MSET Demonstration Package

Magnetic Forces

Mentis Sciences Education Toolkit Vision and Development History

Located in the historic Mill District of downtown Manchester, Mentis Sciences is an engineering firm which provides advanced material design and manufacturing capabilities to Department of Defense customers. Mentis specializes in the design, development and testing of advanced composite materials with a goal of providing unique flexibility, rapid development and prototyping for various composite applications.

Mentis Sciences, Inc. was founded in 1996 by John F. Dignam, following more than thirty years of service at the Army Materials Research Lab, where he served as the Director of Missile Materials. John F. Dignam spent most of his lifetime promoting national security and developing the most effective material systems to aid in countering global threats. He founded Mentis Sciences to continue promoting innovation, expertise, and emerging materials and manufacturing technologies, that will enhance U.S. security and promote economic growth.

His legacy continues under the strong and visionary leadership of John J. Dignam, who brings unique and innovative technical expertise to solving some of the nation's most daunting engineering challenges. The core values of ethics, integrity, community service, and commitment to excellence instilled by John F. Dignam live on with John J. Dignam and the Mentis team, and are apparent in every aspect of the company's structure, personality, and operations.

Mentis Sciences Internship Program recruits local high school students in good academic standing who reside in the HUBZone area of Manchester, NH. Successful youth with good attitudes and high motivation to work and learn have come through various avenues including non-traditional avenues like the Manchester Police Athletic League, The Salvation Army, and Manchester's Office of Youth Services.

Mentis makes a serious commitment of its resources to support the internship program by providing short courses in STEM related disciplines, student engineering activities and mentoring activities. In result of these courses, Mentis Sciences started to see a gap in STEM education. Biology and Life Science concepts were often the focus of science in the classroom, technology often included a smartphone app and engineering was nonexistent. Our interns and every student deserve to be introduced to STEM concepts with tools and resources that allow them to experience concepts hands-on and in a collaborative environment.

With this vision for our students, Mentis transferred skills used in their own manufacturing facility every day and descaled the concepts and tests into one integrated unit. Mentis has developed an integrated STEM toolkit that configures to complete 40 STEM tests. With limited lab space and budgets for lab testing equipment being tight, the Mentis Sciences Engineering Toolkit (MSET) departs from the high cost limited functionality of current educational testing systems.

The MSET offers a unique view into the world of material testing and physical science. Data indicates the MSET Program increased student participation in the classroom, interest in STEM careers and opportunities for females in STEM. Students develop a deep understanding in STEM, engineering and physical science concepts.

In many ways, the internship program and new shared vision has provided Mentis employees a new sense of purpose in their work. Mentis is now expanding their vision for the MSET program, beyond their own interns and are offering the MSETs STEM educational opportunities to other schools and educational partners in their community and around the United States.

Mentis believes that every student, no matter their upbringing or education status, should have the opportunity to learn, pursue their dreams and have the high-quality resources to so. This enrichment MSET program has proven to be beneficial, providing life-changing experiences for interns, students, as well as Mentis employees. We are excited to share it with you.

Magnetic Forces Introduction

In this unit students will explore how magnetic forces act upon a different magnet and all the relevant equations related to the forces. Students will work out the derivation of the relationship between size, Magnetization and relative position of the magnet will have on the forces that are present within the magnetic field. The goal of this exercise is to prepare students and apply these concepts in an inquiry-based project where they design a structure.

The materials in this section have been created and organized to assist teachers in the design of lessons that use the MSET equipment and applied inquiry-based projects that are aligned with the Next Generation Science Standards, as well as the Massachusetts Science and Technology/Engineering Curriculum Framework.

Teachers

Teachers should review the Understanding by Design unit plan with particular attention to the Essential Questions students will be expected to answer by the conclusion of the unit. Throughout the lessons and experiences, teachers should assess students' progress toward their capacity answering the essential questions. Finally, teachers should use the rubric to assess students' comprehension and application of the foundational principles associate with the lesson, experiment and materials covered in the unit.

Students

It is assumed that students participating in this unit will have experience in the following areas:

1. Have basic algebra knowledge of rearranging equations to extrapolate the desired variable from the equations given.
2. Have basic mechanical skills to configure MSET based on written and visual instructions.
3. Have a basic understanding of magnetic fields and how they exist in the real world.

Table of Contents

UbD Chart – Magnetic Forces

<table>
<tr><th colspan="3">Desired Results</th></tr>
<tr><td rowspan="4">STANDARDS/ESTABLISHED GOALS

<u>Next Generation Science Standards</u>

Forces and Interactions:
HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

HS PS2-4. Use mathematical representations of Newton’s Law of Gravitation and Coulomb’s Law to describe and predict the gravitational and electrostatic forces between objects.

