Investigation 2 – Where does the energy in a spark come from?

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INVESTIGATION 2: Where does the energy of a spark come from?

Overview

- *In the previous investigation, students developed a model to keep track of energy using an accounting system. Although kinetic energy was the main focus, the idea of potential energy was briefly introduced as energy that is stored. In this investigation, students will further develop their model of potential energy, focusing on how potential energy can be stored and what factors affect the amount of potential energy that exists in a system.*
- *The driving question for this unit is,* How can a small spark start a huge explosion? *At the beginning of the previous investigation, students identified the limitations of their model of charges and started to use energy as a lens for analyzing phenomena in order to further develop their model. In this investigation, students continue to develop their model of energy by exploring potential energy. By the end of the investigation, students will be able to explain the relationship between energy and a spark. In this unit's subsequent investigations, students will develop a model of reactions and energy in order to explain what causes an explosion.*

The Performance Expectations (NGSS)

MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

Elements from NGSS (NGSS Lead States, 2013, pp. 61-62)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas
Definitions of energy: • A system of objects may also contain stored (potential) energy, depending on their relative positions. *Relationships between energy and forces:* • When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.	In Activity 1, students start by thinking about the potential energy stored in a system made of concrete objects (a spring and objects interacting with the spring). In Activity 2, students build an analogy between the spring and an electric field. Students note evidence that there is potential energy in the system and that they had to exert a force on the system in order to increase the potential energy of the system. Students also develop a model that it is helpful to think of potential energy as being stored in the field between two interacting objects, because this emphasizes the idea that energy is due to the interactions between objects.
Crosscutting concept	

Overview

Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept
Systems and system models: • Models can be used to represent systems and their interactions - such as inputs, processes, and outputs - and energy and matter flows within systems.	Students analyze systems, including a system of a spring and objects interacting with the spring, a system of Earth and a basketball, a system of interacting magnets, and a system of interacting charged particles.
Science and engineering practice	
Science and engineering practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice
Develop and using models: • Modeling in 6-8 builds on K-5 and progresses to developing, using and revising models to describe, test, and predict more abstract phenomena and design systems. ○ Develop a model to describe unobservable mechanisms.	Students will design and conduct several investigations to explore factors that affect the amount of potential energy in a system. Additionally, students will work with several simulations that show interactions between charged objects and their effects on energy. Students will use this information to develop and revise models that use energy to explain observations.

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and[1] the changes in energy of the objects due to the interaction.

Elements from NGSS (NGSS Lead States, 2013, pp. 97-99)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas

[1] Gray text indicates aspects of a Performance Expectation that are not directly addressed in these materials.

Relationship between energy and forces: • When two objects interacting through a field change relative position, the energy stored in the field is changed.	In Activity 2, students explore systems in which objects interact at a distance (through gravitational, magnetic, or electric fields). Students develop a model that when objects interact through a field, it can be helpful to think of the energy as being stored in the field. In Activity 3, students define factors that affect the amount of energy stored in the field—including the amount of force between two interacting objects and the relative position of those objects.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept
Cause and effect: • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.	In Activity 2, students do not use cause and effect because they are not yet thinking about the relationships between factors and outcomes. Instead, students analyze systems, including a system of Earth and a basketball, a system of interacting magnets, and a system of interacting charged particles. In Activity 3, students use cause and effect to evaluate the relationships between the amount of force, the distance objects have moved, and the amount of potential energy stored in a field.
Science and engineering practice	
Science and engineering practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice
Developing and using models: • Modeling in 9-12 builds on K-8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. ○ Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.	Students develop their model of energy and the relationship between energy and forces by gathering additional evidence, specifically evidence about objects interacting through fields.

HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

Elements from NGSS (NGSS Lead States, 2013, pp. 97-99)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas
Conservation of energy and energy transfer: • Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. • Uncontrolled systems always evolve toward more stable states-that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). *Energy in chemical processes:* • Although energy cannot be destroyed, it can be converted to less useful forms - for example, to thermal energy in the surrounding environment.	The Framework includes the following elaboration under the disciplinary core idea of conservation of energy and energy transfer: “Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).” The performance expectation addresses this idea in the context of thermal equilibrium. Activity 4 does not address thermal equilibrium, but it does address the idea that systems that are free to move will tend to move toward lower potential energy states.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept
Systems and system models: • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.	In this activity, students analyze systems of objects to see how they behave. Students also use the lens of energy to build on their earlier model of matter and to explain additional observations.
Science and engineering practice	
Science and engineering practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice

Planning and carrying out investigations: • PLanning and carrying out investigations to answer questions or test solutions to problems in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ○ PLan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.	In Activity 4, students do not plan and carry out investigations. Instead, students use simulations and observations to further develop their model of energy and to use this model to make predictions. As students develop more robust models and modeling skills, they are prepared to develop more reasonable investigations and to use their models to interpret outcomes of investigations. However, students do plan and carry out an investigation in Activity 3 as part of collecting evidence to develop their model of potential energy.

Objective: Target Model

What should the students' conceptual model include?

- *Students will use and apply a model to explain the relationship between electric force and electric potential energy as the distance between two charged particles changes and the amount of charge changes.*
  - *When the amount of charge increases, the amount of force and electric potential energy stored in a field both increase.*
  - *For objects that are interacting through attractive forces (have opposite charges), when the distance between the objects increases, the amount of electric potential energy stored in the electric field increases.*
  - *For objects that are interacting through repulsive forces (have the same charge), when the distance between the objects increases, the amount of electric potential energy stored in the electric field decreases.*
  - *In general, if you have to apply a force to move the objects away from their natural position you have increased the amount of potential energy stored in the system.*
  - *If a system is free to move on its own, it will tend to move in a direction that will lower the potential energy stored in the system.*

Background Knowledge

- *It is useful to think of potential energy as energy that is stored in fields. It is common to talk about energy being stored in a particular object; however, this is not really accurate. For example, when a basketball is held in the air, it is easy to say that the basketball has potential energy, but it is really the system of the basketball and Earth that has potential energy. Therefore, it is more accurate to say that the potential energy is stored in the field or the system of objects.*

Overview

- *The interactions between objects affect the amount of potential energy stored in the field. However, it can be difficult to evaluate the relative amount of potential energy stored in a system. Increasing the distance between a basketball and Earth would increase the amount of potential energy stored in the field, but only because the force between the basketball and Earth is always attractive. If objects are repelling each other, decreasing the distance between them will increase the amount of potential energy stored in the field. It can be most useful to think of a "natural" position for the objects; if a force is used to move the objects away from this natural position, then the amount of potential energy in the field has increased. The amount of force used to move objects and the distance that the objects were moved away from their "natural" position both affect the amount of potential energy stored in the system. Using a greater force over the same distance stores more energy in the system. For example, in stretching a weak spring vs. a strong spring by the same amount, the system with the strong spring stores more energy. Also, applying the same force over a greater distance stores more energy in the system. For example, if you lift a basketball higher than its previous position above the ground, you are applying force over a greater distance, so more potential energy is stored. Observations show that objects move to arrangements that minimize the potential energy stored in the field. The natural position is the point at which forces are balanced.*

Activities

Activity 2.1	*How does potential energy change when things are pushed or pulled?*	*75 min.*
Activity 2.2	*Where does the energy that was used to charge the Van de Graaff generator go?*	*75 min.*
Activity 2.3	*Why is lightning so much bigger than a spark from the Van de Graaff generator?*	*140 min.*
Activity 2.4	*Why do I get shocked if I am too close to the Van de Graaff generator?*	*50 min.*

Activity 2.1: How does potential energy change when things are pushed or pulled?

SUMMARY

In the previous investigation, students described potential energy as energy that is related to the relative position of objects and that can be converted to kinetic energy.In this activity, students explore springs to develop a relationship between force and the potential energy of a spring. Both stretching and compressing a spring lead to a less stable state in which the spring has potential energy. Students will investigate how changing the position of objects in a system (contracting and expanding a spring) changes the potential energy of the system. In subsequent activities, students will think about potential energy of the system when objects interact through a field. Students need a deeper understanding of energy and potential energy stored in electric fields in order to explain how sparks can start a fire. In the next investigation, students will also learn about the relationship between electric potential energy and the formation of bonds in order to explain what happens during chemical reactions (explosions and fire).

LEARNING GOALS

- Students will analyze and interpret data to define the relationship between force and changes in potential energy
    - Applying a force to move something from a stable state increases the potential energy of the system.

Disciplinary core idea	**Crosscutting concept**	**Science and engineering practice**
Conservation of energy and energy transfer: [Energy is] better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). (NGSS Lead States, p. 98)	*Cause and effect:* Students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors... (NGSS Appendix G p.83)	*Analyzing and interpreting data:* Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. (NGSS Appendix F p. 57)

- Students will apply a model of conservation of energy to describe and make predictions about mechanical processes.
    - Energy can transfer from place to place.
    - Energy can convert from one form to another.
    - NOTE: The predictions and descriptions involve the energy of the system and its surroundings.

Activity 2.1 - Teacher Preparation

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Conservation of energy and energy transfer: Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (NGSS Lead States, p. ##)	*Systems and system models:* Students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. (NGSS Appendix G p. ##)	*Developing and using models:* Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (NGSS Appendix F p. ##)

PREPARATION

Class Time: 75 min.

Materials (for each group)

- spring
- toy car or marble

Activity 2.1 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
   a. Introducing the lesson
2. Springs and toy car
   a. Hands-on exploration
   b. Discussion
3. Energy changes of a spring
   a. Simulation
   b. Questions
   c. Discussion - introduce terms “energy transfer” and “energy conversion”
   d. Questions
   e. Discussion
4. Concluding the Lesson

Activity 2.1 (Student materials): How does potential energy change when things are pushed or pulled?

