**4.3 Lab Assignment: Magnetism**

|  |  |
| --- | --- |
| Name: |  |

**Part 1 Electromagnetic Induction**

We all use batteries for flashlights, cell phones, and many other devices. We know they deliver energy through electricity. Where do they get their energy?

If you are not sure, watch the first video listed in the assignment:   
[Discover How Car Batteries Work](https://www.youtube.com/watch?v=4IgHj2Uim_0).

|  |
| --- |
| Briefly explain where a battery gets its energy. |
|  |

The car battery can be recharged while the motor is running because of the alternator.

If you are not sure what an alternator is or how it works, watch the second video listed in the assignment: [How Automotive Alternators Work, made simple](https://www.youtube.com/watch?v=-JURAbC6oRE)

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| An alternator drives current through the battery to recharge it. What kind of device is it and where does it get the energy that is carried by the current into the battery? |
|  |

While the alternator is complicated, there is a much simpler version of the same device, sometimes called a pick-up coil. For a simulation of a pick-up coil, activate the simulation after clicking on the third link listed in the assignment: [Faraday's Law PhET Simulation](https://phet.colorado.edu/en/simulation/faradays-law). Move the magnet around and notice current flow in the coils.

While the alternator is complicated, there is a much simpler version of the same device, sometimes called a pick-up coil. For a simulation of a pick-up coil, activate the simulation after clicking on the third link listed in the assignment: Faraday's Law PhET Simulation (Links to an external site.). (If the Simulation is not available, use the video showing a real magnet and pick-up coil to answer the questions.)

|  |
| --- |
| 1) Position the north end of the magnet closest to the right side of the coil. With the magnet at rest, describe the voltmeter reading. |
|  |

|  |
| --- |
| 2) Push the north end of the magnet into the coil. Describe the voltmeter reading while the magnet is in motion. |
|  |

|  |
| --- |
| 3) Leave the north end of the magnet at rest inside the coil. Describe the voltmeter reading. |
|  |

|  |
| --- |
| 4) Remove the north end of the magnet from the coil by pulling it out to the right. Describe the voltmeter reading while the magnet is in motion. |
|  |

The challenging thing about such a simulation understanding where the energy is coming from to drive current through the circuit. The following videos will make this clearer. Watch the next video listed in the assignment: [Eddy Current Tubes](https://www.youtube.com/watch?v=H31K9qcmeMU).

|  |  |  |
| --- | --- | --- |
| What force is slowing the magnet’s fall? *(Put an X by your choice.)* | | |
|  | a | gravity |
|  | b | electrical |
|  | c | magnetic |
|  | d | nuclear |

If you are not sure, watch the next listed video: [World's First Electric Generator](https://www.youtube.com/watch?v=NqdOyxJZj0U).

|  |
| --- |
| Since energy cannot be created or destroyed, where does the energy come from to drive the current in the pipe that generates the magnetic fields that slow the magnet’s fall? |
|  |

|  |
| --- |
| Since energy cannot be created or destroyed, where does the energy go after the magnet has fallen through the tube? |
|  |

**Part 2 Forces on Charged Particle in an Electric and Magnetic Fields**

Electric and magnetic fields exert forces on charged particles. These forces are at the heart of all important electromagnetic inventions, including motors, generators, transformers, and a device used to measure the mass of individual atoms, the mass spectrometer.

**A: Electric Field Forces**

Open the following simulation: <https://ophysics.com/em6.html>. A picture containing diagram

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Start with the default settings of the simulation, which shows two plates with an electric field between them.

|  |  |  |
| --- | --- | --- |
| Where is the positive and negative charge on the plates? | | |
|  | a | Positive on top, negative on bottom |
|  | b | Negative on top, positive on bottom |
|  | c | The plates are uncharged. |
| Which way do the electric field lines point? | | |
|  | a | Down, that is, from the positive charges toward the negative charges |
|  | b | Down, that is, from the negative charges toward the positive charges |
|  | c | Up, that is, from the positive charges toward the negative charges |
|  | d | Up, that is, from the negative charges toward the positive charges |
|  | e | There is no electric field between the plates because there is no charge. |

With the default (positive) charge, hit the run button and determine the direction of the force on the particle by the direction of the deflection.

