It's Electric!

Physical Science Unit

Lesson #	Lesson Title	Suggested Time
1	The Deep Underground Neutrino Experiment (DUNE) *What Would You Like To Investigate?*	50 minutes
2	What is a Neutrino? *Does Size Really Matter?*	Up to two 50 minute periods
3	How to Catch a Ghost *How Do the DUNE Detectors Work?*	Up to two 50 minute periods
4	Why Argon? *Did Scientists Get It Right?*	Two (+) 50 minute periods
5	What's So Great About Neutrinos? *Is It Worth the Effort?*	Two (+) 50 minute periods

It's Electric! (9-12)

Students will discover how the electromagnetic force is (and isn't) involved in the detection and study of neutrinos in the Deep Underground Neutrino Experiment ("DUNE") detectors to be installed a mile underground at the Sanford Underground Research Facility. Investigations begin with exploring the ghost-like nature of neutrinos, progress to explaining how scientists can detect a particle that rarely interacts with matter and conclude with students evaluating the choice of liquid argon as the detector medium and the overall worthiness of this international mega-science project.

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In Lesson One, students are introduced to the Deep Underground Neutrino Experiment ("DUNE"), the unit phenomenon. DUNE, in tandem with the Long-Baseline Neutrino Facility, is an international mega-science project aiming to shed light on the elusive nature of neutrinos. Scientists understand little about neutrinos, even though they are the second most abundant particle in our universe!

After encountering the unit phenomenon, students engage in asking questions and defining problems as they ponder structure and function relationships of the DUNE. First, students collaborate to generate a list of observations and/or what they have already learned about DUNE from the introductory material. Then, the class develops a list of questions or wonderments to explore over the course of the unit.

Lesson Two addresses the most asked question- What is a neutrino? Students utilize math and computational thinking as they investigate the scale of the atom, the nucleus, and the subatomic particles (including neutrinos). Coulomb's Law and the Universal Law of Gravitation are incorporated to aid students as they attempt to model and explain why neutrinos rarely ever interact with matter (this is why neutrinos are often nicknamed "ghost particles"). Lesson Two should leave students asking how scientists can detect neutrinos, considering they typically pass right through matter without interacting.

In Lesson Three, students figure out how the design of the DUNE detectors enable scientists to determine when (and where in the detector) rare neutrino-argon interactions occur. Free electrons, produced by these interactions, are the key to detection! Therefore, the DUNE detectors consist of 70,000 tons of liquid argon in a strong, uniform, electric field. As an analogy, students explore the electric field between parallel, conductive plates of different charge (using Pasco conductive paper and voltmeters), and consider what would happen to an electron placed within this electric field. Students then develop and use models to illustrate how a system (such as a DUNE detector) can be designed to cause a desired effect. Lesson Three should leave students questioning why liquid argon serves as the target medium within the DUNE detectors.

Lesson Four asks students to obtain, evaluate and communicate information explaining why scientists chose liquid argon for the DUNE. Specifically, students will delve into how electromagnetic forces help determine the chemical properties of elements, as well as the periodic trends evident on the periodic table of the elements. In the end, students discover that a noble gas is necessary for the DUNE, and that argon's low cost and high abundance make it the clear choice (since 70,000 tons are required for the gigantic detectors). Students, therefore, ought to begin questioning just how much the DUNE will cost, and if it's really worth the international effort.

The final lesson, Lesson Five, gives students room to choose the topic of their investigation, but steers students toward investigating something they can utilize in determining whether or not they feel that the DUNE is a worthwhile endeavor. First, students develop a list of prioritized criteria with which they could evaluate the DUNE. Then, students research and share their findings. Finally, students engage in argument from evidence by writing an "op-ed" explaining whether or not they find the DUNE to be a worthwhile endeavor.

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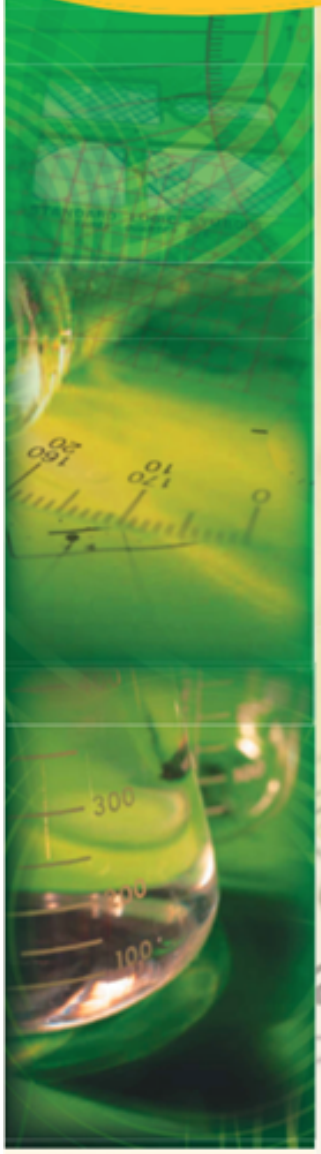
Standards Addressed in the Unit

Lesson	Standards
1	Science and Engineering Practice (SEP): ● Asking questions and defining problems: Ask questions that arise from careful observation of phenomena to clarify and/or seek additional information. Crosscutting Concept (CCC): ● Structure and function: Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.
2	**HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. Science and Engineering Practice (SEP): ● Using math and computational thinking: Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. Crosscutting Concept (CCC): ● Scale, proportion and quantity: Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another.
3	**HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. Science and Engineering Practices (SEP): ● Developing and using models: Develop and use a model based on evidence to illustrate the relationships between components of a system. Crosscutting Concepts (CCC): ● Cause and effect: Systems can be designed to cause a desired effect.
4	**HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. Science and Engineering Practices (SEP): ● Obtaining, Evaluating, and Communicating Information: Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). Crosscutting Concepts (CCC):

	● Structure and Function: Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal It's function and/or solve a problem.
5	Disciplinary core ideas (DCI) and crosscutting concepts (CCC) will vary based upon student interest and choice of topic for final investigations. **9-12-ETS1-3** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. Science and Engineering Practices (SEP): Engaging in Argument from Evidence: Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.

Science and Engineering Practices



1. Asking questions (science) and defining problems (engineering).
2. Developing and using models.
3. Planning and carrying out investigations.
4. Analyzing and interpreting data.
5. Using mathematics and computational thinking.
6. Constructing explanations (science) and designing solutions (engineering).
7. Engaging in argument from evidence.
8. Obtaining, evaluating, and communicating information.

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC 2011)

It's Electric!

Materials List

- **Teacher-Provided**

Lesson	Materials Needed
Prior to Lesson 1	➢ (optional) Materials to create science notebook
1	For each student: ➢ Science notebook For each group of 2-3 students: ● Paper showing two DUNE detector pictures ● Long-Baseline Neutrino Facility brochure For the classroom: ➢ Computer and projector with speakers
2	For each student: ➢ Science notebook For each group of 2-3 students: ● Data chart ● *Lesson Two Task Card* ➢ Calculators with exponential functionality ➢ Craft and/or basic physics lab supplies (if desired) ➢ Internet search capability (if possible) For the classroom: ➢ Computer and projector with speakers
3	For each student: ➢ Science notebook For each group of 2-3 students: ● 6 V Lantern battery ● Voltmeter with leads ● Cork board ● Conductive paper with parallel plates drawn using conductive ink ➢ Copy of grid on regular paper (in Print Masters and on USB) ● 6 metal push pins ● 2 wires with alligator clips ● *Lesson Three Task Card* ● *Lesson Three Information Sheet* ➢ (optional) craft supplies for modeling ➢ (optional) calculators with scientific notation functionality For the classroom: ➢ Computer and projector
4	For each student: ➢ Science notebook For each group of 4 students: ● *Lesson Four Information Sheet* ● Periodic Table

	● Set *Lesson Four- Initial Research Task Cards* (A-D) ● *Lesson Four- Final Analysis Task Card* For the classroom: ➢ Computer and projector with speakers (if students chose)
5	For each student: ➢ Science notebook ➢ Internet search capability ● *Neutrinos Are…* information sheet ● *LBNF/DUNE* information sheet (on back of *Neutrinos Are…*) ● *Lesson Five Task Card* and rubric For the classroom: ➢ Computer and projector with speakers

Important Note	
Science Notebooks	**You may wish to have students set up Science Notebooks prior to the first lesson.** As students develop and refine their understanding of science concepts, it is helpful for them to reflect on and record what they have learned. A science notebook provides them with a record of their questions, ideas, experiences, and evidence. The science notebook can also be used by the teacher to assess the development of student understanding. Science notebooks may be a printed booklet prepared by the teacher, a bound composition, or spiral notebook. Interactive science notebook support material can be found at the end of lesson 1. As students progress through this unit, the goal is for each student to develop more detailed, relevant science documentation in their notebook through explanations, diagrams, and terminology.

A Teacher's Guide to the Interactive Notebook

If you already have a science notebook, or journal, that students use during class please continue to use that format. If you do not require a notebook for your classroom, try using an Interactive notebook for the duration of this unit.

The interactive notebook can be kept in a composition, or spiral, notebook. The front side of the first piece of paper in the interactive notebook should be designated as a table of contents. The table of contents is created as the pages of the notebook are created. Following the table of contents, all pages should be numbered.

The next front side page should be the title page. For this unit students should create a page that reads "*It's Electric!"*.

Beginning with the backside of the second sheet of paper, students begin to make entries in their interactive notebook.

- Student output goes on left-hand pages.
- Input from other sources belongs on the right-hand pages.

Left Side – Output-Student Directed	**Right Side – Input- Teacher Directed**
RAP: Review and Preview or Reflect and Process	WOW – Words of Wisdom
Used for: Organize new information in creative formats. Interact with information from the right page. Lab Reflection questions Warm-ups Express opinions and feelings Explore new ideas. Mind maps, Venn diagrams, Drawings, Vocabulary cards, Analogies, Creating Questions, Wanted posters, etc.	Used for: Class Notes Discussion Notes Handouts with new info Lab Procedures Answer questions from text Sample Problems Vocabulary words/book definitions Movie, video notes

At the end of the unit students can write a summary of what they learned. You may also have them select two items that represent their best work. In this case, students provide the dates of their chosen entries and explain why they chose them, what they learned from them, and how these items reflect scientific thinking or skills. Students must use evidence to defend their choices and should not provide emotional responses such as "that is my best drawing" or "that activity was a lot of fun". Notebooks can be shared during conferences, or any time there are classroom visitors!

