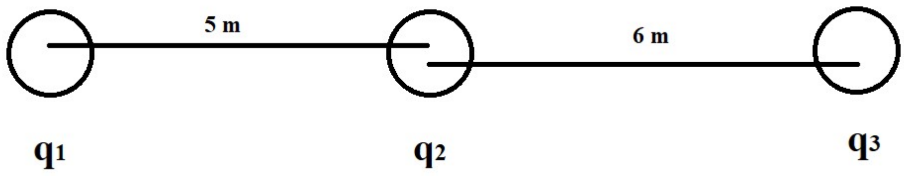
15.E: What will be the magnitude of the electrostatic force between two identical pith balls, each of which has a residual charge of 24.0 μC, which are 15.0 cm apart?

16.E: What will be the magnitude of the electrostatic force between two pith balls 23.0 cm apart if the residual charge on the first ball is -31.0 μC while the residual charge on the second ball is 12.0 μC?

17.E: What will be the electrostatic force between a proton and an electron when they are placed 0.5 Angstroms apart?

18.E: What will be the magnitude of the electrostatic force between two protons in the nucleus of an atom which are approximately 3.00×10^{-15} m apart?

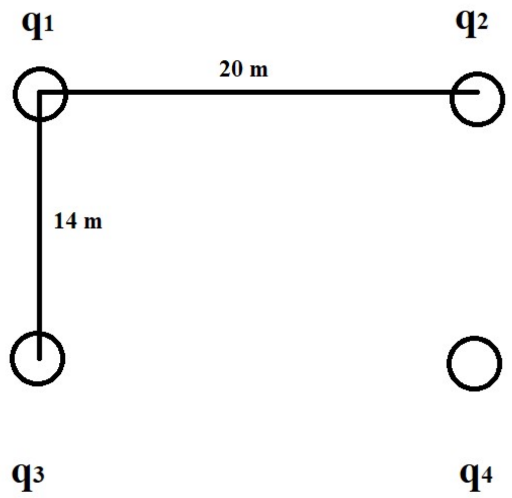
19. E: Use Coulomb's law to determine the electric force on a point charge.



$q_1 = +2 \times 10^{-9}$ C
$q_2 = -3 \times 10^{-9}$ C
$q_3 = +4 \times 10^{-9}$ C

a. q_1 and q_2 are fixed. Find the force on q_3.
b. q_1 and q_3 are fixed. Find the force on q_2.
c. q_2 and q_3 are fixed. Find the force on q_1.

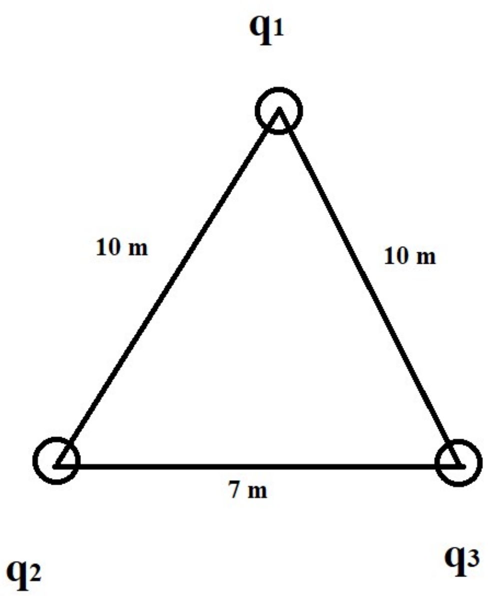
20.C: Use Coulomb's law to calculate the electric force on a point charge.



$q_1 = +2 \times 10^{-9}$ C
$q_2 = -3 \times 10^{-9}$ C
$q_3 = -4 \times 10^{-9}$ C
$q_4 = +5 \times 10^{-9}$ C

a. q_1, q_2, and q_3 are fixed. Find the force on q_4.
b. q_1, q_2, and q_4 are fixed. Find the force on q_3.
c. q_1, q_3, and q_4 are fixed. Find the force on q_2.
d. q_2, q_3, and q_4 are fixed. Find the force on q_1.

