Stage 1 Physics: Nuclear Models and Radioactivity Unit Plan

## Topic Outline (From SACE 2017)

In this topic, students build on their understanding of the basic structure of the nucleus and the uses of radiation to develop an understanding of the concepts involved in the complex structure of the nucleus, stable and unstable nuclei, radioactivity, nuclear fission, and nuclear fusion. This understanding includes the concepts of nuclear force, nuclear reactions, radioactive decays, and mass–energy equivalence. They recognize that science is a global endeavor with significant contributions coming from many people.

## More Specifically

**Subtopic 6.1: The Nucleus**

Students develop an understanding of the structure of the atom and the nucleus, and the forces that exist within the nucleus. They also learn how to represent various nuclei.

**Subtopic 6.2: Radioactive decay**

Students learn about the factors that determine whether a nucleus is stable or unstable and undergoes radioactive decay. They also learn how the composition of the nucleus determines the type of decay that will occur.

**Subtopic 6.3: Radioactive Half-life**

Students learn about the rate of radioactive decay. They explore how the rate of decay is related to the activity of radioactive samples, and the implications for managing radioactive materials. Students also investigate how the rate of decay can be used to determine the age of artefacts and other items.

**Subtopic 6.4: Induced Nuclear Reactions**

Students discuss the characteristics of induced nuclear fission reactions and apply them to the example of a nuclear fission reactor used for the generation of electrical power. The concept of mass–energy equivalence is used to explain the source of the energy produced in nuclear reactions.

Students also examine the fusion reactions in stars, and consider some advantages and disadvantages of fusion as a future source of power.

They explore nuclear reactions that are used to produce isotopes for scientific, medical, and industrial purposes. These isotopes can either be produced using neutrons from a nuclear reactor or using particle accelerators.

## Assumed Knowledge

* Basic electrostatics (like charges repel, conservation of charge, etc.)
* Energy of photons are related to frequency. Not essential to know now as it will be introduced a little bit in the gamma ray section.

Resources & Materials Required

# Websites

* Alpha and Beta Decay Kahoot: <https://play.kahoot.it/#/k/2e58d896-83fe-4c32-97d6-0a3368ffe6de>
* Random dice roller: <https://www.random.org/dice/>

# Physical

* Dice for a practical in lesson 8. You’ll need 50 x (students/3) or the random website above.

# Videos

* Brief history of the Rutherford atom model: <https://www.youtube.com/watch?v=9B3DDY27ZtE>

# Programs

* <https://phet.colorado.edu/en/simulation/build-an-atom>
* <https://phet.colorado.edu/en/simulation/alpha-decay>
* <https://phet.colorado.edu/en/simulation/beta-decay>
* <https://phet.colorado.edu/en/simulation/radioactive-dating-game>

Note, these PHET simulations are Java programs and can be downloaded and brought to class if there is no internet in the classroom.

# Documents

* <https://upload.wikimedia.org/wikipedia/commons/8/80/Isotopes_and_half-life.svg>
* The end of unit test: “Nuclear Models and Radioactivity Test.docx”
* The SHE: “SHE - Model of the Atom.pdf”
* Printouts of the N vs Z chart: “N vs Z.svg”
* A chart on the alpha, beta and gamma radiation: “Ionizing Radioactivity Chart”
* A chart on radiation dosage from different things: “Radiation Dosage XKCD.png”
* <http://practicalphysics.org/simple-model-exponential-decay.html>
* Half Life Assignment: “Half Life Assignment With Answers.doc”
* Dice Practical: “Radioactive Half Life Practical.docx”
* Nuclear Power Plant Schematic: “nuclear\_plant.gif”

Assessment Plan

## Science as a Human Endeavour (SHE)

For this topic, there is no regular prescribed daily homework. Instead, there will be a SHE handout at the end of lesson two. This handout is about the development of Rutherford nuclear model and the physicists that contributed to it. This will be their homework for the first two weeks.

Due end of lesson 8.

## Half-Life Questions

There is a formative question sheet on half-lives to be handed out after the half-life lesson for practice.