<u>Massachusetts State Standards</u>

HS-PS-1. Analyze data to support the claim that Newton’s second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

HS-PS-4. Use mathematical representations of Newton’s law of gravitation and Coulomb’s law to both</td><td colspan="2">Transfer</td></tr>
<tr><td colspan="2">Students will be able to independently use their learning to make determinations and applications about magnetic forces in modern technology.</td></tr>
<tr><td colspan="2">Meaning</td></tr>
<tr><td>UNDERSTANDINGS
Students will understand that…
1. Distinguish between bonding forces holding compounds together and other attractive forces, including hydrogen bonding and van der Waals forces.
2. Compare the magnitude and range of the four fundamental forces (gravitational, electromagnetic, weak nuclear, strong nuclear).
3. Relate the configuration of static charges to the electric field, electric force, electric potential, and electric potential energy.
4. Describe how the gravitational force between two objects depends on their masses and the distance between them.
5. Investigate and explain that when a force is applied to an object but it does not move, it is because another opposing force is being applied by something in the</td><td>ESSENTIAL QUESTIONS

1. How are magnetic fields used in determining direction and travel with a compass?
2. How are electromagnets used in propulsion of objects such as a high-speed train?</td></tr>
</table>

qualitatively and quantitatively describe and predict the effects of gravitational and electrostatic forces between objects.	environment so that the forces are balanced. 6. Investigate and describe that the greater the force applied to it, the greater the change in motion of a given object. 7. Identify familiar forces that cause objects to move, such as pushes or pulls, including gravity acting on falling objects. 8. Investigate and describe that the more mass an object has, the less effect a given force will have on the object's motion. 9. Investigate and describe that an unbalanced force acting on an object changes its speed, or direction of motion, or both. 10. Explore the Law of Gravity by recognizing that every object exerts gravitational force on every other object and that the force depends on how much mass the objects have and how far apart they are. 11. Investigate and describe types of forces including contact forces and forces acting at a distance, such as electrical, magnetic, and gravitational 12. Classify and compare substances on the basis of characteristic	

	physical properties that can be demonstrated or measured; for example, density, thermal or electrical conductivity, solubility, magnetic properties, melting and boiling points, and know that these properties are independent of the amount of the sample. 13. Explain the relationship between moving charges and magnetic fields, as well as changing magnetic fields and electric fields, and their application to modern technologies. 14. Explore the theory of electromagnetism by explaining electromagnetic waves in terms of oscillating electric and magnetic fields. 15. Demonstrate and explain that mixtures of solids can be separated based on observable properties of their parts such as particle size, shape, color, and magnetic attraction.	
	Acquisition	
	Students will know… ● Definition of polar and nonpolar covalent bonds. ● Definitions of the four fundamental forces.	*Students will be skilled at…* ● Apply mathematical computations to mathematical model(s) to determine magnetic forces

	• The relationship between electricity and magnetic forces.	• Interpret graphs to draw conclusions • Use computer software to collect data and model magnetic forces in a variety of conditions. • Apply the scientific method in an experiment

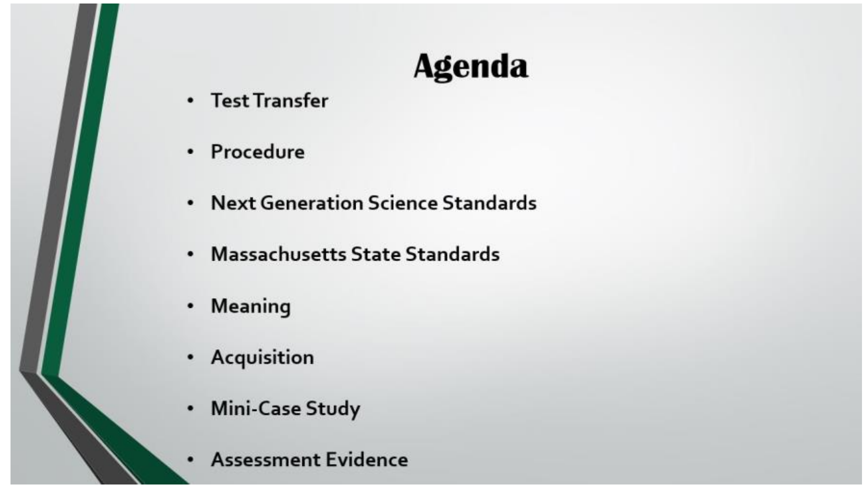
Evidence
Assessment Evidence
PERFORMANCE TASK(S): There is one performance task and one experiment related to magnetic forces. The experiment which will be conducted during different class periods. The performance task will be conducted in a separate class. Assessment evidence will be collected from the experiment and performance task to help evaluated student understanding: 1. In the experiment, students will use the MSET device, learn to measure and calculate the attractive and repellent forces of magnets located at different distances and apply their results to help solve a real-world problem. Assessment evidence will be in the form of calculations and results depicted in tables and graphs included in students' final reports. They will then discuss the possible reasons for the variance in the attractive and repellent forces at the set distances. 2. Students will conduct a field performance task, orienteering to examine the application of magnetic forces in compasses. They will navigate a preset course to a variety of targets and distances with a compass. The teacher will provide a data sheet to examine the accuracy of the students' application of the students' application of the compass bearings.
OTHER EVIDENCE: The essential questions will be used as an entrance/exit slip to determine growth in understanding. The following computational problem will also be used as an entrance and exit slip. *Consider the configuration below.*