Then make the charge negative (keep the amount of charge the same) and determine the direction of the force on the negative particle. Report your results below.

|  |  |  |
| --- | --- | --- |
| Type of charge | Direction of Electric Field | Direction of Force |
| Positive | Up |  |
| Negative | Up |  |

Reset and set the simulation to the values of Electric Field, Velocity, and Charge in the table below. For each set of values, record how long it takes the particle to hit the plate after entering the field.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Quantity | Electric Field | Velocity | Charge | Time |
| Trial 1 | 1000 N/C | 5 x 105 m/s | +5 μC |  |
| Trial 2 | 2000 N/C | 5 x 105 m/s | +5 μC |  |
| Trial 3 | 1000 N/C | 5 x 105 m/s | +10 μC |  |
| Trial 4 | 1000 N/C | 10 x 105 m/s | +5 μC |  |

Note that the greater the force, the less time it should take for the particle to hit the plate, because the same mass has a larger force acting on it, creating a greater acceleration.

Based on these results which conclusions can we draw about the effect of the strength of the electric field, the amount of charge, and the velocity of motion on the force exerted on the particle?

|  |  |  |
| --- | --- | --- |
| If the strength of the electric field is increased, | | |
|  | a | the force on the charged particle decreases. |
|  | b | the force on the charged particle does not change. |
|  | c | the force on the charged particle increases. |

|  |  |  |
| --- | --- | --- |
| If the amount of charge on the particle is increased, | | |
|  | a | the force on the charged particle decreases. |
|  | b | the force on the charged particle does not change. |
|  | c | the force on the charged particle increases. |

|  |  |  |
| --- | --- | --- |
| If the velocity of the particle is increased, | | |
|  | a | the force on the charged particle decreases. |
|  | b | the force on the charged particle does not change. |
|  | c | the force on the charged particle increases. |

The formula for calculating the force on a charge particle in an electric field is

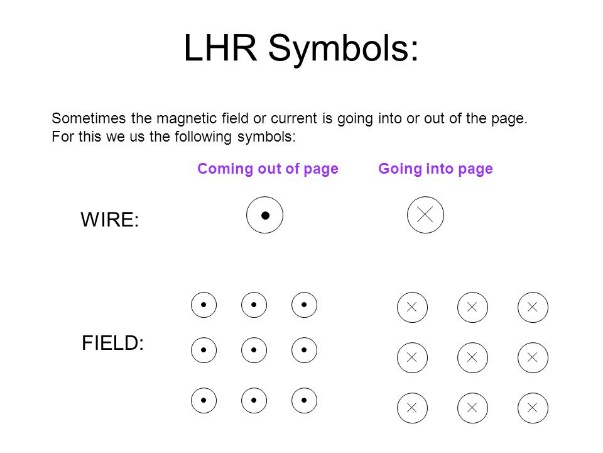
Force = (Charge)(Electric Field Strength) or *F* = *qE*

**B: Magnetic Field Forces**

Open the following simulation: <https://ophysics.com/em7.html>

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At left is the notation used to represent vectors that are oriented so they would come out of the plane of the page or into the plane of the page, perpendicular to the page.

Start with the default values of the simulation and record the information listed below:

|  |  |  |
| --- | --- | --- |
| What type of charge is used in the default settings? | | |
|  | a | positive |
|  | b | negative |

|  |  |  |
| --- | --- | --- |
| In which direction is the magnetic field pointing? | | |
|  | a | Left, in the plane of the simulation field. |
|  | b | Right, in the plane of the simulation field. |
|  | c | Up, in the plane of the simulation field. |
|  | d | Down, in the plane of the simulation field. |
|  | e | Coming out of the plane of the simulation (indicated by dots) |
|  | f | Going into the plane of the simulation (indicated by x’s) |

Hit “Start” and observe the path of the particle in the field.

|  |  |  |
| --- | --- | --- |
| Based on the motion, in what direction is the force on the charge | | |
|  | a | The particle moves in a straight line, so there is no force on the particle. |
|  | b | The particle is constantly deflected upward. |
|  | c | The particle is constantly deflected downward. |
|  | d | The particle is not deflected but accelerates in the direction of motion, indicating a force in the same direction as the particle’s velocity. |
|  | e | The particle is not deflected but decelerates, indicating a force in the opposite direction as the particle’s velocity. |
|  | f | The particle moves in a counterclockwise circle, indicating a force that is perpendicular to the particle’s velocity and making it curve to the left. |
|  | g | The particle moves in a clockwise circle, indicating a force that is perpendicular to the particle’s velocity and making it curve to the right. |

Study the following information to understand how you can predict the direction of the force on the particle using your right or left hand.