## Nuclear Models and Radioactivity Topic Test

Students will sit a topic test in lesson 12 that covers everything in this unit. The test has 50 marks and runs for 50 minutes. Students will require at least a scientific calculator. There’s no advantage to graphics calculator users. It is expected that students will revise the topic as homework after submitting their SHE.

Lesson Delivery Sequence

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| **Lesson 1 of 12** | **SACE Subtopic: 6.1 The Nucleus** | |
| **Learning Objectives** | * Understand a brief history of the current model of the atom * Understand the notation used to describe a nucleus * Describe the structure of various nuclei from their symbols * Describe the structure of an atom including the relative size and location of the nucleons. | |
| **Materials Required** | * Program at <https://phet.colorado.edu/en/simulation/build-an-atom> * YouTube Video: <https://www.youtube.com/watch?v=9B3DDY27ZtE> | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Settle the class with instructions to draw what an atom looks like. | Get books out, start sketching an atom. |
| 20 minutes | Give a brief history of the atom via the YouTube video. (6 minutes)  Reiterate: At the time the experiment was done, it was unknown what exactly an alpha particle was. We now know it’s the nucleus of a hydrogen atom. It makes sense that two heavy, positively charged nuclei would fly apart.  Give examples of marbles in the middle of the oval for the scale of the atom. | Watch the YouTube video in class  Sketch and label the atom described in the in the video. |
| 10 minutes | Talk about how the nucleus is described by  notation. Reiterate that A is the weight but Z determines the element. Nothing in that specification has anything to do with the number of electrons.  Keep adding protons and neutrons to your diagram and ask how the symbol changes | Draw and label the (currently) correct model of an atom.  Interact with the class by answering the teacher’s questions. |
| 15 Minutes | Have students play with the PHET simulation on their own computers (if they have them) OR bring it up on the computer at the front of the class to demonstrate building atoms. Use the game to assess the knowledge retained. | Play with the simulation |
| Total: 50 Minutes |  |  |

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| **Lesson 2 of 12** | **SACE Subtopic: 6.1 The Nucleus** | |
| **Learning Objectives** | * Understand what an isotope is * Know the role of a neutron in a nucleus * Understand the properties of the strong nuclear force | |
| **Materials Required** | * <https://phet.colorado.edu/en/simulation/build-an-atom> * Print copies of a N vs Z chart * SHE handout. | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Have prepared on the board a diagram of an atom and have students work out the symbol that you would give it.   Have a symbol of an atom and have the students draw it. | Get books out and refresh memory on the last lesson. |
| 10 minutes | Use the PHET program to build a Carbon atom. Use Symbol mode and enable the stable/unstable indicator. Demonstrate that there are various configurations of neutrons that change the mass of the element. The difference is important. It’s called an isotope.  Write definition: Isotopes are elements with different numbers of neutrons but the same number of protons. | Watch the demonstration or get the demonstration up on their own device.  Copy the definition of an isotope into books. |
| 15 minutes | Ask: Do we even need neutrons?  They are there so they must be important, right?  Protons are positively charged. Like charges repel each other. Why doesn’t the nucleus fly apart?  Introduce the strong nuclear force   * Acts between nucleons * Very short range * Incredibly strong – able to overcome the electrostatic repulsion in a small nucleus   The neutrons job is to increase that strong nuclear force without increasing the electrostatic repulsion. | Engage in discussion about neutrons.  Copy down the properties of the strong nuclear force.  Copy down the role the neutron plays. |
| 15 minutes | Ask: Can we just keep adding neutrons? What could go wrong?  Discuss neutron stability. Too many neutrons reduce nucleus stability. A balance between protons and neutrons is needed. Hand out an N vs Z chart. | Engage in discussion about neutrons.  Get a copy of the N vs Z chart and store it in a folder or in books. |
| 5 minutes | Hand out SHE that’s due in 2 weeks.  Inform that students start radioactive decay next week. | Take home SHE. |
| Total: 50 Minutes |  |  |
| **Lesson 3 of 12** | **SACE Subtopic: 6.2 Radioactive Decay** | |
| **Learning Objectives** | * Know what makes a nucleus unstable * Know how to represent a radioactive decay with an equation * Understand the process of alpha decay | |
| **Materials Required** | * <https://phet.colorado.edu/en/simulation/alpha-decay> * Print copies of a N vs Z chart | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Draw a picture of a Carbon-12 atom on the board with instructions: “make the nucleus unstable”. | Get books out and refresh memory on the last lesson. |
| 15 minutes | Recall that the neutrons make the nucleus stable because the protons are repulsed by one another. The strong nuclear force holds the nucleus together.  Teach:   * Instability is caused by unbalanced protons and neutrons * After Z = 82 (lead), the nucleus is so proton rich that the repulsive force finally overcomes the strong nuclear force.   Use the N vs Z graph to help explain. Everything is trying to get to a black square. | Listen and take notes.  Trace out alpha decay on the N vs Z graph handed out previously. |
| 15 minutes | Introduce alpha decay.   * Generally, too many protons (high Z > 82) OR * A severe lack of neutrons (low Z <=82) * Alpha particle is a helium nucleus (no electrons).   Demonstrate the generic equation for a decay  .  Have students trace out alpha decays on the N vs Z graph. | Listen and then suggest valid decays and write the equations to them from the N vs Z graph. |
| 15 minutes | Play with the PHET simulator or use this time to catch up with content that wasn’t finished in the previous lessons. | Watch the simulation or run the simulation on their own device. |
| Total: 50 Minutes |  |  |

