

MAKING IT 'ROUND THE BEND

TEACHER NOTES

DESCRIPTION

This set of three classroom activities allows students to explore some basic physics at the heart of particle physics accelerator design. Students will study how magnetic and electric fields accelerate, turn and focus the particles in the Large Hadron Collider (LHC) beam. The activities provide examples from modern physics that can be incorporated in a general study of electricity and magnetism or as part of a unit of study focused on particle physics. Additionally, the activities help students understand the role of magnets in the LHC.

The activities include:

DIPOLES AND QUADRUPOLES

Students use permanent magnets and compasses to explore two common magnets used in particle accelerators: dipoles and quadrupoles. Students arrange simple bar magnets in predetermined layouts to create fields similar to those used in accelerator magnets. They then use a compass to map out the field lines in each magnet.

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CHARGED PARTICLES IN A MAGNETIC FIELD

Students use an online activity to explore the forces felt by charged particles moving through magnetic fields. Students can change values such as strength of the field, mass and velocity of the injected particle and observe the particle's path. The activity URL: (<http://tinyurl.com/c8ju8pr>)

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LHC CONTROL ROOM

Students use another online activity to explore effects that electric and magnetic fields have on the particles in the series of accelerators at the LHC. This activity adds a component not explored in the previous two: the electric field. Students know that opposite charges attract and similar charges repel. That understanding is sufficient to complete this activity that asks them to accelerate, bend and then focus the LHC particle beam. The activity URL: (<http://tinyurl.com/cgckyqa>)

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BACKGROUND MATERIAL

When a charged particle moves through a magnetic field, it can feel a force. When it acts, this force always changes the particle's direction and never changes the particle's speed. The more momentum a particle has, the larger the force needed to turn it. Large magnetic fields create larger forces on moving particles. These simple ideas lie at the heart of the excitement about restarting the LHC. (<http://tinyurl.com/yzhq54h>)

Particles in the CERN accelerators move inside beam pipes about the size of your index finger. Magnets in the curved segments of these accelerators send the particles around the bend. Each revolution of the ring increases the momentum of the particle; each momentum increase requires a stronger turning force; these stronger forces come from adjusting the field of the bending magnets. Electromagnets can do this—sending more current through one of these magnets increases the magnetic field.

In September of 2009, the LHC magnets were tuned to create a large enough force to turn particles with 5.5 TeV units of energy; this is well below the design energy of the LHC. The magnets in the LHC are "superconducting"; this means that there is no electrical resistance to the flow of electricity. The accident happened when the electrical current met a poorly assembled

joint within the circuit; this assembly provided resistance when none was expected. The resistance created a great deal of thermal energy. That thermal energy melted components and boiled away six metric tons of liquid helium. The helium vented in a very short time; the large pressure differences moved the massive magnets like toys. (<http://tinyurl.com/4er6r7>)

After the accident, CERN carefully checked all of the assemblies that failed and many others in the complex. Physicists are slowly, methodically turning the LHC back on. They will "ramp-up" the beam energy, carefully watching the performance of all of the magnets in the accelerators. Come explore the fields used in the LHC complex to control the particles.

IMPLEMENTATION

Look for implementation tricks in each of the activities here.

ASSESSMENT

Individual teachers will create their own assessment plans for these activities.

ADDITIONAL INFORMATION

Additionally, students can use other resources to explore the LHC. These might include:

- Follow the LHC on Twitter. (<http://twitter.com/uslhc>)
- Keep up with the late breaking news from CERN's press office. (<http://tinyurl.com/gqpm7>)
- Link to CERN. (<http://www.cern.ch>)
- The Large Hadron Rap was an Internet meme in summer of 2009. Check it out! (<http://tinyurl.com/yjxpm7e>)

The URLs in this document are shortened using the service found on <http://tinyurl.com>. This makes long URLs far more manageable and makes errors in typing the URL into your browser less likely.

DIPOLES AND QUADRUPOLES

TEACHER NOTES

DESCRIPTION

Students use permanent magnets and compasses to explore two common magnets used in particle accelerators: dipoles and quadrupoles. Students arrange simple bar magnets in predetermined layouts to create fields similar to those used in accelerator magnets. They then use a compass to map out the field lines in each magnet.

STANDARDS

National Science Education Standards (U.S. National Research Council)

- Physical Science Content Standard B:
 - As a result of the activities . . . students should develop an understanding of:
 - Motion and forces.

