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| **Title** | | **Exotic Metals** |
| **Introduction** | | Thermoelectric Energy Generators could be one of the most promising forms of energy harvesting we’ve been able to perfect this century. The idea of thermoelectric energy generating is not a new concept. The voyager unmanned spacecrafts (Voyager 1 and Voyager 2) use a form of it, using radioisotopes as the heat source. This will allow them to continue their voyage through space until about 2020. Since its launch in 1977 Voyager 1 is currently the farthest known manmade object from the Earth. One current use of TEG’s (Thermoelectric Energy Generators) is for wearable devices. The goal is for these devices to be self-powered and energy saving with a long lifespan. The wearable will use heat energy from the body and the colder environment around the user as a means to generate electricity.  In this lesson students will learn the best materials to be used for TEG’s. Through data analysis of various element’s properties (specifically electrical conductivity and thermal conductivity) students will deduce that TEG’s need a metalloid or some alloy of these for the generators to work most efficiently. |
| **Real Science Application** | | TEG’s produce an electric current using the Seebeck Effect. The Seebeck Effect explains that when there is a temperature difference between two sides of a material a small electric current is produced. The larger the difference in temperature the greater the production of electricity. Since the material itself will carry an electric charge it also needs to conduct electricity. Many elements on the periodic table are either both good conductors of heat and electricity or poor conductors.  There are some sections on the periodic table that are overlooked. Often these elements are among the most rare and most useful. These elements are very important and very unique. One such element is Silicon. Where would we be in today’s technologically driven world if Silicon was not available for use in computer chips?  In this lab students will attempt to find the most suitable elements on the periodic table to fit the criteria necessary to make a thermoelectric power generator. The materials must be a good conductor of electricity but a poor conductor of heat energy in order to maximize the Seebeck Effect.  Students should be able to identify the groups and periods on the periodic table. It will be helpful if students know where the metals, metalloids, and nonmetals are located on the periodic table. |
| **Curriculum Alignment** | North Carolina Essential Standards   |  |  |  |  |  | | --- | --- | --- | --- | --- | | Content Area | Grade Level | NC ES | Objective 1 | Objective 2 | | Chemistry | High School | Chm.1.3 - Infer the physical properties (atomic radius, metallic and nonmetallic characteristics) of an element based on its position on the Periodic Table. | Classify elements as metals, nonmetals, or metalloids based on their location on the periodic table. | Predict properties of elements based on their location on the periodic table. |   Next Generation Science Standards   |  |  | | --- | --- | | Content Standard | Objective | | Physical Sciences – Chemistry | HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. | | |
| **Learning Outcomes** | * Students will be able to identify the properties of metals, nonmetals, and metalloids. * Students will know which elements conduct heat * Students will know which elements conduct electricity * Students will understand the importance of electrical conductivity and heat conductivity to TEG’s * Students will be able to follow activity instructions from the teacher * Students will conclude with 90% accuracy which types of elements would be ideal for use in TEG’s * Students will know that metalloids have properties of both metals and nonmetals. | |
| **Time Required and Location** | *Total Time: 45 minute class period*   * Warm-up: Reading an article or watching a video on the voyager spacecrafts and brainstorm how they are able to continue moving through space. *10 min*. * Discuss TEG’s and their uses here. Relate to wearable devices being developed now. Pursue conversation on the best types of material to lead into lab. *5 min* * Analyzing graphs and reading data exercise to decide on the best elements to use. This can be done using computers or using physical printouts of the graphs. *15-20 min* * Follow up discussion *10 min* | |
| **Materials Needed** | | **Teacher List**   * 8 laminated Electrical Conductivity Periodic Tables <http://periodictable.com/Properties/A/ElectricalConductivity.html> * 8 laminated Thermal Conductivity Periodic Tables <http://periodictable.com/Properties/A/ThermalConductivity.cl.html> * 16 clear periodic tables. (photocopied on transparencies) The above Thermal and Electrical Conductivity Periodic Tables are not labeled with elements so these are needed to overlay on top.   *Instead of the materials listed above you can choose to complete the activity using computers. For a class of 32 a minimum of 16 computers is needed.)*   * Copies of **Exotic Metals Activity Sheet** for all students * Class set of the Voyager Spacecraft Article * <http://www.npr.org/2015/02/21/387266477/exploring-the-solar-system-through-the-eyes-of-robotic-voyagers> * <http://www.space.com/22729-voyager-1-spacecraft-interstellar-space.html> (This link contains the videos that discus the spacecrafts.) * <http://voyager.jpl.nasa.gov/spacecraft/> * Projector * Computer hooked to projector * Speakers   **Student List**   * Paper * Pencil |
