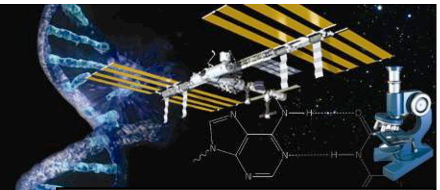
MATH AND SCIENCE @ WORK

AP* PHYSICS Educator Edition



IONIZING RADIATION EXPOSURE

Instructional Objectives

Students will

- practice and review atomic physics concepts and equations;
- apply Planck's constant;
- determine the deBroglie wavelength of a proton; and
- analyze the frequency of photons.

Degree of Difficulty

For the average student in AP Physics B, this problem is moderately difficult due to the limited amount of time available in AP Physics B to the study of atomic and nuclear physics. Students should be provided with the mass of a proton, speed of light, and the necessary equations located on the AP physics equation sheet.

For part C, students should understand the relationship between frequency and energy of electromagnetic waves, and the relationship between the speed of these waves, both in wavelength and frequency.

Class Time Required

This problem requires 25–35 minutes.

- Introduction: 10 minutes
  - Read and discuss the background section with the class before students work on the problem.
- Student Work Time: 10–15 minutes
- Post Discussion: 5–10 minutes

Background

This problem is part of a series of problems that apply Math and Science @ Work in NASA's research facilities.

The International Space Station (ISS) orbits the Earth at an approximate altitude of 407 km (252 mi). At this altitude, astronauts are not as well protected by the Earth's atmosphere, and are exposed to higher levels of space radiation than what is experienced on the Earth's surface.

Space radiation is different from radiation experienced on Earth and can have very different effects on human DNA, cells, and tissues. Space

Grade Level
11–12

Key Topic
Atomic physics

Degree of Difficulty
Moderate

Teacher Prep Time
10 minutes

Class Time Required
25–35 minutes

Technology
- TI-Nspire™ Learning Handhelds
- TI-Nspire document: *Ionizing_Radiation.tns*

Materials
AP Physics equation sheet

Learning Objectives for AP Physics
Atomic and Nuclear Physics:
- Atomic Physics and Quantum Effects

NSES Science Standards
- Physical Science
- Science in Personal and Social Perspectives
- History and Nature of Science

radiation, created as atoms, is comprised of positively charged ions which accelerate toward the speed of light. Eventually, only the nucleus of each atom remains, and the radiation becomes ionized. This “ionizing radiation” contains such abundance of energy, that it can literally “knock” the electrons out of any atom it strikes, thereby ionizing the atom. This effect can cause damage to the atoms within living cells, leading to potential future health problems, such as cataracts, cancer, and disorders of the central nervous system.

To better understand the long-term effects of space radiation on the human body, NASA is conducting research to identify and quantify types of radiation existing in the space environment. Scientists know that when the ISS travels in low-Earth orbit, it is exposed to ionizing radiation from three main sources: solar eruptions, galactic cosmic rays, and the Van Allen radiation belts. The Van Allen radiation belts are two, donut-shaped magnetic rings surrounding the Earth in which ionized particles become trapped.

Open the document, *Ionizing_Radiation*, on your TI-Nspire handheld. On page 1.2, use the arrows to rotate the model of the Van Allen radiation belts.