Discussion of Homework
Review Reading for Activity 1.4: Energy Conservation

Possible questions:

- *What was the main idea of this reading?*
- *How does the idea of the law of conservation of energy relate to the idea that we should conserve or save energy?*
- *If energy never goes away, how is it possible to waste energy?*

Introducing the Lesson
Revisit the driving question board to review the question for the unit, other questions students still need to answer, and the activities and driving question from the previous investigation.

Discussion
Recall the discussion about the bow and arrow from the end of the previous investigation. Ask students to summarize their conclusions about the types of energy changes that occur as an archer releases a bow.

Possible questions:

- *What does an archer need to do to the system to add energy to it?*
- *How does the force the archer exerts to pull the string back influence the amount of energy the system acquires?*
- *How do you think the energy would be affected if the bow were strung much tighter?*
- *What other examples can you give where the force exerted on the system changes the potential energy of the system?*

Ask students what question they have. Then review the questions from the driving question board to determine what has been answered and what still needs to be answered.

Page title:
Introduction

In the previous investigation, you learned that there are two types of energy–kinetic and potential. In this activity, you will begin to characterize the potential energy of systems and what happens to cause the potential energy to change .

Page title:
Springs and toy car

Materials
- spring
- toy car or marble

Explore stretching a spring (pulling it apart) and compressing the spring (pushing it together).

Caution
When pulling the spring, make sure to be gentle. If you pull the spring too much, you can easily deform it. If this happens, the spring will not return to its original shape, and it will be unusable for these activities.

What do you feel when stretching and compressing the spring?

Student responses:
- The spring pulls or pushes back.
- I can feel a force from the spring.

2. What evidence do you have that the energy of the spring is higher when you stretch or compress it?

Student responses: There are several possible sources of evidence that students may identify:
- I feel a force. If they let go, the spring will move.
- The spring can be used to make something else move.

3. [drawing prompt] Use the spring to push the toy car. Draw two energy graphs: one showing the energy of the car and spring just before releasing the car, and one showing the energy of the car and spring after the car is moving.

Student responses: Students' energy graphs should indicate that the spring has potential energy initially, the car has kinetic energy in the end, and the total amount of energy is conserved.

4. What evidence do you have that there was potential energy in the system before the car moved?

Student responses:
- The car ended up with kinetic energy, so that had to come from somewhere.
- I had to apply a force to keep the spring from moving.

5. Which part of the system had potential energy before the car moved?

Student responses: Answers may vary. At this point, students may not agree.

- It came from the spring.
- It came from me because I pushed it in the beginning.
- It came from the car.
    - *Ask student how the car got potential energy.*

Discussion

Display the graphs students created. Use the graphs to discuss the evidence that there was potential energy and what part of the system had potential energy . If the spring is released after it has been compressed, something will move. In this case, the car moved because it was pushed by the spring.

Possible questions:

- *What kind of energy do you observe when the toy car moves? Who has other ideas?*
- *What evidence do you have that there was potential energy before the car moved? What different ideas do others have?*
- *Where did this energy come from? Who has some other ideas? How are you ideas related?*
- *What part of the system had potential energy? What evidence do you have to support your ideas?*

By the end of the discussion, make sure students agree that potential energy was involved and that the spring has potential energy when it is stretched or compressed.

As you guide students in discussion, use questions such as the following.

Possible questions:

- *How are your ideas similar and different?*
- *Which ideas best account for what we observed and what we know?*
- *Who can add more to the discussion?*
- *Who has a different way of thinking about these ideas?*
- *What evidence do you have to support your ideas?*

Page title:

Energy of springs

6. To increase the potential energy of the system, what do you have to do to the spring?

Student responses:

- Move the spring more.
- Compress the ends closer together.
- Pull them farther apart.

7. Springs have a specific length, or "natural" or "rest" position. How does the potential energy of the spring change when you stretch it beyond its natural position? Support your claim with evidence and reasoning.

Student responses: Students should note that the amount of potential energy increases. Students may use different sources of evidence to support their claim. For example, you can feel the spring pulling back; the spring can be used to move something; you have to pull the spring to stretch it. For the reasoning portion, students should draw on what they know about potential energy.

- Potential energy can be used to move things. Before the spring is stretched, it can't move. After the spring has been stretched, it can move. Therefore, the amount of potential energy increases when the spring is stretched.

Discussion

Students should note that the spring has potential energy when a force has been applied to the spring. The spring has a "natural" or "rest" position, which is the most stable position. Both pulling the spring to stretch it out from this position and pushing the spring to compress it require applying force to the spring; both of these positions are less stable because the spring has potential energy.

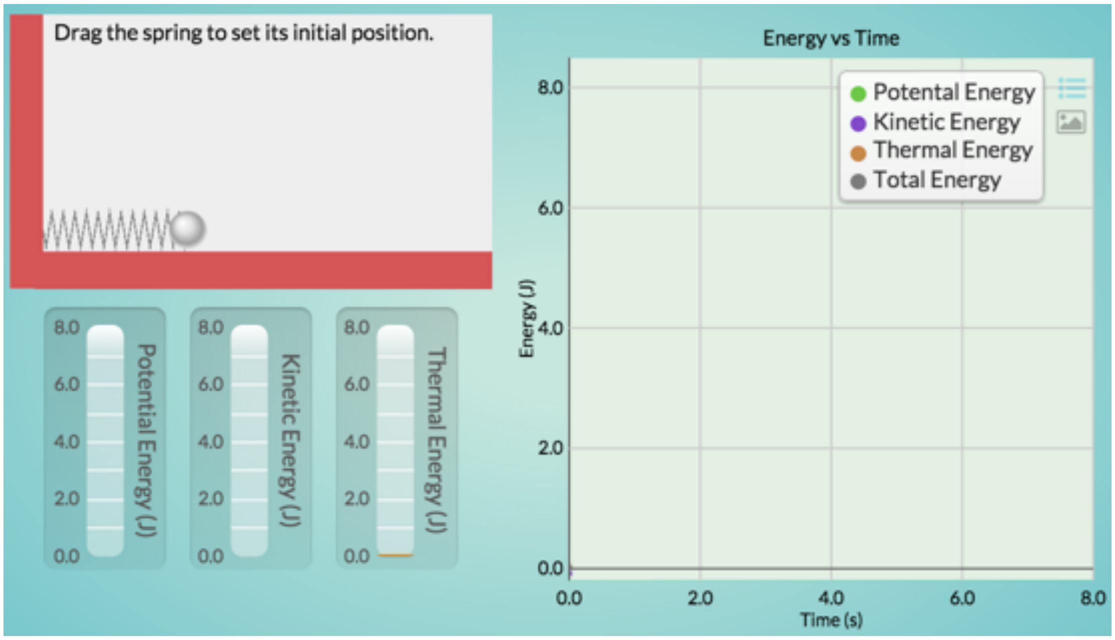
Possible questions:

- *When is the spring most stable?*
- *Why does stretching or compressing the spring move it to a less stable position?*
- *What did you have to do to stretch out the spring? How is energy related to what you did?*
- *What did you have to do to compress the spring? How can we add energy to the discussion? Who else can contribute? What evidence do you have?*

Be sure to ask students to support their answers using evidence.

Page title:
Energy changes in a spring

Explore the simulation.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/spring.json

8. To increase the potential energy of the system, what did you have to do?

Student responses:

- I had to move the spring away from its natural position.
  - *Students may elaborate on the relationship between the distance the spring was moved and the amount of potential energy.*

Discussion

In this lesson, the relationship between applied force and change in potential energy was investigated. At this point, students should begin to connect the force and the change in energy both when they compress the spring and when they pull it apart.

Possible questions:

- *What did you need to do to the system in order to increase the potential energy of that system? Who has other ideas?*
- *What type of energy transfer and conversion did you encounter in this lesson? What is your evidence?*

9. [snapshot prompt] In the simulation, move the spring to increase the potential energy of the system. Take a snapshot before starting the simulation. (This will be your "before" snapshot.).

Student responses: The "before" snapshot should indicate that there is a large amount of potential energy.

10. [snapshot prompt] Start the simulation, and take a snapshot while the simulation is running before the spring returns to its natural, or rest, position. (This will be your "during" snapshot.)

Student responses: Answers will vary depending on when students take the snapshot. In general, the snapshot should have a mix of potential, kinetic, and thermal energy.

11. [snapshot prompt] Take a final snapshot after the spring has stopped. (This will be your "after" snapshot.)

[text prompt] Referring to your *before*, *during*, and *after* snapshots, explain what happens to the energy from the beginning to the end of the simulation.

Student responses: The "after" snapshot should show that the potential energy and kinetic energy are minimal, while the thermal energy has increased. In their explanation, students should indicate that the total amount of energy stays the same, but it moves from the spring to the air (or surroundings).

Discussion

Use the snapshots students took to revisit the energy graphs that were drawn in Unit 2, Investigation 1, and introduce the idea of stacked bar graphs.

Display students' models and compare the snapshots and responses.

Possible questions:

- *What are some similarities and differences between the models?*
- *What observations do the different models support?*

Discuss what happens to the energy as the spring oscillates.

Possible question:

- *What happens to the potential energy of the spring as it stretches and contracts?*

Introduce stacked bar graphs. Bar graphs can be shown side-by-side, but the bars can also be stacked one on top of the other. Use one of the displayed examples to demonstrate how to make a stacked bar graph. Discuss what the stacked bar graph shows.