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| **Lesson 4 of 12** | **SACE Subtopic: 6.2 Radioactive Decay** | |
| **Learning Objectives** | * Know what causes beta plus and minus decay | |
| **Materials Required** | * <https://phet.colorado.edu/en/simulation/beta-decay> * <https://play.kahoot.it/#/k/2e58d896-83fe-4c32-97d6-0a3368ffe6de> | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Have some equations for alpha decay from different elements written on the board. | Get books out and refresh memory on the last lesson by finishing the equations. |
| 20 minutes | Introduce beta minus decay.   * A few too many neutrons. * Neutron ejects an electron and a antineutrino and becomes a proton. * Conservation of charge * Neutron equation given by * Nucleus equation given by * Happens in the region above the line of stability in the N vs Z chart.   Introduce this with the aid of the chart.  Explain that there exists neutron emission where there is a severe surplus of neutrons and a neutron is simply ejected but most isotopes above the line are B- emitters.  Demonstrate the phenomena with PHET simulator. | Take notes and refer to their N vs Z charts.  Watch or use the PHET simulator. |
| 10 minutes | Introduce beta plus decay   * Almost the reverse of beta minus. * A few too many protons/a shortage of neutrons. * Protons highly unstable, so one of them spits out a positively charged electron called a positron and a neutrino to become a neutron. * Proton equation is given by * Nucleus equation is given by   Go through a few nucleus equation examples of beta plus and minus decay | Take notes |
| 15 minutes | Extra time if required then Play Kahoot! | Play Kahoot! |
| Total: 50 Minutes |  |  |

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| **Lesson 5 of 12** | **SACE Subtopic: 6.2 Radioactive Decay** | |
| **Learning Objectives** | * Understand the practical uses for radiation in smoke detectors and PET scanning * Know what gamma radiation is and where it comes from. | |
| **Materials Required** | * PET scan video: <https://www.youtube.com/watch?v=GHLBcCv4rqk> * Smoke detectors video: <https://www.youtube.com/watch?v=aJkx6hAD-4E> | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Have some equations for beta plus/minus and alpha decay on the board and have students identify the type of decay. | Get books out and refresh memory on the last lesson by identifying the decay in the equations. |
| 25 minutes | Ask “Is radiation bad?” and get the class involved.  Introduce radio tracers.  Watch the PET scan video  Ask   * “what type of decay did we see?” * Where on the N vs Z chart is it? * How might the detector get a 3d image?   Help students understand the scanning process.  Explain that hospitals have special particle accelerators called cyclotrons where they can create radioactive isotopes on demand.  If there is time, teach about the alpha particle emitting americium and how it works in a smoke detector. If you are really keen, try to rebuild the test setup in the video and use it in class. | Watch the video of a PET scan.  Get involved in the questioning.  Watch a video on smoke detectors |
| 20 minutes | Introduce gamma radiation as it follows naturally after PET scanning.   * The symbol * Unlike alpha and beta decay, gamma rays are electromagnetic radiation. * Occurs after alpha decay when the nucleus is in an excited state. * Seen in positron-electron annihilation. * General equation is | Listen and ask questions |
| Total: 50 Minutes |  |  |