A screenshot of a computer

Description automatically generated with medium confidence**Right-Hand Rule**

Right-Hand Rule determines the directions of magnetic force, positive charge velocity, and the magnetic field.  Given any two of these, the third can be found. 

Using your right-hand:   
point your index finger in the direction of the charge’s velocity (v).

Point your middle finger in the direction of the magnetic field (B).

Your thumb now points in the direction of the magnetic force (F).

Use the right hand when the moving charge is positive and the left hand when the moving charge is negative.

Satisfy yourself that the rule works for the case just demonstrated. Point your right index finger to the right as you look at the simulation on your screen (the direction of the particle’s velocity). Extend your index fingers until they are pointing generally away from the screen (the direction of the magnetic field). You may have to shift your body around to make this possible. Extend your thumb and it should naturally point downward (the initial direction of the force on the particle).

Complete the following table by indicating the initial direction of the force on the particle based on the direction of the field and the type of charge on the particle.

To make the charge negative, move the charge slider to the left until it indicates a negative number in the field.

To make the magnetic field go into the page, move the magnetic field strength slider to the left until it indicates a negative number in the field.

You may want to clear the simulation field of the previous trace by hitting the “Clear Trace” button.

|  |  |  |
| --- | --- | --- |
| Type of charge (+ or –) | Field Direction (in or out) | Initial Force direction (up or down) |
| + | out 🞊 |  |
| + | in **⊗** |  |
| – | out 🞊 |  |
| – | in **⊗** |  |

Next, we want to experiment to determine what quantities affect the magnitude of the force exerted on the charge by the magnetic field.

First, let’s see if the strength of the magnetic field affects the amount of force. The greater the centripetal force, the smaller the radius the circular motion will be.

Return your simulation to the default values by reloading the simulation.

Change the charge to

Change the magnetic field strength to 6.3 T

Run the simulation and record the radius of the circle (check the box “Show Radius”).

|  |  |
| --- | --- |
| Quantity | Value and unit |
| Charge | -3 x 10-16 C |
| Magnetic field strength | 6.3 T |
| velocity | 7.5 x 10^6 m/s |
| radius |  |

Now double the charge and run the simulation again.

|  |  |  |
| --- | --- | --- |
| Result. When the charge is doubled the radius | | |
|  | a | is doubled |
|  | b | is cut in half |
|  | c | does not change |

|  |  |  |
| --- | --- | --- |
| This means that when the charge increases, the force | | |
|  | a | decreases |
|  | b | increases |
|  | c | does not change |

Hit “Reset” and “Clear Trace,” adjust the simulation to the following values, run the simulation, and record the radius.

|  |  |
| --- | --- |
| Quantity | Value and unit |
| Charge |  |
| Magnetic field strength |  |
| velocity |  |
| radius |  |

Double the Magnetic field strength and run the simulation.

|  |  |  |
| --- | --- | --- |
| Result. When the field strength is doubled the radius | | |
|  | a | is doubled |
|  | b | is cut in half |
|  | c | does not change |

|  |  |  |
| --- | --- | --- |
| This means that when the field strength increases, the force | | |
|  | a | decreases |
|  | b | increases |
|  | c | does not change |

There is a third influence on the force on a moving particle in a magnetic field, the velocity, but that is harder to understand using this simulation.

The formula for calculating the force (*F*) on a moving particle in a magnetic field is

*q* = the charge in Coulombs

*v* = the velocity in m/s

*B* = the magnetic field strength in a unit called a Tesla, which it the field strength which will cause a 1 kg particle with 1 C of charge moving at 1 m/s to experience a force of 1 N.

The formula for centripetal force is

If we set these two force formulas equal and solve for the radius (*r*) we get

So, if mass, charge, and magnetic field stay constant and we double the velocity, we expect this to double the radius.

Reset, Clear Trace, set the simulation to the following values, run the simulation, and record the radius.

|  |  |
| --- | --- |
| Quantity | Value and unit |
| Charge |  |
| Magnetic field strength |  |
| velocity |  |
| radius |  |

Double the velocity of the charge (), keeping the other quantities the same as before. Run the experiment and record the results below.