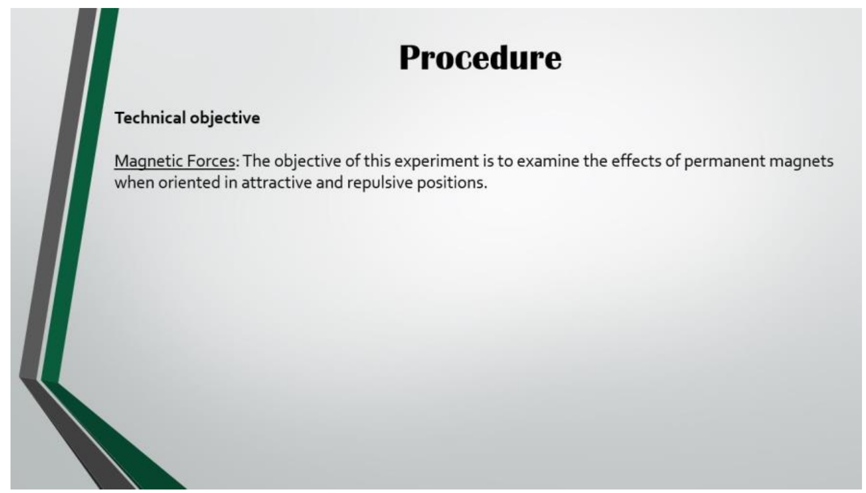
Stage 3 – Learning Plan

Summary of Key Learning Events and Instruction

See outline of Magnetic Forces experiment summary included.

PowerPoint Template for Instruction – Magnetic Forces





Procedure

Approach

Magnetic Forces: The theoretical magnetic force will be computed and compared to fixed permanent magnets that are moved relative to each other while measuring the reaction force.

Standards/Established Goals

Next Generation Science Standards

Forces and Interactions:

- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Forces and Interactions:

- HS-PS2-4. Use mathematical representations of Newton's Law of Gravity and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects

Standards/Established Goals

Massachusetts State Standards

Forces and Interactions:

- HS-PS-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Forces and Interactions:

- HS-PS-4. Use mathematical representations of Newton's law of gravitation and Coulomb's law to both qualitatively and quantitatively describe and predict the effects of gravitational and electrostatic forces between objects.

Meaning

Meaning

UNDERSTANDINGS:

Students will understand that…

1. Distinguish between bonding forces holding compounds together and other attractive forces, including hydrogen bonding and van der Waals forces.
2. Compare the magnitude and range of the four fundamental forces (gravitational, electromagnetic, weak nuclear, strong nuclear).
3. Relate the configuration of static charges to the electric field, electric force, electric potential, and electric potential energy.
4. Describe how the gravitational force between two objects depends on their masses and the distance between them.
5. Investigate and explain that when a force is applied to an object but it does not move, it is because another opposing force is being applied by something in the environment so that the forces are balanced.
6. Investigate and describe that the greater the force applied to it, the greater the change in motion of a given object.
7. Identify familiar forces that cause objects to move, such as pushes or pulls, including gravity acting on falling objects.
8. Investigate and describe that the more mass an object has, the less effect a given force will have on the object's motion.
9. Investigate and describe that an unbalanced force acting on an object changes its speed, or direction of motion, or both.
10. Explore the Law of Gravity by recognizing that every object exerts gravitational force on every other object and that the force depends on how much mass the objects have and how far apart they are.
11. Investigate and describe types of forces including contact forces and forces acting at a distance, such as electrical, magnetic, and gravitational
12. Classify and compare substances on the basis of characteristic physical properties that can be demonstrated or measured; for example, density, thermal or electrical conductivity, solubility, magnetic properties, melting and boiling points, and know that these properties are independent of the amount of the sample.
13. Explain the relationship between moving charges and magnetic fields, as well as changing magnetic fields and electric fields, and their application to modern technologies.
14. Explore the theory of electromagnetism by explaining electromagnetic waves in terms of oscillating electric and magnetic fields.
15. Demonstrate and explain that mixtures of solids can be separated based on observable properties of their parts such as particle size, shape, color, and magnetic attraction.

Acquisition

Acquisition	
Students will know… • Definition of polar and nonpolar covalent bonds. • Definitions of the four fundamental forces. • The relationship between electricity and magnetic forces	*Students will be skilled at…* • Apply mathematical computations to mathematical model(s) to determine magnetic forces • Interpret graphs to draw conclusions • Use computer software to collect data and model magnetic forces in a variety of conditions. • Apply the scientific method in an experiment

Mini-Case Study

Scenario:

In an upcoming superhero movie, there will be a dramatic scene in which the hero must lift a car to save his friend. Rather than using computer graphics, the director would like the actor to perform a real stunt with the help of two identical cylindrical magnets. Because the windows of the car are tinted, the lower magnet will be stealthily concealed in the car's interior. The overhead magnet must be suspended above by a crane, and it must maintain a distance of at least 4 m so it won't be visible in the frame of the movie camera.