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| **Lesson 6 of 12** | **SACE Subtopic: 6.2 Radioactive Decay** | |
| **Learning Objectives** | * Recap the 4 different types of radiation discussed. * Understand the effects of radiation on humans and the safety measures to take. | |
| **Materials Required** | * XKCD radiation dose chart (not entirely scientific but a good way to relate radiation dosage) <https://xkcd.com/radiation/> * Print copies of “Ionizing Radioactivity Chart” | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Have prepared on the whiteboard two questions: “Where kind of radiation is used in a PET scanner?” and “What kind of radiation is used in a smoke detector?” | Get books out and refresh memory on the last lesson by answering the questions on radiation. |
| 35 minutes | Ask “After last lesson, do we think that radioactive materials are good for us now?”  The answer is ‘it depends’. Introduce radiation sickness as a combined effect of alpha, beta and gamma radiation.  Everything can damage your body, it just depends if the benefit is worth it (like in PET).  The amount of damage depends on the time you are exposed.  Discuss the physical effects of each type of radiation and how you can limit the exposure.  Discuss mobile phones (they produce radiation, but not ionizing radiation)  Show a relevant XKCD (Radiation dose chart) | This whole section is supposed to be a discussion as well as ‘lecturing’. Students should take notes and participate in the discussion. |
| 10 minutes | Wrap up the different types of radioactive decay that we have talked about and hand out copies of the “Ionizing Radioactivity Chart”. | Ask questions and take notes to summarise what has been learned.  Receive a handout and store it safely. |
| Total: 50 Minutes |  |  |

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| **Lesson 7 of 12** | **SACE Subtopic: 6.3 Radioactive Half-life** | |
| **Learning Objectives** | * Radioactivity: how many radioactive nuclei decay over a time interval. * The time taken for a nucleus to decay is not known but a large sample o | |
| **Materials Required** | * <https://phet.colorado.edu/en/simulation/radioactive-dating-game> * Half Life Assignment With Answers.doc | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Write up instructions for students to list ways to reduce exposure to gamma, beta and alpha radiation. | Get books out and refresh memory on the last lesson by answering the questions on radiation safety. |
| 15 minutes | Introduce half life with the PHET animation and discuss these properties.   * A sample has a finite number of decays. * The decay process is random so cannot be accurately predicted. * With a large sample of nuclei, we can statistically measure how long it takes for half the radioactive nuclei to decay. Call this time the half-life. * Half-life is different for every isotope * Half-life is not dependent on the physical state of the material. * The definition of radioactivity as how many decays over a time interval.   Be prepared to answer a question on extrapolation if someone asks how we know U-238 has a 4 billion year half life. | Watch and play with the animations if they have their own computers.  Take notes on the properties of decay. |
| 15 minutes | Demonstrate some half-life calculations.   * Simple questions with times that are multiples of half-lives. * Solve for mass after lapsed time. * Solve for time after mass required. * Estimate half life from data   Formulas for half-life are listed here if you forget: <https://en.wikipedia.org/wiki/Half-life> | Help answer questions as a class that are on the board. |
| 10 minutes | Play with the PHET simulator for carbon dating and get the students to run it too if they have their own computers | Watch the simulations and play with the simulations if they have their own devices. |
| 5 minutes | Hand out the formative half-life homework. Warn the students that the next lesson will be a formative practical. |  |
| **HOMEWORK** | Half life assignment due at the end of lesson 9 |  |
| Total: 50 Minutes |  |  |