PRIOR KNOWLEDGE

Before starting this activity, students must understand that opposite charges attract and like charges repel. They must also know how to use a magnetic compass.

BACKGROUND MATERIAL

This activity is part of a packet called “Making it ‘Round the Bend.’” We have provided one background reference that creates context for all of these activities and included it on the first page of the packet.

IMPLEMENTATION

Hang a magnet on a string from the ceiling. It helps with the mystery if you use a black binder clip with a magnet attached underneath so the students cannot tell that there is a magnet present. Then use a “wand” to make the pendulum move in unexpected ways. The “wand” can be made using a screwdriver with a few strong magnets attached to the shaft. Ask the students to reflect individually upon what could be causing the strange behavior of the pendulum. Then ask them to discuss their ideas in their groups. When the students have decided upon a model for this event, reveal the secret of the hidden magnets. Ask the students to reflect upon how well their model described what was really going on.

Student groups need:

- Four blank sheets of paper per group
- One compass (as small as possible works best) per group
- Four rectangular magnets per group
(Neodymium magnets are too strong and make the lab difficult to perform.)
- Pencil

Sources for Materials:

Small magnetic compasses:

<http://www.dealextreme.com/details.dx/sku.3295> \$2.50 for a pack of five
Oriental Trading Company #IN-39/37 \$7.99 for 144

Rectangular magnets:

Sargent Welch #WLS1762-44 \$4.35 for two
Steve Spangler Science #WMBM-110 \$5.95 for a pack of 10

Show the students how moving a magnetic compass around a permanent magnet will deflect the compass needle. Point out that the end of the needle will always point to one magnetic pole and away from the other. Discuss that the needle shows the direction of the field line at that point.

PROCEDURE – DIPOLE FIELD MAPPING

Direct the students to place two magnets about 15 cm apart on a sheet of paper. Remind the students to make sure they outline the positions of the magnets on their paper.



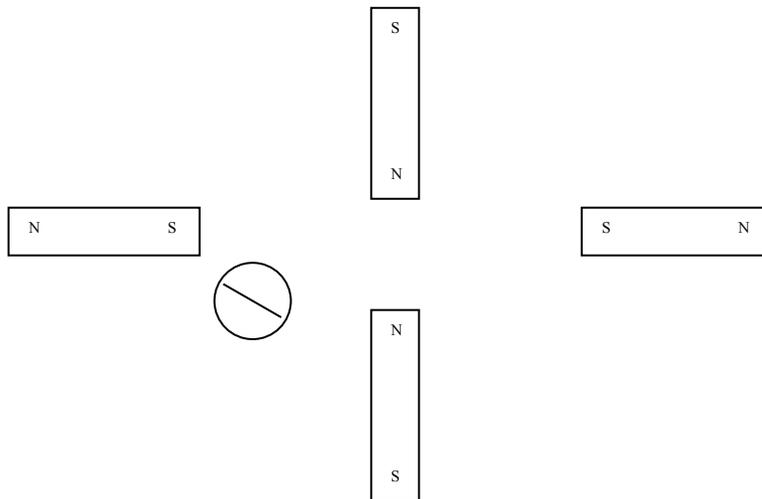
Direct the students to place the compass near one of the magnets and mark the paper to indicate each end of the compass needle. Connect these two points. This line shows the direction of the field at that point in space. Repeat this at least 30 additional locations on the paper. These 30 lines should indicate the general shape of the field around this arrangement of magnets.

PROCEDURE – QUADRUPOLE FIELD MAPPING PART I

Repeat this mapping procedure for any arrangement of four magnets. Students select the orientation for these magnets. As you walk around, encourage the students to select an orientation different from the groups around them.

PROCEDURE – QUADRUPOLE FIELD MAPPING PART II

Repeat this mapping procedure for an arrangement of four magnets as indicated. Map the lines of force with the compass in the same manner as above.



ASSESSMENT

You might ask questions like:

- Was the shape of the magnetic field the same for all configurations?
- Compare the shape of the magnetic field for the two magnet and the four magnet cases. What were the similarities and what are the differences?
- Predict what the field would look like if you used four magnets with the N poles always pointed into the center.
- Predict what the field would look like if you use two magnets with the S poles facing each other.

ADDITIONAL INFORMATION

Framework for Inquiry

Hook/Discovery/Observation

- Demo of magnetic effects by teacher
- Trying to influence a magnet on a string
- What factors affect the movement of the magnetic on a string?