Possible questions:

- *How should the height of the "before" stack compare with the height of the "during" stack and the "after" stack?*
- *Why do all the stacks end up the same height?*

12. [drawing prompt] Based on the snapshots you took for the previous questions, make a stacked bar graph of the energy before, during, and after the simulation ran.

Student responses: Students should use the graphs from the simulation to help them construct their stacked bar graphs. All three stacks should be the same height. The "before" stack should show a larger amount of potential energy; it may also include a small amount of thermal and, possibly, kinetic energy. The "after" stack should indicate that all, or almost all, of the energy is thermal. What the "during" stack shows will depend on when the student took the snapshot, but it should generally show an energy distribution that is between what is shown in the "before" and "after" stacks (some potential energy and some thermal energy).

13. Does conservation of energy apply to the system shown in the simulation? Justify your answer using the simulation.

Student responses: Students may draw on a variety of sources of evidence, including their answers to the previous questions or their observations of the simulation.

- Yes. The stacked bar graphs showing the energy before, during, and after the simulation ran all ended up being the same height, which indicates that the total energy in the simulation stayed the same. The form of energy changed from potential to kinetic and thermal, but the total amount stayed the same.
- The total energy line in the graph stayed constant before, during and after.

Concluding the Lesson

There are two important ideas to emphasize for this lesson: 1) the relationship between force and potential energy and 2) conservation of energy.

Possible questions:

- *What would you need to do in order to increase the f potential energy of the spring?*
- *If the spring's potential energy was greater at the beginning what do you think you would observe at the end (after the spring stops moving)?*
- *What happens to the total of all the energy?*
- *How do these ideas help to explain the system of the car and spring?*

Revisit the Driving Question Board

To remind students why we are studying energy, recall the driving question for the unit: *How can a small spark start a huge explosion?*

- *How do these ideas about energy help us answer some of our questions?*
- *What can we add to the driving question board?*

Activity 2.2: Where does the energy that was used to charge the Van de Graaff generator go?

SUMMARY

Students will explore potential energy in systems where objects are interacting through fields: electric, magnetic, and gravitational. Potential energy is related to the relative position of interacting objects and the forces between interacting objects. It is useful to think of potential energy as being stored in the field of these interacting objects because this emphasizes that the energy is not associated with an individual object but rather the interactions between objects. In the previous activity, students considered how the potential energy of a spring changes . In this activity, students will apply the same ideas to more abstract situations that involve electric, gravitational, and magnetic fields. In the next activity, students will analyze factors that impact the amount of energy stored in electric fields. Students will develop a model that describes the relationship between potential energy, forces, and the relative position of objects in the field (electric, magnetic, or gravitational). By applying the idea of energy to objects that are charged, students can start to build an explanation for where a spark comes from and how a spark is formed.

LEARNING GOAL

- Students will develop their model of potential energy by describing the potential energy of a system in terms of fields.
    - Gravitational, magnetic, and electric potential energy are stored in fields.
    - Potential energy only exists in a system made of two or more interacting objects.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Definitions of energy: [Potential energy can be understood as] energy associated with the configuration (relative positions of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). (NGSS Lead States, p. 98)	*Systems and system models:* Students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. (NGSS Appendix G p. 85)	*Developing and using models:* Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (NGSS Appendix F p. 53)

POINTS FOR CONSIDERATION

While gravitational, electric, and magnetic potential energies are all stored in fields and are all due to forces that act through fields, they have some important differences:

- Gravitational forces are always attractive, while magnetic and electric forces can be either attractive or repulsive.
- When a magnet is broken into smaller pieces, each piece will have both poles (N and S). There is no way to have a magnetic piece that is just N or just S. However, electric charges can be separated. A particle may have both positively and negatively charged sides, but it is also possible for a particle to have just a negative charge or just a positive charge.

PREPARATION

Class Time: 75 min.

Materials (for each group)

- 2 magnets
- spring

HOMEWORK

Reading for Activity 2.2: Potential Energy and Fields

Activity 2.2 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introducing the lesson

2. Introduction

    a. demonstration and discussion

3. Magnets versus springs

    a. activity

    b. discussion

4. Electric charge simulation

    a. simulation

    b. discussion

    c. questions

    d. discussion

5. Revisiting the driving question

    a. questions

    b. discussion

Activity 2.2 (Student materials): Where does the energy that was used to charge the Van de Graaff generator go?

DQ

Introducing the Lesson
Review the main ideas from Activity 1.

Possible questions:

- *What did you learn about energy while working with the springs?*
- *What did you need to do to increase the amount of energy in the system that included the spring?*
- *What about objects that can exert forces when they are not touching (such as magnets or charged particles)? When a force is used to move magnets or charged particles, where do you think the energy goes? Any other ideas?*

NOTE: This last question is what students will be investigating in this activity. Elicit students' ideas, but do not evaluate or answer the question at this point.

Page title:
Introduction

Recall that in the last activity, you noticed that when you pulled or compressed a spring, the force moved the spring from its stable position so the system had potential energy. What about a system where objects are not in contact? For example, if you use a force to pick up a basketball from the ground and hold it in the air, where is the potential energy in the system? You will be exploring these ideas in this activity.

Introducing the Lesson
Hold a basketball in the air and discuss the system and whether there is potential energy. .

Possible questions:

- *What would happen if I let go of the ball?*
- *What causes the ball to fall?*
- *What if you could push a magic button and make Earth disappear? Would the ball still fall?*
- *What is the system?*
- *How can we explain where the energy is in the system?*

The basketball itself does not have potential energy; the system made up of the basketball and Earth has potential energy. This system includes the field of the interacting objects. Since the field is associated with multiple objects, relating the potential energy to the field helps emphasize the idea that the energy is associated with the relative position of **both** objects and the interaction between them.

Page title:
Magnets versus springs

Materials
- 2 magnets
- spring

Arrange the magnets so that they repel each other, then try to push them together. Then compare pushing the magnets together to pushing on both ends of a spring to compress it.

1. How does what you feel when pushing the magnets together compare with what you feel when pushing on the spring?

Student responses:
- In both cases, the object pushes back.

2. The force you applied to the spring led to potential energy in the spring system. How are the spring system and the magnet system similar?

Student responses: Students may identify a range of similarities; these are just a few examples.
- The magnet and the spring both push back.
- Both can also pull back (if you pull the spring and adjust the magnets so that they are attracting rather than repelling).
- Both systems can store energy.

3. How are the spring system and the magnet system different?

Student responses: Students may identify other differences.
- Magnets do not need to be in contact to interact.
- Magnets will always either attract or repel, but because a spring has a neutral point, you have to do something to the spring to make it push or pull on other objects.

4. When you push repelling magnets together, is there potential energy in the system? If so, where? If not, what happens to the energy used to push the magnets together?

Student responses: Students may not agree at this point and will be collecting additional evidence to answer this question.

- Yes, there potential energy in the system
- Yes, if you let go of the magnets, they would move
  - *Ask students what would make them move*
- No, there is nothing to store the potential energy
- Yes
  - *Ask students where they think that potential energy is coming from*

Discussion

Review students' ideas about the system involving the magnets and where the potential energy is stored in the system. The system consists of the magnets and the magnetic field of the interacting objects

NOTE: Students will explore this idea more in the following simulation, so students do not need to agree on a certain idea at this point.

Possible questions:

- *What does the system with the magnets consist of?*
- *How can magnets interact without touching?*
- *Where do you think the energy goes when you push the magnets together?*
- *How could pushing the magnets together affect the magnetic field?*
- *How can exerting a force to push the magnets together affect the potential energy of the system?*
  - *Does anyone have other ideas?*
- *What about if you were pulling attracted magnets apart instead of pushing repelling magnets together. Would that change where the energy goes?*

Try to get a variety of ideas from students. Do not evaluate ideas at this point.

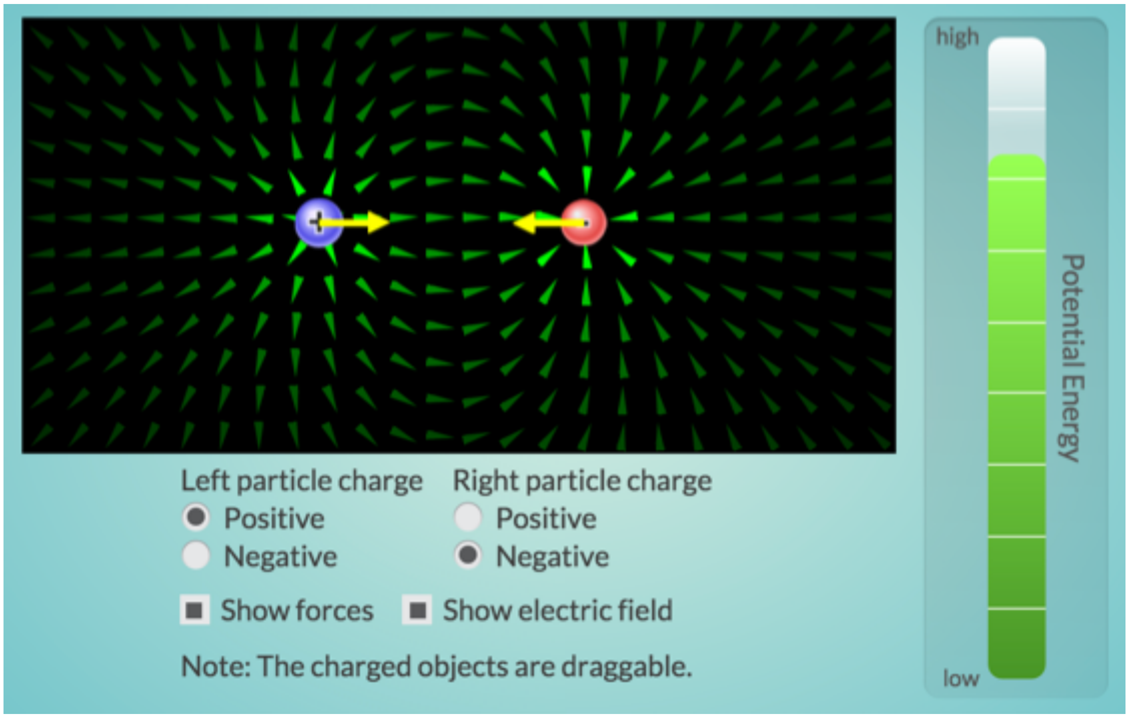
Draw connections between the magnets and electrically charged particles.