Lesson 1	The Deep Underground Neutrino Experiment (DUNE)
Overview Standard(s) & Objectives	**Overview** In this lesson, students will be introduced to the Deep Underground Neutrino Experiment (DUNE). The far-site detectors for the experiment will be housed a mile underground at the Sanford Underground Research Facility in Lead, SD. The basic set-up for the experiment will be introduced as the unit phenomenon, and students will generate questions they would like to investigate. **Standards** Science and Engineering Practice (SEP): ● Asking questions and defining problems: Ask questions that arise from careful observation of phenomena to clarify and/or seek additional information. Crosscutting Concept (CCC): ● Structure and function: Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. **Student Objectives** ● Gain an introductory knowledge of the Deep Underground Neutrino Experiment (DUNE) and the Sanford Underground Research Facility. ● Record what the class learns about DUNE from the introductory material (video, brochure, and pictures). ● Generate a list of questions to investigate. ● Group/chunk questions into logical categories. ● Develop a sequence of investigations/explorations for the unit.
Background Information (for teachers)	**Sanford Underground Research Facility** Sanford Lab, located in the former Homestake Gold Mine, was a science landmark long before being converted into a dedicated science facility. Nuclear chemist Ray Davis first recognized the potential for deep science in the mid-1960s when he built his solar neutrino experiment at Homestake. In 2002, his groundbreaking research earned him the Nobel Prize in Physics. Why do scientists go so deep underground to study particles that come from the universe? Hold out your hand. On the surface, one cosmic ray passes through it every second. However, nearly a mile underground, it's about ten million times quieter! If you held your hand out underground, you would have to wait about 3 months for a cosmic ray to go through

	your hand. The rock acts as a natural shield, blocking most of the radiation that can interfere with sensitive physics experiments. It turns out Sanford Lab is particularly suited to large physics experiments for another reason—the hard rock is perfect for excavating the large caverns needed for big experiments. Sanford Lab also hosts experiments in other disciplines—including biology, geology and engineering. Experiments include the search for life underground, gravitational waves and seismic activity. For more information about the Sanford Lab, visit http://www.sanfordlab.org/ **LBNF/DUNE** The Deep Underground Neutrino Experiment (DUNE) is a leading-edge, international experiment for neutrino science and proton decay studies. Discoveries over the past half-century have put neutrinos, the most abundant matter particles in the universe, in the spotlight for further research into several fundamental questions about the nature of matter and the evolution of the universe — questions that DUNE will seek to answer. DUNE will consist of two neutrino detectors placed in the world's most intense neutrino beam. One detector will record particle interactions near the source of the beam, at the Fermi National Accelerator Laboratory in Batavia, Illinois. A second, much larger, detector will be installed more than a kilometer underground at the Sanford Underground Research Laboratory in Lead, South Dakota — 1,300 kilometers downstream of the source. These detectors will enable scientists to search for new subatomic phenomena and potentially **transform our understanding of neutrinos and their role in the universe.** For more information about LBNF/DUNE, visit http://www.dunescience.org/ and/or DUNE at LBNF (fnal.gov)
Materials	For each student: ➢ Science notebook For each group of 2-3 students: ● Paper showing two DUNE detector pictures ● Long-Baseline Neutrino Facility brochure For the classroom: ➢ Computer and projector with speakers
Prior Knowledge	Students do not require any prior understandings to begin this lesson.

Launch (5-10 minutes)	
Engagement and Communication of Student Expectations	**Each student will need a copy of the Long-Baseline Neutrino Facility brochure, and a copy of the paper showing 2 pictures of the Deep Underground Neutrino Facility (DUNE) detectors.** Tell students that they are starting a new unit. During this unit, they are going to learn about an international mega-science project called "LBNF/DUNE", short for the "Long-Baseline Neutrino Facility/Deep Underground Neutrino Experiment". The detectors for this gigantic project (which extends from Fermi Lab near Chicago, Illinois, all the way to the Sanford Underground Research Facility in Lead, South Dakota) are what you are going to share with them today. Allow students 3-5 minutes to look at the brochure and pictures of the Deep Underground Neutrino Experiment detectors. Play the *Phenomenon Introduction Video* (2 min 38 sec) available on the USB located in the front of the teacher binder (zip pocket). The file is located in the *Lesson One* folder.
Explore (30-40 minutes)	
Procedure	Students should collaborate in groups of 2-3. Ask groups to take about 5 minutes to discuss and record (in their science notebooks) everything they have learned about the Deep Underground Neutrino Experiment (DUNE). They may also want to record what they *notice* about the DUNE. Bring students together to make a class list of what they have learned and/or noticed. Ask students to go back to their groups and take about 10 minutes to discuss and record at least five questions they have about the Deep Underground Neutrino Experiment (and/or anything associated with understanding the experiment that they would like to investigate). What do they wonder about? Bring students together to make a class list of their questions. Facilitate as students work to group/chunk questions into logical categories. You may want to use sticky notes that can be moved around easily. Finally, ask students to look at their question categories to see if there is a logical progression… where should they begin their exploration? What questions would naturally follow another question or questions? Can they agree on a sequence of investigations for this unit? Help facilitate and guide your students through this process. Attempt to guide the class toward a progression that includes Lessons Two, Three and Four of the *It's Electric* unit. Though this unit is written with a particular sequence in mind,

	these lessons could certainly be rearranged to fit student preference (though you may need to adjust lessons to accommodate such changes).
Questions	**Driving Question** ● What is the Deep Underground Neutrino Experiment (DUNE)? **Probing Questions** ● What have we noticed and/or learned about DUNE? ● What do we wonder about or want to investigate? ● Should some questions be answered before investigating others? ● Is there an obvious sequence that could guide our explorations?
Summarize (5-10 minutes)	
Communicate	Once the class has finished grouping questions, and has mapped out their intended set of investigations, make sure that everything has been recorded in science notebooks. It is recommended that the list of questions be posted in the classroom during the entire unit so that students can add questions and track their progress. If time allows, you may begin *Lesson Two*.
Terminology and Concepts to Solidify	**From NGSS Appendix F: Science and Engineering Practices in the NGSS** Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution. (NRC Framework 2012, p. 56) Scientific questions arise in a variety of ways. They can be driven by curiosity about the world, inspired by the predictions of a model, theory, or findings from previous investigations, or they can be stimulated by the need to solve a problem. Scientific questions are distinguished from other types of questions in that the answers lie in explanations supported by empirical evidence, including evidence gathered by others or through investigation. While science begins with questions, engineering begins with defining a problem to solve. However, engineering may also involve asking questions to define a problem, such as: What is the need or desire that underlies the problem? What are the criteria for a successful solution? Other questions arise when generating ideas, or testing possible solutions, such as: What are the possible trade-offs? What evidence is necessary to determine which solution is best? Asking questions and defining problems also involves asking questions about data, claims that are made, and proposed designs. It is important to realize that asking a question also leads to involvement in another practice. A student can ask a question about data that will lead to further analysis and interpretation. Alternatively, a student might ask a question

	that leads to planning and design, an investigation, or the refinement of a design. Whether engaged in science or engineering, the ability to ask good questions and clearly define problems is essential for everyone.
Connection to Big Ideas (Phenomena)	This will be student's first experience with the phenomenon, the Deep Underground Neutrino Experiment (or DUNE). The goal is to initiate student interest, engage students in question development, and allow the class to develop a logical sequence of investigations. Therefore, the science and engineering practice of *asking questions and defining problems* is the focus of this lesson.
Optional Follow Up	If any students strongly disagree about the questions to investigate and/or the logical progression of investigations, consider allowing these students to work using their own plan. Independent study can be a powerful differentiation tool. *Lesson Five* allows room for students to investigate their individual yet-left-unanswered questions. Therefore, if students have only a single wonderment that differs from the class consensus, save these questions for the final lesson.
Assessment	**Ticket Out the Door**: Each student should write down their favorite question (the one they are most interested in learning about) and explain why they are interested in that question.

Lesson 2	Does Size Really Matter? … or… What is a Neutrino?
Overview Standard(s) & Objectives	**Overview** In this lesson, students will discover that there is a very common subatomic particle (in addition to the more familiar electron, proton, and neutron) called the neutrino. As the neutrino is a nearly massless particle with no charge, which only interacts with matter through the gravitational and weak nuclear forces, it passes easily through matter and is extremely difficult to detect. **Standards** HS-PS2-4 Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. Science and Engineering Practice (SEP): ● Using math and computational thinking: Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. Crosscutting Concept (CCC): ● Scale, proportion, and quantity: Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another. **Objectives** ● Develop a model explaining why neutrinos typically pass through matter without interaction. ● Explain why neutrinos are difficult to detect. ● Understand that neutrinos do not interact through the strong nuclear or electromagnetic forces. ● Determine that neutrinos essentially only interact via the weak nuclear force.
Background Information (for teachers)	**The Fundamental forces** Currently, scientists consider there to be four fundamental forces: the gravitational force, the weak force, the electromagnetic force, and the strong force. Gravitational Force- The weakest of the four fundamental forces, though it is far reaching, essentially infinite. It is associated with the mass of objects (M_1 and M_2), the gravitational constant (G), and the distance between the objects (d): $F(grav) = G(M_1)(M_2)/d^2$ Weak Force- Incredibly short ranged, as it is a nuclear force, and weak… though not as weak a force as gravity. It predominates in radioactive decay and neutrino interactions, and is involved in the unification or dissociation of a neutron and its' component parts—an electron, proton, and neutrino: $n^\circ \rightarrow p^+ + e^- + \nu$ Electromagnetic Force- The interactions between charged particles, covering electrostatic and magnetic phenomena. The electromagnetic force has an infinite range and is considerably stronger than the gravitational and weak forces. Much like the gravitational force, the magnitude of the electrostatic force of attraction or repulsion between objects is directly proportional to the

	product of the magnitudes of the charges (q_1 and q_2) and the Coulomb's law constant (k), and inversely proportional to the square of the distance between them (d). $F(elect) = k(q_1)(q_2)/d^2$ The Strong Nuclear Force- A nuclear force operating over a very short range, but it is the strongest of the forces. It holds quarks together to form nuclear particles and keeps the nucleons (protons and neutrons) together within the nucleus. Within the scale of the nucleus, the strong force becomes stronger as the distance between nuclear particles increases. **What is a neutrino?** A neutrino is a subatomic particle very similar to an electron, but it has no electrical charge and a very-very small mass (close to zero). Neutrinos are one of the most abundant particles in the universe, second only to photons. Because they have very little interaction with matter, however, they are incredibly difficult to detect. Nuclear forces treat electrons and neutrinos identically; neither participate in the strong nuclear force, but both participate equally in the weak nuclear force. Particles with this property are termed leptons. Neutrinos do participate in the gravitational force, but since the neutrino mass is so close to zero, it is considered negligible. Therefore, neutrinos essentially interact with matter only via the weak force.
Materials	For each student: ➢ Science notebook For each group of 2-3 student's: ● Data chart ● *Lesson Two Task Card* ➢ Calculators with exponential functionality ➢ Craft and/or basic physics lab supplies (if desired) ➢ Internet search capability strongly suggested (if possible) For the classroom: ➢ Computer and projector with speakers
Prior Knowledge (for students)	Students should be familiar with the subatomic structure of the atom, and the Universal Law of Gravitation. Prior familiarity with Coulomb's Law is useful, but not essential.
Launch (10 minutes)	
Engagement and Communication of Student Expectations	Many of you have been asking "what is a neutrino". Some of you have asked "how do the DUNE detectors work". Well, today we are going to begin trying to answer some of these questions. Show *What is a Neutrino with Professor Ed Kearns*. Ask students what questions they still have about neutrinos. Make a list on the board. Neutrino literally means "little neutral one" in Italian, and this is in comparison

	to the subatomic particles you probably already know (proton, neutron, and electron). It's not easy to wrap our heads around the size of an atom, let alone one of the subatomic particles, but analogies can help. Let's start by looking at an analogy for the size of a nitrogen atom and its' nucleus. Show *Just How Small is an Atom?*. Allow students a few minutes to discuss the video. If they have new questions, write those on the board as well.
Explore (30-70 minutes)	
Procedure	**Each group of 2-3 students will need a data chart and task card.** Physicists often consider electrons and neutrinos to be "point particles". Point particles are so small that they are assumed to take up essentially no volume. In thinking back to the nitrogen atom as a blueberry the size of a stadium, you would not have been able to visualize the electrons because they are many times smaller than the protons and neutrons of the nucleus! Yet, point particles can have additional aspects that are far from zero. These aspects combine to give the atom, and all matter, the properties that we observe every day. In fact, protons and neutrons are each made up of three-point particles called *quarks*. Different combinations of quarks are what give protons and neutrons their unique properties. Neutrinos, sometimes called *ghost particles,* are particularly interesting because they can pass easily through matter. In fact, they very rarely interact with anything at all. Your task is to develop a model that utilizes mathematical, computational, and/or algorithmic representations to describe and explain why neutrinos may easily pass through matter, as compared to one other subatomic particle.
Questions	**Driving Question** ● How can neutrinos pass through matter without interaction? **Probing Questions** ● How are neutrinos different from the more familiar subatomic particles? ● What forces do neutrinos use when interacting with other particles?
Summarize (15-20 minutes)	
Communicate	Groups share their models, using them to explain why they think neutrinos rarely interact with matter. Mathematical/computational/algorithmic representations must be incorporated. Wrap-up by showing *Ask Symmetry- Why can a Neutrino Pass Through Solid Objects?* Ask students what questions they have at this point. Write student questions on the board, or in student science notebooks. Direct or encourage discussion toward the question of how scientists can detect a particle that typically passes right through matter without interacting (Lesson Three!). **Helpful Examples for Teachers:** Students might compare neutrinos with electrons and find that (using Coulomb's Law) neutrinos are unaffected by the electromagnetic force, but that electrons are. Therefore, an electron approaching an atom might be expected to