21.E: Use Coulomb's law to calculate the electric force on a point charge.



$q_1 = +2 \times 10^{-9}$ C
$q_2 = -3 \times 10^{-9}$ C
$q_3 = -3 \times 10^{-9}$ C

Point charges q_2 and q_3 are fixed. Find the force on q_1.

22.C: Explain the meaning of charge being quantized.

23.C: Give an example of how two objects can transfer electric charge by

a. friction

b. electrostatic induction

c. contact

d. grounding/earthing

24.C: Define *electric field strength* $\vec{E} = \frac{\vec{F}}{q} = k\frac{q_1}{r^2}$. What is the minimum number of objects required to use the equation for *electric field strength*?

25.C: Draw a graph of electric field vs. distance of a positively charged solid sphere.

26.E: What will be the strength of the electric field at a point in space where a 5.00 μC charge feels an electrostatic force of $F = 0.0450$ N?

27.E: A charge of 8.50 μC is placed in a uniform electric field which has an intensity of $E = 8.00 \times 10^3\ \frac{\text{N}}{\text{C}}$. What will be the magnitude of the resulting force?

28.E: A proton is placed in a uniform electric field which has an intensity of $6.50 \times 10^5\ \frac{\text{N}}{\text{C}}$.

a. What will be the magnitude of the resulting electrostatic force?

b. What will be the resulting acceleration of the proton as a result of this field?

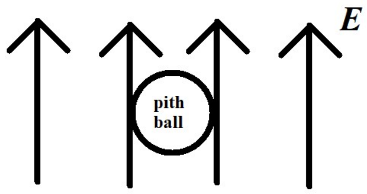
29.E: What will be the electric field strength 45.0 cm from a pith ball which has a residual charge of 5.50 μC?

30.E: What will be the electric field strength a distance 2,450 Angstroms from the nucleus of

a. a helium atom?

b. a carbon atom?

31.E: A small pith ball, which has a mass of 0.056 g and contains a residual charge of 5.00 μC, is sitting in a vertically oriented electric field as shown below. The force of gravity acting downward on this ball is exactly balanced by the electric field directed upward.

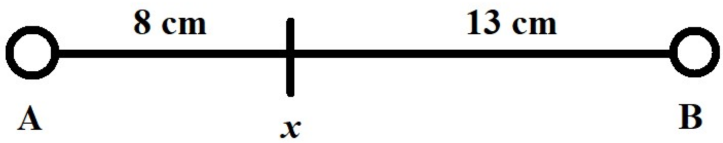


a. What will be the gravitational force acting on the pith ball?

b. What will be the magnitude of the electrostatic force acting on the pith ball?

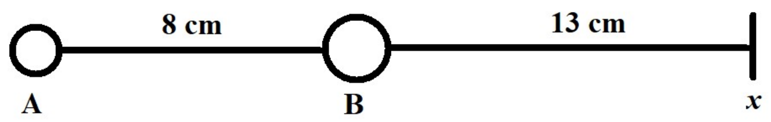
c. What is the magnitude of the electric field that is supporting this ball?

32.E: Determine the magnitude and direction of the electric field at point *x*.



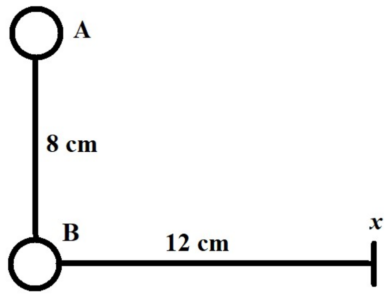
$Q_{\mathrm{A}} = -5.00 \times 10^{-6}\ \mathrm{C}$
$Q_{\mathrm{B}} = +7.20 \times 10^{-6}\ \mathrm{C}$

33.E: Determine the magnitude and direction of the electric field at point *x*.