Possible questions:

- *How are the magnets similar to charged particles?*
- *How are they different?*
- *Could energy be involved with pushing together or pulling apart charged particles?*
  - *Where might that energy be in the system?*

Page title:
Electric charge simulation

Explore the simulation.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/electricPE.json

5. [snapshot prompt] Arrange the particles so that there is only a small amount of electric potential energy. Then take a snapshot.

Student responses: There are two possible responses

- 1) students can make the objects oppositely charged and place them close together,
- 2) students can make the objects similarly charged and place them as far apart as possible (at opposite corners).

Discussion
Note that students may show the potential energy minimized with either similarly or oppositely charged particles—this would change the response. Display several student responses, being sure to share some in which both particles have the same charge and some in which the two particles have different charges.

Possible questions:

- *What do you notice when you compare the different images showing low potential energy?*
- *How are the images similar? How are they different? How can you account for the phenomena?*
- *How is it possible that different positions can have similar potential energies?*
- *How is what we have explored up to now related to the unit driving question:* How can a small spark start a huge explosion?
    - *What questions have we answered?*
    - *What questions still need to be answered?*

6. Notice that you could have high potential energy when the particles have opposite charge, but also high potential energy when the particles have the same charge. How do the forces at the relative positions compare in these two scenarios (high potential energy with similar charges versus high potential energy with opposite charges)?

Student responses:

- The similarly charged particles are close together when there is high potential energy, the oppositely charged particles are far apart.
- The similarly charged particles that are close together have a larger force.

7. In addition to having high potential energy, what are some additional similarities between the scenarios (high potential energy with similar charges versus high potential energy with opposite charges)?

Student responses:

- In both cases, the particles would move if allowed to
- In both cases, the particles are interacting through a field.

Discussion: Discuss the relationship between position, forces, interactions between particles, field, and potential energy.

Possible questions:

- *Does more force mean more energy?*
- *What are some things that are true about the different situations that have high potential energy?*

Prepare students for the following questions by reviewing similarities and differences between different types of non-contact forces and the relationship between these forces and potential energy.

Possible questions:

- *In addition to electric charges interacting through an electric field, what are some other interactions that also occur through fields?*
- *What are some examples of things that can push or pull on each other without being in contact?*
- *How are these different types of interactions similar and different?*
- *How is potential energy stored for each type of interaction?*
    - *What is similar and different among the different types of interactions?*

8. Describe the similarities between gravitational potential energy and electric potential energy.

Student responses: Students may identify a variety of similarities based on the demonstrations or they may also pull in information about gravity from other courses.

- Both interact through fields
- Both include objects that interact without touching
    - Ask students how objects interact without touching
- In both cases, the interactions are weaker when objects are far apart.

9. Describe the differences between gravitational potential energy and electric potential energy.

Supplemental content: Gravitational potential energy is always attractive, but electric potential energy can be either attractive or repulsive. Therefore, gravitational potential energy always increases as objects get farther apart. However, in the case of electric potential energy, the amount of energy stored in the system depends on the type and amount of charge the objects have. For example, if objects have the same amount and type of charge, the interaction between them is repulsive, and electric potential energy decreases as they get farther apart.

Clarification - students may not already know that gravity is always attractive, but this idea should be brought up during the discussion following these questions.

Student responses: Students may identify a variety of differences based on the demonstrations or they may also pull in information about gravity from other courses.

- Gravitational potential energy is related to amount of mass, and electric potential energy is related to amount of charge.
- Gravity only attracts things together but electric interactions can be attractive or repulsive.
    - *How does this affect the amount of energy stored in a gravitational field versus an electric field?*

10. Describe the similarities between magnetic potential energy and electric potential energy.

Supplemental content: Both types of potential energy are stored in fields. Both magnetic and electric interactions can be attractive or repulsive, so the amount of energy stored in the field depends on both the distance of the objects and whether the interaction is attractive or repulsive.

Clarification - magnetic interactions are not a focus of this curriculum so students may not be aware of all the similarities and differences between magnetic and electric interactions.

Student responses:

- Both types of potential energy change as objects get farther apart.
- Both can attract or repel
    - *How do the attractive or repulsive forces impact/relate to the energy stored between the objects?*

11. Describe the differences between magnetic potential energy and electric potential energy.

Supplemental content: The relationship between electric potential energy and magnetic potential energy is complex because a moving electric charge creates a magnetic field and a moving magnet creates an electric field. Therefore, electrically charged and magnetic objects can interact with each other through both attractive and repulsive forces if one is moving. A key difference in the interactions is that a magnet always has a north and south pole. Even if a magnet is broken into smaller pieces, the smaller pieces will all have a north pole and a south pole. So two magnets can always be arranged to be either attractive or repulsive. On the other hand, electric charges come from protons and electrons. While most objects contain both protons and electrons, the electrons can be separated from protons.

Clarification - students are not expected to know the complex relationship between magnetic and electric fields or that magnets always have a north and south pole. The differences students describe may be fairly superficial.

Student responses:

- Magnetic potential energy and electric potential energy are related to different properties of the material. (Electric potential energy is related to the amount of positive and negative charge; magnetic potential energy is related to the orientation of the object in the magnetic field.)

Discussion

There are two important ideas to review at this point:

1. The relationship between force and energy

Possible questions:

- *What did you have to do to store energy in the system when using the springs and magnets, and when exploring the simulation that showed charged particles??*
- *How are force and energy related?*

2. The relationships and differences between gravitational, magnetic, and electric energy/forces

Possible questions:

- *How are gravitational, magnetic, and electric forces different? How are they similar?*
- *How are gravitational, magnetic, and electric energy different? How are they similar?*
- *Did anyone notice different patterns in the relationships between electric, magnetic, and gravitational forces?*

Page title:
Revisiting the driving question

12. In a previous investigation, you observed that the Van de Graaff generator can be used to create a spark.

The light you observed in the spark indicated that energy was transferred from one object to another. Where do you think the energy was stored before the spark was created?

Student responses: This is a complex idea and students may need support connecting the idea that the charged that built up around the Van de Graaff generator means that energy is stored in the field around the Van de Graaff generator. They may not agree on an answer at this point.

- In the electric field around the Van de Graaff generator.

13. Van de Graaff generators are capable of generating strong electric fields. What effect do you think this might have on the amount of electric potential energy that can build up around a Van de Graaff?

Student responses:

- The strong electric field can store a large amount of electric potential energy.

14. In this unit, you have been working to answer the question, *How can a small spark start a huge explosion?* Before you can develop a complete answer to this question, you will need to explore additional questions. However, at this point, you do have enough information to start developing an answer to the unit question. How does what you have learned about energy help explain how a spark is formed and why it might start an explosion?

Student responses: The goal of this question is to make sure students are reflecting about the ideas they have been developing in terms of the driving question. Students may have a range of ideas and additional questions at this point.

- The spark indicates that potential energy stored in an electric field is being transferred to something else. That energy can be used to do something, such as start an explosion.

Revisiting the Driving Question
Review with students why we have been discussing energy and how energy could help us answer the driving question: *How can a small spark start a huge explosion?*

Possible questions:

- *How do these ideas relate to our driving question for the unit?*
- *How is a spark formed, and why might a spark start an explosion?*
- *What additional questions do we need to answer to explain how a small spark can start huge explosion?*

If the class agrees that particular ideas are significant for answering the driving question, record those ideas on the driving question board. Also, record additional questions that need to be answered.

Homework: Reading for Activity 2.2
Potential Energy and Fields

Activity 2.3: Why is lightning so much bigger than a spark from the Van de Graaff generator?

SUMMARY

In the last activity, students explored the idea that potential energy is stored in a field generated by two or more interacting objects. In this activity, students will focus on potential energy caused by either an electric and magnetic field. Students will evaluate the strength of the magnet or amount of charge, the distance between the objects, the amount of force required to move the objects, and whether the objects are interacting through attractive or repulsive forces. All of these points are important to consider when evaluating the relative amount of potential energy associated with a field. In the next activity, students will note that when objects interacting through a field are free to move, they will tend to move to a state that reduces the potential energy stored in the field.

In this activity, students further develop their understanding of potential energy. In upcoming activities, students will use the ideas developed in this section to understand changes in energy when atoms form and break bonds, which is part of explaining what happens during an explosion and how a reaction can continue without adding additional energy or sparks.