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| **Lesson 8 of 12** | **SACE Subtopic: 6.3 Radioactive Half-life** | |
| **Learning Objectives** | * Investigate the link between the probability of decaying and the half-life of a material. | |
| **Materials Required** | * Dice: 50 x (Students/3) or a dice simulator such as <https://www.random.org/dice/> * Practical handout: “Radioactive Half Life Practical.docx” | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Have the dice already counted and ready to hand out to groups of 3 along with the practical instructions. | Get into groups of 3 and wait for materials. |
| 40 minutes | Supervise the practical | Do the practical. |
| 5 minutes | Collect materials and student work and the SHE. | Hand up materials, practical and the SHE. |
| Total: 50 Minutes |  |  |

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| **Lesson 9 of 12** | **SACE Subtopic: 6.4 Induced Nuclear Reactions** | |
| **Learning Objectives** | * Understand what causes a fission reaction and which materials support it. * Understand the process of a chain reaction. | |
| **Materials Required** | * www.phet.colorado.edu/en/simulation/nuclear-fission. * Photo of Nagasaki bomb. | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Get the class organised with their books but leave the photo of the Nagasaki bomb on the board and have a title “Induced Nuclear Reactions” | Get books out |
| 15 minutes. | Ask the students:   * When we have a few too many neutrons we have which decay? * When we have a few too many protons we have which decay? * When we start getting heavy atoms with lots of protons we get which decay?   The aim is to remind the students of the opposing goals of the strong nuclear force and the electrostatic force in large atoms.  Discuss   * Nuclear fission is when a nucleus is given an energetic neutron and it becomes so unstable that it splits in two major pieces plus a few more neutrons. * Those pieces weigh less than the original nucleus and using E=mc2 we can calculate the energy released. * The difference in the mass of the nucleus and the components of the nucleus is called the mass defect. * Energy is in the form of kinetic energy of the two parts and gamma rays. * Remember that kinetic energy of particles is what we would call heat and it can be used   An analogy would be having a rubber band holding two masses together that is fully stretched. The extra neutron is what it takes to break it and the rubber band’s energy is released instantly and disappears. | Answer questions in class discussion.  Take notes on nuclear fission |
| 20 minutes | Demonstrate energy calculations and have the students practice them from the textbook that the school uses. Be sure to use nuclear equations to represent the reaction. | Take notes on calculation and practice calculations |
| 10 minutes | Play with the PHET simulation on the computer. Get students onto it if they have their own devices. Be prepared to explain the potential well that is shown here. The students will also be introduced to uranium as a fissile isotope. State that plutonium is another one but it’s not as good.  Use this to introduce a chain reaction. In this program, it’s an atom bomb.  Tell students that there is a lot of uranium in the earth’s crust. Ask them and discuss why the earth hasn’t exploded like these uranium atoms do. Cover proportions of U-238/5 and enrichment.  Collect Half Life Question Sheets. | Watch/play with the simulator.  Think about why earth hasn’t exploded if it takes one neutron to set it off.  Give back half-life question sheet. |
| Total: 50 Minutes |  |  |

