GENERAL PHYSICS 2
2nd Semester – Module 7
SOURCES OF MAGNETIC FIELD
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What I Need to Know

This module will help you understand the concepts associated with the source of a magnetic field. At the end of this module, you should be able to:

1. Evaluate the magnetic field vector at a given point in space due to a moving point charge, an infinitesimal current element, or a straight current-carrying conductor;

2. Calculate the magnetic field due to one or more straight wire conductors using the superposition principle;

3. Calculate the force per unit length on a current-carrying wire due to the magnetic field produced by other current-carrying wires;

4. Evaluate the magnetic field vector at any point along the axis of a circular current loop; and

5. Solve problems involving magnetic fields, forces due to magnetic fields, and the motion of charges and current-carrying wires in contexts such as, but not limited to, determining the strength of Earth’s magnetic field, mass spectrometers, and solenoids.

What’s In

One of the aspects of magnetism was introduced in the previous module. This module focuses on moving charges, the forces exerting on a moving charge, and on currents in a conductor. The lessons and activities in this module will now help you answer the question: How are magnetic fields produced through moving charges and currents?

The module will also deal with the production of magnetic fields from current-carrying wires and various conductors. It also introduces the general methods in computing the magnetic field produced by currents – Biot-Savart Law and Ampere’s Law. Bio-Savart Law is analogous with Coulomb’s Law, while Ampere’s Law is analogous with Gauss’s Law. These laws have a high degree of symmetry.
Critical Reading

Biomagnetic monitoring of atmospheric pollution is a growing application in the field of environmental magnetism. Particulate matter (PM) in atmospheric pollution contains readily-measurable concentrations of magnetic minerals (Hofman et al., 2017).

The process measures the magnetic properties of tree leaves. The leaves serve as indicator of pollution levels in terms of accumulated particles. In this case, the leaves are exposed to a strong magnetic field. The sample leaves are then removed from the magnetic field to measure residual magnetism. The residual magnetism is caused by iron present in smoke. Hence, stronger values of residual magnetism would mean higher levels of iron compounds.

Trees which are exposed to streets with heavy traffic areas are proven to be ten times more magnetic than the trees from less busy roads. Their leaves have higher magnetism levels. These areas are also highly polluted during rush hours.

Activity 1: Biomagnetic Monitoring

Direction: Create a map showing the location of different tree species in your neighborhood or town.

Based on this map, which species will do you recommend for biomagnetic monitoring in your area? Why?

_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________
Magnetic Field of a Straight Conductor

Figure 1 shows the shape of a magnetic field around a long and straight wire current-carrying conductor. The field is composed of concentric circles with the current at the center. In determining the directions of quantities, you need to grasp the wire with your right hand so that your thumb points to the direction of the current. The curled finger shows the direction of the magnetic field.

The magnetic field is expressed as:

$$ B = \frac{\mu_0 I}{2\pi r} $$

Where $\mu_0$ is equal to $4\pi \times 10^{-7} \, \text{Tm/A}$, $I$ is the current expressed as Amperes (A), and $r$ is the distance from the rod to a certain point in terms of meter (m).

Example 1:
A long, straight conductor carries a current of 100 A. At what distance from the conductor is the magnetic field caused by the current equal to the Earth’s magnetic field?

<table>
<thead>
<tr>
<th></th>
<th>What is/are given?</th>
<th>I = 100 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>What is asked?</td>
<td>B = ?</td>
</tr>
<tr>
<td>B</td>
<td>Are the units</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>consistent with the formula?</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>What strategy must be employed?</td>
<td>We rearrange the formula and solve for $r$ since it is unknown. Then, we plug-in the values.</td>
</tr>
<tr>
<td>E</td>
<td>Solution</td>
<td>$r = \frac{\mu_0 I}{2\pi B} = \frac{(4\pi \times 10^{-7} \frac{Tm}{A})(100 , \text{A})}{2\pi (0.5 \times 10^{-4} , \text{T})} = 0.4 , \text{m}$</td>
</tr>
<tr>
<td>F</td>
<td>What is the conclusion?</td>
<td>Therefore, at 0.4 m from the conductor, the magnetic field is equal to Earth’s magnetic field.</td>
</tr>
</tbody>
</table>
The force between Parallel Conductors

Figure 2. Forces between parallel conductors

Figure 2 shows two parallel wires a distance apart that carry currents $I_1$ and $I_2$, respectively. The magnitude of the field is

$$B = \frac{\mu_0 I_1}{2\pi r_1} \quad \text{and} \quad B = \frac{\mu_0 I_2}{2\pi r_2}$$