LEARNING GOALS

- Students will build on their models of electric interactions to relate electric force and electric potential energy to explain sparks.
    - Using a force to change the relative positions of interacting objects in a system changes the amount of potential energy stored in the system/field.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Definitions of energy: In some cases the relative position energy can be thought of as stored in fields (which ediate interactions between particles). (NGSS Lead States, p. 98)	*Cause and effect:* Students suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. (NGSS Appendix G p. 83)	*Developing and using models:* Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (NGSS Appendix F p. 53)

- Students will explain and make predictions about the effect that changes in the amount of charge and the distance between charges have on the potential energy of the system of charges objects.
    - Changing the electric field changes the amount of potential energy stored in the electric field.
    - The electric field is affected by changing
        - the amount of charge
        - the position of the charged objects (distance)

Activity 2.3 - Teacher Preparation

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Relationship between energy and forces: When two objects interacting through a field change relative position, energy stored in the field is changed. (NGSS Lead States, p. 99)	*Cause and effect:* Students suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. (NGSS Appendix G p. 83)	*Planning and carrying out investigations:* Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible variables or effects and evaluate the confounding investigation's design to ensure variables are controlled (NGSS Appendix F p. 55)

POINTS FOR CONSIDERATION

- The relationship between force and potential energy is complicated. It is important that students have time to compare these ideas to sort out how they are related and how they are different.
    - Forces are necessary to have potential energy, but force and potential energy are not the same thing.
    - One way to think of the relationship is to think about how much force you would have to use to maintain the objects' relative positions. For example, if two objects attract each other, a force is needed to keep them apart. On the other hand, if the objects repel, a force is needed to keep them from moving apart. In both situations, potential energy is being stored in the field.
- Students may have a difficult time with potential energy and electrical fields because the amount of energy depends on the relative position of the objects as well as their respective charges. If two particles with the same charge are close together, there will be a large amount of potential energy stored in the electric field; however, if those particles were at the same positions but were oppositely charged, then the amount of potential energy stored in the electric field would be low. Students should be asked to think about the strength of the forces and then assess the potential energy associated with the field; the relationships here cannot be distilled to simple rules.

PREPARATION

Class Time: 140 min.

Materials (for each group)

- 2 springs of different strengths
- 4 magnets of different strengths (2 strong and 2 weak; small neodymium magnets would work best for the strong magnets)
- paper clip or other small metal object (should be nonmagnetic but able to stick to a magnet)

Activity 2.3 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introducing the lesson

2. Factors that affect the potential energy of a spring

    a. Discussion

3. Simulation

    a. Discussion

4. Conclusion

Activity 2.3 (Student materials): Why is lightning so much bigger than a spark from the Van de Graaff?

DQ

Introducing the Lesson
Discuss Reading for Activity 1.4

Possible questions:

- *What happens to energy when we use it, for example, to light a room or work on the computer?*
- *How are the ideas of the law of conservation of energy and the need to conserve or save energy related?*

Remind students that in Unit 1, they considered how the Van de Graaff generator could be seen as a model for storm clouds and lightning. Ask about what makes a Van de Graaff different from the lightning observed in nature.

Possible questions:

- *In what way does the Van de Graaff generator act like lightning? Does anyone else have other suggestions to add to this?*
- *What might be some reasons that lightning can get so much bigger than a spark from the Van de Graaff generator?*

NOTE: The goal of this discussion is only to elicit students' ideas. Students don't need to agree at this point.

We have seen that when two objects interact, potential energy can be stored in the system. To emphasize that the potential energy is due to the interaction of two objects, the potential energy can be thought of as being stored in the field between those two objects. Now we will look at what factors might affect how much potential energy is stored in a field.

Possible question:

- *What factors do you think might affect the amount of potential energy stored in a field?*

Record students' predictions on the driving question board.

We will start by looking at the amount of potential energy of a physical object (spring) first. Then, we will work with magnets that interact through a magnetic field. And finally, we will use a simulation to explore interactions between charged particles.

Page title:
Introduction

In the reading for Activity 2.2, "Potential Energy and Fields," you learned that it is helpful to think of potential energy of a system as energy that is stored in a field when objects are interacting without touching. In this activity, you will evaluate factors that can affect the amount of potential energy that is stored in a field.

Page title:
Factors that affect the potential energy of a spring

Materials

- 2 springs of different strengths

Stretch and compress the two springs. Compare the amount of force that is needed to change each spring.

Student responses:
- The stiffer spring requires more force to change it.
- The weaker the spring, the less force is required to compress it.

2. If you were going to use a spring to launch something, what could you do to make it move faster?

Student responses:
- Compress the spring more.
- Use a stiffer spring.

3. When compressed by equal amounts, which spring has more potential energy? Justify your answer.

Student responses:
- The stiffer spring has more potential energy because it requires more force to push it so it would apply more force to another object make it move faster if the spring was used to launch it.

Discussion

It is important to reinforce the relationship between force, the distance over which that force was applied, and the amount of potential energy that was stored in the system. If a force was needed to move an object from its "resting" or "natural" position, energy was added to the system. Either moving an object farther from its natural position or using a greater force to move it the same distance increases the amount of energy that is stored in the system.

Possible questions:

- *Before discussing energy changes, we need to define the system. What components do we want to include in our system?*
- *Did the amount of potential energy that was stored in the spring system depend on whether you pushed or pulled on the spring? Support your answer.*
- *Did the amount of potential energy that was stored in the spring system depend on how far you pushed or pulled on the spring? Support your answer.*
- *If you pulled both springs apart the same distance, how would the potential energy stored in each spring system compare?*
- *Does anyone have a similar or different idea?*

Page title:
Factors that affect magnetic potential energy

Materials
- 2 pairs of magnets (a stronger pair and a weaker pair)
- paper clip (or other small metal object)
- ruler
- stopwatch

Compare the strengths of each type of magnet by testing how difficult it is to separate the magnet from the paper clip.

4. Identify which magnets are stronger and which magnets are weaker. Be sure to justify your answer.

Student responses: Students should identify the weaker and the stronger magnets based on how hard it was to pull each magnet away from the paper clip.
- The ______ magnet is strongest because it hardest to pull the paper clip away from this magnet.

5. Experiment with magnets to feel the force between different pairs of magnets at different distances. Which pair stores the most potential energy in the field? Justify your answer.

Student responses:
- The pair consisting of two of the __________ [strong] magnets can have the most potential energy because it takes the most force to push them close together when they repel each other (or pull apart when attracting)

6. Experiment with arrangements of pairs of magnets that attract and repel. Compare what you feel and what you think might be happening to the amount of potential energy associated with the magnetic field.

Student responses:
- Whether the magnets are attracting or repelling, there is a force between them.
- The force between the magnets is always strongest when the magnets are closer together.
- When the magnets are touching and attracting, their is no potential energy associated with them, because they cannot move any further due to the attractive force. But if the magnets are touching and repelling, then the potential energy is really high because they are pushing apart with a lot of force.

7. Remember that potential energy is stored in fields. **Describe which two magnets you would use and how you would arrange them in order to have the most potential energy in the magnetic field.**

Student responses: There are two possible answers to this question.

- Magnets that are oriented so that the forces attract can be held apart from each other;
- Magnets that are oriented so that the forces repulse can be held close together.

In either case, you would want to choose two strong magnets.

Discussion

Have students share and compare the results of their experiments with magnets. Students could develop a list of factors that impact the amount of potential energy stored in the magnetic field and how each factor affects the amount of potential energy in the magnetic field. Be sure students are developing a consensus based on the data they collected.

Possible questions:

- *What are some factors that affect the amount of potential energy stored in the magnetic field created by the two interacting magnets? What is your evidence?*
- *What do other groups think? Does this relationship make sense?*
- *Is there a group that identified a different factor?*

Be sure to compare systems involving attractive and repulsive forces as well as strong and weak magnets.

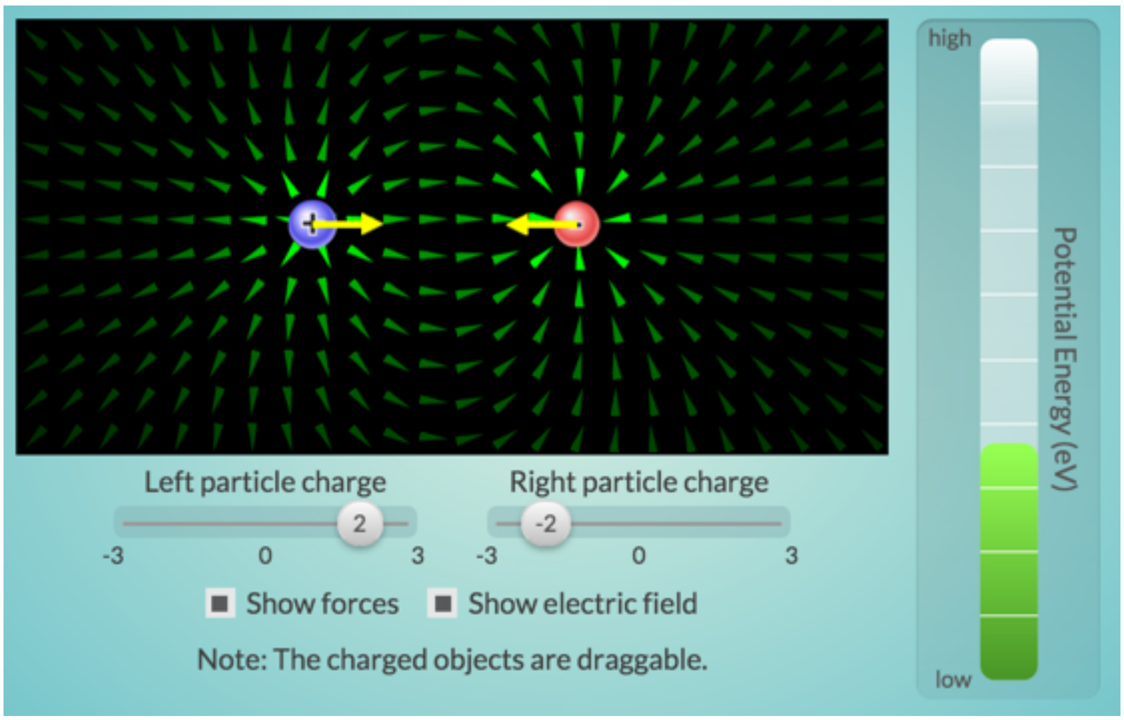
Possible questions:

