Unit 2

The Fundamental Interactions

Introduction

> *It is inconceivable, that inanimate brute matter should, without the mediation of something else, which is not material, operate upon and affect other matter without mutual contact... That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance, through a vacuum, without the mediation of anything else… is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall into it. Gravity must be caused by an agent, acting constantly according to certain laws; but whether this agent be material or immaterial, I have left to the consideration of my readers.*
>
> – Sir Isaac Newton, 1693

If you drop your keys, they fall to earth. But how do the keys "know" that the earth is there? How does an electron "know" that the other one is there? As Newton muses above, what is the mechanism by which things act at a distance? The concept of *fields* has been developed to describe how something can affect another thing without physically touching it, and *field theory* describes how this interaction occurs at quantum scales, via the exchange of *virtual particles*. Among the fundamental forces of nature, however, gravity stands out as a substantial enigma, as will be covered in Unit 3. Additional discoveries about the nature of fields and forces are likely to be made in the future, especially with the experiments at the *Large Hadron Collider (LHC)* that allow scientists to probe particles at energies higher than ever before.

What Will Participants Learn?

Participants will be able to:

1. Describe the mechanism by which two charged objects interact without touching (*action at a distance*).
2. List the four fundamental forces and compare them in terms of key aspects, such as the distances over which they act, the particles they affect, and how those particles are acted on by each force (e.g., *charge*, or *color*).
3. Describe how scientific models provide predictions of what experimental scientists will see, and guide experimental scientists by suggesting promising lines of research.

What's in this Unit?

Text: Unit 2: *The Fundamental Interactions* describes the nature of fields and forces, as well as the four fundamental forces—electricity and magnetism, gravity, the weak force and the strong force. Particles can be distinguished as either matter (*fermions*) or force carriers (*bosons*), which are responsible for the interactions between matter. In field theory, matter particles are described as excitations of fields, and forces are the exchange of virtual particles between matter. Electricity and magnetism behaves differently at tiny distances than at larger distances, and so *quantum electrodynamics (QED)* was developed in order to describe electromagnetism at quantum scales and account for observed measurements. *Quantum chromodynamics (QCD)* describes the interaction of *quarks* through *gluons*, generating the strong force that binds together nuclei. QED and the *weak force* were unified into the *electroweak* interaction, which is compatible with QCD. Only *gravity* remains as an outstanding puzzle—it is not unified with the other three forces, has no quantum theory to explain its effect at microscopic scales, and its force carrier (the hypothesized *graviton*) has yet to be observed. That is the subject of the next unit.

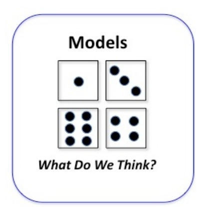
Video: The program for *Unit 2* describes the ATLAS experiment, which measures proton-proton collisions at the Large Hadron Collider (LHC). The high energies of these collisions produce particle interactions never before seen in science, and may provide missing links within the Standard Model as well as evidence for the elusive Higgs boson. Data selection and interpretation at the LHC are very complicated tasks. Srini Rajagopalan is a theorist at Brookhaven National Laboratory working with a group of physicists to generate models that allow them to automatically select the most potentially interesting data from the millions of events that are recorded. Ayana Arce is a physicist at Lawrence Berkeley National Laboratory using simulations to predict what scientists expect to see in this experiment so that it may be compared to the recorded data.

Interactive Lab: *Discovering Neutrino Oscillation* allows you to explore how the basic properties of neutrinos affect effect their oscillations and design an experiment to learn more about the quantum behavior of this elusive particle.

Activities:

- The Hook: Why Don't We Fall Through Our Chair? (10 minutes)
- Activity 1: What Is a Field? What Is a Force? (15 minutes)
- Activity 2: Feynman Theater (20 minutes)
- Activity 3: Force Jigsaw (45 minutes)
- Activity 4: Visual Map of the Forces
- Activity 5: Watch and Discuss the Video (50 minutes)
- Back to the Classroom (10 minutes)

Nature of Science Theme: *Models*. You may wish to display the *Models* icon during the session and remind participants of the central ideas of this theme. Scientists create models, or hypotheses and theories, to make sense of their observations. Thus, a model is a scientific account of nature. A good model is testable and suggests evidence that would support or refute it. When experimental observations do not match the existing model, scientists do and have changed their ideas about nature.



