Problems

1. Most experiments in atomic physics are performed in a vacuum. Describe the effect on the Millikan oil drop experiment, of performing it in a vacuum.

2. A charge, \( q_1 = +5.00 \text{ C} \) is placed in an electric field between two charged plates. The electric field strength is \( E = 4.00 \text{ N/C} \). The mass of the charged particle is \( m = 2.00 \times 10^{-4} \text{ kg} \).

   ![Diagram of charged particle between plates]

   a. Determine the magnitude and direction of the acceleration of the charged particle between the plates.

   b. If the particle is released from rest, what will be the displacement of the particle after a time of 8.00 ms (8.00 \times 10^{-3} \text{ s})? \( \Delta x = \text{ ?} \text{ cm} \)

3. How many electrons must be removed from an electrically neutral silver dollar to give it a charge of \( +2.4 \times 10^{-9} \text{ C} \)?

4. An oil drop, whose mass is found to be \( 4.95 \times 10^{-15} \text{ kg} \) is balanced between two large horizontal plates with the upper plate positive. The electric field strength between the plates is \( E = 5.10 \times 10^{4} \text{ N/C} \). What is the charge on the oil drop, both in coulombs and in elementary charges, and is it an excess or deficit in electrons?

   \( \Delta x = \text{?} \text{ cm} \)

   \( \text{or } 6 \text{ electrons gained.} \)
1) The oil droplets needed to reach terminal velocity so Millikan could calculate the droplets' velocity. Terminal velocity is only possible with air resistance. Without air in the chamber, the droplets would continue to accelerate until they hit the bottom of the chamber.

2) 

\[ q_1 = +5.00 \, \text{C} \]
\[ E = 4.00 \, \text{N/C} \]
\[ m_q = 2.00 \times 10^{-4} \, \text{kg} \]

**Figure:**
- The **+ve** rest charge is directed towards the direction of the electric field \( E \).
- The **-ve** charge is opposite the direction of the electric field.

\[ F_{\text{net}} = F_3 + F_E \]
\[ = mg + qE \]
\[ = (2.00 \times 10^{-4} \, \text{kg} \times 9.8 \, \text{m/s}^2) + (5.00 \, \text{C})(-4.00 \, \text{N/C}) \]
\[ = -1.96 \times 10^{-3} \, \text{N} + -20 \, \text{N} \]
\[ = -20.00196 \, \text{N} \]

Also, \( F_{\text{net}} = ma \)
\[ \Rightarrow a = \frac{F}{m} = \frac{-20.00196 \, \text{N}}{2.00 \times 10^{-4} \, \text{kg}} \]
\[ = -1.00 \times 10^5 \, \text{m/s}^2 \]
6  \( \vec{v}_1 = 0 \)
\( \vec{a} = -1.00 \times 10^5 \text{ m/s}^2 \)
\( t = 8.00 \text{ ms} \)
\( = 8.00 \times 10^{-3} \text{ s} \)

\( \vec{v}_f = ? \)

1. \( \vec{v}_f = \vec{v}_1 + a \cdot t \)
\( = 0 + (-1.00 \times 10^5 \text{ m/s}) \cdot (8.00 \times 10^{-3} \text{ s}) \)
\( = -800 \text{ m/s} \)

2. \( \vec{d} = \vec{v} \cdot t \)
\( \overrightarrow{\Delta d} \) 
\( \overrightarrow{\Delta \Delta v} = \frac{\vec{v}_1 - \vec{v}_f}{\Delta t} \)
\( = \frac{-800 \text{ m/s}}{0} \)
\( = -400 \text{ m/s} \)

3. \( q^+ = 2.4 \times 10^{-6} \text{ C} \)
\( e^- = 1.602 \times 10^{-19} \text{ C} \)