Questions from Observation

- Student generated
- Brainstorm (accept all) – “Why” questions are OK here.
- Categorize – Testable vs. not testable

How does “*IV*” affect “*DV*”?

- Possible IVs: Shape of magnet, type of magnet, medium through which the field travels, distance from the magnet, 2D effects vs. 3D effects . . .
- Possible DVs: Shape of field, size of field, strength of field . . .

Testable Questions

- How does “orientation of the magnets” affect “the shape of the magnetic field”?
- Control is the standard for comparison; no magnet present vs. magnet present
- All else held as constant as possible

Hypothesis – Proposed answer to the research question based on limited evidence. “The shape of the magnetic field will be the same for all orientations of the magnets.”

Experiment on Own

- Teacher questions to guide student experiences
 - Whole class vs. small group – How can you visualize a magnetic field? Which end of your compass points towards North? How does the direction of the compass needle indicate the direction of the arrow drawn on your paper? What happens if your magnets move?
 - Provide support mechanisms while walking around the classroom. Use questions to head off unproductive research.

Share Results/Revise Procedures

Products may include paper with arrows and lines.

Experimentation Revised

What worked? What did not work?

Draw Conclusions Based on the Evidence

- Does the evidence support or fail to support your hypothesis?
- How close is close enough? – Experimental uncertainty, special factors which may have affected your research

Summarize conclusions and communicate.

- Reflection – What do you know based on the evidence of your research?
- Next Questions – What other configurations might be useful? Are there applications for the configurations tested?
- Making Connections to Particle Physics – Particle confinement and acceleration
- Relevance in school and in life – How a compass works, orienteering . . .

DIPOLES AND QUADRUPOLES

Your teacher has a demo of an unusual pendulum. Record your observations and ideas of what is causing the pendulum to move in such an unusual manner.

When everyone in your group has recorded their own ideas, discuss the demo and come to a consensus about what your group members think is causing the unusual movement of the pendulum. Record the model that your group thinks best explains the unusual motion of the pendulum. If the group cannot come to agreement, record all ideas.

Your teacher will now reveal the secret of the unusual pendulum. How well did your group's model describe what was actually going on?

PROCEDURE – DIPOLE FIELD MAPPING

Place two magnets about 15 cm apart on the paper. Make sure you outline the positions of the magnets on your paper so you can always put them back in the same place.



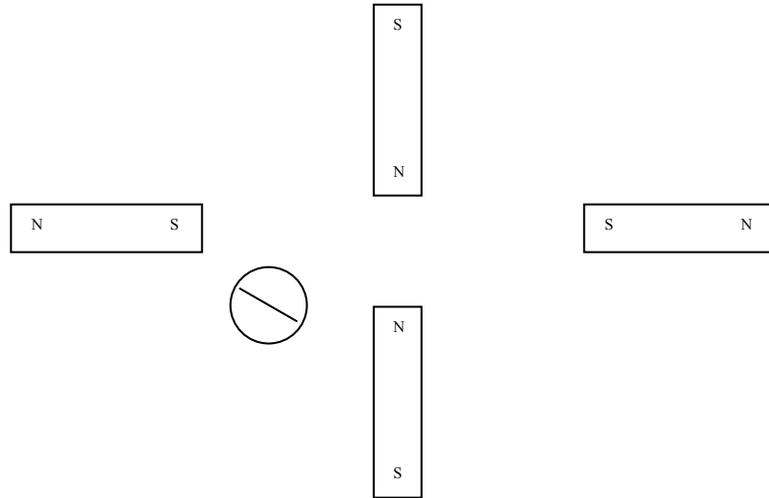
Place the compass near one of the magnets and mark the paper to indicate each end of the compass needle. Connect these two points and indicate the direction of the field using the technique that your teacher demonstrated. This line shows the direction of the field at that point in space. Repeat this at least 30 additional locations on the paper. These 30 lines should indicate the general shape of the field around this arrangement of magnets.

PROCEDURE – QUADRUPOLE FIELD MAPPING PART I

Repeat this mapping procedure for an arrangement of four magnets. Select the orientation for these magnets. Look around and make sure that you select an orientation different from the groups around you.

PROCEDURE - QUADRUPOLE FIELD MAPPING PART II

Repeat this mapping procedure for an arrangement of four magnets as indicated. Map the lines of force with the compass in the same manner as above.