- *What is one way to store a lot of potential energy in the magnetic field of the two interacting magnets? (Be sure to ask students for details: Which magnets did they choose? Why?)*
- *Did anyone have a different way?*
- *Is there a different way?*

Page title:
Factors that affect potential energy in a magnetic field

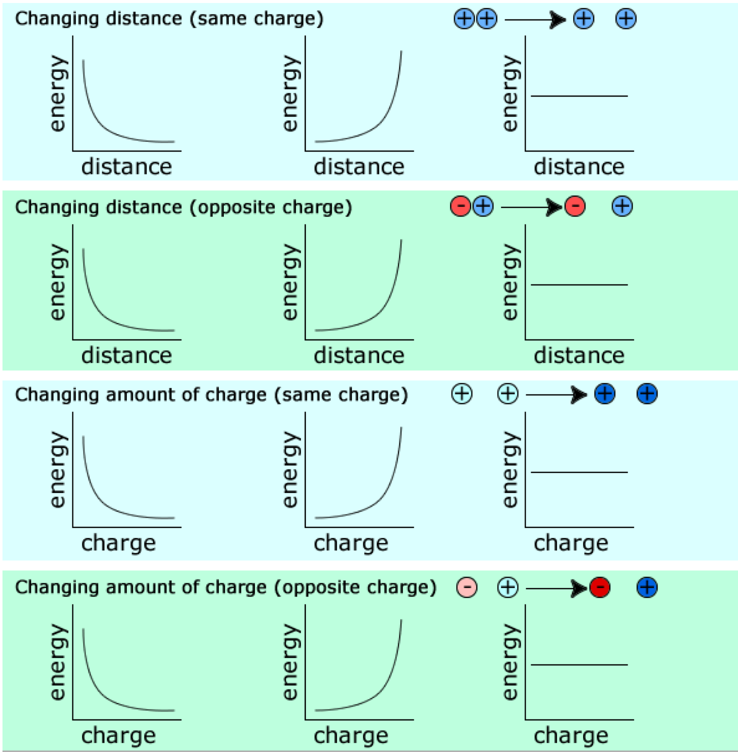
Use the simulation to explore how different factors might affect the amount of potential energy in an electric field. Be sure to test the following:

- Similar and opposite charges
- Different distances between the charges
- Amount of charge



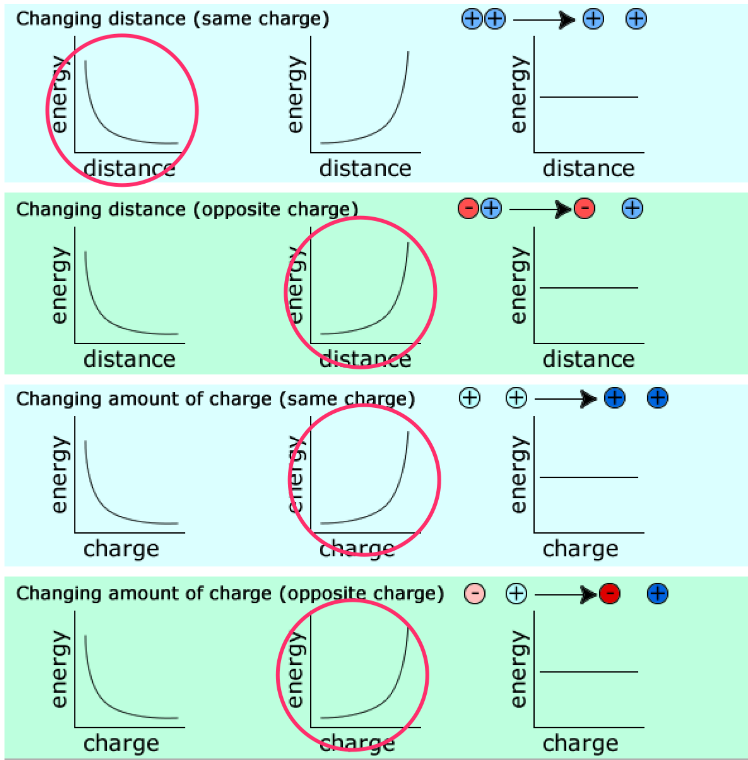
Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/electricPE2.json

8. [drawing prompt] For each row, circle the graph that indicates how changing distance or amount of charge affects potential energy in the electrical field. Note: ***For the positive and negative charges shown, darker shades of red and blue coloring indicate a greater amount of charge.***



Tip: If students' have not learned exponential equations yet, they may be uncertain about how to interpret these graphs. Ask students to compare the extremes of the graph and identify if each variable is high or low and use those relationships to select the appropriate graph.

Student responses:



Discussion

Have students share and compare their answers to question 17. Ask questions to help students interpret the relationships between energy, distance, amount and type of charge shown in the graphs and discuss their answers.

Possible questions:

- *What is the relationship between the potential energy and the electrical field with the distance between two objects with the same charge changes? What about two different charges? What is your evidence?*
- *What is the relationship between potential energy and the electrical field with the amount of charge for two objects with the same charge? What about two different changes? What is your evidence?*

9. Using the answers to the previous question, identify all of the factors that influence the amount of potential energy that is stored in an electric field.

Student responses:

- Distance between charged objects, whether the objects have the same or different charges, and the amount of charge.

10. Use the ideas of energy and charge to explain why bolts of lightning are so much bigger than sparks from the Van de Graaff generator.

Student responses: Answers may vary. Students should identify at least one cause that would lead to more energy being stored and involved when a lightning strike occurs. For example:

- More charge is built up in clouds than on the Van de Graaff.
- The distance between the ground and the cloud is greater than the distance between the Van de Graaff and the discharge wand.

Concluding the Lesson

It is important to emphasize the relationship between distance, whether there is an attractive or repulsive force, and the amount of potential energy that is stored. Be sure to compare attractive and repulsive forces as well as amount of charge. It might be helpful for students to think about the position of the objects relative to where the objects would naturally be and what would need to happen to get the objects into those positions.

Possible questions:

- *What are factors that affect the amount of energy stored in an electric field between two charges?*
    - *What is the relationship between that factor and the amount of electric potential energy?*
    - *Does that relationship depend on whether the charges are similar or opposite?*
- *What is one way to store a lot of potential energy in the field between two charged object?*
    - *Be sure to ask the students for details. What kinds of charges and what amount of charge? Why?*
    - *Is there a different way?*
- *What is more dangerous, being struck by lightning or by a spark from the Van de Graaff generator? Why? Does anyone have a different explanation? Can anyone build on that idea?*

Activity 2.4: Why do I get shocked if I am too close to the Van de Graaff generator?

SUMMARY

In previous activities, students explored the meaning of potential energy and examined the factors that affect the amount of potential energy. In this activity, students will investigate what happens to objects when they are allowed to move freely within a system. Students should note that objects tend to move toward positions that minimize the potential energy of the system. This helps answer the driving question for the activity by explaining where the shock comes from. In upcoming activities, students will analyze the relationship between the formation of bonds and potential energy, and note that bonds form at more stable/lower potential energy points.

LEARNING GOAL

Students will make predictions about the motion of objects in a system based on a model of energy that includes the natural tendency of systems to move toward more stable states.

- Clarification: A more stable state means the energy is more evenly distributed and the potential energy has been minimized. This investigation focuses only on minimizing the potential energy.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Conservation of energy and energy transfer: Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (NGSS Lead States, p. 98)	*Cause and effect:* Students suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. (NGSS Appendix G p. 83)	*Developing and using models:* Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (NGSS Appendix F p. 53)

PREPARATION

Class Time: 50 min.

Materials (for each group)

- new pencil with a flat eraser at the end

HOMEWORK

Reading for Activity 2.4: How Does Lightning Happen?

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
   a. Prediction
2. Dropping pencils
   a. Discussion
3. Charge, distance and potential energy
   a. Discussion
4. Sparks
   a. Discussion
5. Revisiting phenomena
   a. Discussion
6. Revisiting the driving question

Activity 2.4 (Student materials): Why do I get shocked if I am too close to the Van de Graaff generator?

Introducing the Activity
Revisit the driving question for the unit and ideas that students have developed so far.

Possible questions:

- *What do we know so far about how a spark triggers an explosion?*
- *At this point, what can we say about energy?*
- *What do we still need to explore?*

Activity 2.4

Page title:
Introduction

You have defined factors that affect the amount of potential energy in a system. In this activity, you will investigate what happens to the potential energy of a system when objects are allowed to move freely (not held in place).

1. [prediction question] What do you think will happen to the potential energy of a system if the objects in the system are allowed to move freely?

A. The potential energy will increase.
B. The potential energy will decrease.
C. The potential energy will stay the same.
D. It depends on the situation.

Student responses: Answers will vary. This question is just meant to elicit students' initial ideas; students do not need to agree at this point.

Introducing the Lesson
Display the histogram of responses to the prediction question. Briefly discuss students' initial ideas.

Possible questions:

- *Who picked ___? Can you explain your choice?*
- *Did anyone pick that same answer for a different reason?*
- *Does anyone agree or disagree? Explain why.*

Page title:
Dropping pencils

Materials
- new pencil with a flat eraser at the end

Your challenge: Try to drop your pencil so that it lands standing on its eraser.