\( q = Ne \)
\( N = \frac{q}{e} \)
\( = \frac{2.4 \times 10^{-6} \text{ C}}{1.602 \times 10^{-19} \text{ C}} \)
\( = 1.498 \times 10^{13} \text{ electrons} \)
\( = 1.5 \times 10^{13} \text{ electrons} \)
\[ m_i = 4.95 \times 10^{-15} \, \text{kg} \]
\[ E = 5.10 \times 10^6 \, \text{J} \]

1. \[ F_3 = F_3' \]

So \[ F_3 = mg = (4.95 \times 10^{-15} \, \text{kg}) \times (-9.8 \, \text{m/s}^2) \]
\[ = -4.85 \times 10^{-14} \, \text{N} \]

2. \[ E = \frac{|F_3'|}{q'} \]

\[ q' = \frac{|F_3'|}{E} \]
\[ = \frac{|-4.85 \times 10^{-14} \, \text{N}|}{5.10 \times 10^6 \, \text{J} / \text{c}} \]
\[ = -9.51 \times 10^{-19} \, \text{C} \]

Another Way

\[ q = \frac{mg}{E} \]
\[ = \frac{(4.95 \times 10^{-15} \, \text{kg}) \times (-9.8 \, \text{m/s}^2)}{5.10 \times 10^6 \, \text{J} / \text{c}} \]
\[ = -9.51 \times 10^{-19} \, \text{C} \]

3. \[ q' = n_e \, e^- \]

\[ N = \frac{q}{e} \]
\[ = -9.51 \times 10^{-19} \, \text{C} \]
\[ = -1.602 \times 10^{-19} \, \text{C} \]

- 60 electrons gained
CHAPTER 21

Study Guide

Fill in the blanks as you study the chapter.

21.1 CREATING AND MEASURING ELECTRIC FIELDS

The Electric Field

A(n) **charge** produces an electric field. The electric field can be observed because it produces a **force** on other **charges**. An electric field is measured by placing a small **test charge** in it. According to **Coulomb**'s law, the force is proportional to the test charge. The equation used to calculate the magnitude of an electric field is \( \frac{F}{q} = k \). In this equation, \( \frac{F}{q} \) represents the magnitude of the field, \( F \) represents the force on the test charge, and \( q \) represents the magnitude of the test charge. The magnitude of the field is a(n) **vector**, because it has both magnitude and **direction**. The direction of the electric field is **the same as** the direction of the force on the positive test charge.

The magnitude of the intensity of an electric field is measured in **N/C**. To measure the entire field, the **test charge** is moved to locations throughout the field until all locations have been tested. The total electric field is the **vector sum** of the fields of the individual charges.

Picturing the Electric Field

When electric field lines are used to show a field, the direction of the field at any point is the **tangent** drawn to the field line at that point. The **strength** of the field is indicated by the spacing between the lines, and is **stronger** where the lines are closer together. Near a positive charge, the direction of the force on a positive test charge is **away from** the positive charge. Near a negative charge, the direction of the force on a positive test charge is **toward** the charge. Field lines **do not** exist, but electric fields **do** exist. The field provides a way of calculating the **force** on a charged body. It does not explain why **charged** bodies exert **forces** on each other.

Millikan's Oil Drop Experiment

The measurement of the charge of a(n) **electron** was made by Robert A. Millikan. In this experiment, **fine drops of oil** were sprayed by a(n) **atomizer** into the **chamber**. The drops were charged by **friction** as they passed through the **aperture**. The drops fell due to **gravity**. Some of the drops were trapped between two charged parallel **plates**. The potential difference between the plates was adjusted until a charged drop was **suspended** between the plates. At this point the **gravitational** force of the weight of the drop was **equal to** the **magnetic** force of the electric field. Although the drops had a wide variety of charges, the **total** of the charge were always a multiple of \(-1.6 \times 10^{-19}\) C. Millikan concluded that this was the **smallest** change in charge that could occur, and was equal to the charge of one **electron**.

Daniel McIntyre Collegiate 11 Physics Fields: Electric Fields 2011
CHAPTER 21 Enrichment

Electric Field Lines

Draw diagrams that show the electric field lines for each of the following situations.