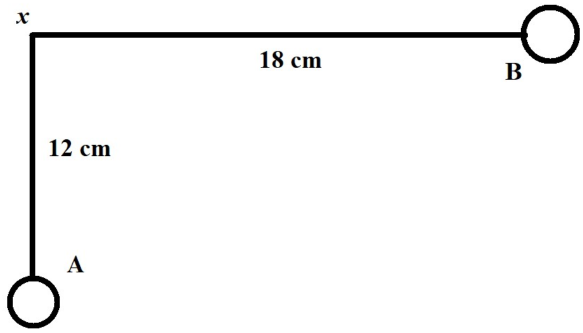
$Q_A = -5.00 \times 10^{-6}$ C
$Q_B = +7.20 \times 10^{-6}$ C

34.E: Determine the magnitude and direction of the electric field at point *x*.



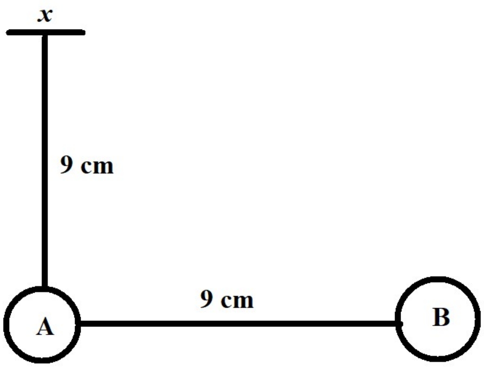
$Q_A = +1.20 \times 10^{-5}$ C
$Q_B = -8.00 \times 10^{-6}$ C

35.E: Determine the magnitude and direction of the electric field at point *x*.



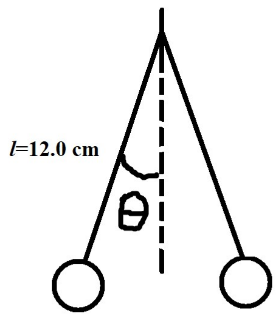
$Q_A = -8.00 \times 10^{-6}$ C
$Q_B = +1.20 \times 10^{-5}$ C

36.E: Determine the magnitude and direction of the electric field at point *x*.



$Q_{\mathrm{A}} = -8.00 \times 10^{-6}\ \mathrm{C}$
$Q_{\mathrm{B}} = -5.00 \times 10^{-6}\ \mathrm{C}$

37.E: Two pith balls, each of which is suspended from the end of a piece of very thin thread, are attached to a common point of suspension. Each pith ball has a mass of 0.130 g and each piece of thread is 12.0 cm long. Each of the two pith balls is given a net charge and as a result the two balls repel one another until the angle between a pith ball and the vertical increases to 16.0°.



a. What will be the magnitude of the electrostatic force between these two balls?

b. Determine the magnitude of the charge on each ball if the charge is distributed evenly between the two balls.

c. Assuming that this charge is negative, how many excess electrons would be found on each ball?