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| **Lesson 10 of 12** | **SACE Subtopic: 6.4 Induced Nuclear Reactions** | |
| **Learning Objectives** | * Understand the proportions of uranium in the earth and the need for enrichment * Understand how a nuclear power plant operates | |
| **Materials Required** | * Excellent video on enrichment: <https://www.youtube.com/watch?v=apODDbgFFPI> * Print outs for each student of ‘nuclear\_plant.gif’ | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Have written on the board: “Why hasn’t the earth exploded with all the uranium?” It might be worth mentioning that the reason that the reason the crust is hotter as you get deeper is actually because of the nuclear decay of uranium and other isotopes. | Come in, get settled and try to answer the question from last lesson. |
| 10 minutes | Set the scene for the requirement of enrichment. Discuss   * Uranium has multiple isotopes * Two of them are found in useful quantities in the earth’s crusts * U-238 has half life of 4.47 billion years and makes up 99.27% of uranium found. Starts decay chain via alpha decay. * U-235 has a half life of 703.8 million years and makes up 0.72% of the uranium found in the crust. Also starts decay via alpha decay. * When hit with neutrons, U-238 absorbs it and later decays down another path but is not fissile like U-235. * U-235 accepts the neutron and becomes unstable and 82% of the time sets off a fission reaction. The rest of the time it emits a gamma ray and stays as U-236.   Ask “Based on this information, what might we need to do in order to get a useful chain reaction?” (Enrichment). | Participate in class discussion and take notes on enrichment. |
| 10 minutes | Watch the YouTube video and answer questions. Note: the narrator says a centrifuge uses ‘physics’ to separate heavier and lighter molecules. Be prepared to explain this. | Watch the YouTube video and ask questions. |
| 25 minutes | Discuss how a nuclear power plant works by building it up in stages. Make sure you discuss safety of the users and environment.   * We have fuel pellets. Need some way of putting them together. * Need a way to start a chain reaction. * Need something to slow the neutrons (heavy water or graphite – moderator) * Need some way of turning heat energy into mechanical energy (turbine) * Need a way of turning mechanical energy into electrical energy (generator) * Need a way of cooling the working water down. (cooling tower) * Need a way of slowing the rate of reaction (control rods) * Need a way of stopping gamma rays from getting to the workers from the fission reaction (isolation chamber). * Need a place to store spent uranium!   Hand out ‘nuclear\_plant.gif’ | Participate in building a nuclear power plant.                   Collect handout for a nuclear power plant schematic. |
| Total: 50 Minutes |  |  |

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| **Lesson 11 of 12** | **SACE Subtopic: 6.4 Induced Nuclear Reactions** | |
| **Learning Objectives** | * Know how atomic bombs are constructed. * Understand the process of nuclear fusion * Calculate energy released in nuclear fusion | |
| **Materials Required** |  | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 5 minutes | Have instructions on the board: “Draw what you think the internals of an atomic bomb might look like.” | Get books out and think about how one might make an atomic bomb. |
| 10 minutes | Use the class ideas of what an atom bomb might look like and build one up on the board like the power plant. Nuclear weapons have evolved a lot and it would be good to for them to research their evolution. They’ll understand everything they need after this class. | Participate in class discussion on atom bomb design. |
| 15 Minutes | Introduce fusion   * In large atoms like uranium, there are many protons pushing the nucleus apart. There is a lot of potential to do work, it just needs a boost of energy to get it to crack. Fully stretched elastic band analogy. * In smaller atoms, there is less electrostatic repulsion and the strong force is dominant. If we get the nucleons close enough together, they will bind and in the process, release energy. It’s like magnets – except the magnets are strongly repulsive just until just before they touch. * The balance point is Lead. It’s the heaviest stable element with Z = 82.   Ask: “Suppose we wanted to fuse hydrogen into helium. What might the problem be with doing this?”   * Repulsion. Need for high energy/heat to get it to happen. * How do we store it when it gets this hot? * Talk about stars and how they burn. | Take notes  Participate in class discussion. |
| 10 minutes | Demonstrate examples of fission again to show the products being lighter than the sources and then show examples of hydrogen fusion. | Watch the calculation demonstration. |
| 10 minutes | Practice fusion questions OR have a quick Q&A on topics before the test. | Practice fusion questions or ask questions about topics before the test. |
| Total: 50 Minutes |  |  |

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| **Lesson 12 of 12** | **SACE Subtopics: 6.1 - 6.4** | |
| **Learning Objectives** | Assess knowledge of the nuclear model and radioactivity. | |
| **Materials Required** | The test: Nuclear Models and Radioactivity Test.docx | |
| **Allocated Time** | **Teacher Activities** | **Student Activities** |
| 50 minutes | Hand out and monitor the test. The test is supposed to take 50 minutes and that’s the length of these classes. Make sure you have students in early or they can be a few minutes late to the next class or run in a double lesson. | Do the test. |
| Total: 50 Minutes |  |  |