1. a single positive charge alone

2. a single negative charge alone

3. two negative charges next to each other but not touching

4. two positive charges next to each other but not touching

5. a positive charge and a negative charge next to each other but not touching
6. a positive charge next to another positive charge that is twice as strong

7. a positive charge between two negative charges

8. a negative charge between two positive charges

Answer the following questions. Use complete sentences.

9. How does the number of field lines on the smaller charge compare to the number of lines on the stronger charge in Question 6?
   - Smaller charge = fewer lines
   - Larger charge = more lines

10. How do the field lines in Question 3 compare to the field lines in Question 4?
    - Same shape but different direction

11. How do the field lines in Question 7 compare to the field lines in Question 8?
    - Same shape but different direction

12. Are electric field lines real? How are they used?
    - No - They are a model to help us visualize the shape of the field

13. Are electric fields real? How are they represented?
    - Yes they are real. They are represented by lines that start at the +ve charge and end at the -ve

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Problems

1. Two spheres are separated by a distance of 1.0 m. If each sphere has a charge of 2.0 C, then what force must exist between the spheres?

2. A positive point charge creates an electric field of $5.0 \times 10^4$ N/C at a point directly south of the charge. If a test charge of -2.0 C is placed at that place, then what is the magnitude and direction of the force on that charge?

3. A positive point charge, $q_1$, produces a field $E_1$, of size 5.0 N/C at a location “P.” A negative point charge, $-q_2$, produces an electric field $E_2$, of size 10.0 N/C at the same location “P.”

\[ \begin{array}{c}
    \bullet \\
    q_1 \quad \bullet \\
    -q_2 \quad \rightarrow P
\end{array} \]

   a) Determine the magnitude and direction of the total electric field at “P.”
   b) If a 4.0 C charge is placed at P, what is the magnitude and the direction of the force on this charge?

4. A positive point charge, $q_1$, produces a field $E_1$, of size 5.0 N/C at a location $P$. A negative point charge, $-q_2$, produces an electric field $E_2$, of size 10.0 N/C at the same location $P$.

\[ \begin{array}{c}
    \bullet \\
    q_1 \quad \bullet \\
    P \quad \bullet \quad -q_2
\end{array} \]

   a) Determine the magnitude and direction of the total electric field at $P$.
   b) If a 4.0 C charge is placed at $P$, what is the magnitude and the direction of the force on this charge?
1)\[ F_e = k_e \frac{q_1 q_2}{r^2} \]
\[ k_e = 8.987 \times 10^9 \text{Nm}^2 \text{C}^{-2} \]
\[ = (9 \times 10^9 \text{Nm}^2 \text{C}^{-2}) \times (2.0 \text{C})(2.0 \text{C}) \]
\[ = 3.595 \times 10^{10} \text{N} \]
\[ \Rightarrow \text{force is repulsive} \]

2) \[ \vec{E} = 6.0 \times 10^4 \text{N/C \ (South)} \]
   \[ \Rightarrow \text{test charge is \(-ve\)} \]
   
   So \( \vec{E} \) and \( \vec{F} \) are opposite \( \vec{E} = 6.0 \times 10^4 \text{N/C \ (-2.0 \text{C})} \).

   \[ q_1 = -2.0 \text{C} \]

   \[ \vec{F}_q' = \vec{E} q' \]
   \[ = (6.0 \times 10^4 \text{N/C})(2.0 \text{C}) \]
   \[ = 10.0 \times 10^4 \text{N/C} \]
   \[ = 1.0 \times 10^5 \text{N/C \ [N]} \]