Objective:

The actor has been working out in preparation for the role, so he can easily provide 120 kg of lifting assistance. Find if the stunt will be safe to perform with a car weighing 2500 kg?

Given Information:

Each magnet has height $h = .1$m, radius $R = .675$m, magnetization $\mu_o M = 1$ T, and density $\rho = 1050$ kg/m^3.

*Assume distance between the two magnets is fixed, even as the car is rising (crane is operated so that the overhead magnet rising at same rate as the car).

Critical Thinking:

Identify at least 3 factors that could be changed to allow for the stunt to be done easier, provide reasoning behind each choice.

Assessment Evidence

In the experiment, students will use the MSET device, learn to measure and calculate the attractive and repellent forces of magnets located at different distances and apply their results to help solve a real-world problem. Assessment evidence will be in the form of calculations and results depicted in tables and graphs included in students' final reports. They will then discuss the possible reasons for the variance in the attractive and repellent forces at the set distances.

Students will conduct a field performance task, orienteering to examine the application of magnetic forces in compasses. They will navigate a preset course to a variety of targets and distances with a compass. The teacher will provide a data sheet to examine the accuracy of the students' application of the students' application of the compass bearings.

The essential questions will be used as an entrance/exit slip to determine growth in understanding. The following computational problem will also be used as an entrance and exit slip.

MSET Experiment Procedure– Magnetic Forces

Technical objective

The objective of this experiment is to examine the effects of permanent magnets when oriented in attractive and repulsive positions.

Background

A magnet is an object that is commonly found and serves a variety of functions. As an example, people use magnets to attach objects to the surface of a refrigerator. Magnets can also be used in sets to generate a force that can attract or repel another magnet or magnetized materials.

A magnet by itself is a material that creates a magnetic field. The magnetic field is an area around the material that has a detectable, yet generally invisible force field. The force field has lines of flux that travel between opposite poles of the magnet. These poles are labeled north and south and are shown in Figure 1.

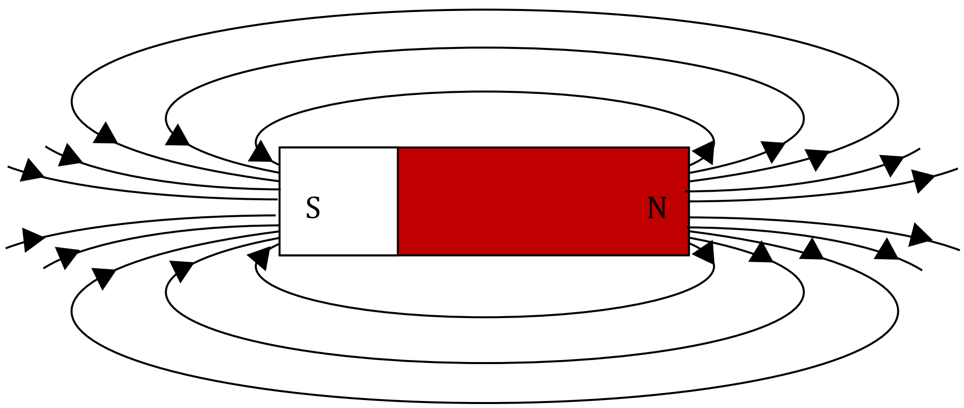


Figure 1: Representation of a Magnetic Field Surrounding a Magnet

The characterization using theoretical studies alone can be complex and inaccurate because magnetic forces are a function of material types, sizes, the surrounding environment and other variables. If using two small magnets made into cylinders of the same geometry, and at relatively large separation distances, the following equation can be used to approximate the force between the set.

$$F(x) = \frac{\pi\mu_0}{4} M^2 R^4 \left[\frac{1}{x^2} + \frac{1}{(x+2h)^2} - \frac{2}{(x+h)^2}\right]$$

Where: R = radius

h = height

M = magnetization of the magnets

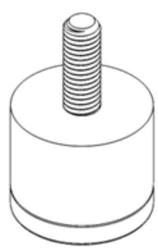
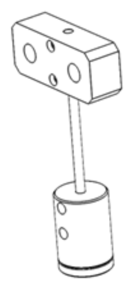
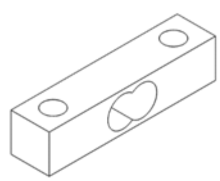
x = separation distance

Approach

The theoretical magnetic force will be computed and compared to fixed permanent magnets that are moved relative to each other while measuring the reaction force.

Experiment Setup

1. Gather the following components:

Magnet x2 	Tower Magnet 	7/8” Thumbscrew x2 
¾” Thumbscrew 	5kg Load Cell 	5/32 Hex Wrench 

2. Attach the tower to the base plate as shown in the Quick Setup Guide.
3. Use the 4mm hex wrench to attach the 5kg load cell to the carriage with the arrow pointing up.