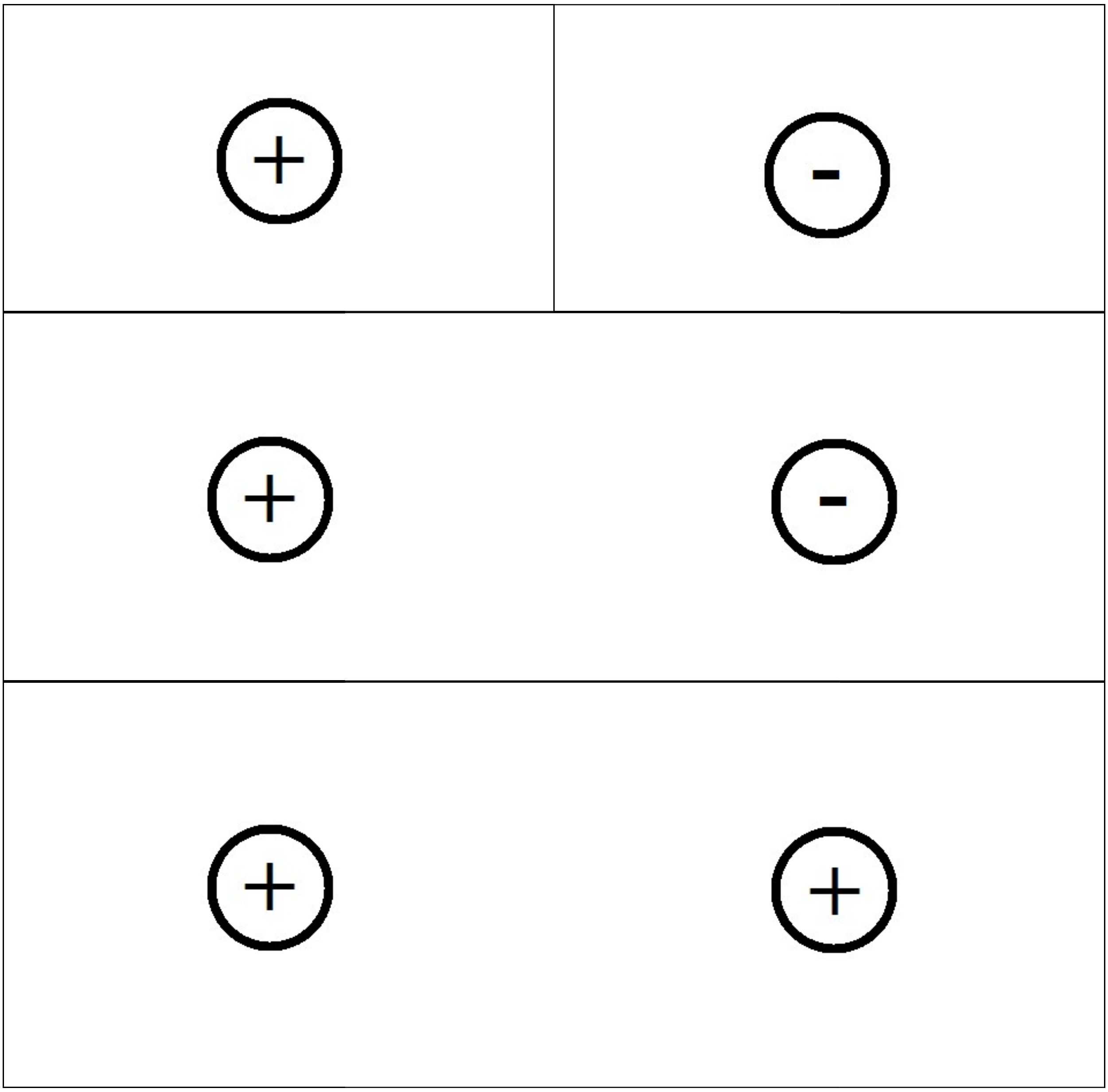
38.C: Define *electric potential difference*. Units?

39.C: What are the units of *voltage*?

40.C: Define *electron-volt*.

41.C: List some rules for drawing electric field lines.

42.C: **Use a pencil and ruler!** Draw electric field lines for each figure.



43.C: **Use a pencil and ruler!**

a. Draw charged *parallel plates*.

b. Draw (and label) six electric field lines between the parallel plates.

c. If a positive charge is placed between the plates then in which direction will it accelerate?

d. If a negative charge is placed between the plates then in which direction will it accelerate?

e. Which variable is constant between charged parallel plates?

f. Define each variable for the equation for parallel plates $V = Ed$.