Exploring the Unit

The Hook: Why Don't We Fall Through Our Chair?

Time: 10 Minutes.

Purpose: To identify prior ideas and generate curiosity about the subatomic world.

To Do and To Notice

Facilitate a Think-Pair-Share on the question, "Why don't we fall through our chair?" After participants have discussed for a short time, pose the following clicker question.

Clicker/Discussion Question:

Why don't we fall through our chair?

A. The chair is in the way
B. We're too big to go through the chair
C. We're solid and so is the chair
D. Our electrons interact with the electrons in the chair
E. Something else/More than one

Shortly after the start of the discussion, suggest that participants draw a force diagram, showing that the chair exerts an upward force in order to balance the force of gravity. Probe them, "What kind of force is that?" The "normal force" is accurate, but incomplete. What kind of fundamental force is it?

You may wish to show the animated "Why can't we walk through walls?" at http://www.perimeterinstitute.ca/en/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/ and discuss as a group.

What's Going On?

The best answer for the clicker question is (D) or (E). We're not simply too big to go through the chair. The atoms of our body and the chair are mostly empty space. Students commonly have the idea that atoms are the smallest piece of a thing, rather than mostly empty space. However, if participants argue that we're too big to *tunnel*[1] quantum-mechanically through the chair, then that is a valid answer. The chair is not just in the way. If gravity exerts a downward force, then the chair must exert an upward force by Newton's second law. What is this force? It's the electrostatic repulsion between our electrons and the electrons of the chair. Answer (C) is also an acceptable partial answer—we're solid. Our atoms interact with each other (as do the atoms of the chair), so that they can't be pushed aside, as would be possible for water or gas.

Neutrinos can pass through walls, and photons can pass through glass, because they don't interact with those materials strongly. An electron on its own can pass through material, but only if it doesn't interact with a nucleon, such as the particles in

[1] *Quantum tunneling* refers to the fact that there is some chance that a particle will tunnel through a barrier due to the probabilistic nature of quantum mechanics.

Rutherford's gold foil experiment. Bound to an atom, however, which is bound to other atoms, electrons simply exert a force against the other electrons in the material.

Explain to participants that the last unit catalogued the different particles that make up the material universe. This unit looks at how those particles interact with each other—the forces between them and how they arise. The interaction of our hand with the wall and our body on the chair is one familiar force (electricity), as is gravity. We'll look at those forces, and less familiar ones, and discuss the mechanisms that make them work.

Activity 1: What Is a Field? What Is a Force?

Time: 15 Minutes.

Purpose: To explore ideas and visuals relating to fields and forces.

Materials:

- "Electric Field Hockey" PhET simulation
  http://phet.colorado.edu/simulations/sims.php?sim=Electric_Field_Hockey
  (*Note:* You do not need to be connected to the internet to run the simulation. You may click "download" to download and run the simulation locally on your machine.)

Optional Materials:

- PhET "Charges and Fields" simulation
  http://phet.colorado.edu/simulations/sims.php?sim=Charges_and_Fields
- Van de Graaff generator
- Mylar balloon
- string

1. Action at a distance

To Do and To Notice

Explain that, of course, things don't have to touch to interact. What types of things interact without touching?

Project the "Electric Field Hockey" PhET simulation on the digital projector. Demonstrate the properties of the simulation yourself, or ask a participant to do so. Leave the "Field" option OFF for now. Explain that this is an aerial view of an air hockey table. The red pucks are fixed once placed. You may wish to start with the simulation in default mode, and move the red pucks to get different effects. Then move to a higher difficulty mode.