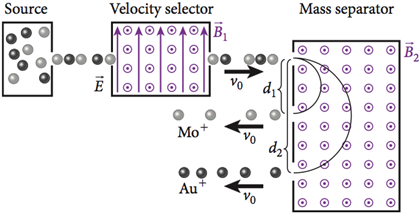
|  |  |  |
| --- | --- | --- |
| Result. When the velocity is doubled the radius | | |
|  | a | is doubled |
|  | b | is cut in half |
|  | c | does not change |

|  |  |  |
| --- | --- | --- |
| This means when the velocity is increases, the force | | |
|  | a | increases |
|  | b | decreases |
|  | c | does not change |

**Part 3 Mass Spectrometer**

Listen for instructions about whether or not this part is required. It will be skipped if there is not enough time to do all parts.

A mass spectrometer is a device determines what elements and isotopes are present in a sample. *Element* refers to the type of atom, such as hydrogen, carbon, iron, etc. *Isotopes* are atoms of the same element but with different numbers of neutrons. Mass spectrometers are sometimes used in forensic science when detectives find an unknown substance at a crime scene and need to figure out what it might be.

Left: Photo of a mass spectrometer. Right: Diagram of how a mass spectrometer works.

Elements to be identified are processed so that an electron is removed from each atom, making the atom have a net positive charge equal to the charge on a single proton. The elements are accelerated to high speeds and passed through a velocity selector, which uses a combination of electric fields and magnetic fields to only allow atoms through with a particular velocity.

Then the atoms move into the area with a magnetic field only. The magnetic force on moving charged particles causes each atom to move in a circular path.

|  |  |  |
| --- | --- | --- |
| The atoms move in a circular path because | | |
|  | a | the force on the atom is in the opposite direction as the velocity. |
|  | b | the force on the atom is perpendicular to the velocity. |
|  | c | the force on the atom is in the same direction as the velocity. |

The atoms collide with a detector which marks where each atom strikes. The further from the opening the atom gets, the more mass it has. The mass helps researchers identify the type of atom or isotope.

Combining all the measurements the mass spectrometer can make, a calculation can be done that calculates the mass of each individual ion that passes through the field.

The mass of each particle can be calculated by using the two force equations used in the previous part.

and

If we set these two expressions equal, we can solve for the mass of the particle:

So, . Simplify by canceling one of the velocity variables (*v*).

We will first do a calculation with a known mass. Then students will get data to calculate for an unknown element.

Because the mass of an individual atom is a very small fraction of a kilogram, we will convert each calculation to a unit called an *atomic mass unit*, which is approximately the mass of a single proton or neutron.

Scientists have used the mass of the most common isotope of carbon as the standard to set the value of this unit. So we will do a calculation for a simulated measurement of the mass of a carbon atom.

Use the values below in the equation to calculate the mass of a carbon atom in kilograms.

|  |  |
| --- | --- |
| charge (*q*) | 1.602 × 10-19 C |
| magnetic field (*B*) | 0.00500 T |
| radius (*r*) | 0.1245 m |
| velocity (*v*) | 5000 m/s |
| Mass in *kg* |  |
| Mass in *amu* |  |

Convert this to *atomic mass units*, where 1 *amu* = 1.6605 × 10-27 kg.

Divide your calculated mass in kilograms by this number. Your answer should be 12.0 (rounded to 3 significant figures).

For the last exercise, see the list of values by your name below. These represent data from a test to identify an element from a pair of isotopes measured with a mass spectrometer. Isotopes are atoms with the same number of protons in the nucleus but different numbers of neutrons. The mass spectrometer will get a different reading for each isotope because the extra neutron or neutrons add mass to the nucleus. Since isotopes behave the same in chemical reactions, the mass spectrometer is needed to separate them and identify them.

Each student is trying to identify a different element. In each case, the element has just two isotopes. This immediately eliminates other elements which have more or fewer isotopes than 2. By calculating the masses, you can identify the element. This is a common use of the mass spectrometer, to identify elements and isotopes.