	feel a repulsive force that increases in strength as it nears the electron cloud of the atom. On the contrary, a neutrino would approach the atom without experiencing any repulsive force at all. This could be modeled using magnets of the same polarity to represent the electron and electron cloud, and a non-magnetic object representing the neutrino. Another example for comparing an electron with a neutrino might incorporate calculations of the gravitational force of attraction between an electron and an atom, using the atomic radius for the distance of separation (or any distance that students desire), comparing it directly to the gravitational force of attraction (at the same distance) between a neutrino and the same atom. Then, for modeling, students might calculate how many times greater the attraction is for an electron as compared to a neutrino… and then create an analogy for describing the scale difference; much like the blueberry analogy of the *Just How Small is an Atom?* Video used in the launch. (For example… if the neutrino-nucleus attraction was represented by the diameter of a penny, then the electron-nucleus attraction would be represented by the diameter of an…)
Terminology and Concepts to Solidify	**Atoms** are mostly empty space, with the bulk of the atomic mass (protons and neutrons) concentrated in a region (nucleus) so small that it is nearly impossible for the human brain to comprehend. **Neutrinos** are neutral subatomic particles with a mass close to zero. The **electromagnetic force** does not affect neutrinos because they have no charge. The **gravitational force** has little effect on neutrinos because their mass is so close to zero. Neutrinos, though abundant, hardly ever interact with matter (atoms). **Strong nuclear force**- the force that holds particles together in the atomic nucleus and holds quarks together in elementary particles. As the name implies, this is the strongest force known in nature. **Weak nuclear force**- responsible for nuclear beta decay (by changing the flavor of quarks) and for neutrino absorption and emission. **Electromagnetic force**- associated with electric and magnetic fields. Responsible for atomic structure, chemical reactions, and the attractive and repulsive forces associated with electrical charge and magnetism. **Gravitational force**- The weakest of the fundamental forces of nature, being the attractive force that arises from gravitational interaction. Newton's law of gravity states that the gravitational force between two bodies is proportional to the product of their masses and inversely proportional to the square of the distance between them.
Connection to Big Ideas (Phenomena)	The DUNE detectors must be very large if scientists are going to detect any signals from passing neutrinos. The likelihood of a neutrino interacting with an argon atom to produce a signal is incredibly low. But scientists can increase their odds of seeing these rare interactions by using huge numbers of atomic

	"targets" (ie: argon nuclei). In fact, the DUNE detectors will use about 70,000 tons of liquid argon!
Optional Follow Up	Students who desire to learn more about neutrinos may delve deeper during lesson five.
Assessment	See *Lesson Two Task Card* and rubric.
Connection to Next Lessons	Students should be asking how the DUNE detectors work… since neutrinos hardly ever interact with matter (*Lesson Three*). Students may also begin asking why the detectors contain liquefied argon… Is there something special about argon that increases the odds of a neutrino interaction (*Lesson Four*)?

Lesson 3	How to Catch a Ghost
Overview Standard(s) & Objectives	**Overview** At the end of *Lesson Two*, students were probably asking how scientists can detect a particle that interacts with matter so rarely that it is often called a *ghost particle*. In this lesson, students learn that it is not the neutrinos that are detected, but the charged particles produced by the neutrino-argon nucleus interaction that does occasionally occur. Specifically, students will investigate the electric field within the DUNE detectors, and the effect it has on free electrons resulting from neutrino interactions. **Standards** HS-PS3-5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. Science and Engineering Practices (SEP):

	● Developing and using models: Develop and use a model based on evidence to illustrate the relationships between components of a system. Crosscutting Concepts (CCC): ● Cause and effect: Systems can be designed to cause a desired effect. **Objectives** ● Explore the electric field between parallel, oppositely charged, conducting plates. ● Qualitatively and/or quantitatively determine the net force, acceleration and change in energy of an electron placed into the electric field between oppositely charged parallel plates. ● Understand that the DUNE detectors at the Sanford Lab are very large parallel plates of contrasting charge. ● Develop a model (drawings, diagrams, etc.) that is utilized to illustrate and explain how the design of the DUNE detectors enables neutrino detection.
Background Information (for teachers)	**Electric Fields and Forces** Scientists have long understood why forces act the way they do when objects touch. Forces that act at a distance, without touching, has proved to be a trickier matter. To help explain these forces at a distance (think about a ball falling to the earth), scientists use the idea of a "field". They imagine that there is an area around the object, and anything entering that area would feel a force. We say, for example, that the Moon has a gravitational field around it, and if you get close to the Moon, it will pull you down to Its surface. An electric field describes the area near any electrically charged object. It could also be called an electrostatic field. Any other charge that enters that area will feel a force, and the original object will also feel that force (Newton's Third Law). It's kind of like a spider sitting at the center of a web. A field is a vector and is represented by arrows. The Earth's (or any planet's) gravitational field would be drawn as arrows pointing toward the ground. A field vector shows the direction of the effect on an object entering the field. Gravity acts downward. For an electric field, things are a little more complicated, since there are two kinds of charges, and some combinations attract while others repel. In order to be in agreement with each other, physicists decided that they would always use positive charges to determine the direction of the effect of a field. So, if the central charge was positive, and you put another positive charge near it, that second charge would be repelled outward. So the field vectors for a central positive charge point outward. If the central charge is negative, a positive charge placed nearby would be attracted toward the center charge, so the field vectors for a central negative charge point inward. Electric fields increase in strength as charged particles move closer to each other. Since fields are directly related to the forces they exert, their strength decreases with distance, and increases with the size of the charge producing the field. When you put charges near one another, their fields interact and change

shape. This results in changes in the PE of the objects and generates forces of repulsion or attraction.

Liquid Argon Time Projection Chambers

In 1977, Carlo Rubbia devised a liquid-argon time projection chamber, or LArTPC, and this is the basis for the Deep Underground Neutrino Experiment (DUNE) detectors. A time projection chamber is a type of particle detector that uses electric (or electric together with magnetic) fields in a volume of gas or liquid to perform three-dimensional reconstruction of a particle trajectory or interaction. The DUNE detectors will use liquid argon and a strong electric field. Liquid argon is advantageous as a medium for several reasons. The fact that argon is a noble element and therefore has a vanishingly small electronegativity (tendency to attract electrons) means that electrons produced by ionizing radiation will not be absorbed as they drift toward the detector readout (anode plane of wires). Argon also scintillates (produces light) when an energetic charged particle passes by, releasing several scintillation photons that is proportional to the energy deposited in the argon by the passing particle.

The body of a typical LArTPC is formed of three parts. On one side of the detector is a high-voltage cathode plane, used to establish an electric field across the TPC. Although the exact electric potential at which this is set is dependent on the detector geometry, this high-voltage cathode typically produces a drift field of 500 V/cm across the detector. On the side opposite the cathode plane is a set of anode wire planes set at potentials much higher (less negative) than that of the cathode. Each plane is separated from Its neighbors by a small gap, usually on the order of 1 cm. A plane consists of many parallel conducting wires spaced by a few millimeters, and the angle at which the wires are oriented relative to the vertical varies from plane to plane. Together, these planes detect signals from the drift electrons. For a detector with N anode wire planes, the inner N − 1 planes are called induction planes. These are set at lower (more negative) potentials than the outer plane, allowing drift electrons to pass through them, inducing signals that are used for event reconstruction. The outer plane is called the collection plane because the drift electrons are collected on these wires, producing additional signals. Having multiple planes with different wire orientations permits two-dimensional event reconstruction, while the third dimension is found from electron drift times.

The third part of a LArTPC is a field cage between the cathode and anode. This field cage maintains a uniform electric field between the cathode and the anode, so that drift electron trajectories deviate as little as possible from the shortest path between the point of ionization and the anode plane.

A light-collection system often accompanies the basic LArTPC, and the DUNE detectors are no exception. Since scintillation light can be detected only nanoseconds after a particle passes through the detector, and this is comparatively (on the order of 1000 times) shorter than the time taken by the freed electrons to drift to the wire planes, it is often sufficient to determine a trigger time (t_0) for an event. With this trigger time, one can then find electron drift times, which enables three-dimensional reconstruction of an event.

	Voltmeters (or *Why You* Couldn't Do This Investigation While Scuba Diving Inside the DUNE Detectors) A voltmeter is an instrument used for measuring electrical potential difference (∆V) between two points in an electric circuit. Since the gridded conductive paper used in this investigation allows an electrical current to flow through it, a voltmeter can be utilized to investigate the electric field between the parallel silver "plates". The liquid argon that fills the Deep Underground Neutrino Experiment (DUNE) detectors, on the other hand, is not conductive. Therefore, a voltmeter would be useless for analyzing the electric field within the DUNE detectors. Luckily, electric fields emanating from charged objects permeate all of space regardless of whether a conductor is present, or not. The use of a voltmeter in this lesson simply gives students a convenient method of exploring the electric field between two parallel, conductive plates of different charge… allowing students to draw analogies to the electric field present within the DUNE detectors.
Materials	For each student: ➢ Science notebook For each group of 2-3 student's: ● 6 V Lantern battery ● Voltmeter with leads ● Cork board ● Conductive paper with parallel plates drawn using conductive ink ➢ Copy of grid on regular paper (in Print Masters or on USB) ● 6 metal push pins ● 2 wires with alligator clips ● *Lesson Three Task Card* ● *Lesson Three Information Sheet* ➢ (optional) craft supplies for modeling ➢ (optional) calculators with scientific notation functionality For the classroom: ➢ Computer and projector
Prior Knowledge (for students)	Students will require a basic understanding of forces, acceleration and energy conservation. The concepts of work, and the work-energy theorem, would be helpful, but are not required. Students might benefit from a strong prior understanding of the gravitational force and the motion of objects within a gravitational field (as an analogy for approaching electromagnetic fields), but it is not required. Students should have a basic understanding of the electromagnetic force (from lesson one).
Launch (5-10 minutes)	
Engagement and Communication of Student Expectations	Play (on loop) the Neutrino Detection in Liquid-Argon Time Projection Chamber animation (the file is on the USB in the front binder pocket of the facilitators guide: 35 seconds in length) as students enter the classroom and you take role. Allow students to stop the animation at any point to read, think, and discuss

	what they are watching. Once the class has experienced the animation a few times and had time to discuss, explain that they will now be investigating how scientists "detect" a particle that almost never interacts with matter. Luckily, neutrinos DO interact sometimes… though it happens extremely rarely. This animation is attempting to demonstrate how the DUNE detectors work. Notice that the detector is collecting data not from neutrinos directly, but from particles created from the interaction of a neutrino with an argon nucleus. Ask students what questions they have after watching the animation. Write these questions on the board. Ask students to discuss which questions most directly pertain to the generation of the signal that the detectors are collecting/sensing (Play the animation again, as necessary). Hopefully, discussion will focus on the electrons drifting toward the positively charged grid work on the left side of the animation (if not, ask questions that might help students focus their attention there). This phenomenon is the focus of Lesson Three.
Explore (40-70 minutes)	
Procedure	**Electric Field Investigation** Each group of 2-3 students will need: ● 6 V Lantern battery ● Voltmeter with leads ● Cork board ● Conductive paper with parallel plates drawn using conductive ink ● Copy of grid on regular paper ● 2 metal push pins ● 2 wires with alligator clips ● *Lesson Three Task Card* and information sheet ● (optional) craft supplies for modeling ● (optional) calculators with scientific notation functionality Explain that the apparatus students are about to set-up and investigate is analogous to the DUNE detectors, with two large, parallel, 2-dimensional planes of contrasting charge on either side (creating a 3-dimensional detector). The main difference is that the set-up for today's investigation creates a 2-dimensional apparatus. Say: *"In Lesson Two, you utilized Coulomb's Law to determine the electromagnetic force between charged objects. Coulomb's Law isn't the only way to calculate electromagnetic forces! All charged objects create an electric field that emanates from that object to infinity… though the field decreases in strength with increasing distance from the charged object, so that the field is essentially zero at infinity. Electromagnetic forces are, in fact, produced through interactions of these electric fields. This is the phenomenon you will be investigating today, and how the design of the Deep Underground Neutrino Experiment (DUNE) detectors enables scientists to observe neutrino-argon nucleus interactions."*

Direct students to the *Lesson Three Task Card*. The goals for this investigation are to:

1. Given $\vec{E} = \frac{\Delta V}{\Delta r}$, and using a copy of the grid to map your findings, explore the electric field between the parallel, conductive plates (silver lines) with the voltmeter probes.
2. Pathways along which ∆V = 0 are called "equipotential lines".
3. Determine the strength and direction of the electric field between the parallel, conductive plates. (Label on your map)
4. On a separate sheet of paper, develop a model (drawing, diagram, etc.) of the electric field within the actual DUNE detectors, and utilize it to qualitatively and/or quantitatively describe what happens to free electrons in the detector (including force(s), acceleration, and energy changes).
5. Summarize how the DUNE detectors were specifically designed to enable scientists to determine when (and where in the detector) rare neutrino-argon nucleus interactions occur.