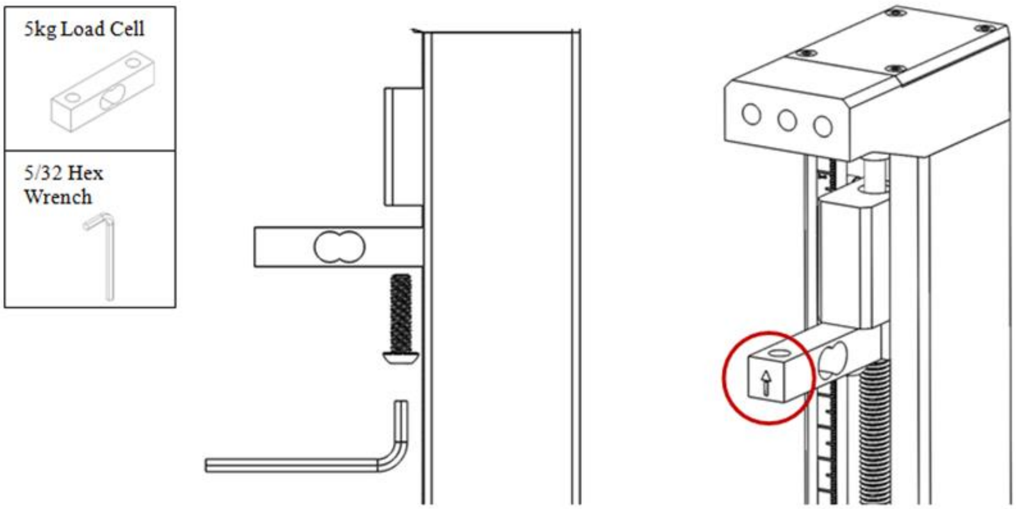


Figure 2: Load Cell Orientation

4. Plug the load cell into port 1 at the back of the SIM.

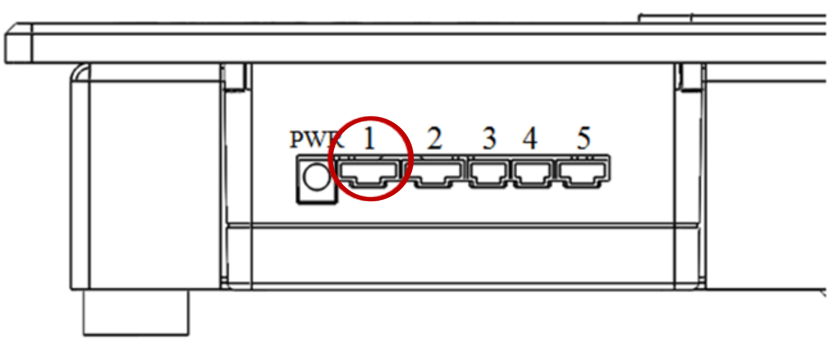


Figure 3: Port 1 on SIM

5. Attach magnet 2 to the base plate as shown in Figure 4

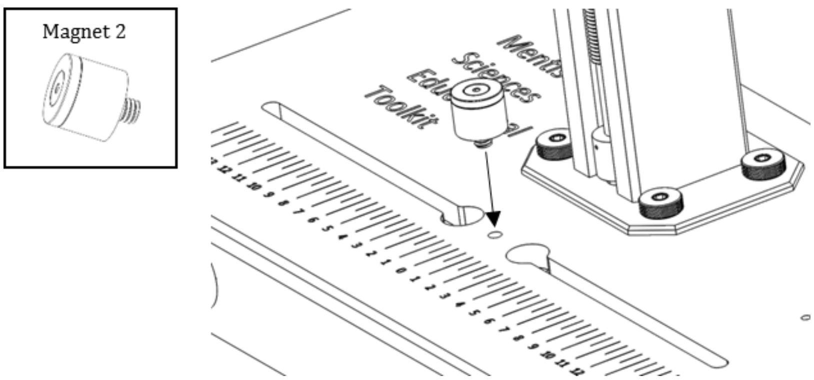


Figure 4: Magnet 2 Location

6. Attach magnet 3 to the top mount with two 7/8” thumbscrews as shown in Figure 5.

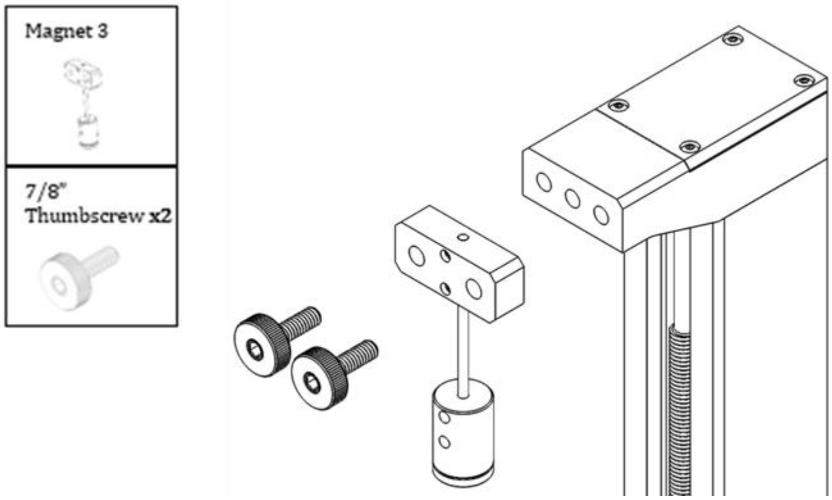


Figure 5: Magnet 3 Location

7. Finally, attach magnet 1 to the load cell in the orientation shown in Figure 6.

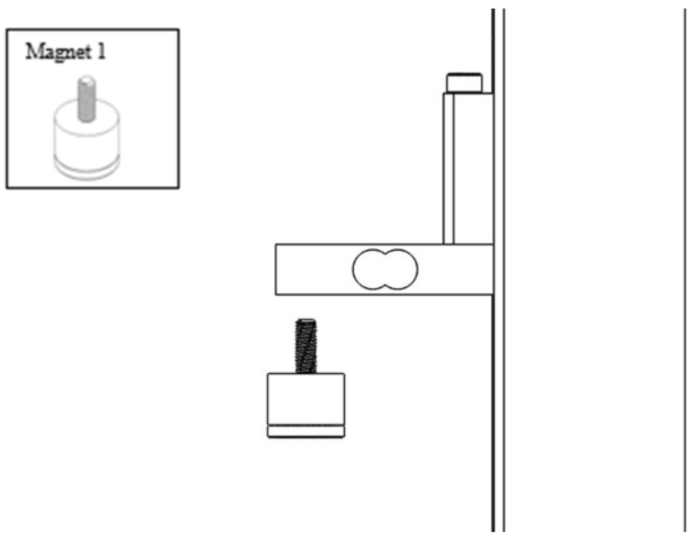


Figure 6: Magnet 1 Location

Experimental Procedure

Repelling Magnets

1. Double click “Magnetic Forces” to launch the magnet experiment.

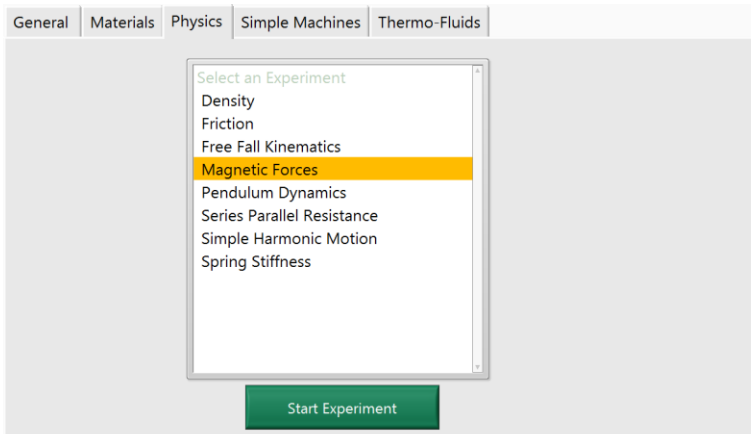


Figure 7. Location of Magnetic Forces Experiment