1. Use the values from the table for magnetic field (B), velocity (v), and the first radius (r1), plus the value for the charge (q) listed in the table above to calculate the mass of the first isotope in kilograms, using the equation:
2. Use the second radius (r2) and all the same values for the other variables to calculate the mass of the second isotope in kilograms.
3. Convert the masses from kilograms to atomic mass units by dividing each mass by the number of kilograms in 1 amu. 1 *amu* = 1.6605 × 10-27 kg.
4. Consult the table below that lists the established values of the mass of elements with just two isotopes and match your masses with one of them to identify which element your data represents.
5. Do an Internet search to identify one interesting fact about this element.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | B (T) | v (m/s) | r1 (m) | r2 (m) |
| Baca, Jacob | 0.0050 | 8000 | 0.2322 | 0.2488 |
| Bltom, Biniam | 0.0070 | 3500 | 0.2589 | 0.2640 |
| Brion, Matthew | 0.0030 | 8000 | 0.2792 | 0.3043 |
| Clevenger, Christopher | 0.0085 | 2000 | 0.2949 | 0.2997 |
| Eldridge, Marcus | 0.0070 | 3000 | 0.2795 | 0.2884 |
| Higgins, Sean | 0.0095 | 1500 | 0.2863 | 0.2879 |
| High, Parker | 0.0050 | 4000 | 0.2900 | 0.3065 |
| Jimenez, Serena | 0.0080 | 2500 | 0.2750 | 0.2815 |
| Mejia, JeffreyLousie | 0.0095 | 1100 | 0.2833 | 0.2845 |
| Mohibi, Hasibullah | 0.0075 | 3000 | 0.2858 | 0.2941 |
| Poor, Travis | 0.0085 | 2200 | 0.2868 | 0.2922 |
| Powell, Anniya | 0.0080 | 2000 | 0.2926 | 0.2977 |
| Smith, Shawn | 0.0015 | 9000 | 0.1876 | 0.2490 |
| Tanner, Anthony | 0.0090 | 1800 | 0.2859 | 0.2880 |
| Instructor | 0.0098 | 860 | 0.1912 | 0.1922 |

1 *amu* = 1.6605 × 10-27 kg

Data used in calculation

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Quantity | Charge | Magnetic Field | Radius | Velocity |
| Variable | q | B | r | v |
| Unit | C | T | m | m/s |
| Isotope 1 | 1.602 × 10-19 C |  |  |  |
| Isotope 2 |  |

Results of Mass Calculations and Identity of Isotopes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Quantity | Mass 1 | | Mass 2 | Isotope |
| Unit | kg | | amu | Element symbol and mass number |
| Isotope 1 |  | |  |  |
| Isotope 2 |  | |  |  |
| Fact about this element | |  | | |

See table on next page to determine your isotopes.

See table below for masses of isotopes.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Element** | **Isotope** | **Relative Atomic Weight (amu)** |  | **Element** | **Isotope** | **Relative Atomic Weight (amu)** |
| Helium | He-3 | 3.016 |  | Silver | Ag-107 | 106.905 |
|  | He-4 | 4.003 |  |  | Ag-109 | 108.905 |
| Lithium | Li-6 | 6.015 |  | Indium | In-113 | 112.904 |
|  | Li-7 | 7.016 |  |  | In-115 | 114.904 |
| Boron | B-10 | 10.100 |  | Antimony | Sb-121 | 120.904 |
|  | B-11 | 11.009 |  |  | Sb-123 | 122.904 |
| Nitrogen | N-14 | 14.003 |  | Lanthanum | La-138 | 137.907 |
|  | N-15 | 15.000 |  |  | La-139 | 138.906 |
| Chlorine | Cl-35 | 34.969 |  | Lutetium | Lu-175 | 174.941 |
|  | Cl-37 | 36.966 |  |  | Lu-176 | 175.943 |
| Vanadium | V-50 | 49.947 |  | Tantalum | Ta-180 | 179.947 |
|  | V-51 | 50.941 |  |  | Ta-181 | 180.948 |
| Copper | Cu-63 | 62.930 |  | Thallium | Tl-203 | 202.972 |
|  | Cu-65 | 64.928 |  |  | Tl-205 | 204.974 |
| Gallium | Ga-69 | 68.926 |  | Polonium | Po-209 | 208.982 |
|  | Ga-71 | 70.925 |  |  | Po-210 | 209.923 |
| Bromine | Br-79 | 78.918 |  | Astatine | At-210 | 209.987 |
|  | Br-81 | 80.916 |  |  | At-211 | 210.987 |
| Rubidium | Rb-85 | 84.912 |  | Neptunium | Np-236 | 236.047 |
|  | Rb-87 | 86.909 |  |  | Np-237 | 237.048 |