2. Did your pencil land standing on its eraser? Describe your observations.

Student responses: It is not possible to get the pencil to land so that it stands on its eraser. The pencil always falls over and lies flat.

Discussion

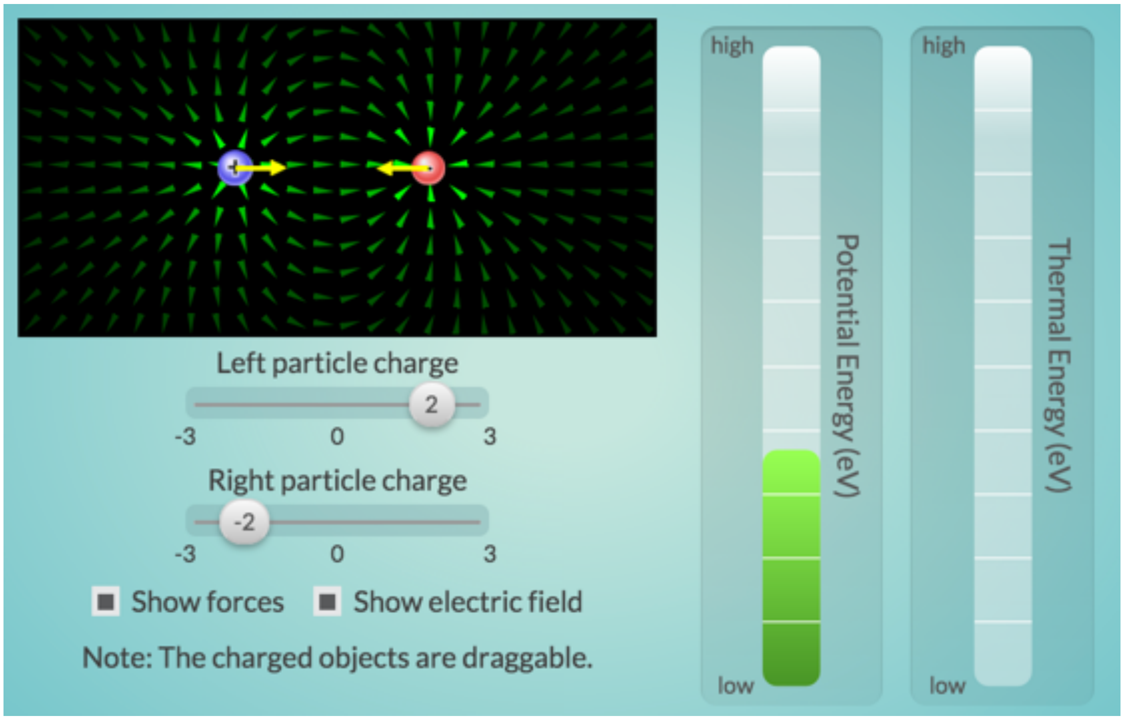
Discuss the the tendency of systems to move toward more stable states by minimizing the potential energy of the system. In the case of the activity performed above, the system includes the Earth and the pencil that is interacting with it. The potential energy of the earth and pencil system is minimized when the pencil lands on its side instead of its eraser. Ask students to think about the experiment using the term *stable.*

Possible questions:
- *What does* stable *mean?*
- *Is this system more stable when the pencil is lying flat or when it is standing on its eraser?*
- *What might cause the system to be more stable?*
- *Any other ideas?*

NOTE: The purpose of this discussion is just to elicit students' ideas. Be sure to ask for a variety of ideas, and do not evaluate the ideas at this point.

Page title:
Charge, distance, and potential energy

Explore the simulation. Observe whether choosing different types of charge, amounts of charge, and distances between the particles affects the potential energy of the system.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/electricPE3.json

3. [drawing prompt] For one setup of the simulation, draw a stacked bar graph to compare the different types of energy before running the simulation with the different types of energy after the simulation stops running.

[text prompt] Describe what your bar graphs show.

Student responses: Students' bar graphs should indicate that the total energy remains the same. Most of the energy will initially be in the form of potential energy. At the end, most of the energy will be in the form of thermal or kinetic energy.

4. For oppositely charged objects, describe the relative position of the two objects when the system has reached the most stable point.

Student responses:

- The objects are as close together as possible.

5. For the objects at this point, what do you notice about their potential energy?

Student responses:
- It is minimized or lowest.

6. What would you have to change in the system for it to be most stable when the objects are in a different relative position?

Student responses:
- Give the objects the same charges.

7. For similarly charged objects, what do you think the relative position of the two objects will be when the system has reached the most stable point?

Student responses:
- The objects are as far apart as possible.

8. What is similar about the most stable point for all the different trials you did with the simulation?

Student responses:
- Potential energy of the charge system is minimized or lowest.

9. Compare your observations of dropping the pencil with your observations of the simulation. Use the idea of energy to explain the similarities between the pencil activity and the simulation.

Student responses:
- In both the pencil activity and the simulation, the objects moved to a more stable point where the potential energy of the system was minimized.

10. Compare your observations of dropping the pencil with your observations of the simulation, use the idea of energy to explain the differences between the pencil activity and the simulation.

Student responses:
- The pencil activity and the simulation involve different types of interactions, or forces.

Discussion

Display some of the energy bar graphs students created for one setup of the simulation.

Possible questions:

- *What do all these graphs have in common?*
- *How does the potential energy before the simulation ran compare with the potential energy after it ran?*
- *How does the total energy before compare with the total energy after?*

Make sure students agree that the potential energy is always lower after the simulation has run but that the total energy stays the same.

Point out to students that the graph of the thermal energy is the *change* in the thermal energy.

Possible questions:

- *Do you think the thermal energy really started at zero? Explain. Does anyone want to add anything? Does anyone disagree?*
- *What is the thermal energy measuring? (It is measuring the movement of the atoms in the air and objects.)*

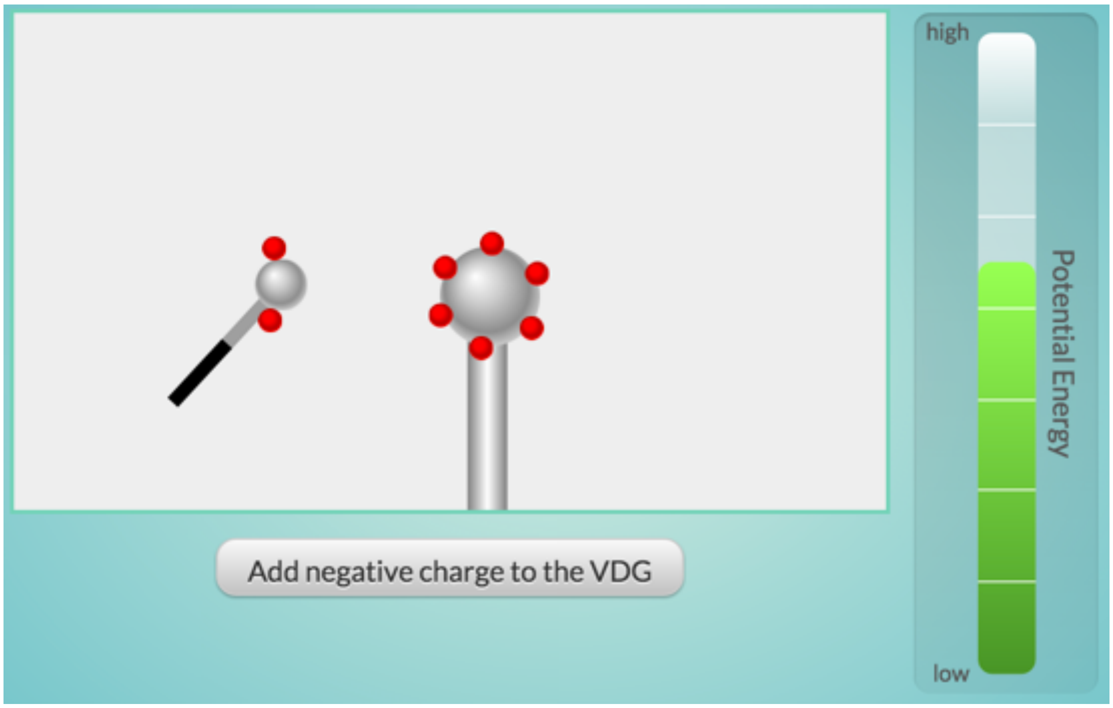
Discuss the idea of a stable, or natural, position. Students should come away from this discussion with the understanding that there are a variety of ways to describe this position, but they all refer to the same idea. The most stable position is the one that objects would naturally move to, which results in the system having the lowest possible potential energy. A force is required to move objects away from their stable, or natural, position.

Possible questions:

- *How would you describe the most stable position of the objects that you observed when the simulation finished running?*
- *Does anyone else describe it in a different way?*
- *What do you notice about the potential energy at the most stable, or natural, position of the charged objects?*
- *Could you predict which way two charged objects would move if they were allowed to move freely? What would you predict?*

Page title:
Sparks

This simulation illustrates the basic principle behind the formation of sparks from the Van de Graaff generator.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/spark.json

11. Recall your observations of the actual Van de Graaff generator and discharge wand. When the Van de Graaff generator and discharge wand were close enough to each other, a spark occurred.

Use the simulation, as well as what you have learned about the tendency of potential energy to decrease, to explain why you observed a spark.

Supplemental content: According to the Framework for K–12 Science Education light and sound are indication of energy transfer. Before the Van de Graaff generator is discharged the system stored a lot of potential energy. When it is discharged, the light and sound provide evidence that energy was transferred to the surroundings resulting in a decrease in the energy of the system.