2. Select the 5 kg load cell from the menu options.

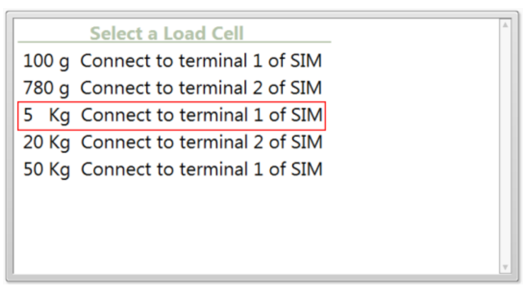
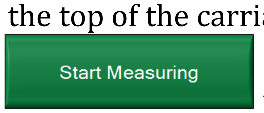
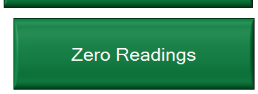
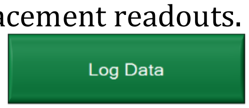


Figure 8. Load Cell Options

3. Align the top of the carriage with the 16cm mark on the tower scale.
4. Click 

to begin reading the sensors.
5. Click 

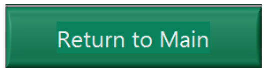
on the MSET program to zero the load and displacement readouts.
6. Press 

to begin collecting data.

7. Using the slowest speed setting, displace the carriage downward until the top of the carriage is level with the 18cm mark. **Stop immediately, do not go any further!**
8. Click 

then 

.
9. Press 

. A window will pop up notifying the user that data will be saved once 

is pressed at the end of the experiment.