The fields are perpendicular to the wire, which means the angle is 90 degrees and $\sin 90^\circ = 1$. Therefore, the force becomes:

$$F = I_1LB \sin\theta = L\frac{\mu_0 I_1 I_2}{2\pi r}$$

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

Example 2:

A power cable contains two long parallel conductors placed 1.0 cm apart. It carries a current of 100 A to a 40 hp electric motor. Find the force exerted on a 1.0 m length of one conductor?

| A | What is/are given? | I = 100 A, r = 1.0 cm and l = 1.0 m |
| B | What is asked? | $F/l = ?$ |
| C | Are the units consistent with the formula? | No, r must be converted from cm to m. Thus $r = 0.01$ m |
| E | What strategy must be employed? | We shall use the formula for the force between parallel conductors. |
What is the conclusion?
Therefore, the force per length between the conductors is 0.20 N/m

**Magnetic Field of a Circular Loop**

Figure 3 shows the magnetic field of a circular loop. The magnitude is directly proportional to the current and inversely proportional to the radius of the loop.

\[ B = \frac{\mu_0 I}{2R} \]

If we have a coil of \( N \) loops instead of a single loop, the loops are closely spaced and have the same radius, then each loop contributes to the field, and the field at the center is just \( N \) times.

\[ B = \frac{\mu_0 NI}{2R} \]

The magnetic field on the axis of a circular loop is expressed as

\[ B_x = \frac{\mu_0 I a^2}{2(x^2 + a^2)^{3/2}} \]
The direction of the magnetic field is given by the right-hand rule. Curl the fingers around the loop in the direction; the thumb points the direction of the magnetic field.

**Example 3:**
A coil used to produce a magnetic field for an electron beam experiment has a radius of 12 cm and has 200 turns. What current is needed to produce a magnetic field of $5.0 \times 10^{-3}$ T?

<table>
<thead>
<tr>
<th><strong>A</strong></th>
<th>What is/are given?</th>
<th>$r = 12$ cm, $N = 200$, $B = 5.0 \times 10^{-3}$ T</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B</strong></td>
<td>What is asked?</td>
<td>$I = ?$</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>Are the units consistent with the formula?</td>
<td>No, $r$ must be converted to from cm to m. Thus $r = 0.12$ m</td>
</tr>
<tr>
<td><strong>E</strong></td>
<td>What strategy must be employed?</td>
<td>We rearrange the formula and solve for $I$. Then, we plug-in the values.</td>
</tr>
</tbody>
</table>

**Solution**

$I = \frac{2RB}{\mu_0 N} = \frac{(2)(0.12 \text{ m})(5 \times 10^{-3} \text{T})}{4\pi \times 10^{-7} \frac{\text{Tm}}{\text{A}}(200)} = 4.8 \text{ A}$

**Conclusion**

Therefore, the current needed is 4.8 A.

**Magnetic Field of a Solenoid**

Figure 4 shows the magnetic field of a solenoid. It is a coil of wire in the form of a helix. If the turns are close together and the solenoid is long relative to the diameter, the magnetic field is uniform and parallel to the axis.

![Image of Magnetic Field of a Solenoid](source.png)

<table>
<thead>
<tr>
<th><strong>B</strong></th>
<th>Magnetic field expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B = \frac{\mu_0 nI}{\sqrt{4R^2 + L^2}}$</td>
<td>solenoid with length $L$ and radius $R$</td>
</tr>
<tr>
<td>$B = \frac{\mu_0 nI}{2\pi r}$</td>
<td>toroidal solenoid</td>
</tr>
</tbody>
</table>
The Biot-Savart Law

Suppose a magnetic field can cause a single-point charge to move with velocity. The location is called the source point, and any point surrounding it is called the field point. The distance between the two points is \( r \).

The magnitude of the magnetic field was found out to be proportional to \( q \) and inversely proportional with \( r \) to the second power. This behavior is consistent with Coulomb’s law. However, the direction of the magnetic field is perpendicular to the plane containing the line and its particle velocity.

If we have several charges, it still follows the superposition principle, where the total magnetic field is influenced by several test charges.