| **Safety** | | There are no safety concerns with this lesson. |
| **Student Prior Knowledge** | | * Basic knowledge of the location of the elements on the periodic table is helpful. * Students should know chemical names and symbols along with their general location on the periodic table. * Knowing where metals, nonmetals, and metalloids are on the periodic table isn’t a requirement if you are trying to make this into an inquiry based lesson. |
| **Teacher Preparations** | | 1. Print off in color and then laminate 8 Electrical Conductivity Periodic Tables 2. Print off in color and then laminate 8 Thermal Conductivity Periodic Tables 3. Photocopy 16 periodic tables on the correct type of transparencies to overlay on the Electrical and Thermal Conductivity Periodic Tables   *Another option is to have the students view above graphics on a computer.*   1. Copy enough **Exotic Metals Activity Sheet** for each student in your classes 2. Copy a class set of the Voyager Spacecraft Articles 3. Setup up Computer, Speakers, and Projector to show videos |
| **Activities** | | **Engagement:**  Warm-up  Students enter the classroom and immediately get an article on the Voyager spacecraft missions. (Pick one of these to use or maybe a combination of them. The biggest deal here is to make sure the students understand that the spacecraft have been on a mission for the last 38 years and are predicted to continue for at least another 5)   * <http://www.space.com/22729-voyager-1-spacecraft-interstellar-space.html> * <http://voyager.jpl.nasa.gov/spacecraft/> * <http://www.npr.org/2015/02/21/387266477/exploring-the-solar-system-through-the-eyes-of-robotic-voyagers>   Students will read this in silence for no more than 5-7 minutes. The Teacher will walk around the room to make sure they are reading.  Option 2 is to watch a video about the Voyager Spacecraft <http://www.space.com/22729-voyager-1-spacecraft-interstellar-space.html>  Option 3 is to have the students do this warm-up as a homework assignment before the first day of the lesson.  Open class discussion by asking the class: How is the voyager spacecraft able to stay in space and function for so long? The students may want to discuss other things pertaining to the voyager missions but try to bring the conversation around to this focus, ‘why the spacecraft is able to stay in space and function for so long.  Begin the discussion by having the kids brainstorm options for energy sources that could be used to power the spacecraft. One popular answer may be solar power. A rebuttal to this incorrect answer can be for them to explain how solar power is possible so far from the sun. Possibly have students use their own cell phones as a quick internet search tool. The end objective is to have students conclude that a type of thermoelectric energy generator is used in the spacecraft.  **Exploration:**  After the warm-up discussion the basics of a thermoelectric energy generator will be introduced.  This video is one of the best I’ve seen for helping to lead this discussion. I like stopping the video at the 3:34 mark and emphasize the concept that we are looking for something with a LOW heat conductivity but HIGH electrical conductivity.  <https://www.youtube.com/watch?v=zzGnNkOxdpI>  TEG’s require material that is a good electrical conductor but poor conductor of heat. Ask the questions: “What kinds of elements would be most appropriate for TEG’s” Allow the students to discuss the problem and come up with a hypothesis. Tell them it doesn’t have to be a select number of elements but instead it can be a region on the periodic table. This will hopefully help lead them to a good conclusion in the next part of the lesson.  Pass out to each student the **Exotic Metals Activity Sheet**. Pass out to each group one laminated Electrical Conductivity Periodic Table, one laminated Thermal Conductivity Periodic Table, and two clear Periodic Tables. (These are the black, green and grey attachments.) Tell the students that they must work in a group to answer the questions on the sheet using the charts. (Another option is to go to a computer lab and have the students look at the graphs online. This is very beneficial because the students will not have to overlay a photocopied periodic table on an already dark colored chart. A draw back to using computers is the inability to look can both periodic tables at the same time)  Links to the graphs are provided below:   * Electrical Conductivity Periodic Table: <http://periodictable.com/Properties/A/ElectricalConductivity.html> * Thermal Conductivity Periodic Table: <http://periodictable.com/Properties/A/ThermalConductivity.cl.html>   Walk around the classroom and make sure the students are on the right track. Make sure they understand how to read the charts. The bigger the square on the element, the higher that property is. The green line shows the trend going across a period, the blue shows the trend going down a group. Ask other probing questions as necessary but try not to get in the way of the students exploration of the charts and solution to the problem. Do not lead them to the answer yet. Have each group complete their lab sheet and come to a consensus for the two elements they choose (Questions #14 on the **Exotic Metals Activity Sheet**.  **Explanation:**  Pass out a whiteboard and a dry erase marker to each group (or a large notecards and a marker.) Instruct each group to put their answer to question 14 on this. Have each group hold their answers up one at a time and share with the class. Another option is to make a data table on the front board of each group’s answers. This is advantageous because the entire class gets a chance to see all of the data. All groups will share their result and we will discuss the data as a class and decide which elements would be the best to use. Give the students about 5 minutes to discuss their result *or unique lab experiences with the rest of the class*. Decide as a class what the best materials should be. The end conclusion should be any combination of metalloids or elements that are close to the metalloid staircase because they conduct electricity but are poor at conducting heat.  Metalloids or elements that are close to the metalloid staircase should be the best material for this type of application. In fact the TEGs in wearable devices use a tellurium and bismuth alloy. If a group or a class does not agree make sure to allow them to speak and explain why they did not get this same answer. Often times these are the most valuable experiences to talk about in the class. Allow students to present their case but make sure they do it in a respectful manner. Something else to discuss would be the type of lab you could do to test these results (one version is provided later in this lesson)  Discuss with the students all characteristics of Metals, Nonmetals, and Metalloids, specifically referring to heat conductivity and electrical conductivity as needed.    **Elaboration:**  To dive deeper into the topic have students answer a series of questions. (I have 45 minute class periods so I would typically give this as a homework assignment) Here are some possible questions to ask: ‘Why is ‘Exotic Metals’ a good name for elements near the staircase?’, ‘What metalloids have you heard of before?’ ‘Are any of them important to your everyday life?’ (trying to get them to mention Silicon here but it is fun to hear their responses) ‘Describe a metal (or nonmetal) that you are familiar with that has any or all properties of metals (or nonmetals) that were discussed in class.’ ‘In your personal experiences are there any metals, nonmetals, or metalloids that do not agree with the characteristics discussed in class?’ |
| **Assessment** | | **Evaluation:**  Students will turn in the data and question sheets. They will also turn in the above mentioned list of questions. These will be collected and read for data collection purposes.  Answer Key for **Exotic Metal Activity** **Sheet**:  The students should be narrowing down their answer to the metalloids on the periodic table. The reason is that these elements have both properties of metals (good electrical conductivity) and properties of nonmetals (not good thermal conductivity)  I will grade their questions 15-16 based off of this answers.  All other questions will be graded accuracy unless there are could be more than one answer. |
| **Critical Vocabulary** | | * Metalloid Staircase – Diagonal step-like line that runs from Boron to Astatine * Metals – Elements found on the left side (to the left of the metalloid staircase) of the periodic table. They have high luster, high electrical conductivity and high heat conductivity. All except for Mercury are solid at Room temperature; they have high melting points. * Nonmetal – Elements found on the right side (to the right of the metalloid staircase) of the periodic table. Many are gases at room temperature. If they are solids they are typically dull looking. Most do not conduct electricity at all. They are poor conductors of heat energy. * Metalloid – Elements that have properties of both metals and nonmetals. These elements touch the metalloid staircase.(Except Aluminum which is a metal) * Alloy – A substance that has the characteristic properties of a metal and contains more than one element. Often there is one principal metallic element, with other elements present. * Thermal Conductivity – The ability of a substance to transfer heat * Electrical Conductivity – The ability of a substance to transfer electricity. |
| **Other Useful Vocabulary** | | * Thermoelectric Generators (TEGs) – Devices that convert heat into electricity using the Seebeck effect. * Seebeck Effect – The conversion of temperature differences directly into electricity. |