- What do the blue lines represent? How can we use these blue lines to answer the question, "How does the black puck 'know' that the red pucks are there?"
- Turn on the "Field" option. Demonstrate how the field responds to the movement and addition of red pucks. Attempt to hit a goal with the simulation in difficulty mode "2".
- What do the field lines represent?
- How are the field lines different from/similar to the force vectors?
- Does the black puck affect the existence of the field lines?
- So, how does the black puck know that the red pucks are there?

What ideas do participants have about how they might use this PhET simulation in their classroom? Brainstorm briefly and write more ideas on the board. Show participants the

PhET website and point out the "Teaching Ideas" listed at the bottom of the link listed above.

What's Going On?

Many things interact without touching, such as wind, electricity, and gravity. The PhET simulation allows us to visualize how electricity acts at a distance.

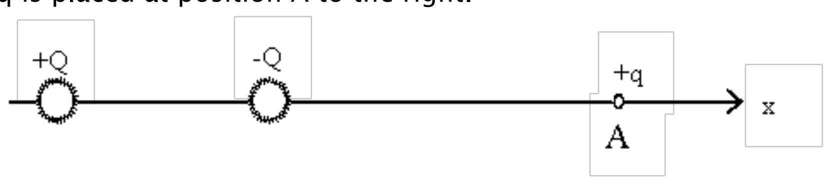
The blue lines are *force vectors*, representing the net force on the black puck from the various red pucks. The *field lines* are a measure of the force that a particle would feel if it were there. They represent the way that an object influences the other objects around it. Both the force and field vectors tell us about how the black puck will move. The field lines permeate all space whereas the force vector only shows us the net effect of the red pucks at the position of the black puck. This field is there even if there's nothing to interact with it, just like we know the earth's gravitational field is there even if we aren't there to feel it. The black puck knows that the red pucks are there because of the presence of this field. Fields explain action at a distance, though we haven't explained how the fields came to exist in the first place.

2. Charges and Fields

To Do and To Notice

Clicker/Discussion Questions: Fields and Forces

Two charges, Q and -Q, are placed along the x-axis as shown. A positive test charge +q is placed at position A to the right.



1. **The test charge feels a force that is**:

   A. Zero
   B. To the right
   C. To the left

2. **If the test charge q is removed, electric field at position A is:**

   A. Zero
   B. To the right
   C. To the left

3. **If a negative test charge is placed at A, it feels a force:**

   A. Zero
   B. To the right
   C. To the left

What's Going On?

Best answers are:

1. (C), to the left

2. the same direction as the force, and

3. (B), to the right, the opposite direction as when a positive test charge was used.

Going Further

Display the PhET "Charges and Fields" simulation. Add charges and select "Show E-field." Watch the electric field change as the charges are moved. Turn off "Show E-field" and use the E-field sensors instead. Since *field = force per unit charge*, these E-field sensors show the force vector that would act on the sensor if the sensor represented a (positive) 1 coulomb charge.

If you have access to a Van de Graaff generator, connect it and charge the Mylar balloon. Show that as you walk around the generator, the balloon string traces out the field lines from the generator. The same may be done with long pieces of tinsel.

Take-home message: Fields are a way of describing how one object influences another without touching it. Fields exist even if there's nothing there to feel them. Later in this session, we'll explore how those fields come to be in the first place.

Activity 2: Feynman Theater

Time: 20 Minutes.

Purpose: Participants will act out the roles of electrons, positrons, and photons to demonstrate the principles of quantum electrodynamics—the quantum theory of electromagnetism that explains the mechanisms by which charged particles interact.