CHARGED PARTICLES IN A MAGNETIC FIELD

TEACHER NOTES

DESCRIPTION

Students use an online activity to explore the forces felt by charged particles moving through magnetic fields. Students can change values such as strength of the field, mass and velocity of the injected particle and observe the particle's path. The activity URL: (<http://tinyurl.com/c8ju8pr>)

STANDARDS

National Science Education Standards (U.S. National Research Council)

- Physical Science Content Standard B:
 - As a result of the activities . . . students should develop an understanding of:
 - Motion and forces.

PRIOR KNOWLEDGE

Before starting this activity, students must be able to operate a web browser.

BACKGROUND MATERIAL

This activity is part of a packet called "Making it 'Round the Bend.'" We have provided one background reference that creates context for all of these activities and included it on the first page of the packet. .

IMPLEMENTATION

Students explore the motion of a charged particle in a magnetic field. Students will be able to investigate several parameters and their effect on a particle's motion. The web application allows users to change magnetic field strength, mass, velocity and injection angle of the particle as it enters the field. The activity URL: : (<http://tinyurl.com/c8ju8pr>)

Ask the students to select two parameters to investigate and write a brief description explaining how the chosen parameters affect the motion of the charged particle.

ASSESSMENT

Ask the students to prepare a presentation for the class explaining what they observed. Use whiteboards if you have them.

ADDITIONAL INFORMATION

Hook/Discovery/Observation

- The previous activity is the hook for this continuation activity.

What is the Relationship between "*IV*" and "*DV*"?

- Students generate testable relationships; each group selects different parameters to test.

Testable Questions

- How does "*parameter chosen*" affect "*bending of the charged particle*"?
- Control is the standard for comparison; path of the charged particle when no field is present
- All else held as constant as possible

Hypothesis – Proposed answer to the research question based on limited evidence. Many are possible; example – Changing the direction of the magnetic field will not change the path of the charged particle.

Experiment on Own (Pilot Phase)

- Teacher questions to guide student experiences
 - Whole class vs. small group – Each group tests one or more parameter and its effect on the path of the charged particle.
 - Provide support mechanisms while the students are working to be sure that their research efforts are appropriate.

Share Results/Revise Procedures

Students must determine the method of presenting their results. This can include graphing, charts, graphs; use of poster paper or white boards.

Experimentation Revised

Questions for further testing. What additional questions arise from the observations made and the data collected?

Draw Conclusions Based on the Evidence

- Does the evidence support or fail to support your hypothesis?
- Evidence from the data must be used to support conclusions.
- How close is close enough? – Experimental uncertainty
- Communication – Summarize conclusions.
- Reflection – Presentation of results must include their reflection upon what information the evidence gave in support of the chosen research question.
- Next Questions – Presentation must include the next questions that arise from their investigation
- Making Connections – Presentation must make connections with the need for magnets in the Large Hadron Collider.
- Relevance in their life – Presentations must include connections to the use of magnets in power plants, colliders, accelerators . . .

CHARGED PARTICLES IN A MAGNETIC FIELD

In this activity you will explore the motion of a charged particle in a magnetic field. You will be able to investigate several parameters and their effect on a particle's motion. The web application allows you to change magnetic field strength, mass, velocity and injection angle of the particle as it enters the field. The activity URL: : <http://tinyurl.com/c8ju8pr>

PROCEDURE

Select two parameters to investigate. Make sure that you have chosen different parameters than the groups nearby. Make a data table to organize your observations. If you can, collect quantitative data. Make graphs of your data to look for trends.

REFLECTION GUIDELINES

Prepare a presentation for the class explaining what you observed. Your presentation must include:

- A summary of your results with enough evidence to support your reasoning.
- Did your evidence support your research question?
- What next questions arose from your research?
- How do your results relate to the use of magnets in the Large Hadron Collider?
- What relevance your results might have in your life.

LHC CONTROL ROOM

TEACHER NOTES

DESCRIPTION

Students use another online activity to explore effects that electric and magnetic fields have on the particles in the series of accelerators at the LHC. This activity adds a component not explored in the previous two: the electric field. Students know that opposite charges attract and similar charges repel. That understanding is sufficient to complete this activity that asks them to accelerate, bend and then focus the LHC particle beam. The activity URL: (<http://tinyurl.com/cgckyqa>)

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PRIOR KNOWLEDGE

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BACKGROUND MATERIAL

This activity is part of a packet called “Making it ‘Round the Bend.’” We have provided one background reference that creates context for all of these activities and included it on the first page of the packet.