Additional details to discuss:

- Gently touch voltmeter probes to the paper without pushing into it.
- Place the two thumbtacks into the pre-punched holes of the conductive paper (do not make extra holes in the paper).
- Use the thumbtacks to make good contact between the alligator clips and the conductive "plates" (thick silver lines).
- Disconnect an alligator clip from the battery when not taking data (to extend battery life).
- Turn voltmeter off when not in use (to extend battery life).
- The conductive paper has a high resistance; it is safe to touch all parts of the equipment with bare hands while current is flowing through the circuit.

Students should consult both Lesson Two and Lesson Three data and information tables. Also, encourage students to imagine that the 2-dimensional apparatus they are using today was fully 3-dimensional like the DUNE detectors.

Teacher Hints

Depending on your students, you may want to give them time to discuss and share ideas concerning how to explore the electric field between the parallel conductive plates. Some students may want to fix the voltmeter probes so that they are always the same distance apart (∆r), and then investigate how ∆V changes depending upon placement of the voltmeter probes. Others may want to graph ∆V (y-axis) versus ∆r (x-axis) and observe the slope of the best fit line to analyze the electric field. And there may be some who place one probe without moving it, and vary the placement of the second probe, only, to see how voltage and displacement are related between the conductive plates. There are, in fact, many more ways for students to explore the electric field between the parallel conducting plates… encourage them to be creative and try many techniques!

In the end, students should have accumulated evidence that the equipotential lines are parallel to the silver conductive lines, and the electric field between the plates is uniform and perpendicular to the silver lines (i.e., "plates"). In essence,

	the electric field is unidirectional from one plate to the other. The same holds true for the electric field between the anode and cathode of the Deep Underground Neutrino Experiment (DUNE) detector.
Questions	**Driving Question** ● How does the Deep Underground Neutrino Experiment (DUNE) detector design enable neutrino detection? **Probing Questions** ● How is voltage related to electric field strength? ● What factors determine the electric force applied to a charged particle in a uniform electric field? ● Why do free electrons in an electric field migrate toward the more positively charged plate (anode)? ● What happens to the energy of a free electron in a uniform electric field? Why? How is this analogous to an object in a gravitational field?
Summarize (10-20 minutes)	
Communicate	Facilitate a class discussion focusing on the goals for this investigation (see *Lesson Three Task Card*). One group might volunteer to share their analysis, and then the class offers feedback, poses questions, and generally assesses the validity of the proposed analysis. Then, the discussion could open for groups with a different analysis to share… with the same class feedback, questioning and assessment. In the end, every student should be able to explain how the DUNE detectors work (qualitatively and/or quantitatively) utilizing a model that they develop (drawing, diagram, etc.), addressing the electric force on, acceleration of, and energy changes of a free electron generated from a neutrino-argon nucleus interaction. Then, students should summarize how the DUNE detector design enables scientists to determine when (as well as where in the detector) that a neutrino-argon nucleus interaction occurs. You may allow any format you desire for student explanations/summaries. At the end of class discussion, if students have not posed questions for further investigation, try to elicit from students what they still wonder about. You might play the Neutrino Detection in Liquid-Argon Time Projection Chamber animation again, and/or suggest looking back at the Lesson One phenomenon about the Deep Underground Neutrino Experiment (DUNE). Focus attention on the fact that the detectors are filled with liquid argon. Does anyone wonder why it is liquid argon? Could anything else be used and work just as well? Why was argon chosen? Are neutrinos more likely to interact with an argon nucleus, as compared to other elements? This will be the focus of Lesson Four! Student models and explanations may be produced in class, or as homework. But, if time allows, it is strongly recommended to provide students time for peer-review and revision before submission for teacher feedback… and final revisions (if desired).
Terminology and Concepts to Solidify	The **electric field** between oppositely charged parallel plate conductors is uniform, and points from the positive plate toward the negative plate. The magnitude of this electric field is proportional to the change in voltage (in volts),

	and inversely proportional to the distance (in meters) over which that voltage change occurs. Electric fields exert an **electric force** on charged particles, the magnitude of which is proportional to the charge (in coulombs) multiplied by the electric field strength (in volts/meter). The direction of the electric force depends upon the sign of the charge on the particle: Negatively charged particles are attracted to the positive plate (anode), and positively charged particles are attracted to the negatively charged plate (cathode). **Electric forces** can cause charged particles to accelerate, inversely proportional to their mass, according to Newton's Second Law. The **electric potential energy** of a charged particle depends upon Its position. If free to accelerate, a charged particle in an electric field will travel to a region of lower potential energy… and since energy is conserved, the "missing" potential energy is converted to kinetic energy of the particles motion. Work can be done upon a charged particle to move it opposite to the direction it would travel if free to accelerate, thereby increasing the potential energy of that charged particle, according to the work-energy theorem ($W=F\triangle d=\triangle E$).
Connection to Big Ideas (Phenomena)	The DUNE detectors host a uniform electric field of about 50,000 V/m. When a rare neutrino-argon nucleus interaction occurs, new particles may be produced which knock valence electrons from neighboring argon atoms. These free electrons drift toward the uncharged anode (array of wires) under the influence of an electric force… changing potential energy of the free electron into kinetic energy. What the DUNE detectors "sense" is a quick current pulse when the free electrons contact the conducting metal of the anode. Since the anode is an array of wires (two sets, at 90 degree angles to one-another), and many electrons are knocked free as the particles come to rest, scientists can analyze the data to determine where in the detector the neutrino-argon interaction occurred, and what direction the interaction-created particles were traveling. Therefore, it is not neutrinos that the DUNE detectors are sensing, it's the free electrons knocked loose from neighboring argon atoms that are being directly "detected". This is an example of scientists using "indirect evidence" to study something that they can't see for themselves!
Optional Follow Up	Point out the array of wires (two sets, perpendicular to one another… though some designs in consideration have as many as 4 anode plane arrays) evident in the picture of the inside of a DUNE detector model (available on the USB, or laminated pictures found in the kit). Challenge students to determine why scientists desire such a configuration, and what extra information this arrangement allows scientists to glean from their data. There is also a short video demonstrating the fabrication process of the anode plane array (1 min 30 sec): https://www.youtube.com/watch?v=Mo8NNzoIcgA&feature=em-uploademail
Assessment	See *Lesson Three Task Card* and rubric.
Connection to Next Lesson	Now that students understand how the DUNE detectors function by accelerating and sensing the free electrons caused by a neutrino-argon nucleus interaction, they should be starting to question why argon is used as the detector medium (lesson four).

Lesson 4	Why Argon?
Overview Standard(s) & Objectives	**Overview** At the end of *Lesson Three*, students were probably beginning to ask why the Deep Underground Neutrino Experiment (DUNE) detectors will be filled with 68,000 tons of liquid argon. What is special about liquid argon? What are the properties of liquid argon that make it well suited for neutrino detection? Is liquid argon really the best choice for very large neutrino detectors? In this lesson, students will investigate the answers to these questions as they delve into how electromagnetic forces determine the chemical properties of elements, as well as the periodic trends evident on the periodic table of the elements. **Standards** HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. Science and Engineering Practices (SEP): ● Obtaining, Evaluating, and Communicating Information: Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). Crosscutting Concepts (CCC): ● Structure and Function: Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. **Objectives** ● Explain the periodic trends in atomic radius using qualitative and/or quantitative analysis of the electromagnetic force between electrons and atomic nucleus and using electron configuration and energy level concepts. ● Explain the periodic trends in ionization energy using qualitative and/or quantitative analysis of the electromagnetic force between valence electrons and atomic nucleus and using electron configuration and energy level concepts. ● Explain the periodic trends in electron affinity using qualitative and/or quantitative analysis of the electromagnetic force between valence

	electrons and atomic nucleus and using electron configuration and energy level concepts. ● Identify and explain the physical and chemical properties of the noble gases (utilizing electron configuration and energy level concepts), as well as abundance, price, and typical sources of each. ● Communicate, both orally and graphically, why scientists chose argon for the Deep Underground Neutrino Experiment (DUNE) detectors.
Background Information (for teachers)	**Electron Configuration-** a representation of the arrangement of electrons distributed among the orbital shells and subshells of an atom. Many of the physical and chemical properties of elements can be correlated to their unique electron configurations. The valence electrons, electrons in the outermost shell, are the determining factor for the unique chemistry of each element. Electron orbitals are defined as the volume of space in which an electron can be found within 95% probability. The four different types of orbitals (s,p,d, and f) have different shapes, and one orbital can hold a maximum of two electrons. The p, d, and f orbitals have different sublevels, thus can hold more electrons. The electron configuration of each element is unique to Its position on the periodic table. The energy level is determined by the period, with greater energy levels generally being found farther away from the nucleus, and the total number of electrons is given by the atomic number of the element. Orbitals on different energy levels are like each other, but they occupy different areas in space. The 1s orbital and 2s orbital both have the characteristics of an s orbital (spherical shape, can only hold two electrons, etc.) but, as they are found in different energy levels, they occupy different spaces around the nucleus. **Atomic Radius-** a measure of the size of an atom, usually the mean or typical distance from the center of the nucleus to the boundary of the surrounding cloud of electrons. Electrons do not have definite orbits, or sharply defined ranges. Rather, their positions must be described as probability distributions that taper off gradually as one moves away from the nucleus, without a sharp cutoff. Moreover, the electron clouds of the atoms usually overlap to some extent, and some of the electrons may roam over a large region encompassing two or more atoms. Under most definitions, the radii of isolated neutral atoms range between 30 and 300 pm (trillionths of a meter). Therefore, the radius of an atom is more than 10,000 times the radius of Its nucleus (1–10 fm), and less than 1/1000 of the wavelength of visible light (400–700 nm). For many purposes, atoms can be modeled as spheres. This is only a crude approximation, but it can provide quantitative explanations and predictions for many phenomena, such as the density of liquids and solids, the diffusion of fluids through molecular sieves, the arrangement of atoms and ions in crystals, and the size and shape of molecules. **Ionization Energy-** the amount of energy required to remove the most loosely bound electron, a valence electron, of an isolated gaseous atom to form a

(positively charged) cation. Generally, the closer the electrons are to the nucleus of the atom, the higher the atom's ionization energy.

As nuclear charge increases, the electrons are held more strongly by the nucleus (greater electromagnetic force of attraction) and so the ionization energy also increases. The number of electron shells also affects ionization energy. The greater the size of the atom (atomic radius) due to increasing electron energy levels, the less tightly the electrons are held by the nucleus, and thus ionization energy is decreased.

Additionally, the greater the number of energy levels in an atom, the greater the "shielding effect" of the electrons generally found between the nucleus and valence electrons. This shielding effect lessens the electromagnetic force of attraction between the nucleus and valence electrons, further decreasing their ionization energy.

Electron Affinity- the amount of energy released when an electron is added to a neutral atom or molecule in the gaseous state to form a negative ion (anion). To use electron affinities properly, it is essential to keep track of sign. For any reaction that releases energy, the change $\triangle E$ in total energy has a negative value and the reaction is considered an exothermic process.