3) \[ q_1 = -q_2 \]

   a) \[ \vec{E}_T = \vec{E}_1 + \vec{E}_2 \]
   \[ = 5.0 \text{N/C} - 10.0 \text{N/C} \]
   \[ = -5.0 \text{N/C} \]
   \[ = 5.0 \text{N/C \ [L]} \]

   b) \[ q_2 = 4.0 \text{C} \]
   \[ \vec{E}_2 = 5.0 \text{N/C \ [L]} \]
   \[ \vec{F}_q = \vec{E}_2 q' \]
   \[ = (5.0 \text{N/C})(4.0 \text{C}) \]
   \[ = 20 \text{N \ [L]} \]
\[ q_1, +ve \]
\[ E_1 = 5.0 \text{ N/C} \]
\[ q_2, -ve \]
\[ E_2 = 10.0 \text{ N/C} \]

\[ a) \quad \text{Magnitude} \quad - \quad C^2 = a^2 + b^2 \]
\[ E_T = E_1^2 + E_2^2 \]
\[ = (5.0^2 + 10.0^2)^{1/2} \]
\[ = 11.1 \text{ N/C} \]

\[ \tan \theta = \frac{E_1}{E_2} \]
\[ \theta = \tan^{-1} \left( \frac{5.0}{10.0} \right) \]
\[ = \tan^{-1} \left( \frac{1}{2} \right) \]
\[ = 26.5^\circ \]
\[ = 27^\circ \]
1. How are a gravitational and an electric field similar? both have inverse square relationships

2. Why is an electric field considered a vector quantity? has both magnitude and direction

3. a) What are electric field lines? A model of the shape of the electric field - the number of lines is proportional to field strength

b) How do their directions compare with the direction of the force that acts on a positive test charge in the same region? The force is tangent to the field lines at any given point

4. How is the strength of an electric field indicated with field lines? The density of the line is proportional to the field strength

5. How do the electric field lines appear when the field has the same strength at all points in a region? Electric field is uniform so lines appear as a series of parallel lines

6. How is an electric field different from a gravitational field? \( \vec{F}_g \) is always attractive (\(-ve\)) \( \vec{F}_e \) can be either attractive (\(-ve\)) or repulsive (\( +ve \))

7. The vectors for the gravitational field of the earth point toward the earth; the vectors for the electric field of a proton point away from the proton. Explain.
   * The test mass is attracted toward the earth; vector points to earth
   * The test charge is +ve so it is repelled by a proton; vector points away

8. If a “free” electron and a “free” proton were placed in an electric field, how would their accelerations and directions of travel compare? They would have equal but opposite accelerations toward each other

**BONUS**

9. Suppose that the strength of the electric field about an isolated point charge has a certain value at a distance of 1 m. How will the electric field strength compare at a distance of 2 m from the point charge? What law guides your answer?

\[
\begin{align*}
F_e & \propto \frac{1}{r^2} = \frac{1}{1} \text{ at } 1 \text{ m} \quad \text{governed by an inverse square law} \\
F_e & \propto \frac{1}{r^2} = \frac{1}{4} \text{ at } 2 \text{ m}
\end{align*}
\]
GRADE 11 PHYSICS: ELECTRIC FIELDS WORKSHEET

Answer the following questions in your notebook.

1. Sketch the electric field lines around a -1.0 μC charge.

2. A positive test charge of 6.5 \times 10^{-6} \text{ C} experiences a force of 4.5 \times 10^{5} \text{ N}. What is the magnitude of the electric field intensity? $$E = \frac{F}{q} \text{ N/C}$$

3. A charge experiences a force of 3.0 \times 10^{3} \text{ N} in an electric field of intensity 2.0 \text{ N/C}. What is the magnitude of the charge? $$q = \frac{F}{E} = 1.5 \times 10^{-3} \text{ C}$$

4. An oil drop has a charge of 8.0 \times 10^{-19} \text{ C}. How many excess electrons does the oil drop have? 5 \text{ electrons}

5. Calculate the charge on a metal-leaf electroscope that has an excess of 5.0 \times 10^{10} \text{ electrons}. $$q_b = -8.0 \times 10^{-7} \text{ C}$$

6. How many electrons have been removed from a positively charged pith-ball electroscope if it has a charge of 7.5 \times 10^{-11} \text{ C}? $$5 \times 10^8 \text{ electrons removed}$$