This leads us to the equation below. In finding the magnetic field at any point in space due to the current in a circuit, you need to solve for the vector sum of the magnetic field in each segment of the conductor. This is expressed in Biot-Savart law as:

\[
\Delta B = \frac{\mu_0 I \Delta l \sin \theta}{4\pi r^2}
\]

The Ampere’s Law

The law provides a different perspective on the relationship between the magnetic field and the sources. This is more convenient than Biot-Savart law. The law is considered to be analogous with Gauss’s law. In a closed curve that encloses one or more conductors, the curve is divided into segments known as \( \Delta s \). At each segment, the parallel component of magnetic field \( B \) is considered known as \( B_\parallel \). We take the products of the magnetic field and its segment until we have completely covered the whole curve. The result is expressed as:

\[
\sum B_\parallel \Delta s = \mu_0 I
\]

The equipotential surfaces are always perpendicular to the electric field lines. There is no work when a charge is moved from point \( a \) to point \( b \) within the same
equipotential surface. When all charges are at rest, the surface of a conductor is always an equipotential surface. Electric fields are always directed perpendicular to the surface. This also holds true for charges at rest in an entire solid volume of the conductor.

**What’s More**

**Activity 2: Qualitative Problems**

**Direction:** Answer the following questions. You may use a separate sheet of paper.

(1) Streams of charged particles emitted from the sun during unusual sunspot activity create a disturbance in the Earth’s magnetic field. How does this happen?

_____________________________________________________________________________

(2) Pairs of conductors carrying current into and out of the power-supply components of electronic equipment are sometimes twisted together to reduce magnetic field effects. Why does this help?

_____________________________________________________________________________

(3) Suppose you have three long parallel wires. They are arranged in a way that the cross-sections are at the corners of an equilateral triangle. Is there any way to arrange currents, so the three wires attract each other? So the three wires repel each other?

_____________________________________________________________________________

**What I Have Learned**

**Activity 3: Quantitative Problem**

**Direction:** Solve the problem as directed. Write your answers on a separate sheet of paper. You may also consult your Physics teacher.

A coil consisting of 100 circular loops with radius 0.60 m carries a 5.0-A current.

(a) Find the magnetic field at a point along the axis of the coil, 0.80 m from the center.

(b) Along the axis, at what distance from the center of the coil is the field magnitude 18 as great as it is at the center?

<table>
<thead>
<tr>
<th>Criteria</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics Approach</td>
<td>The approach is</td>
<td>The approach contains</td>
<td>Some of the concepts and</td>
<td>The solution doesn’t</td>
</tr>
<tr>
<td></td>
<td>appropriate and</td>
<td>minor</td>
<td>and</td>
<td>doesn’t</td>
</tr>
</tbody>
</table>

8
<table>
<thead>
<tr>
<th>Procedure</th>
<th>Mathematical and logical procedures are clear, complete and connected</th>
<th>Mathematical and logical procedures are missing/contain errors</th>
<th>Most of the mathematical and logical procedures</th>
<th>All procedures are incomplete and contain errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Diagrams and symbols used are appropriate and complete</td>
<td>Parts of the diagrams and symbols contain errors</td>
<td>Most of the parts of the diagrams and symbols are not useful</td>
<td>The entire visualization is wrong or did not include visualization.</td>
</tr>
</tbody>
</table>

What I Can Do

**Activity 4. Building Concept Map**

**Direction:** Create a concept map using the concepts that you have learned from this module. You can use words, terms, phrases, or formulas in connecting the concepts. Refer to the scoring guide below.

<table>
<thead>
<tr>
<th>Legible (easy to read)</th>
<th>No (0-1)</th>
<th>Yes (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accurate (The concepts were used accurately.)</td>
<td>Many inaccuracies (0-2)</td>
<td>A few inaccuracies (3-4)</td>
</tr>
<tr>
<td>Complete (sufficient number of relevant concepts and relationships)</td>
<td>Limited use of concepts (0-2)</td>
<td>Some use of concepts (3-4)</td>
</tr>
<tr>
<td>Sophisticated (finding meaningful connections between relevant concepts)</td>
<td>Little or none (0-1)</td>
<td>Few meaningful connections made (2-4)</td>
</tr>
</tbody>
</table>

Mueller's Classroom Concept Rubric
Assessment

Directions: Write the letter of your choice in the space provided.