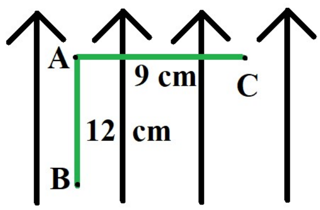
44.E: A charge of 15.0 μC is placed in a uniform electric field which has a field strength of $E = 8.80 \times 10^4 \ \frac{\text{N}}{\text{C}}$.

a. What will be the magnitude of the electrostatic force acting on this charge?

b. How much work would be done in moving this charge a distance of 135 cm against the electric field?

c. What will be the potential difference between these two points?

45.E: A proton is placed at point A in a uniform electric field which has a field strength of $E = 4.50 \times 10^3 \ \frac{\text{N}}{\text{C}}$ and which is directed toward the top of the page as shown in the diagram below:



a. What will be the direction of the electrostatic force acting on this proton while at point A?

b. What will be the magnitude of the electrostatic force acting on this proton while at point A?

c. How much work will be done in moving this charge a distance of 12.0 cm against this electric field to point B?

d. How will the electrostatic potential at point B in this field compare with the electrostatic potential at point A?

e. What will be the potential difference between points A and B?

Suppose that this proton is then released and is allowed to accelerate back to point A.

f. What will be the velocity of this proton when it returns to point A?

Suppose that the proton is again at rest at point A.

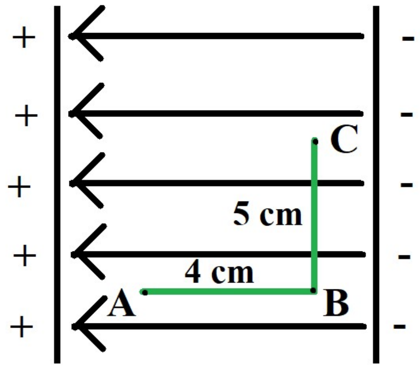
g. How much work would be done in moving this proton from point A to point C?

h. How will the electrostatic potential at point C compare to the electrostatic potential at point A?

i. What will be the potential difference between point C and point B?

j. How much work will have to be done on a proton to move it from point C to point B?

46.E: Two parallel plates are arranged as shown below. The electric field between the plates is uniform and is directed from the positive plate to the negative plate. The electric field strength is $E = 6.00 \times 10^4 \ \frac{\mathrm{N}}{\mathrm{C}}$ and the two plates are $d = 6.00$ cm apart. A particle, which has a charge of $q = -0.0150\ \mu\mathrm{C}$, is initially placed at point A.



a. How much work would have to be done to move this particle from point A to point B?

b. What is the potential difference between point A and point B?

c. How much work would have to be done in moving this particle from point A to point C?

d. What is the potential difference between points B and C?

Suppose that another particle, which has a charge of $2.00\ \mu\mathrm{C}$, is placed, initially, on the negative plate. This particle is then moved from the negative plate to the positive plate.

e. How much work would be done in moving this particle from the negative plate to the positive plate?

f. What will be the potential difference between these two plates?

47.C: List some differences between the electric force and the magnetic force.

48.C: What are two situations in which magnetic fields are observed?