IMPLEMENTATION

This activity helps students describe the adjustments needed to accelerate charged particle, bend charged particles and then focus the charged particles so that collisions occur in the detectors. Ask the students to point a web browser to (<http://tinyurl.com/cgckyqa>). The web activity appears in three sections.

Students explore how electric fields accelerate particles in the first section. They control the electric field and “tune” it so that the particles end up with the most energy. They have not explored electric fields in the two previous activities. We assume that they understand that opposite charges attract and like charges repel.

The second section of the web activity yields an opportunity to control the magnets that turn the particles around the bends in the LHC. Students must increase the strength of these magnets—but not too much—in order to guide the particle around the circular accelerator.

The last section of the web activity allows students to use focusing magnets (called quadrupoles) to squeeze the beam in two directions. This increases the density of particles and increases the chance of collisions. Students control the field strength in two directions here; one effects lateral focus, the other vertical focus.

Have the students follow the on-screen instructions in each section and note what they did for success in each one. Here are some guiding questions that you may wish to give to your students:

1. Section 1

- a. What did you have to do to keep the particle moving?
 - b. At what point in the particle's path were the adjustment made?
2. Section 2
 - a. What would you have to do differently if the particle had the opposite charge?
 - b. What would have to be changed if the particle went in the opposite direction?
 3. Section 3
 - a. What adjustments were required to focus the beam?

Ask the students to select two parameters to investigate and write a brief description explaining how the chosen parameters affect the motion of the charged particle. Ask the students to prepare a presentation for the class explaining what they observed. Use whiteboards if you have them.

ASSESSMENT

Have students write their own response to the question below and then discuss in small groups.

Explain in your own words the role of magnets in the LHC. Remember to cite evidence from the previous activities to develop a complete explanation of the role of magnets in the LHC.

ADDITIONAL INFORMATION

Framework for Inquiry

Hook/Discovery/Observation

- Previous activities in this lesson

Testable Questions

- How does “changing electric field polarity” affect “the acceleration of the particle”?
- Control is the standard for comparison; what happens to the particle when the electric field is not changed?
- How does “changing magnetic field strength” affect “the path of the particle”?
- Control is the standard for comparison; what happens to the particle when the magnetic field strength is not changed?
- How does “changing magnetic field strength” affect “the bunching of the particles”?
- Control is the standard for comparison; what happens to the bunching of the particles when the magnetic field strength is not changed?
- All else held as constant as possible

Hypothesis – Proposed answer to the research question based on limited evidence

Experiment on Own (Pilot Phase)

- Teacher questions to guide student experiences
 - Whole class vs. small group – Clarifying the operation of the simulation
 - Provide support mechanisms while the students work

Share Results/Revise Procedures

Written reflections

Experimentation Revised

Not appropriate with this simulation

Draw Conclusions Based on the Evidence

- Does the evidence support or fail to support your hypothesis?

- How close is close enough? – Experimental uncertainty

Communication – Summarize conclusions.

- Reflection
- Next Questions
- Making Connections
- Relevance

LHC CONTROL ROOM

In this activity you will learn about adjustments needed to accelerate charged particle, bend charged particles and then focus the charged particles so that collisions occur in the detectors of the Large Hadron Collider. Point a web browser to (<http://tinyurl.com/cgckyqa>) . The web activity appears in three sections.

PROCEDURE

In the first section, explore how electric fields accelerate particle. You control the electric field and “tune” the accelerator so the particles end up with the most energy. You have not explored electric fields in the two previous activities here, but you do know that opposite charges attract and like charges repel.

The second section offers an opportunity to control the LHC magnets that turn the particles around the bends. You must increase the strength of these magnets—but not too much—in order to guide the particle around the circular accelerator.

In the last section you use focusing magnets (quadrupoles) to squeeze the beam in two directions. This squeezing increases the density of particles and increases the chance of collisions. You can control the field strength in two directions here; one effects lateral or sideways focus, the other vertical focus.

Follow the on-screen instructions in each section and note what you did for success in each one. Here are some questions to guide your note taking.

Section 1

- What did you have to do to keep the particle moving?
- At what point in the particle’s path were the adjustment made?

Section 2

- What would you have to do differently if the particle had the opposite charge?
- What would have to be changed if the particle went in the opposite direction?

Section 3

- What adjustments were required to focus the beam?

Reflection

Explain in your own words the role of magnets in the LHC. Remember to site evidence from the previous activities to develop a complete explanation of the role of magnets in the LHC.