Electron capture for almost all non-noble gas atoms involves the release of energy, and thus are exothermic. Electron affinity generally increases across a period (row) in the periodic table prior to reaching group 18. This is caused by the filling of the valence shell of the atom; a group 17 atom releases more energy than a group 1 atom on gaining an electron because it obtains a filled valence shell (containing 8 electrons) and therefore is more stable. In group 18, the valence shell is already full, meaning that added electrons are unstable, tending to be ejected very quickly.

Additionally, electron affinity generally decreases down a group of elements because each atom is larger than the atom above it. This means that an added electron is further away from the atom's nucleus compared with Its position in the smaller atom. With a larger distance between the negatively charged electron and the positively charged nucleus, the electromagnetic force of attraction is relatively weaker.

Therefore, electron affinity decreases. Moving from left to right across a period, atoms become smaller as the forces of attraction become stronger. This causes the electron to move closer to the nucleus, thus increasing the electron affinity from left to right across a period.

Noble Gases- (column 18 on the periodic table) a group or family of chemical elements with similar properties. Under standard conditions, they are all odorless, colorless, mono-atomic gases with very low chemical reactivity. The six noble gases that occur naturally are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and radon (Rn).

Noble gases are typically unreactive, except when under extreme conditions, and the inertness of noble gases makes them suitable in applications where

	reactions are not wanted. For example, argon is used in light bulbs to prevent the hot tungsten filament from oxidizing. Also, helium is used in breathing gas by deep-sea divers to prevent oxygen, nitrogen, and carbon dioxide toxicity. The properties of the noble gases can be explained by modern theories of atomic structure: the outer shell of valence electrons is considered to be "full", giving them little tendency to participate in chemical reactions. Neon, argon, krypton, and xenon are obtained from air through liquefaction and fractional distillation. Helium is sourced from natural gas fields, which have high concentrations of helium, and radon is usually isolated from the radioactive decay of radium, thorium, or uranium compounds.
Materials	For each student: ➢ Science notebook For each group of 4 students: ● *Lesson Four Information Sheet* ● Periodic Table ● Set of *Lesson Four- Initial Research Task Cards* (A-D) ● *Lesson Four- Final Analysis Task Card* For the classroom: ➢ Computer and projector with speakers (if students chose to utilize)
Prior Knowledge (for students)	Students should be familiar with the idea that charged particles and/or objects produce electric fields, and the interaction of electromagnetic fields generates electromagnetic forces. The direction of the electromagnetic force is dependent upon the sign of the interacting charges: Opposite charges attracting, and like charges repelling away from one another (*Lesson Three*). Additionally, students should be familiar with the idea that electromagnetic forces are directly proportional to the product of the magnitude of the charges, and inversely proportional to the distance of separation between the charges (*Lesson Two*). Any familiarity with the periodic table would be helpful, but not necessary for this lesson.
Launch (5-10 minutes)	
Engagement and Communication of Student Expectations	**Introduce lesson** Form groups of 4 students, each. These will be the "home" groups for Lesson Four. It is acceptable to have a few groups of 5, if necessary. Pass out the *Lesson Four Information Sheets* and periodic tables to students (one to each group), as well as project the atomic radii chart on the board. Allow students a few minutes to look at the charts, wonder, and discuss. Ask students if they notice any interesting patterns in the charts on the *Lesson Four Information Sheet* (this will serve as the lesson phenomenon). Ask students what questions they would like to investigate/answer (note these on the board and/or in science notebooks).

	In looking at the atomic radii chart, ask students what ideas they have for explaining why the atomic radius decreases progressing left to right along the periodic table. Note student ideas on the board, and/or in science notebooks. Explain to students that at the end of Lesson Three, many were wondering why the Deep Underground Neutrino Experiment (DUNE) is planning to fill the detectors with 68,000 tons of liquid argon. During this lesson, you will work together to determine the properties of argon that led scientists to choose it for the DUNE detectors.
Explore (40-80 minutes)	
Procedure	***Initial Research*** Provide each group of students with a set of *Lesson Four- Initial Research Task Cards* A-D (A = atomic radius, B = ionization energy, C = electron affinity, D = noble gases). There should be one task card for each student, so each group member will have a slightly different task. Provide time for students to investigate, research, and reflect on their assigned task. One full class period is recommended. Groups should utilize the Lesson Two, Three and Four data and information sheets, as well as their new understanding of the electromagnetic force from the previous two lessons, as they work to comprehend their particular periodic table phenomenon. Students map also utilize the internet, a library, and/or a variety of chemistry texts. ***Expert Group Analysis*** Once students have had adequate time to (individually) investigate their periodic table phenomenon, form four new "expert" groups. Each student in an expert group will have had the same topic and task card for their initial research. One at a time, each student in the expert group should share what they discovered (~3 minutes per student). When not presenting, the other students should take careful notes in their science notebooks. Once each student has shared, expert groups will collaborate to generate a clear, concise synopsis of their combined efforts. When students return to their original "home" group, they will be required to share their expert synopsis so the group can *put it all together* in determining why Argon was chosen for the Deep Underground Neutrino Experiment (DUNE) detectors.
Questions	**Driving Question** ● Why was argon chosen for the Deep Underground Neutrino Experiment (DUNE) detectors? ● **Probing Questions** ● Why is a noble gas desirable for the DUNE detectors? ● Why was argon chosen out of all the noble gases? ● How does the molecular structure of argon (and/or all the noble gases) convey the properties desired for the DUNE detectors? ● If the only consideration for the DUNE detectors was the "best" noble gas, which noble gas would scientists have chosen?
Summarize (40-60 minutes)	

Communicate	***Final Analysis*** Reassemble the original "home" groups and provide the *Lesson Four- Final Analysis Task Card*. Each student, in turn, will share the synopsis of his or her expert group (3-5 minutes per student). Students should listen carefully and take notes when not presenting. Once each student expert has presented their findings, the group will work to *put it all together* in an explanation of why argon was chosen for the Deep Underground Neutrino Experiment (DUNE) detectors. Groups may choose any format desired for the final product, but it must address at least three reasons, in detail, at the atomic level.
Terminology and Concepts to Solidify	While scanning left-to-right across a period on the periodic table, the increasing nuclear charge draws the electrons in more strongly (increasing coulombic attraction due to greater **electromagnetic force**) causing reduced **atomic radii**, increasing **ionization energy** (energy required to remove an electron), and (generally) increasing **electron affinity** (energy released upon acquisition of an electron).
Connection to Big Ideas (Phenomena)	Though xenon and krypton have been shown to form a few molecules, the noble gases are generally considered unreactive due to a large ionization energy and (generally) lack of electronegativity and electron affinity. Thus, the noble gases are generally a good medium through which electrons can travel for great distances without being attracted to (i.e., stopped or caught by) nearby atoms. The small atomic diameter of the noble gases contributes to a high density in the liquid phase, and when combined with a dense/high mass nucleus, increases the odds of neutrino-nucleus interactions within the detector. The high abundance of argon, combined with its easy and inexpensive liquefaction from the atmosphere, makes it the noble gas of choice for the Deep Underground Neutrino Experiment.
(Optional) Extension	Hold a class debate concerning whether students believe that argon was the best choice for the DUNE detectors, including why or why not. Remember to insist that all statements be supported with evidence! Consider providing an electronegativity chart of your choice, like this one (hyperlinked), and ask students to explain the observed trends.
Assessment	See *Lesson Four Final Analysis Task Card* and rubric.
Connection to Next Lesson	Now that students have a handle on what a neutrino is (lesson two) and how scientists plan to detect and study them with the DUNE detectors (lessons three and four), they will most likely begin questioning if this huge international mega-science project is worth the time, effort, and cost. Lesson Five, the final lesson of the *It's Electric* unit, provides a glimpse into the strange behavior and characteristics of neutrinos… the reasons why scientists around the globe desire to study neutrinos. Students are then asked to perform one final investigation (of their choice), share their findings with the class, and write an op-ed evaluating whether they believe the DUNE is a worthwhile endeavor.
Lesson 5	**What's So Great About Neutrinos?**
Overview Standard(s) & Objectives	**Overview**

	In this lesson, students will investigate why scientists are so interested in neutrinos. What is so special about neutrinos, anyway? Why go through all this effort? Is it worth it? Students will choose the topic of their final investigation, then share what they have learned with their classmates. The unit concludes with students writing an "op-ed" newspaper article evaluating the Deep Underground Neutrino Experiment (DUNE) based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. **Standards** Disciplinary core ideas (DCI) and crosscutting concepts (CCC) will vary based upon student interest and choice of topic for final investigations. 9-12-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. Science and Engineering Practices (SEP): ● Engaging in Argument from Evidence: Construct, use, and/or present an oral and written argument or counterarguments based on data and evidence.
Background Information (for teachers)	**More About Neutrinos** In the Standard Model of Particle Physics, neutrinos belong in the lepton family, fermions that make up matter. They are very tiny, have mass, travel near the speed of light and pass right through matter, making them very difficult to detect. They are also quite tricky. As they travel over long distances, they oscillate, changing types, or flavors, along the way. More than 60 years after they were first discovered, we still have much to learn about these ghostlike particles. What is the mass of a neutrino? Why do neutrinos oscillate, or change flavors, as they travel? Is the neutrino its own antiparticle? What is the neutrino's role in the universe? What can neutrinos tell us about supernova and newly formed neutron stars? Several neutrino experiments around the world hope to answer these questions and more, including the Majorana Demonstrator Project and the Deep Underground Neutrino Experiment (DUNE), both located at the Sanford Underground Research Facility. **LBNF/DUNE Projected Cost** Researchers hope to begin building the DUNE detector in 2019 and complete it by 2024. But it is only one piece of the project. The rest—the particle accelerator at Fermilab, the infrastructure in South Dakota, and the cryostats that will hold 70,000 metric tons of liquid argon—are nominally parts of DUNE's partner, the Long-Baseline Neutrino Facility (LBNF). LBNF/DUNE would be funded mainly by the U.S. Department of Energy, which envisions spending a total of $1.5 billion. That contribution would cover 75% of the cost of the LBNF and 25% of the cost of DUNE. DUNE itself will cost roughly $480 million. $88 million of which was recently pledged by the United Kingdom.

	You can read the economic impact report and environmental assessment for LBNF/DUNE at: DUNE at LBNF (fnal.gov)
Materials	For each student: ➢ Science notebook ➢ Internet access for research ● *"Neutrinos Are…"* information sheet ● *"LBNF/DUNE"* information sheet (on back of *Neutrinos Are…*) ● *Lesson Five Task Card* and rubric For the classroom: ➢ Computer and projector with speakers
Prior Knowledge (for students)	Students should already be familiar with the idea that neutrinos are tiny, nearly massless, and pass easily through matter (from *Lesson Two*). They should also be familiar with the fact that neutrinos do occasionally interact with matter, and that scientists detect and study these interactions using electromagnetic forces (from *Lesson Three* and *Lesson Four*).
Launch (5-10 minutes)	
Engagement and Communication of Student Expectations	**Each student will need the [1]*Neutrinos Are…* and [2]*LBNF/DUNE: An international mega-science project in the US* information sheets.** Play the video *Why I Love Neutrinos* located on the USB in the *Lesson Four* electronic folder (2 min 32 sec). Allow students time to discuss what they have watched, read over the literature provided, and discuss with their classmates.
Explore (40-90 minutes)	
Procedure	Hand out the *Lesson Five Task Card* and rubric, one to each student. Tell students that Lesson Five, the final lesson of the *It's Electric* unit, is where they get to explore one last question about neutrinos and/or the Deep Underground Neutrino Experiment (DUNE). This is an individual exploration (or student pairs, if you prefer) so that every student has the opportunity to investigate what interests them most. Students will investigate and gather information, and then be required to present their findings to the class during a short 3–5-minute presentation. Once each student has shared their findings, they will be asked to consider what they have learned during this unit and use it as evidence in a final written assessment. This written assessment will be an "op-ed" newspaper article evaluating the Deep Underground Neutrino Experiment (DUNE) based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. In essence, is the international effort worthwhile? Support students, as needed, as they select topics to investigate and proceed with research and presentation preparation. There should be plenty of unanswered questions left from *Lesson One*, encourage students to look back at the original list of questions/wonderments as they consider what to investigate.