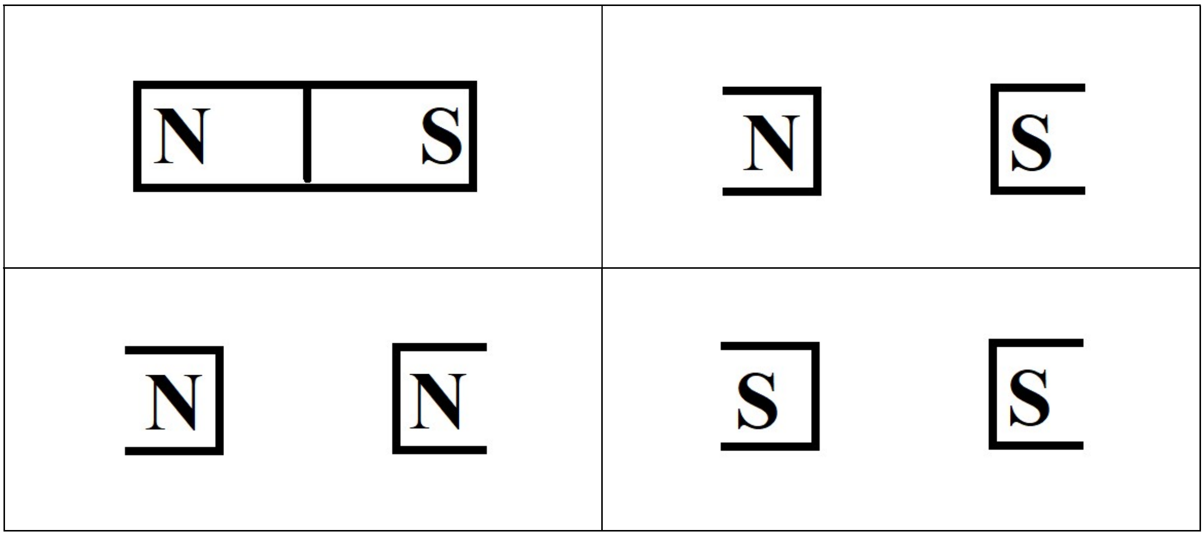
49.C: List some metals which have magnetic properties.

50.C: Define *hard magnet*. Define *soft magnet.*

51.C: How can you demagnetize a magnet?

52.C: Give some rules for drawing magnetic field lines.

53.C: **Use a pencil and ruler!** For each figure draw six magnetic field lines with arrows.



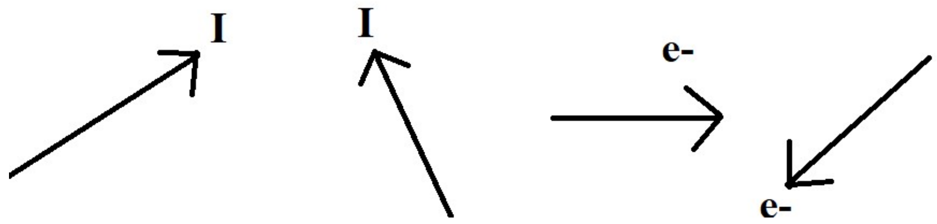
54.C: Draw and label the Earth's magnetic north pole (MN), magnetic south pole (MS), geographic north pole (GN), and geographic south pole (GS). Draw four magnetic field lines with arrows.

55.C: What are some differences between magnetic field lines and electric field lines?

56.C: What is a *magnetic monopole*? Where in the universe can we find a *magnetic monopole*?

57.C: Draw the symbols for an axis going into the page and out of the page.

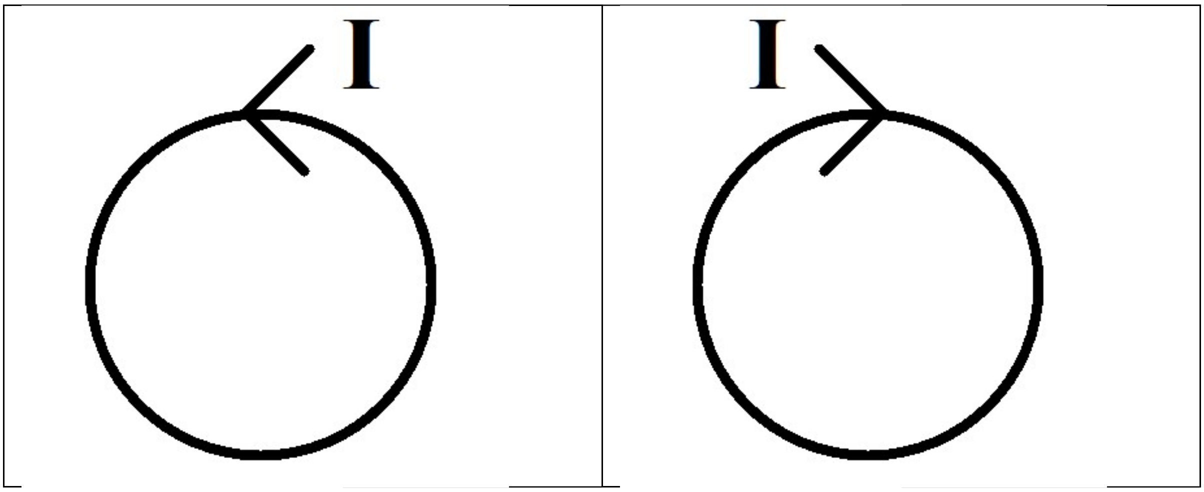
58.C: **Use a pencil!** Draw magnetic field lines for each current carrying wire.