Materials:
- 1-2 tennis balls

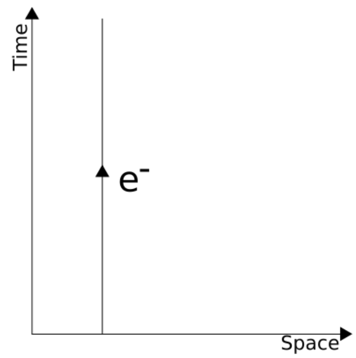
Optional Materials:
- skateboards

1. Feynman Diagrams

To Do and To Notice

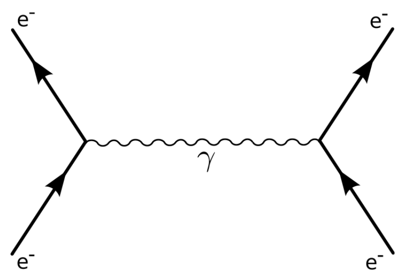
Tell participants that we'll get to gravitational fields in the next session, but now we'll talk about what causes electric fields. Ask participants to share their understanding of this mechanism from the text.

Project or draw the following Feynman diagram without labeling it as a stationary electron. Ask participants, what is going on here? How would you show an electron that was moving through both time and space?



Feynman diagram of a stationary electron

Project the following Feynman diagram showing two electrons interacting by the exchange of a virtual photon. What does the squiggly line represent? How would we label time on this diagram? What do the arrows represent? How is conservation of momentum demonstrated in these graphs?



Interaction of two electrons[2]

What's Going On?

Feynman diagrams represent particle interactions in space and time. Time is the y-direction and space is the x-direction. If something is stationary in space, then its path is vertical. These are called *worldlines* and we'll see them again in Unit 4. If the particle is moving in both space and time, its path is at an angle[3]. (*Note*: These diagrams represent one-dimensional motion in space). The squiggly line represents a virtual photon. A virtual particle is one that exists for such a brief time that we can't really talk about it having a definite velocity or energy. A virtual photon is energy briefly "borrowed" from the energy of the surrounding electric field. The arrows represent momentum, not velocity; Feynman diagrams aren't graphs in the standard sense (i.e., the units of the graph would suggest that the arrows would represent velocity). Thus, conservation of momentum is demonstrated by the vector addition of arrows in the graphs.

[2] Source: © Wikimedia Commons, License: CC ShareAlike 3.0. Author: Papa November, 9 March 2008. http://commons.wikimedia.org/wiki/File:Feynmandiagram.svg.

[3] A 45° angle represents the speed of light on these diagrams. The angle cannot be greater than 45° (i.e., closer to the x-axis than the y-axis). One subtle point about these diagrams: Because quantum particles do not have a well-defined position (they are waves spread out in space), they should not be thought of as small billiard balls moving through space with a definite velocity, as this diagram seems to suggest. Instead, the arrow represents the momentum of a delocalized particle; these diagrams say *nothing* about the position of the particle.

2. Skit

To Do and To Notice

Ask for two volunteers to act out the Feynman diagram showing the interaction of two electrons. You may choose to give them some sort of labels such as “Electron 1” and “Electron 2” with paper or tape. Give them the tennis balls (and skateboards if you have them). Encourage the participants to ask questions and make suggestions. Should the two balls representing electrons be moving or are they stationary? How do they know which way to throw the ball representing the photon?[4] Is the photon thrown once, or multiple times? If one were moving faster than the other, how would the Feynman diagram change? How can we use this to understand why we can’t walk through a wall (but a neutrino can)?

If the group charged with teaching the electricity and magnetism force generated an idea for a similar skit as part of their lesson, you may ask them to present that portion of their lesson here.

Possible discussion questions:

- Are the hockey pucks in the “Electric Field Hockey” simulation exchanging virtual photons?
- So, why can’t we walk through a wall?
- So how do two things interact without touching each other?
- Could two quarks exchange virtual photons? What couldn’t exchange virtual photons?
- How is conservation of mass-energy not violated by the ejection of a virtual photon?
- How are these diagrams related to *Models*?

What’s Going On?