	Sample investigation topics: ● How/why do neutrinos oscillate between three types? ● How could neutrinos explain the matter/anti-matter imbalance? ● How are neutrinos produced? ● What is the weak force, and how do neutrinos interact via the weak force? ● How could black holes emit neutrinos? ● How might the DUNE effect people living in Lead, SD? ● How many countries and scientists are involved in the DUNE? Why so many, and what are they all doing/contributing? ● How is a large detector (like those for DUNE) designed and built?
Questions	**Driving Question** ● Is the Deep Underground Neutrino Experiment (DUNE) a worthwhile effort? **Probing Questions** ● What criteria should be used in evaluating the DUNE? ● What criteria matter to you most, when evaluating the DUNE? ● Why are scientists so interested in neutrinos? ● What lingering questions do you have about neutrinos and/or the Deep Underground Neutrino Experiment (DUNE)? ● What could a better understanding of neutrinos tell us about our Universe?
Summarize (50-90 minutes)	
Communicate	Arrange presentation time for each student (or pair): 3-5 minutes. The rest of the class should be encouraged to take notes in their science notebooks, ask questions, and develop new questions. Show the *Phenomenon Introduction Video* once again (2 min 38 sec). The video file is on the USB in both the *Lesson One* and *Lesson Five* folders. Ask students to consider everything that they have learned during this unit as they approach the final written assessment, an "op-ed" newspaper article evaluating the Deep Underground Neutrino Experiment. Students should use what they have learned as *evidence* that supports their written arguments. You might assign the "op-ed" as homework or provide class time. However, it is suggested that students be given sufficient time for peer-review and revision before final submission.
Terminology and Concepts to Solidify	Science is a cooperative and collaborative endeavor. Some scientific topics are difficult to study, and yet very important to our basic understanding of the Universe we live in. Therefore, international teams of scientists often work together. Additionally, international collaborations between countries can be required to house and fund these scientific investigations.
Connection to Big Ideas (Phenomena)	The goal of *Lesson Five* is to leave students with a desire to learn even more. Equipped with a basic comprehension of the Deep Underground Neutrino Experiment, students are (hopefully) tantalized by the strange behavior and properties of neutrinos (such as oscillation), and left with a new appreciation for and interest in science and engineering.

Optional Follow Up	Allow students to explore further (on their own) any lingering questions/wonderments. Consider holding a classroom debate concerning whether U.S. taxpayer dollars should be spent on the Deep Underground Neutrino Experiment.
Assessment	See *Lesson Five- Task Card* and rubric.

Print Masters

Level 3	Level 4
Progressing	Excelling
Model ...porates data ...alculations ...are **relevant** ...redicting the ...teractions **-AND-** ...planation utilizing ...thematical, ...putational, ...r algorithmic ...esentations **...inimally** ...dresses the task.	Model incorporates needed data or calculations that are **relevant** to predicting the interactions **-AND-** Explanation utilizing mathematical, computational, and/or algorithmic representations **coherently** addresses the task.
...dent is doing ...ractice, and is ...ring to justify ...analysis using ...the DCI.	Student is doing the practice, and is justifying the analysis using the DCI.
...' + Some DCI	DCI + SEP

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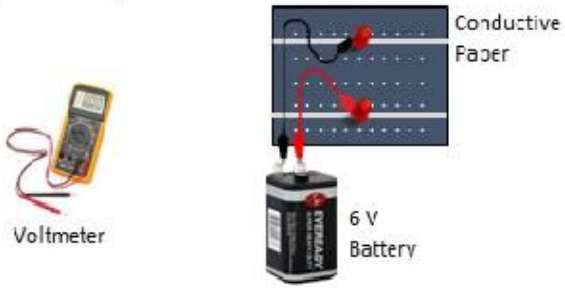
It's Electric!
Task Card

Lesson #3- *How to Catch a Ghost*

Driving Question
How does the DUNE detector design enable neutrino detection?

Investigation Set-Up



Your Task *(Use the Lesson Three Information Sheet for help!)*

1. *Given $\vec{E} = \frac{\Delta V}{\Delta r}$, and using a copy of the grid to map your findings, explore the electric field between the parallel, conductive plates (silver lines) with the voltmeter probes.*
2. *Pathways along which $\Delta V = 0$ are called "equipotential lines".*
3. *Determine the strength and direction of the electric field between the parallel, conductive plates. (Label on your map)*
4. *On a separate sheet of paper, develop a model (drawing, diagram, etc.) of the electric field within the actual DUNE detectors, and utilize it to qualitatively and/or quantitatively describe what happens to free electrons in the detector (including force(s), acceleration, and energy changes).*
5. *Summarize how the DUNE detectors were specifically designed to enable scientists to determine when (and where in the detector) rare neutrino-argon nucleus interactions occur.*

Dimensions

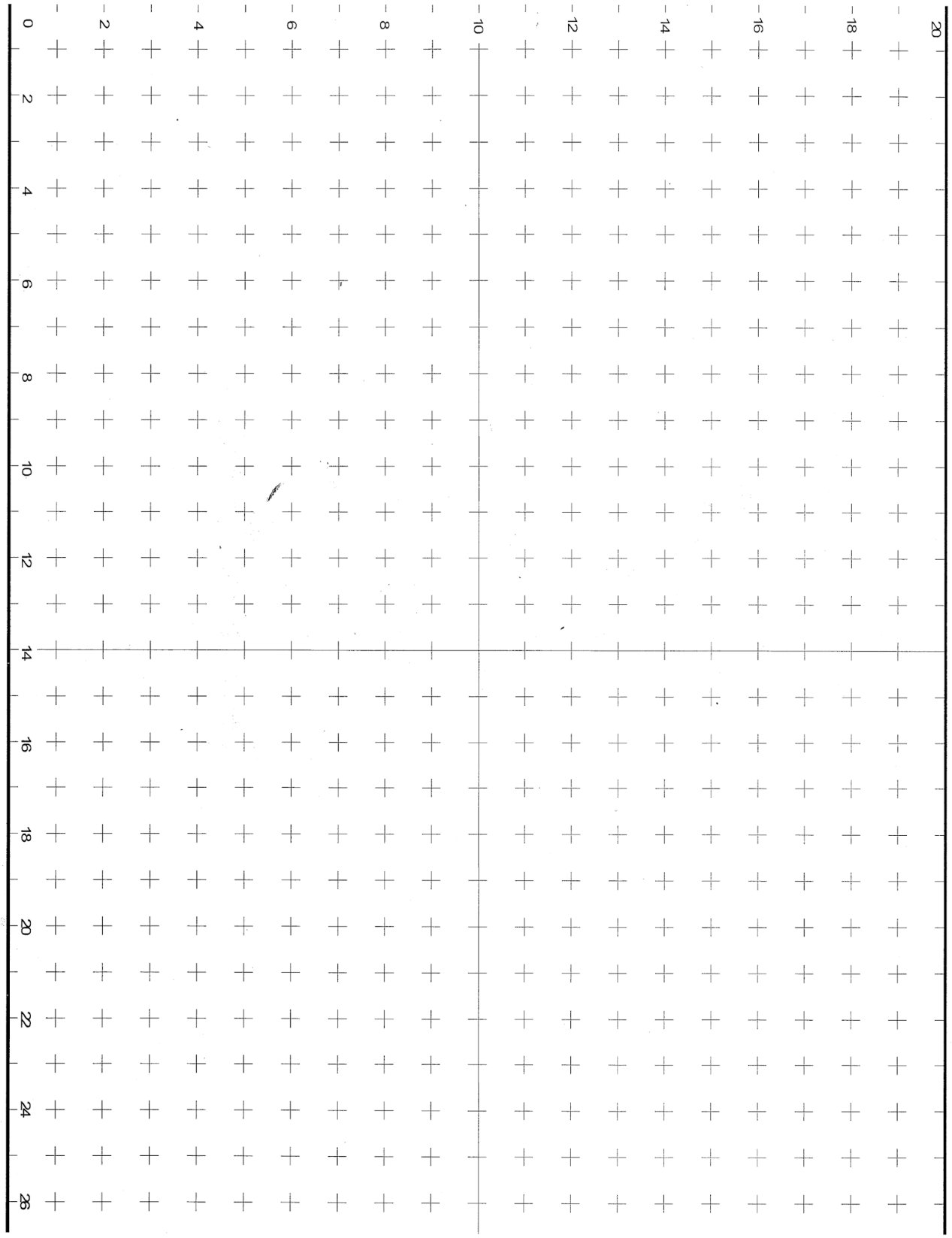
Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. DCI

Develop and use a model based on evidence to illustrate the relationships between components of a system. SEP

Systems can be designed to cause a desired effect. CCC

Level 1	Level 2	Level 3	Level 4
Emerging	Developing	Progressing	Excelling
Model illustrates forces and energy changes that are **not** relevant to the interactions **-AND-** Explanation of how detector design enables neutrino detection is **missing** or **does not address** the task.	Model illustrates forces and energy changes that are **relevant** to the interactions **-HOWEVER-** Explanation of how detector design enables neutrino detection is **missing** or **does not address** the task.	Model illustrates forces and energy changes that are **relevant** to the interactions **-AND-** Explanation of how detector design enables neutrino detection **minimally** addresses the task.	Model illustrates forces and energy changes that are **necessary** and **relevant** to the interactions **-AND-** Explanation of how detector design enables neutrino detection **coherently** addresses the task.
Student is responding to the task, but is not addressing the CCC or DCI.	Student is beginning to address the DCI, but is not connecting analysis to the CCC.	Student is addressing the DCI, and is beginning to connect the analysis to the CCC.	Student is addressing the DCI, and is connecting the analysis to the CCC.
Neither	Some DCI	DCI + Some CCC	DCI + CCC

Feedback:


0
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26

Lesson Three Information Sheet

Electric Fields $\vec{E}$

- Vector
- Positive to negative (High potential to low potential)
- Perpendicular to equipotential lines
- Determine strength along field lines
- $\vec{E} = \frac{\Delta V}{\Delta r}$ Electric field strength = voltage difference / displacement (volts) (meters)

Electric Force

- Vector
- Direction depends on charge (opposites attract, likes repel)
- Parallel to electric field
- $\vec{F} = q\vec{E} = q(\frac{\Delta V}{\Delta r})$ = ma q = magnitude of charge in Coulomb's (C)

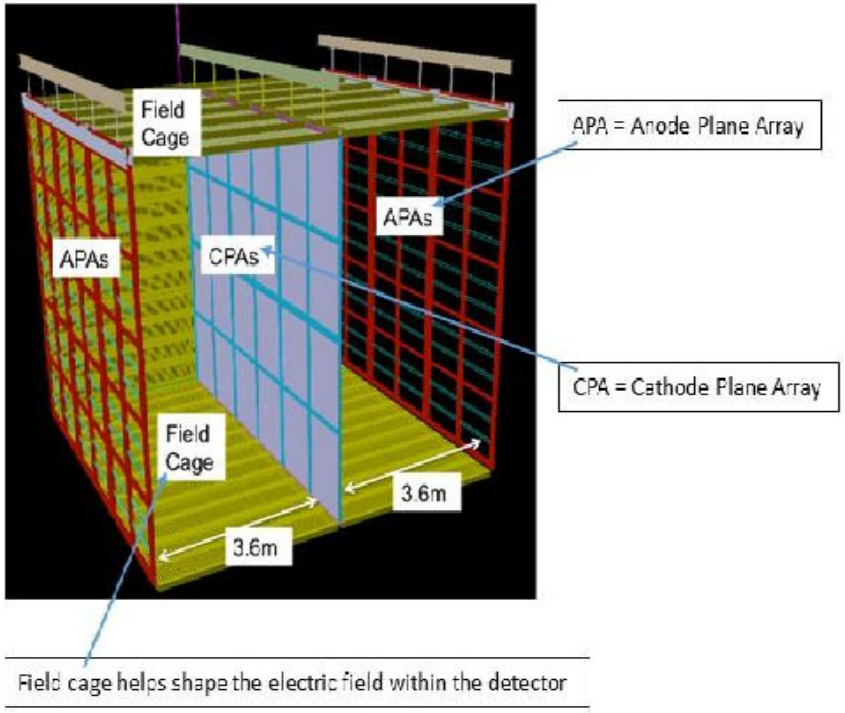
Work-Energy Theorem

- Work done equals change in energy
- ON object/system positive
- BY object/system negative
- $W = F\Delta d = \Delta E$ Work = force time displacement = energy change (Newtons) (meters) (Joules)