59.C: **Use a pencil!** Describe and draw a *solenoid*. Use the right hand rule to draw magnetic field lines and the poles.

60.C: State three ways we can we increase the magnetic field inside a solenoid.

61.C: Draw magnetic field lines in a circular current carrying loop.



Additional HL Content

62.C: The following problem refers to *electric potential energy* E_P. This is also called *electrostatic potential energy* E_P.

a. Define *electric potential energy* E_P. Is it a scalar or a vector?

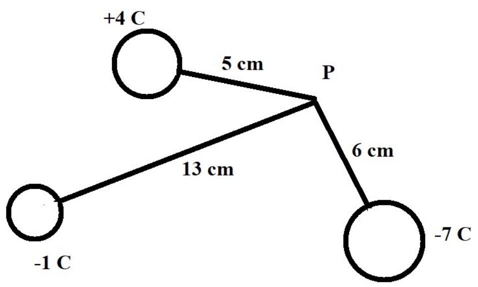
b. What is the equation for *electric potential energy* E_P? Units?

63.C: The following problem refers to *electric potential* V_e. This is also called *electrostatic potential*.

a. Define *electric potential* V_e. Is it a scalar or a vector?

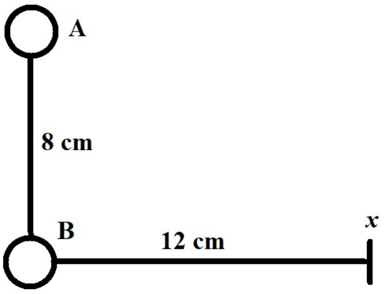
b. What is the equation for *electric potential*? Units?

64.Determine the electric potential at point P in the figure below:



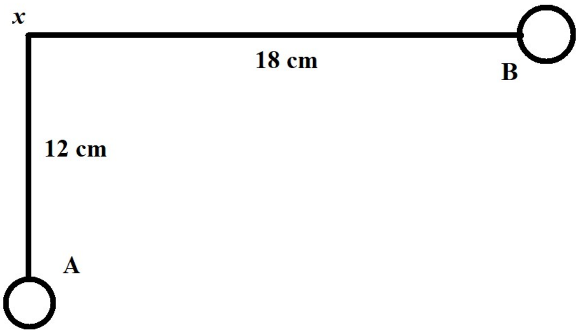
65.E: What will be the electrostatic potential of a point P which is both 12.0 cm from a 25.0 μC charge and 6.00 cm from a 50.0 μC charge?

66.E: Determine the electrostatic potential at point *x*.



$Q_A = +1.20 \times 10^{-5}$ C
$Q_B = -8.00 \times 10^{-6}$ C

67.E: Determine the electrostatic potential at point x.



$Q_A = -8.00 \times 10^{-6}$ C
$Q_B = +1.20 \times 10^{-5}$ C

68.C: Draw a graph of *electric potential vs. distance* of a positively charged solid sphere.