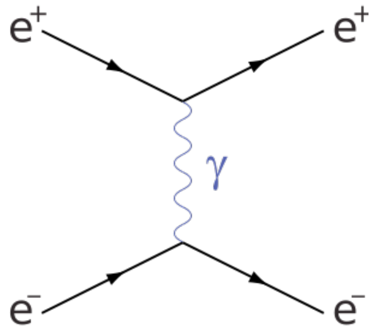
The hockey pucks in the PhET simulation aren’t exchanging virtual particles, unless they’re electrons or protons. The exchange of virtual photons only happens at the quantum level. Instead, the electrons of the hockey pucks are interacting with the field generated by the electrons of the other hockey pucks. We can’t walk through a wall because our electrons are exchanging virtual photons with the electrons of the wall. Things interact without touching each other by exchanging virtual particles across the gap. Thus, we now have a mechanism for understanding action at a distance. Quarks can exchange virtual photons because they’re charged; anything uncharged, like neutrons or neutrinos, can’t exchange virtual particles. That’s why neutrinos can pass through walls. Exchanging virtual photons doesn’t violate conservation of mass or momentum because a photon has zero mass. However, more importantly, a virtual particle doesn’t exist long enough to have a well-defined mass. Feynman diagrams are a visual representation of our mathematical model of particle interactions.

[4] The virtual photon does not really travel from one to the other, and it doesn’t matter which electron emits or absorbs the photon.

3. Going Further: More Complicated Diagrams

To Do and To Notice

You may challenge participants to act out the following Feynman diagram. What is happening? What does a downward pointing arrow represent?



Electron-Positron Scattering[5]

What's Going On?

It may be confusing to consider that a downward arrow indicates backward motion in time. An electron (e^-) moving forward in time, however, is the same as a positron (e^+) moving backward in time. So, you may want to redraw these diagrams with arrows that point in the positive y-direction, indicating forward motion in time. Then this can be understood as annihilation of an electron/positron pair, generating a virtual photon, which in turn generates an electron/positron pair.

Activity 3: Force Jigsaw

Time: 45 Minutes.

Purpose: To learn about the different forces and how they compare to one another.

To Do and To Notice

Ask participants to sit with their group and work together to prepare a 5-10 minute lesson to the class on the force that they were assigned. As part of that preparation, they should complete their column of the table as a small group. They may want to consider creating or showing a Feynman diagram for their particular force and its exchange particle. At the end of the lessons, the class as a whole should have a group version of this table.

Facilitate a discussion among participants regarding the different forces and the similarities and differences between them. Discuss any questions that arise during the mini-lessons and subsequent discussions.

Possible discussion questions:

- What forces hold you together?
- What holds an atom's nucleus together?

[5] Source: © Wikimedia Commons, License: CC ShareAlike 3.0. Author: JabberWok2, 29 November 2007. http://commons.wikimedia.org/wiki/File:Electron-positron-scattering.svg.

- What causes friction?
- Where does the Higgs boson fit into this?

What's Going On?

The forces that hold us together are electricity and magnetism and the strong force. The nucleus is held together by the strong force between quarks in one proton and quarks in another proton. This strong force overcomes the electrostatic repulsion between the protons in the nucleus. Friction is caused by the electric attraction between atoms. The Higgs boson isn't a force carrier in the same sense as the others; but just as electrons interact with the electromagnetic field, particles with mass interact with the Higgs field.

Below is an example of a completed table (copy available in the online resource: *Facilitator's Guide High Resolution Graphics*).

	Electricity & Magnetism	Gravity	Strong Force	Weak Force
What visible effect does this force have on our world? What kinds of objects does it affect?	Atomic and molecular structure; Contact forces	Structures, like earth and solar system	Nuclear structure (or else the nucleus would blow apart from electrostatic repulsion)	Rare beta decay of a neutron into a proton, electron, and an anti-neutrino[6]
What particles mediate this force? *(The boson, or exchange particle)*	Photons	Graviton (not yet observed)	Gluon	Intermediate vector bosons: W+, W-, Z
What property does this force act on?	Electric charge	Mass-energy	Color charge	Weak charge
Which particles experience this force?	All charged particles	All	Quarks	Quarks and leptons
Physical range of this force (how far does it extend?)	Infinite	Infinite	Diameter of a nucleus	0.1% of the diameter of a proton
Is it attractive or repulsive or both?	Either (so can be screened at large distances)	Always attractive (so dominates at large distances)	Attractive	
Relative strength[7]	10^{36}	1	10^{38}	10^{25}
Other notes	Follows inverse square law	Follows inverse square law	Grows stronger at larger distances	Quarks exchanging W or Z boson don't conserve flavor

Take-home message: The four fundamental forces affect objects at different size scales, each acting through different mediating particles. The range of these forces varies greatly, and gravity dominates at large distances because it is always attractive.