Voltage ≅ Potential Difference (used interchangeably)

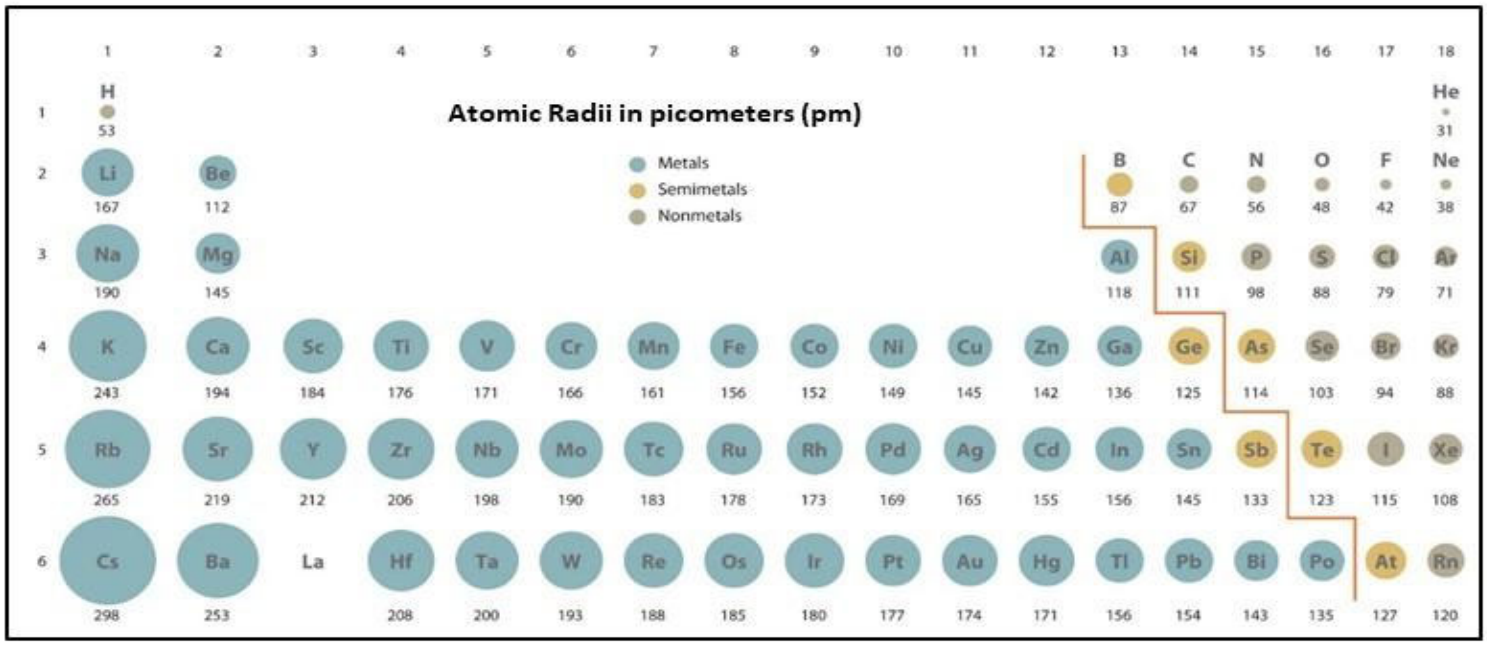
Deep Underground Neutrino Experiment

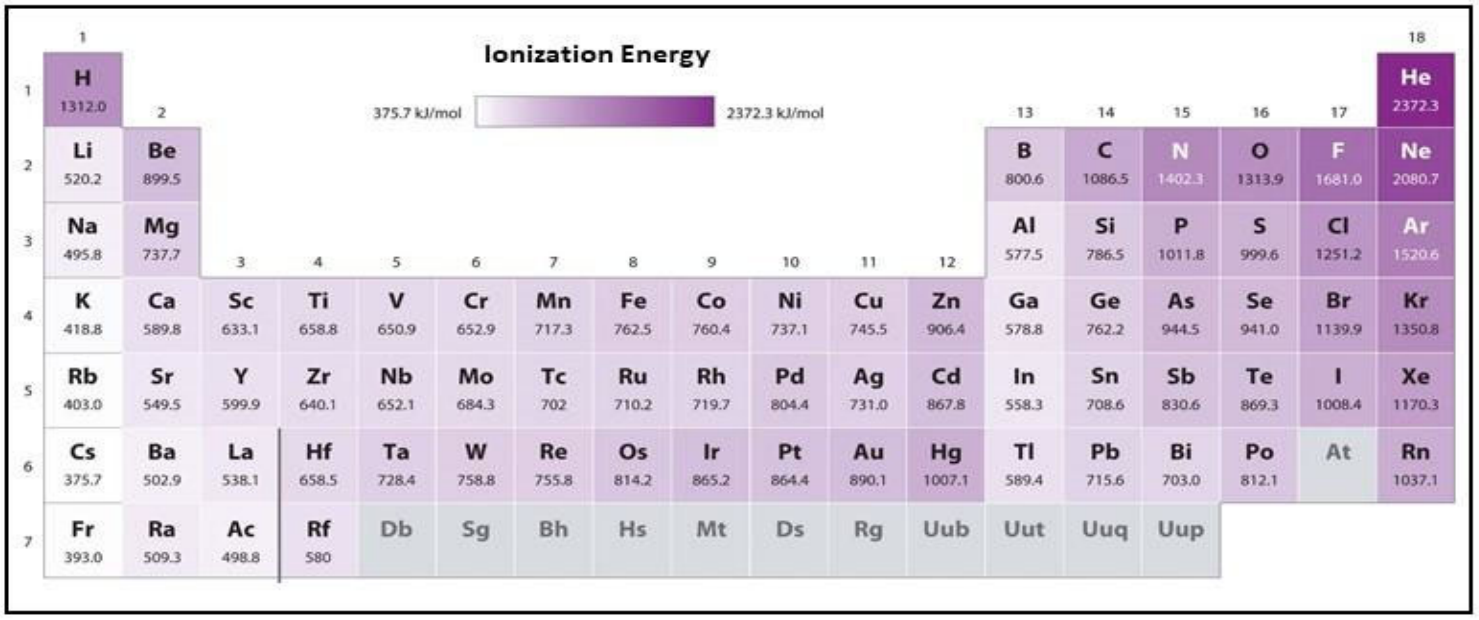
- -180 kV cathode (negatively charged plane)
- 3.6 m from anode (uncharged plane)

