PAN/JINA Lesson Plan – Cosmic Rays and the Standard Model
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Audience: Introductory Regents Physics Class

<u>Objectives:</u>
Students will understand

- Cosmic Rays are really particles that arise from explosions of stars in space. Over time these collisions result in nuclei or ionized particles.
- Cosmic Rays interact collide with the particles of our atmosphere at very high energy. The result of these collisions is a "shower" of high energy particles that are not found in the matter that we are familiar with.
- The particles that result from collisions between Cosmic Rays and the atoms in our atmosphere undergo a series of mass-energy conversions in an attempt to reach a more stable state of energy.
- If you take a snap shot of the different phases of the energy mass conversions you would find evidence for the existence of quark and lepton combinations other than proton, neutrons and electrons.
- The term decay does not mean that the resulting particle was contained within the prior "generation". It refers to a change in energy that will results in a new particle (which can be from a different category of matter).
- Many of the particles from the Standard Model such as mesons, muons etc are short lived particles that are unstable and therefore exist only briefly after high energy collisions.
- Scientists use advance equipment such as particle accelerators (cyclotron, Linac, Cern) and a number of detectors (MONA/LISA, LHC, ATLAS, Satellites etc) to recreate these collisions in order to better understand the processes that created the universe and governed its evolution to its current state. This research allows scientists to better understand how Cosmic Rays influence life on Earth as well as processes in stars etc.

<u>Prior Knowledge</u>:

- Students will already have been introduced to the twelve particles of the Standard Model and the corresponding anti-particles.
- Students will have been introduced to the ways in which these particles interact in terms of the fundamental forces.
- Student will have had a brief introduction to the idea of $E=mc^2$ and the connection between energy and mass.

KEY TERMS: Quark (Up/Down, Charm/Strange, Top/Bottom), Lepton (electron, muon, tau, neutrino), Hadron, Baryon, Meson, Strong Force, Weak Force, EM Force, matter, anti-matter, beta-decay, order of magnitude.

<u>Standards addressed or reinforced</u>.
Performance Indicators from the New York State Core Curriculum - Physics
5.3f Among other things, mass-energy and charge are conserved at all levels (from sub-nuclear to cosmic).

5.3g The Standard Model of Particle Physics has evolved from previous attempts to explain the nature of the atom and states that:

- Atomic particles are composed of subnuclear particles
- The nucleus is a conglomeration of quarks which manifest themselves as protons and neutrons.
- Each elementary particle has a corresponding antiparticle.

5.3h Behaviors and characteristics of matter, from the microscopic to the cosmic levels are manifestations of atomic structure. The macroscopic characteristics of matter, such as electrical and optical properties are the result of microscopic interactions.
5.3i The total of the fundamental interactions is responsible for the appearance and the behavior of the objects in the universe.
5.3j The fundamental source of all energy in the universe is the conversion of mass into energy.

Materials and Resources:

- Fragmentation box (JINA)
- Powerpoint with supporting visuals [Resource in Development from JINA/PAN materials]
    - Slides (Cosmic Ray collision macro and micro)
    - Animation of Cosmic Rays over Chicago
    - Animation of particle accelerators (CERN, NSCL/FRIB)
    - Animations of stellar evolution processes

Activities and Sequence:

Introduction:

- With the help of a student volunteer, model a series of collision using the fragmentation box. Note on the front whiteboard observations of students relating to what occurred in the collisions. Discuss the possible types of interactions that occur when high energy collisions between nuclei occur. Ask students to give examples of events that might occur in these collisions that are not possible to model with protons and neutrons.
- Show students a series of images and animations that represent a high speed collision between a cosmic ray and the atmosphere. (First discuss the nature of a Cosmic Ray).
- Discuss with students the similarities between atmospheric events and the events that occur in particle accelerators. Show examples of facilities such as CERN which have already been discussed and other laboratories around the country and the world that are involved in the research.
- Students will view an image and read a synopsis of a collision event involving high energy cosmic rays and a nitrogen atom in the atmosphere. (ARTICLE UNDER DEVELOPMENT). Students will complete questions that analyze the event in terms of time, energy and particles using terms introduced earlier in the unit. Questions will reinforce categories of particle in the Standard Model, the conversion of mass to energy, orders of magnitude with respect to time and energy.

- In groups, students will investigate a current cutting edge research projects occurring at facilities such as CERN, NSCL/FRIB, SLAC etc that involve the "other" particles of the Standard Model (ie, muon, tau, neutrino, kaon, pion etc). Students may report findings of their research through a presentation mode of their choice. The goal of this project will be to answer the following (including but not limited to):
    - The main problem/question that the researchers are aiming to answer
    - Connect the mechanism of investigation to basic concepts learned earlier in the year such as conservation of energy, magnetism etc.
    - How this research has led to advances in technology or knowledge of the fundamental nature of the cosmos.
    - In your discussion or presentation you must define any relationships to current terms. Ie you must not simply state moun or neutrino without identifying it by category.