[6] Neutrons and protons are made of quarks, so this can also be described as beta decay of quark into lighter quarks.
[7] Depending on the source, participants' values of relative strength may vary from these. Rank ordering is fine. The value depends on the particular particles and definition of "strength." These values are from Wikipedia.com.

Activity 4: Visual Map of the Forces

<u>Purpose</u>: To explore what physical objects are affected by the different forces.

To Do and To Notice

What do these forces affect in the universe? Give participants the following list of words. Ask them to make a drawing, picture, or concept map that links these together appropriately. At what scale (big? small?) are these forces relevant? Discuss as a group.

Earth	Ball	Sun	Molecule
Proton	Neutron	Electron	Quark
Atom	Gluon	Photon	W-boson

What's Going On?

Gravity and electricity and magnetism operate at the largest scales, on objects we're familiar with. The strong force and weak force operate at the smallest, subatomic scales.

Activity 5: Watch and Discuss the Video

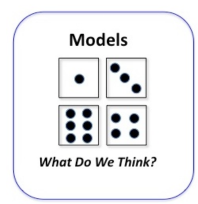
<u>Time</u>: 50 Minutes.

If participants are watching the video in class, have them view it now. Remind them of the guiding questions listed in *Between Sessions* from the previous unit.

- How does the scientific model of nature relate to each researcher's work?
- How does theory affect experiment in these two stories?

Discuss these questions as a group. Discuss analogies for these researchers' work. How do we do the same thing in our everyday lives?

What's Going On?



Srini Rajagopalan and his team use theory to determine where to look within the data for the most interesting events. Ayana Arce and her team calculate the results that the scientific model should yield, directing scientists in how to compare their data to theory. For example, if we're looking for a good restaurant, we don't start with a systematic search of every city block. Instead, we use models to help us search, such as the theory that more good restaurants are located in Little Italy.

Back to the Classroom

Time: 10 Minutes.

Following is a list of high school topics and standards that are relevant to this material. See http://strandmaps.nsdl.org/ for a visual representation of science standards and benchmarks.

- **Where might this unit fit into your curriculum?** Brainstorm a list of topics with participants. You may share additional items from the list below, as you see fit.
- **What do your students know about this topic?** Brainstorm with participants.
- Optionally, you may ask participants to **find one or more of the relevant topics on the Science Literacy Maps**, and explore related ideas and misconceptions.

Topics and Standards

Forces and Motion. An unbalanced force acting on an object changes its speed, or direction of motion, or both. Any object maintains a constant speed and direction unless an unbalanced outside force acts on it.

Electricity and Magnetism. The nuclear forces that hold the protons and neutrons together in the nucleus of an atom are much stronger than the electric forces between the protons and electrons of the atom. That is why much greater amounts of energy are released from nuclear reactions than from chemical reactions. Electric forces hold solid and liquid materials together and act between objects when they are in contact—as in sticking or sliding friction. Electric forces acting within and between atoms are vastly stronger than the gravitational forces acting between the atoms. At larger scales, gravitational forces accumulate to produce a large and noticeable effect, whereas electric forces tend to cancel.

Atoms and Molecules. Scientists continue to investigate atoms and have discovered even smaller constituents of which neutrons and protons are made. The nuclear forces that hold the protons and neutrons in the nucleus of an atom are much stronger than the electric forces between the protons and electrons of the atom.

Size and Scale. When describing and comparing very small and very large quantities, express them using powers-of-ten notation. Natural phenomena often involve sizes, durations, and speeds that are extremely small or extremely large. These phenomena may be difficult to appreciate because they involve magnitudes far outside human experience.