Clarification - students do not need to recognize that light and sound are indication of energy transfer

Student responses:

- The potential energy built up on the Van de Graaff was converted and transferred to the surroundings. I saw light and heard sound as evidence of that transfer.
- Students may also say that the potential energy was changed to light and sound energy.
  - NOTE: This is not consistent with how the Framework for K–12 Science Education talks about light and sound. However, it is how many students have been introduced to the ideas of light and sound, and it is a reasonable answer at this level.

12. What happens to the overall charge of the surfaces of the the Van de Graaff generator and discharge wand after a spark occurs? **Justify your answer.**

Supplemental content: This is a very complex question, and even scientists could provide reasonable and contradicting answers. Students could give a variety of answers, some of them shown below, but it is important that students provide reasonable support for their answer.

Clarification - students should come to an agreement that there is no single “right: answer in this situation

Student responses:

- the overall charge is zero because the potential energy is lowest
- the two objects are made of atoms, which are made of positive and negative particles, so the overall charge is not zero, just neutral
- the charge is lower, but not all the way to zero, because you could make another spark

13. The process that causes a spark to occur when the discharge wand is close to the Van de Graaff generator is similar to the process that causes lightning to form. Use what you have learned about the tendency of potential energy to decrease to try to explain how lightning occurs.

Supplemental content: Heat from Earth's surface warms up the air and water vapor above it. Warm air and water vapor rise, forming clouds. The temperature above Earth's surface decreases as you go higher, so some of the water vapor in the clouds condenses to form small water droplets and, sometimes, ice crystals. These drops and/or crystals collide with each other inside the cloud. Initially, the particles in the drops and/or crystals are neutral. However, multiple collisions cause electrons to be knocked off the neutral particles, producing positively and negatively charged particles. Evidence shows that positively charged particles tend to gather at the top of the cloud, and negatively charged particles tend to gather at the bottom of the cloud. There are many hypotheses about why this happens, but it is not completely understood at this time. Whatever the cause, the result is that positive and negative charges within the cloud become separated. As the charges build up, the electric potential energy in the electric field increases. The charges keep building up until the energy of the system gets too high.The potential energy stored in the cloud increases as the charges build up, and eventually, the charge separation can't be maintained by the system. When this happens, some of the potential energy stored in the cloud is converted to heat, and some is transferred to the surroundings through light and sound.

Clarification - Students will likely not have a complete answer at this point. Students may not know where or how the charges build up. But they can infer that there is a buildup or separation of charges, and therefore energy is stored in the electric field.

Student responses:

- There is a buildup or separation of charges in the cloud, and therefore energy is stored in the electric field. Electric potential energy stored in an electric field is converted and transferred, and therefore light and sound can be observed

Discussion

Remind students that irrespective of the nature of the potential energy, the system always acts in a way that minimizes the potential energy of the system.

Possible questions:

- *Why does a dropped pebble eventually fall on the ground?*
- *What examples of electric potential energy minimization can you give?*

Page title:
Revisiting phenomena

In this activity, you will use ideas of potential energy of the electric field, charge buildup, and the tendency of systems to move toward more stable states to revise your model of the pie pans and the Van de Graaff generator.

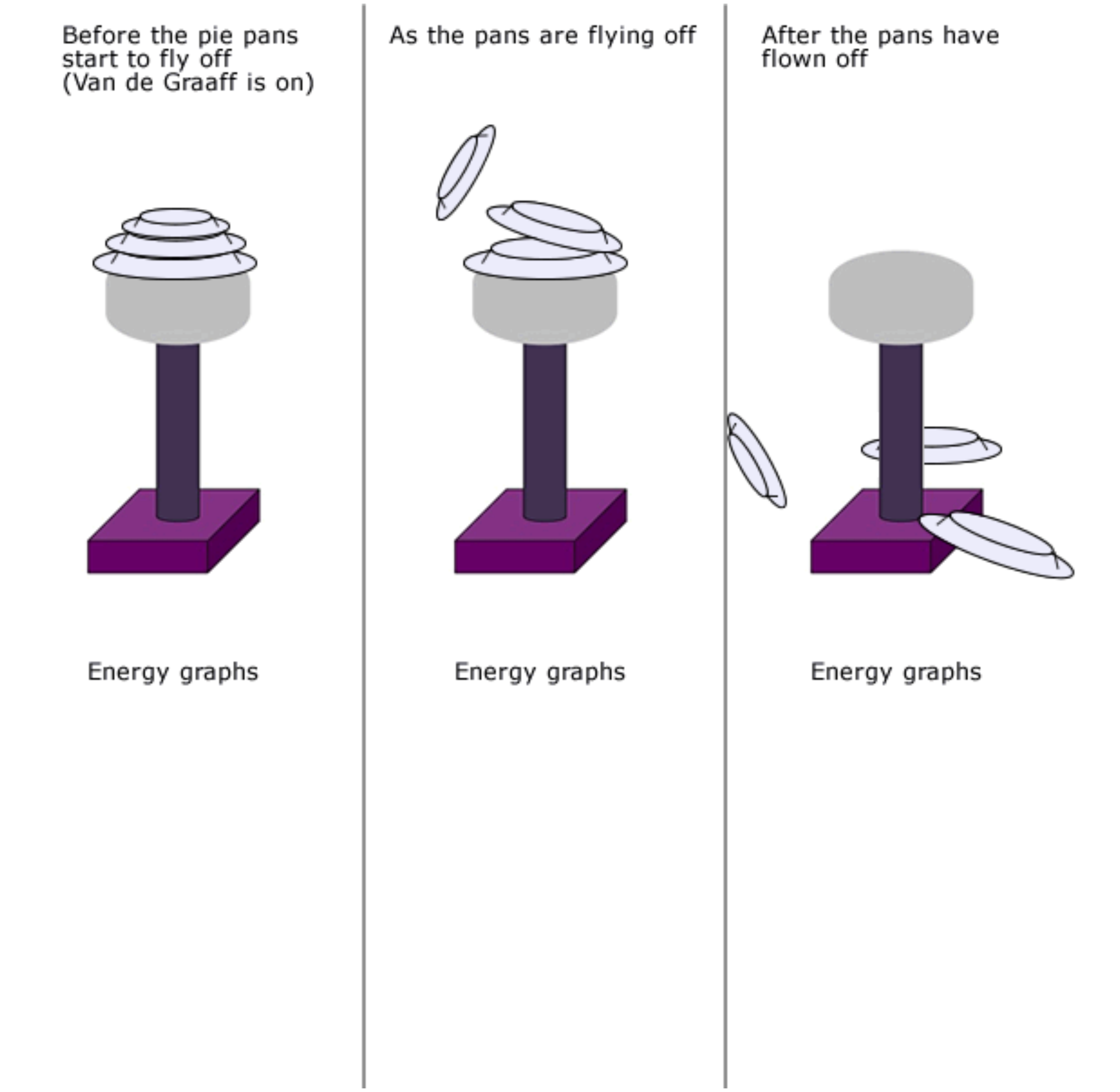
Discussion
Lead a class discussion to help students think about how the ideas of energy and charges discussed so far (potential energy, charge accumulation, tendency to move toward more stable stated) relate to their observations of pie pans flying off the Van de Graaff generator. Revisit the demonstration of the pie pans flying off the Van de Graaff generator. If you do not wish to perform the demonstration again, you can show students the following video: Pie pan demonstration.

Possible questions:
- *Do the pie pans have energy before the VDG is turned on?*
- *Do the pie pans have energy after the VDG is turned on?*
- *Why do the pie pans fly off the VDG?*
- *Where is the energy stored?*
- *Why don't the pie pans fly off right after VDG is turned on?*

Be sure students provide reasoning for all their answers and include charges and the particle nature of matter in their explanations.

14. [drawing prompt] Add charges to the Van de Graaff images and energy graphs below them to explain why the pie pans fly off the Van de Graaff generator. In your graphs, indicate the amount and type of energy for the following: 1) when the generator is turned on but before the pie pans start to fly away, 2) as the pie pans are flying through the air, and 3) after everything has stopped moving.

[text prompt] Describe how the graphs and charges you added explain your observations of the pie pans and the VDG. Be sure to include your new ideas about energy.



https://interactions-resources.concord.org/unit2/inv2/VDW-in-various-states.png

Student responses: At this point, students should be able to develop sophisticated models. Students should include charge and possibly fields (most likely in the text not the image) in their models. In their graphs, students should indicate that as the Van de Graaff is turned on, similar charges build up near each other, and therefore the amount of potential energy that is stored in the field increases. As the pie pans fly off, the potential energy stored in the field is converted to kinetic energy. Finally, at the end, the electric potential energy and kinetic energy return to lower amounts.

- NOTE: In their graphs, in order to indicate conservation of energy, students should show that the energy came from somewhere and ended up in the surroundings.

Page title:
Revisiting the driving question

Revisiting the Driving Question
Revisit the driving question for the unit: *How can a small spark trigger a huge explosion?* NOTE: Students do not have enough information to fully answer the question at this point, but they do have enough information to begin answering it.

Possible questions:
- *What have we learned that can help us begin to answer this question?*
- *How do the ideas of energy, potential energy, and electric fields relate to this question?*

15. While you still need to know more about what happens in an explosion to answer the driving question, you do have new information that can be used to make sense of what happens when you observe a spark. Use the ideas about energy that you have learned to write a possible explanation for how a spark might start an explosion.

Student responses: Answers will vary, but students should tie what they have learned to the question they are trying to answer.
- the energy store in the electric field can be transferred to cause an explosion

Homework: Reading for Activity 2.4
How Does Lightning Happen?