7. An oil drop carries a charge of three electrons and is balanced in a field of intensity of 5.0 \times 10^4 \text{ N/C}. If the charge on the electron is 1.6 \times 10^{-19} \text{ C}, what is the weight of the oil drop? $$m = 2.5 \times 10^{-15} \text{ kg}$$

8. An oil drop weighs 5.8 \times 10^{-14} \text{ N}. It is suspended in an electric field intensity of 6.0 \times 10^4 \text{ N/C}.
   a. What is the charge on the drop? $$9.4 \times 10^{-18} \text{ C}$$
   b. If the particle is negative, how many excess electrons does it carry? 6 \text{ electrons}

9. A charge of 3.5 \times 10^{-4} \text{ C} is placed between parallel plates that produce an electric field of 2860 \text{ N/C}. What force does this charge experience? 1.0 \text{ N in the direction of E}

10. The electric field between these charged parallel plates is 23 800 \text{ N/C}. The drop’s mass is 2.4 \times 10^{-14} \text{ kg}. What force would be experienced by the drop if it had the charge of three excess electrons? $$1.14 \times 10^{-15} \text{ N}$$
Electric Field Worksheet

1) $q' = -1.5 \mu C$

2) $F_q = 4.5 \times 10^{-5} N$
   $q_b = 6.5 \times 10^{-6} C$
   $E = \frac{F_q}{q_b} = \frac{4.5 \times 10^{-5} N}{6.5 \times 10^{-6} C}$
   $E = 6.9 \times 10^3 N/C$

3) $F_{q'} = +30 \times 10^{-3} N$
   $E = +2.0 \times 10^3 N/C$
   $q' = \frac{F_{q'}}{E} = \frac{30 \times 10^{-3} N}{2.0 \times 10^3 N/C}$
   $q' = 1.5 \times 10^{-3} C$

4) $q_b = 8.0 \times 10^{-19} C$
   $e = 1.602 \times 10^{-19} C$
   $N = \frac{q_b}{e} = \frac{8.0 \times 10^{-19} C}{1.602 \times 10^{-19} C}$
   $N = 4.993$
   $q = 8.5 \text{ electrons}$
5) \[ N = 5.0 \times 10^{10} \text{ electrons} \]
\[ e^- = 1.602 \times 10^{-19} \text{ C} \]
\[ q = ? \]
\[ q = N e^- = (5.0 \times 10^{10}) \times (1.602 \times 10^{-19}) \text{ C} \]
\[ q = -8.0 \times 10^{-9} \text{ C} \]

6) \[ q = 7.5 \times 10^{-11} \text{ C} \]
\[ e^- = 1.602 \times 10^{-19} \text{ C} \]
\[ N = ? \]
\[ N = \frac{q}{e^-} = \frac{7.5 \times 10^{-11}}{1.602 \times 10^{-19}} \text{ C} \]
\[ N = 4.68 \times 10^{4} \text{ electrons} \]

The electroscope has

\[ \text{About 5 \times 10}^{8} \text{ electrons were removed} \]

7) \[ q = 3(1.60 \times 10^{-19}) \text{ C} \]
\[ = 4.80 \times 10^{-19} \text{ C} \]
\[ E = 5.0 \times 10^{4} \text{ N/C} \]
\[ \dot{E} = \frac{F_q}{q} \]
\[ F_q = E \dot{q} = (5.0 \times 10^{4} \text{ N/C}) \times (4.80 \times 10^{-19}) \text{ C} \]
\[ F_q = 2.403 \times 10^{-14} \text{ N} \]

This is the weight of the drop.