1. A straight wire is placed below the compass. A large current passed flows upward the conductor. Where should the North pole of the compass point?
   a. undeflected
   b. south
   c. east
   d. west

2. Parallel wires carry different electric currents in the same direction. What happens to the force in A and B?
   a. $F_{BonA} = 4 F_{AonB}$
   b. $2F_{BonA} = 4 F_{AonB}$
   c. $F_{BonA} = 8 F_{AonB}$
   d. $F_{BonA} = F_{AonB}$

3. The magnetic field inside a solenoid is directed towards (the) ______.
   a. left
   b. right
   c. none
   d. upward/downward

4. A solenoid consists of 100 circular turns. Part of 3 turns, A, B and C is shown below. When the current flows,
   a. both A and C are repelled by B
   b. A is attracted to B; C is repelled by B
   c. neither A nor C is attracted/or repelled by B
   d. both A and C are attracted to B

5. The vertical parallel metal rods of a microwave filter oscillates currents in the rods. Sometimes, they have the same magnitude and direction of current. At that instant, the rods will
   a. move apart horizontally
   b. move together horizontally
   c. shift vertically downwards
   d. shift vertically upwards

6. Two parallel loops of radius $a$ are placed at a distance $L$. The current for each loop is in the same direction. Halfway between the loops, the magnetic field (in terms of the formula for circular loop) is equal to _____.
   a. zero
   b. $1/4$
   c. $1/2$
   d. the same
7. Three parallel straight wires carry equal currents to the right. The direction of magnetic force in the middle is___.
   a. out of the plane
   b. down to the plane
   c. upwards/downwards
   d. none

8. A long wire shown below is placed on a table. When a current goes through the conductor, the component of the magnetic field at point X is_____.

![Diagram of a long wire with a point X](image)
   a. into the table
   b. out of the table
   c. parallel to the segment nearest to the point
   d. perpendicular to the segment nearest to the point

9. There are two wires with equal currents I travelling out of the page. What is the direction of the magnetic field at point X?

![Diagram with two wires and a point X](image)
   a. east
   b. southeast
   c. west
   d. southwest

10. Student A said that the magnetic field outside the long solenoid would be no larger than the field caused by each turn. Student B said it is zero since the magnetic field is located inside the solenoid. Who is correct?
   a. Student A, since each loop cancels out the magnetic field of the other
   b. Student B, since each loop cancels out the magnetic field of the other
   c. Student A, since magnetic fields cancel at equal position of the loop
   d. Student B, since magnetic fields cancel at equal position of the loop

11. A solenoid is 3 cm long and has a radius of 0.50 cm. The wire carries 2.0 A of current. The magnetic field at the center is
   a. 0.0419 T
   b. 0.099 T
   c. 0.0013 T
   d. 20 T

12. Two parallel wires placed 4 cm apart carry 2A and 4A current respectively in the same direction. The force/length in each wire is
   a. 0.00004 N/m, attractive
   b. 0.00004 N/m, repulsive
   c. 0.00001 N/m, attractive
   d. 0.00001 N/m, repulsive
13. Two parallel wires placed 4 cm apart carry 2A and 4A current respectively in the opposite direction. The force/length in each wire is
   a. 0.00004 N/m, attractive
   b. 0.00004 N/m, repulsive
   c. 0.00001 N/m, attractive
   d. 0.00001 N/m, repulsive

14. The magnetic field at a distance of 2 cm from a straight wire is 0.00002 T. The current in the wire is
   a. 3A
   b. 2A
   c. 0.16 A
   d. 25 A

15. Solenoid B has twice the radius and six times the number of turns to that of Solenoid A. The ratio of the magnetic field in the interior of B to that of the interior of solenoid A is ___.
   a. 2
   b. 4
   c. 6
   d. 1

Additional Activities

Activity 5. Social Context
Direction: The community is a rich source of learning opportunities of sources of magnetic forces and fields. Choose one from the following suggested activities in understanding the importance and utilization of electric potential in our daily lives:

1. Conduct simulations on Biot-Savart and Ampere's Laws. From this, write a short reflection. Scan the QR code to gain access to the simulations.

2. If you are to produce a right-hand rule using your left hand, will you still be able to locate the field and direction of current? How would you do it? Provide a diagram and a short explanation of how this works.


**Answer Key General Physics 2 Module 7**

| 13. B | D | 17. B | C |

**Assessment**

\[
 \frac{w}{m} + 1 \cdot \frac{r}{r} = x \ (q) \\
1 \cdot 1 \times 1 = 1 \ (q)
\]

**Activity 3. Quantitative Problems**

A negative positive neutral depends on number of charges ....

**References**

**Printed Resources**


**Online References**


Errors Most of the parts of the diagrams and symbols are not useful.

Example 3 A coil used to produce a magnetic field for an experiment.

In addition to the material in the main text, Notes to the Teacher are also available.

What’s, one of the aspects of magnetism, was introduced in the previous module.

X X 14 11A solenoid is 3 cm long and has a radius of 0.50 cm.