69.C: The following problem refers to *electric field strength E*. This is also called *electrostatic field strength*.

a. Define *electric field strength E*. Is it a scalar or a vector?

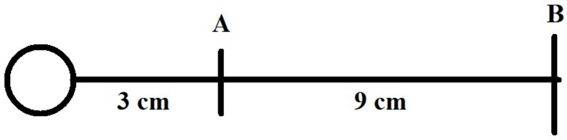
b. What is the equation and what are the units for *electric field strength*? Define each variable.

c. Where is the *electric field strength* zero? Where is the *electric field strength* maximum?

d. What are the mathematical limits of *electric field strength*? Can *electric field strength* be positive? Negative? Zero?

e. What is the relationship between the *electric field strength* and *electric potential*?

70.E: A small sphere contains a charge of $+5.00 \times 10^{-6}$ C.



a. What will be the direction and magnitude of the electric field at point A?

b. What will be the direction and magnitude of the electrostatic force acting on a proton placed at point A?

c. What will be the electrostatic potential at point A?

d. What will be the direction and magnitude of the electric field at point B?

e. What will be the direction and magnitude of the electrostatic force acting on a proton placed at point B?

f. What will be the electrostatic potential at point B?

g. What will be the potential difference between points A and B?

h. How much work would be required to move a proton from point B to point A?

i. How much work would be required to move a proton from point A to point B?

j. Which point is at the higher potential, A or B?

k. What will be the electrostatic potential at infinity?

l. What would be the potential difference between infinity and point B?

m. How much work would be required to move a proton from infinity to point B?

n. How much work would be required to bring an electron from infinity to point B?

71.E: An atom of C-12 contains six protons in its nucleus.

a. What will be the total charge of the nucleus of a C-12 atom?

b. What will be the strength of the electric field a distance of 0.5 angstroms from this C-12 nucleus?

c. What will be the electrostatic potential a distance of 0.5 angstroms from this C-12 nucleus?

d. What will be the electrostatic potential infinitely far from this C-12 nucleus?

e. What will be the potential difference between a point 0.5 angstroms from the C-12 nucleus and infinity?

f. How much work will be done in moving an electron from infinity to a point 0.5 angstroms from the nucleus of the C-12 nucleus?

g. What will be the potential difference between a point 0.5 angstroms from the nucleus of a C-12 atom and a point 1.5 angstroms from that same nucleus?

h. How much work will be done in moving an electron from a point 0.5 angstroms from the nucleus of a C-12 atom to a point 1.5 angstroms from the same C-12 nucleus?

72.E: Protons in the nucleus of an atom are on average a distance of 3.00 Fermi apart.

a. What will be the electrostatic potential 3.00 Fermi from a proton?

b. What will be the electrostatic potential infinitely far away from a proton?

c. What will be the potential difference between a point infinitely far away from a proton and a point 3.00 Fermi from a proton?

d. How much work will be required to move a proton from infinity to a point 3.00 Fermi from a second proton?

Suppose that you hold onto one of these protons and allow the other to accelerate to infinity.

e. What will be the velocity of this proton when it is very far away?

73.C: The following problem refers to *equipotential surfaces*.

a. What is an *equipotential surface*?

b. How much work is done in moving a charge along the same *equipotential surface*?

c. How much work is done in moving a charge along a different *equipotential surface*? State the equation.

74.C: What is the relationship between an objects *equipotential surfaces* and *electric field lines*?

75.C: Draw a spherical negative charge and a spherical positive charge, both with equal magnitudes of charge and volume, with *electric field lines* and *equipotential surfaces*.

76.C: Draw two spherical negative charges, both with equal magnitudes of charge and volume, with *electric field lines* and *equipotential surfaces*.

77.C: Draw *electric field lines* and *equipotential surfaces* between parallel plates with an equal and opposite charge. For parallel plates remember the equations $W = Fd = q\Delta V$ and $V = Ed$.