When the drop is at rest in the electric field, \( F_g = F_q \)

\[ F_g = F_q \]
\[ m g = 2.403 \times 10^{-14} \text{ N} \]
\[ m = \frac{2.403 \times 10^{-14} \text{ N}}{9.8 \text{ m/s}} = 2.45 \times 10^{-15} \text{ kg} \]

\[ m = 2.5 \times 10^{-15} \text{ kg} \]

\[ \text{This is the mass of the drop} \]
8. a) \( m_{\text{drop}} = 5.8 \times 10^{-14} \text{ kg} \)

\[ F_g = F_g' \]

\[ mg = E q' \]

\[ q' = \frac{mg}{E} \]

\[ F_g = \frac{(5.8 \times 10^{-14} \text{ kg}) (9.8 \text{ m/s}^2)}{6.0 \times 10^4 \text{ N/C}} \]

\[ q' = 9.47 \times 10^{-18} \text{ C} \]

b) \( q = Ne \)

\( N = \frac{q}{e} \)

\[ = \frac{9.47 \times 10^{-18} \text{ C}}{1.602 \times 10^{-19} \text{ C}} \]

\[ = 59.13 \text{ e}^- \]

\[ = 59 \text{ electrons} \]

It carries 59 excess electrons.
9  \( q' = 3.5 \times 10^{-4} \text{C} \)
\( E = 2860 \text{ N/C} \)
\( F = \) ?

\[
F_{q'} = E \frac{q'}{q'}
\]

\[
F_{q'} = (2860 \text{ N/C})(+3.5 \times 10^{-4} \text{C})
\]
\[
= 1.001 \text{ N}
\]

\[
F_{q'} = +1.0 \text{ N} \text{ (In the direction of } E \text{)}
\]

10  \( E = 23800 \text{ N/C} \)
\( m_{q'} = 2.4 \times 10^{-14} \text{ kg} \)
\( q' = 3(1.602 \times 10^{-19} \text{ C}) \)
\[
= -4.806 \times 10^{-19} \text{ C}
\]

\( g = -9.8 \text{ m/s}^2 \)

\[
F_g = m_g \frac{g}{g}
\]
\[
= (2.4 \times 10^{-14} \text{ kg})(-9.8 \text{ m/s}^2)
\]
\[
= 2.352 \times 10^{-13} \text{ N}
\]

\[
E = \frac{F_g}{q'}
\Rightarrow F_g = E \frac{q'}{q'}
\]

\[
= (23800 \text{ N/C})(-4.806 \times 10^{-19} \text{ C})
\]
\[
= -1.14 \times 10^{-15} \text{ N}
\]
\[
= 1.14 \times 10^{-15} \text{ N} \text{ [up]}
\]

Since charge is -ve \( E \) and \( F \) are in opposite directions
Electric Field Lines

Unlike charges

Like charges
Electric Field Lines

1. In the figures, two charged objects are surrounded by metal filings that have been aligned by an invisible force. What is creating that force?
   The changes create the electric field

2. How are the charged objects in the top figure charged? How can you tell?
   They have opposite charges

3. How are the charged objects in the bottom figure charged? How can you tell?
   They are like charges (either both +ve or both -ve)

4. Where do the field lines coming from the positive conductor in the top figure terminate?
   at the -ve charge or at a distant negative charge

5. Where do the field lines coming from the conductors in the bottom figure terminate?
   at infinity or at a distant negative charge

6. In the first figure, what do the concentric circles represent?
   Complete lines of electric force that begin

7. What does the density of the field lines represent?
   The strength of the field

8. Where do field lines cross one another?
   They do not cross
Millikan's Apparatus

1. For what purpose did Millikan use this apparatus?
   To find the charge of an electron

2. Under what conditions do the oil drops between the plates remain suspended in air?
   $|F_d| = |F_e|$

3. For what is the atomizer used?
   Create small droplets of charged particles

4. For what is the battery used?
   Create charged plates to produce a uniform electric field

5. How do the oil drops become charged?
   Friction

6. Millikan's experiment showed that charge is quantized. What does this mean?
   There is only one size for the smallest piece of electric charge ($1.602 \times 10^{-19}$ C)

7. Toward which plate are the oil drops attracted?
   +ve plate

8. What role do the charged plates play in Millikan's experiment?
   Create the force $F_e$ that balanced $F_g$