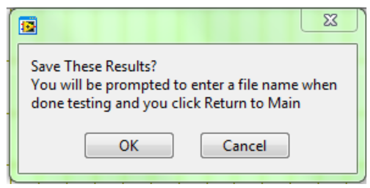


Figure 9. Save Results Prompt

10. Press “ok”.

Attracting Magnets

1. Reconfigure magnet 1 so that it is now facing toward magnet 3 as seen in Figure 10.

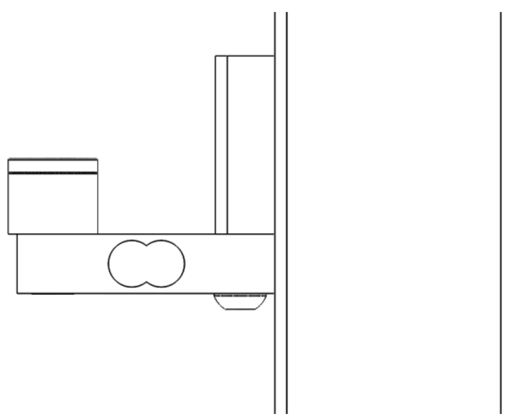
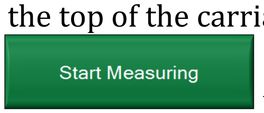


Figure 10: Magnet 1 Orientation for Magnets Attracting

2. Align the top of the carriage with the 6cm mark on the tower scale.

a. Click 

to begin reading the sensors.

b. Click  on the MSET program to zero the load and displacement readouts.

c. Press  to begin collecting data.

3. Displace the carriage upwards until the magnets contact each other than stop immediately.
4. Press  then  .
5. Press  . A window will pop up notifying the user that data will be saved once  is pressed at the end of the experiment.

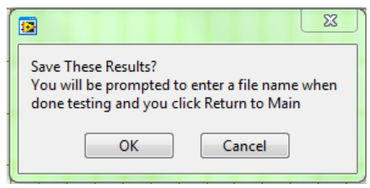
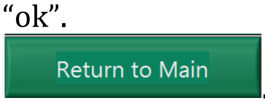


Figure 11. Save Results Prompt

6. Press “ok”.
7. Press  .
8. Enter a file name and press “ok”
9. The data collection portion of this experiment is now complete.

<u>Data Analysis</u>

1. Retrieve the data collected in the previous section by navigating the C: drive then MSET > Physics. Import the saved data from the repelling and attracting magnets into a data processing program such as Excel. Using the information in the table below, generate a plot for each data set showing the force vs magnet proximity.

Orientation	Starting Distance (cm)
Repelling	2.34
Attracting	4.06

2. Based on the shape of the plots, what can be inferred about the relationship between magnetic force between two magnets and their proximity?

MSET – MAGNETIC FORCES

Purpose

Measure the attractive and repelling forces generated by a set of permanent magnets located at controlled distances from each other.

Magnets

Magnets are used to either attract or repel other materials. An engineering application using electromagnets is high speed rail transport which levitates and propels the train along a track.

Theory

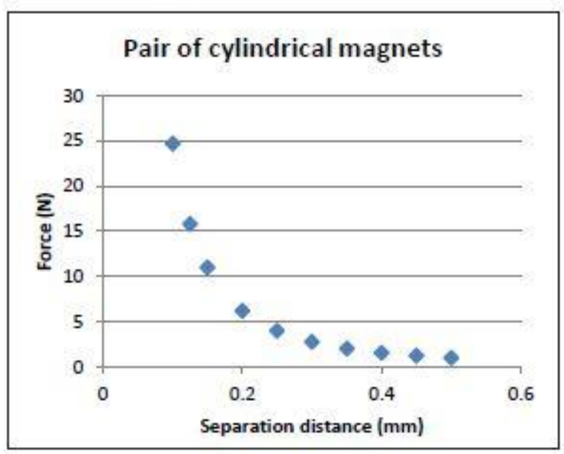
The force that a pair of permanent magnets can impart on each other is a function of the separation distance "x", geometry, magnetization "M", and free space permeability "U". Common cylindrical magnets of radius "R" and height "H" generate a force "F".

$$F = \frac{\pi \, U}{4} M^2 R^4 \left[\frac{1}{X^2} + \frac{1}{(x+2H)^2} - \frac{2}{(x+H)^2} \right]$$

Setup

Results

A pair of magnets, and or magnetized materials will be moved to measureable distances from each other and the resultant repulsion, and or attractive forces will be measured. Equations of force versus distance will be generated and compared to theoretical values.



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Inquiry-Based Mini Project – Magnetic Forces

1. In an upcoming superhero movie, there will be a dramatic scene in which the hero must lift a car to save his friend. Rather than using computer graphics, the director would like the actor to perform a real stunt with the help of two identical cylindrical magnets. Because the windows of the car are tinted, the lower magnet will be concealed in the car's interior. The overhead magnet must be suspended above by a crane, and it must maintain a distance of at least 4 m so it won't be visible in the frame of the movie camera. The actor has been working out in preparation for the role, so he can easily provide 120 kg of lifting assistance. Will the stunt be safe to perform with a car weighing 2500 kg?

   Each magnet has height h = .1m, radius R = .675m, magnetization $\mu_0 M$ = 1 T, and density ρ= 1050 kg/m^3.

   *Assume distance between the two magnets is fixed, even as the car is rising (crane is operated so that the overhead magnet rising at same rate as the car).

2. Identify at least 3 factors that could be changed to allow for the stunt to be done easier, provide reasoning behind each choice.