Gravity. Gravitational force is an attraction between two masses; the strength of the force is proportional to the masses and weakens rapidly with distance between them. Gravity is the force that keeps planets in orbit around the sun. Everything on or anywhere near the earth is pulled towards the earth's center by gravitational force.

Nature of Science. A mathematical model uses rules and relationships to describe and predict objects and events in the real world. Mathematical models and computer simulations are used in studying evidence from many sources in order to form a scientific account of the universe. Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

Classroom Resources

Concept map of fundamental forces at Hyperphysics http://hyperphysics.phy-astr.gsu.edu/hbase/forces/fforcon.html#c1 and another one at http://en.wikipedia.org/wiki/File:Particle_overview.svg.

What is QCD? An explanatory website, with a small Java applet to demonstrate the attraction of quarks in a proton. http://webphysics.davidson.edu/mjb/qcd.html.

Printable particle and forces wall chart:
http://www.cpepweb.org/cpep_sm_large.html.

The Particle Adventure from Lawrence Berkeley National Laboratory. Interactive website on particle physics, including wall-charts, classroom activities, and explanatory text. http://particleadventure.org/. See particularly, "What holds the world together?" http://particleadventure.org/4interactions.html.

Alice and Bob in Wonderland. A charming set of 1-minute animated shorts, suitable for classroom viewing, on some of the mysteries of nature. From the Perimeter Institute of Theoretical Physics. Relevant videos include "Why can't we walk through walls?"
http://www.perimeterinstitute.ca/en/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/.

"Forces of Nature" Classroom Activities from PBS's *Elegant Universe*. Classroom activities to understand the four fundamental forces.
http://www.pbs.org/wgbh/nova/teachers/activities/3012_elegant_02.html.

"Beyond the 1930's atom" set of classroom activities from The Wright Center for Science Education. A 52-page PDF with a set of activities, student worksheets, quizzes, and other material on the standard model and particle interactions.
http://www.tufts.edu/as/wright_center/products/lessons/pdf/docs/activities/beyond_atom.pdf.

PhET Simulation - Electric Field Hockey. Shows forces and fields on charged "pucks" which players try to shoot into a goal using the properties of electric fields and forces. http://phet.colorado.edu/simulations/sims.php?sim=Electric_Field_Hockey.

Magnetic Oscillators can demonstrate the effects of magnetic fields, creating action at a distance. Below is an example activity from Paul Doherty at the Exploratorium. http://www.exo.net/~pauld/summer_institute/summer_day16magnetism/MagneticOscillators/MagneticOscillators.html.

Feynman Diagrams: The Science of Doodling on the Physics Central website (explore this site for more topics). http://www.physicscentral.com/explore/action/feynman-1.cfm.

Between Sessions

FACILITATOR

You may wish to share the *Classroom Resources* section of the next unit with participants for their homework. *(NOTE:* Unit 3 contains a particularly long set of classroom resources. You may wish to assign each participant to research one or two of the resources and have them report back to the group during *Back to the Classroom.)*

You may wish to share the learning goals of the next unit from *What Will Participants Learn?* with participants in preparation for the next session.

Describe the homework, below, and ensure that participants know that they will be expected to present their research during the next session.

PARTICIPANTS

Text: Read *Unit 3: Gravity* for the next session. Pick a topic in the reading that you are particularly curious about, and research one of the following:

- A use of this topic in scientific research or practical or technical applications, or
- A classroom lesson or activity on this topic or related ideas.

Preparatory assignment: In preparation for the next session, please:

1. Plan to give a 1-2 minute presentation on your topic and research during class.
2. Prepare a half-page of notes to guide you during your presentation.
3. Plan to discuss why you chose that topic, and what open questions you have about it.

Video: Watch the video for Unit 3 for the next session. As you watch, consider these discussion questions:

- What results would lead to a *Eureka!* moment in either of these experiments?
- What are the implications of negative or *null* results in each of these experiments?
- What would be the implications of positive results in each of these experiments?