| **Community Engagement** | | * Have students brainstorm about other possible uses for TEG’s or benefits of using them more. * For homework tell the students to create a bumper sticker with a thoughtful slogan or illustration that captures their idea. These will be collected and passed to be shared with others. * Have the students share their ideas with the class. * Instruct the students that for the next week they have to present their bumper sticker to ten other people outside of school personnel and students either individually or as a big group of 10 family, friends, or strangers. Each person must sign off on a designated sheet of paper to be turned in. |
| **References** | | Electrical and Thermal Conductivity Charts   * <http://periodictable.com/Properties/A/ElectricalConductivity.html> * <http://periodictable.com/Properties/A/ThermalConductivity.cl.html>   Thermoelectric Generators Video   * <https://www.youtube.com/watch?v=zzGnNkOxdpI>   Voyager Spacecraft Articles   * <http://www.npr.org/2015/02/21/387266477/exploring-the-solar-system-through-the-eyes-of-robotic-voyagers> * <http://www.space.com/22729-voyager-1-spacecraft-interstellar-space.html> * <http://voyager.jpl.nasa.gov/spacecraft/>   Voyager Spacecraft Video   * <http://www.space.com/22729-voyager-1-spacecraft-interstellar-space.html>   For Chemistry Concepts and Definitions   * Chemistry the Central Science; Brown, LeMay, Bursten |
| **Comments** | | At first I explored doing this lesson as a lab. I realized that obtaining the elements that I would need to create a large enough sample size of each group (metal, nonmetal, and metalloid) would be difficult due to cost and safety constraints. I also realized that the amount of data I wanted students to analyze on the electrical conductivity and thermal conductivity was too large to observe in a high school laboratory. I considering doing a web quest where they looked through tables of data but then I ran across these periodic table charts that illustrate the data very well. I feel like the trade for more data instead of lab experience was a good one as the main point of the lesson is for them to analyze data to get to a meaningful result. A version of my lab lesson I first created is provided above as an “Alternate Lab Lesson Plan” |
| **Author Information** | | My names is James Lamberth. In 2005 I graduated from North Carolina State University with a B.S. in Science Education and a B.A. in Chemistry. I student taught at Garner Magnet High School in the Fall of 2005. I have been teaching at Enloe Magnet High School in Raleigh, NC since January of 2006. I have taught earth science, physical science, astronomy, and chemistry.  In the summer of 2014 I learned about Dr. Gail Jones and Dr. Jess Jur’s work at the ASSIST center at North Carolina State University. The ASSIST center’s goal is to create, using nanotechnology, a self-powered health monitoring device as small as a patch that uses small amounts of energy to upload to a smartphone. Another important goal for the ASSIST center is to educate educators and students about nanotechnology and about the work that the ASSIST center does. The experience in the ASSIST’s Center’s labs is the inspiration for this lesson.  If you have any questions feel free to email me at jel4983@yahoo.com |

Name:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Exotic Metals Activity Sheet** Date:\_\_\_\_\_\_\_\_\_\_\_\_\_Group #:\_\_\_\_Period:\_\_\_\_\_

Use the charts provided to answer the following questions. Keep in mind the problem we are trying to solve.

Problem: Which elements will be most beneficial for use in thermoelectric generators?

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| 1. Which group contains the elements that are the best conductors of heat energy? |  |
| 1. Which group contains the elements that are the worst conductors of heat energy? |  |
| 1. Which group contains the elements that are the best conductors of electricity? |  |
| 1. Which group contains the elements that are the worst conductors of electricity? |  |
| **Rate the following on a scale of 0-5 with 0 being not at all, 1 being poor and 5 being very good.** | |
| 1. Electrical conductivity of metals | 0 1 2 3 4 5 |
| 1. Electrical conductivity of metalloids | 0 1 2 3 4 5 |
| 1. Electrical conductivity of nonmetals | 0 1 2 3 4 5 |
| 1. Thermal conductivity of metals | 0 1 2 3 4 5 |
| 1. Thermal conductivity of metalloids | 0 1 2 3 4 5 |
| 1. Thermal conductivity of nonmetals | 0 1 2 3 4 5 |
| 1. Do you notice any major difference in the two charts? | |
| 1. Do you notice any major differences in the graphs that may lead us to solving our problem?   Problem: Which elements will be most beneficial for use in thermoelectric generators? | |
| 1. Identify a list of elements that would be poor conductors of thermal energy yet still conduct and an electric current. |  |
| 1. Decide on two elements that your group concludes will be the best for use in TEG’s | 1.  2. |

1. Describe why you chose these elements?
2. Is there a specific region of the periodic table your group focused on?
3. Why does this region of the periodic make the most sense to focus on?