Teacher Solution Key – Magnetic Forces

Relevant Formulas:

Magnetic forces:

$$F(x) = \frac{\pi\mu_0}{4} M^2 R^4 \left[\frac{1}{x^2} + \frac{1}{(x+2h)^2} - \frac{2}{(x+h)^2}\right]$$

Where μ_o is a magnetic constant, M is the magnetization of the magnets, R is the Radius of the magnet, x is the separation and h is the height of the magnets. Let it be noted that the $\mu_o M$ can be treated as a constant magnetization.

$$F(x) = m * g$$

Given:

Distance between the magnets x= 4m
Lifting assistance from actor: 120 kg
Mass of car: 2500kg
g= 9.81 m/s^2
h= .1 m
R= .675 m
$\mu_0 M$ = 1 T or $\frac{H}{C*^{m}/_{s}}$
μ_0= $4*\pi*10^{-7}$ $\frac{H}{m}$ or $\frac{N}{A^2}$
ρ= 1050 kg/m^3

Find:

1. Lifting Force provided from the actor:

$$F(upwards\_actor) = m * g = 120kg * 9.81\frac{m}{s^2} = 1{,}177\ N$$

Force the car exerts downwards:

$$F(downwards\_actor) = m * g = 2500kg * 9.81\frac{m}{s^2} = 24{,}525\ N$$

Mass of the magnets:

$$Mass(magnets) = \rho * \pi * R^2 * h = 1050\ \frac{kg}{m^3} * 3.14 * (0.675m)^2 * 0.1m = 150\ kg$$

Force the magnets exerts downwards due to mass:

$$F(downwards\_magnets) = m * g = 150kg * 9.81\frac{m}{s^2} = 1{,}474\ N$$

Magnetization of the Magnet:

$$M = \frac{\mu_o M}{\mu_o} = \frac{1\ \dfrac{H}{C * {}^{m}/_{s}}}{4 * \pi * 10^{-7}\ \dfrac{H}{m}} = 795{,}775\ \frac{s}{C}$$

Force exerted upwards from magnets:

$$F(x) = \frac{\pi * \ \mu 0}{4}(\mathrm{M})^2(\mathrm{R})^4\left[\frac{1}{x^2} + \frac{1}{(x+2h)^2} - \frac{2}{(x+h)^2}\right] = 24{,}787\ N$$

Sum of all Forces:

$$\begin{aligned} F(total) &= F(upwards) - F(downwards) \\ &= \left[F(upwards_{actor}) + F\left(upwards_{magnets}\right)\right] \\ &- \left[F(downwards_{car}) + F\left(downwards_{magnets}\right)\right] \\ &= [1177N + 24787N] - [24525N + 1474N] = \mathbf{-35N} \end{aligned}$$

Since the sum of all of the forces are negative the stunt is not safe and the actor should not attempt to lift the car.

2. Typical variables of the problem that could be changed would be as follows:
   Use a lighter car, have the magnet closer to the car magnet, increase the size of the magnet (increasing R would help with the force of the magnet pulling upwards). use a stronger magnet, have the actor be able to assist more in the lifting of the car, use a less dense magnet (change the weight of the magnet but also might change the magnetism strength), ect.

Inquiry-Based Mini Project Rubric – Magnetic Forces

	3	2	1	0	Score
Proper Use of Equipment	Used the MSET effectively to plot force vs. proximity of two magnets.	Struggled with using the MSET and getting accurate data. Was able to plot force vs. proximity of two magnets but needed some assistance.	Even at the end of the experiment, struggled with the use of the MSET to accurately plot force vs. proximity of two magnets.	Didn't use the MSET	
Accuracy of Use of Terminology	Used all terms accurately including, gravitational forces, electromagnetic forces, polar/non-polar covalent bonds, magnetic field, mass, density, and Newton's Laws of Motion.	May have used all of the terms but one or two were not used accurately.	Used some of the terms but not all of them, or the terms were used but not used accurately.	Didn't use any of the terms in the explanation of the solution	
Rationale for Solution	Provided a detailed rationale for their solution to the mini-project. Explanation included why the stunt is safe or not safe by discussing the size of the	Provided a rationale for their solution, but could only briefly explain why the stunt is safe or not safe by discussing the size of the magnet,	Provided a rationale, but their explanation was lacking the proper connections between their solution and the concepts of magnetization,	Didn't provide a rationale for their solution	

	magnet, magnetization, and density as factors. The student used Newton's Laws of Motion to help explain their solution as well as their knowledge of gravitational and electromagnetic forces, especially the relationship between force and proximity. The student also provided an explanation of variables that could be changed to make the stunt easier and a rationale for their ideas.	magnetization, and density as factors. The student may not have used Newton's Laws of Motion to help explain their solution or their knowledge of gravitational and electromagnetic forces. The student may have provided an explanation of variables that could be changed to make the stunt easier but their rationale was limited.	density, force vs. proximity of the magnets, Newton's Laws, and gravitational and electromagnetic forces.		
Use of Mathematical Computations	Accurately completed calculations and was able to use calculations to explain the reasoning behind their solution.	May have accurately calculated the sum of all the relevant forces, however could not use the calculations to explain the reasoning behind their solution.	Attempted to calculate sum of all the relevant forces, but included some miscalculations.	Did not complete calculations or calculations were incorrect.	