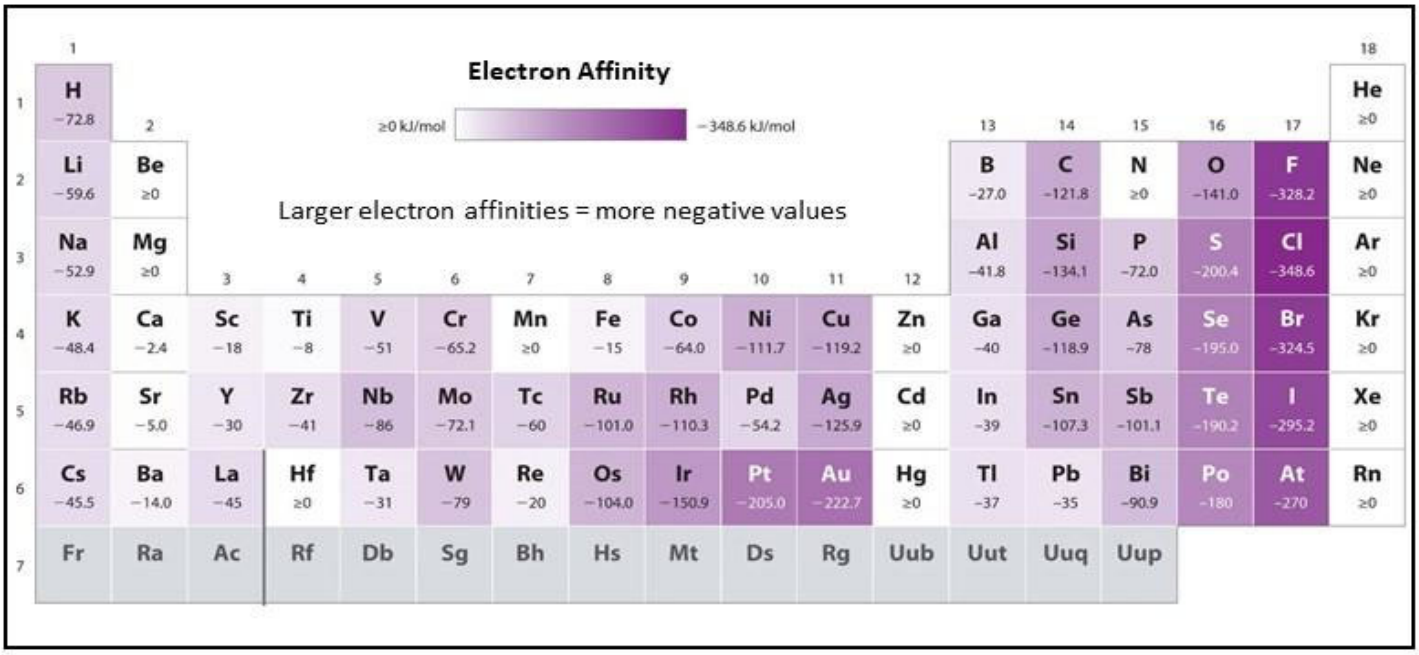


Field cage helps shape the electric field within the detector

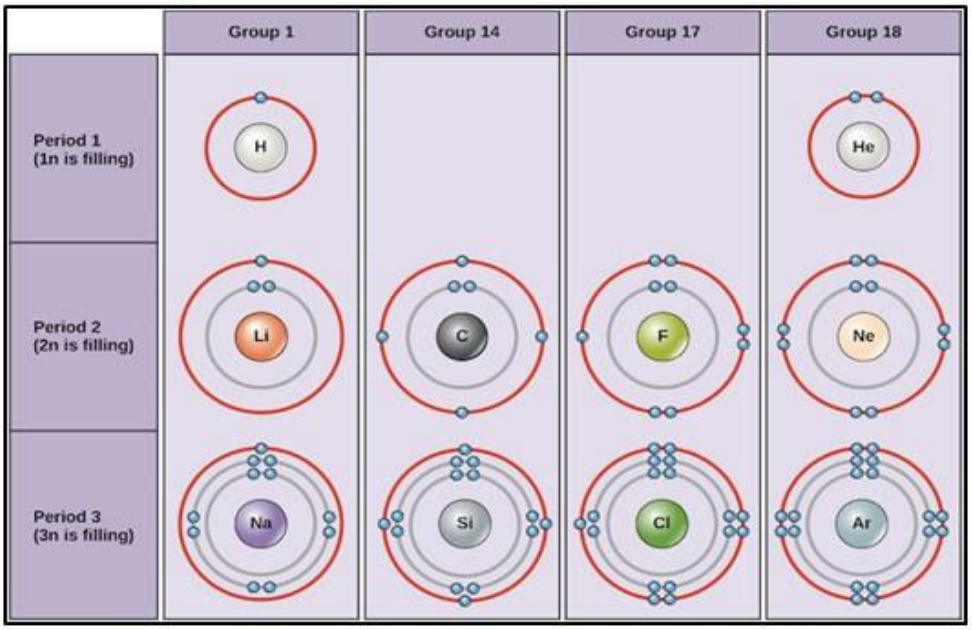
Lesson Four Information Sheet





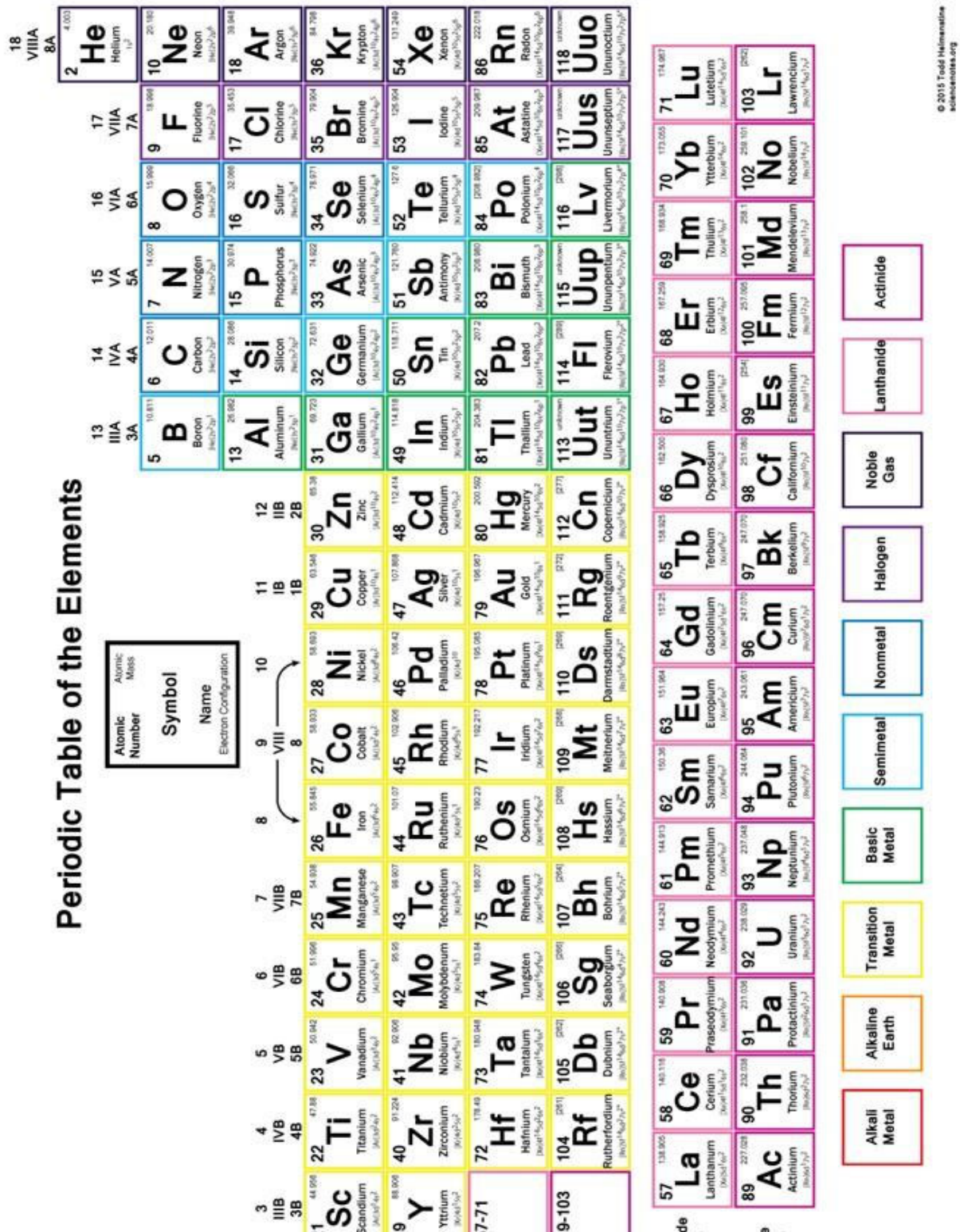


Electron Configuration



Nuclear Radius ≈ $(1.25\ \text{fm})(A^{1/3})$

fm = femtometers ($x10^{-15}$ m)
A = Relative Atomic Mass


Periodic Table of the Elements
Atomic Number
Symbol
Name
Electron Configuration
Atomic Mass
Alkali Metal
Alkaline Earth
Transition Metal
Basic Metal
Semimetal
Nonmetal
Halogen
Noble Gas
Lanthanide
Actinide
Lanthanide Series
Actinide Series
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Task Card

Lesson #4- *Initial Research Task Card* **C**

Driving Question

Why did scientists choose argon for the Deep Underground Neutrino Experiment (DUNE) detectors?

Your Challenge

How can the periodic trends in ***electron affinity*** *(→ and ↓) be explained using qualitative and/or quantitative analysis of the electromagnetic force between valence electrons and atomic nucleus, and using electron configuration and energy level concepts.*

Use the Lesson Two, Three and Four data and information sheets, as well as what you have learned from the previous two lessons. You may also use the internet, a library, and/or a variety of chemistry text books.

- *What is electron affinity? How will you explain it to your team?*
- *How is the electromagnetic force involved in electron affinity?*
- *How does the electromagnetic force, between valence electrons and nucleus, change → and ↓ the periodic table?*
- *What is unusual about the electron affinity of the noble gases, like argon? What is the cause?*
- *How might the* ***electron affinity*** *of argon be important for the Deep Underground Neutrino Experiment (DUNE) detectors?*

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Task Card

Lesson #4- *Initial Research Task Card* **D**

Driving Question

Why did scientists choose argon for the Deep Underground Neutrino Experiment (DUNE) detectors?

Your Challenge

Identify and explain the physical and chemical properties of the ***noble gases*** *(utilizing electron configuration and energy level concepts), as well as abundance, price, and typical sources/uses of each.*

Use the Lesson Two, Three and Four data and information sheets, as well as what you have learned from the previous two lessons. You may also use the internet, a library, and/or a variety of chemistry text books.

- *What are the noble gases, and why are they called "noble"?*
- *What is unique about the electron configurations of the noble gases? How are the electron configurations of each noble gas alike? How do they differ?*
- *What are the typical sources of each noble gas, how are they collected and what are they used for?*
- *How abundant are the various noble gases? Which are most affordable?*
- *Why was a* ***noble gas*** *chosen for the Deep Underground Neutrino Experiment (DUNE) detectors? Why argon?*

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Task Card

Lesson #4- *Final Analysis Task Card*

Driving Question

Why did scientists choose argon for the Deep Underground Neutrino Experiment (DUNE) detectors?

Put It Together!

Collaborate with the other student experts in your home group to prepare a final product that explains at least four reasons why argon was chosen for the Deep Underground Neutrino Experiment. At least three of the reasons must be at the atomic level.

Final Product

Scientists use communication skills on a daily basis. Sometimes it is for collaboration with other scientists working on the same (or similar) problems, sometimes it is for brainstorming new ideas, and sometimes it is to explain research results in a journal article, poster or conference talk. In order for scientists to communicate clearly, they rely on a variety of presentation formats. As a general rule, a minimum of two presentation formats is advisable. Scientists communicate orally, graphically/visually, textually, and mathematically.

Suggestions for your final product:

- *Creative, eye-catching visual aids (static or moving)*
- *Clear, concise explanations... in your own words*
- *Two or more communication formats*
- *Your names and class period*
- *At least 3 explanations at the atomic level (4 total)*

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Task Card

Lesson #4- *Final Analysis Task Card*

Level 1	Level 2	Level 3	Level 4
Emerging	**Developing**	**Progressing**	**Excelling**
Final product communicates scientific and technical information that is **not** relevant to explaining why the molecular-level structure of argon is important in the functioning of DUNE **-AND-** Communication of scientific and/or technical information/ideas in multiple formats is **missing** or **does not address** the task.	Final product communicates scientific and technical information that is **relevant** to explaining why the molecular-level structure of argon is important in the functioning of DUNE **-HOWEVER-** Communication of scientific and/or technical information/ideas in multiple formats is **missing** or **does not address** the task.	Final product communicates scientific and technical information that is **relevant** to explaining why the molecular-level structure of argon is important in the functioning of DUNE **-AND-** Communication of scientific and/or technical information/ideas in multiple formats **minimally** addresses the task.	Final product communicates scientific and technical information that is **relevant** to explaining why the molecular-level structure of argon is important in the functioning of DUNE **-AND-** Communication of scientific and/or technical information/ideas in multiple formats **coherently** addresses the task.
Students are responding to the task, but not doing the practice or DCI.	Students are beginning to do the practice, but not justifying analysis using the DCI.	Students are doing the practice, and beginning to justify the analysis using the DCI.	Students are doing the practice, and justifying the analysis using the DCI.
Neither	Some SEP	SEP + Some DCI	DCI + SEP

Feedback:

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Task Card

Lesson #5- *What's So Great About Neutrinos?*

Driving Question

Is the DUNE a worthwhile endeavor?

Your Task (3 part)

Part 1- Brainstorming/Planning

Develop a list of prioritized criteria and trade-offs that will be used for evaluating whether the DUNE is a worthwhile endeavor. Be sure to account for a range of constraints [including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts].

Part 2- Final Investigation and Presentations:

Investigate a final topic concerning neutrinos and/or DUNE that will help you answer the driving question. Prepare and deliver a 3-5 minute presentation. Pay close attention to the presentations of your classmates; take notes, ask questions, record new wonderments.

Part 3- Final Written Assessment:

Write an "op-ed" addressing the driving question (above). Be sure to support your arguments with evidence and logical reasoning (using your list of prioritized criteria).

Dimensions

Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. ETS

Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. SEP

Level 1	Level 2	Level 3	Level 4
Emerging	Developing	Progressing	Excelling
Argument incorporates data and evidence that are **not** relevant **-AND-** Evaluation based on prioritized criteria and trade-offs that account for a range of constraints is **missing** or **does not address** the task.	Argument incorporates data and evidence that are **relevant** **-However-** Evaluation based on prioritized criteria and trade-offs that account for a range of constraints is **missing** or **does not address** the task.	Argument incorporates data and evidence that are **relevant** **-AND-** Evaluation based on prioritized criteria and trade-offs that account for a range of constraints **minimally** addresses the task.	Argument incorporates needed data and evidence that are **relevant** **-AND-** Evaluation based on prioritized criteria and trade-offs that account for a range of constraints **coherently** addresses the task.
Student is responding to the task, but is not doing the practice or ETS.	Student is beginning to do the practice, but is not justifying analysis using the ETS.	Student is doing the practice, and is beginning to justify the analysis using the ETS.	Student is doing the practice, and is justifying the analysis using the ETS.
Neither	Some SEP Only	SEP + Some ETS	SEP + ETS

Feedback:

It's Electric Refurbishment Inventory

Lesson	*Quantity*	*Item*
All	1	Facilitator Binder w/ USB
	1	Shipping Tote
Lesson 1	10	Paper w/ DUNE detector pictures
	10	Long-Baseline Neutrino Facility Brochure
Lesson 2	10	Data Chart
	10	Lesson 2 Task Card
Lesson 3	10	6 V Lantern Battery
	10	Voltmeter with Lead
	10	Cork board
	10	Conductive paper w/ Plates drawn
	1 box	Metal push pins
	20	Wires w/ alligator clips
	10	Lesson 3 Task
	10	Lesson 3 Information Sheet
Lesson 4	10	Lesson 4 Information Sheet
	10	Periodic Table
	8 sets of 4	Initial Research Task Cards
	8	Lesson 4 Final Analysis Task Card
Lesson 5	30	Neutrinos Are…, LNBF/DUNE info sheet
	30	Lesson 5 Task Card and Rubric
***		6 Volt batteries should register at least 5 volts
***		Conductive paper should have lines that are not fully broken by holes

NOTICE: THE HEADER/FOOTER AND REVISION HISTORY OF THIS ATTACHMENT IS NOT INCLUDED IN THE PRINTED DELIVERABLE.ANY BLANK PAGES ARE LEFT SO INTENTIONALLY.

Revision History

Rev	Date	Section	Paragraph	Summary of Change	Authorized by
01	2/27/2024	NA	NA	Initial Release	CCR 911