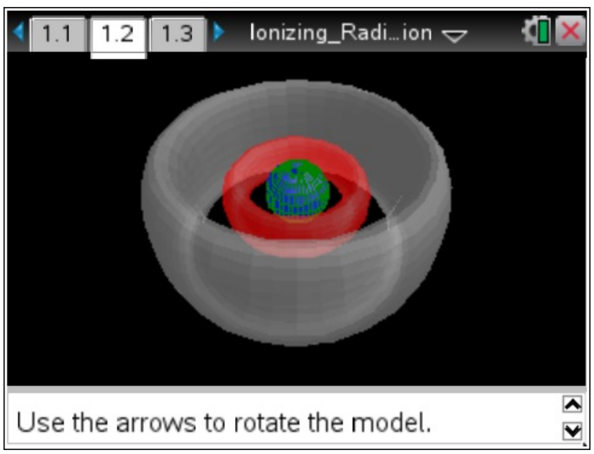


Figure 1: Model of the Van Allen radiation belts

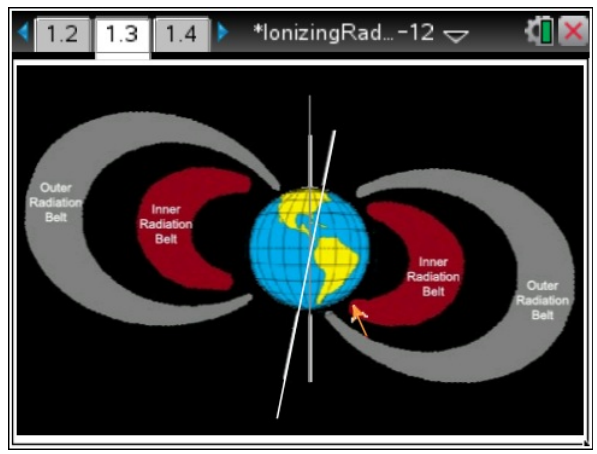


Figure 2: The Van Allen belts in relation to Earth’s rotational and magnetic axes

These Van Allen radiation belts are symmetrical about the Earth’s magnetic axis, which is tilted with respect to the Earth’s rotational axis (Figure 2). This tilt causes the inner Van Allen belt to come closer to the Earth’s surface (approximately 200 km, or 124 mi, from the Earth’s surface) over the South Atlantic Ocean. In this area (known as the South Atlantic Anomaly), there is an increased flux of energetic particles, as well as increased levels of radiation for any exposed satellites including the ISS.

On page 1.3 of the TI-Nspire document, use your cursor to find Earth’s rotational and magnetic axes and the location of the South Atlantic Anomaly.

Scientists and engineers are also working to understand the risks that astronauts face during long-duration exposure to space radiation. Countermeasures are being developed to mitigate (reduce or eliminate) those risks. One type of countermeasure used on the ISS for the protection of ionizing radiation is shielding. Improved shielding in the most frequently occupied locations of the ISS, such as the sleeping quarters and galley, has proven to reduce the crew’s exposure to space radiation. Shielding protects both the vehicle and the crew from each source of radiation exposure, including the increased exposure while the orbit is within the South Atlantic Anomaly.

In addition to shielding, all ISS crewmembers must wear physical dosimeters during flight—devices which measure personal exposure to ionizing radiation. Real-time, active monitoring of space radiation levels helps astronauts locate the best-shielded locations on the ISS and can help reduce radiation exposure. Active monitoring can also provide a warning should radiation levels increase due to solar disturbances. To further reduce risks following radiation exposure, crewmembers in-flight undergo physical examinations (blood draws) that measure radiation damage to chromosomes in blood cells. Pre and post-flight, astronauts are encouraged to maintain a healthy lifestyle, including the dietary intake of antioxidants.

Space radiation research also has many Earth-based implications. Advancements in technology have led to better detection and protection from radiation exposure experienced on Earth. Advances in the understanding of nuclear theory and astrophysics have also been made.

Learning Objectives for AP Physics

Atomic and Nuclear Physics

- Atomic Physics and Quantum Effects
  - Wave-particle duality

NSES Science Standards

Physical Science

- Interactions of energy and matter

Science in Personal and Social Perspectives

- Personal and community health
- Natural and human-induced hazards

History and Nature of Science

- Science as a human endeavor
- Historical perspectives

Problem and Solution Key (One Approach)

Students are given the following problem information within the TI-Nspire document, Ionizing_Radiation.tns. Give students instructions to either record their answers on their handheld or on the student handout according to your preference.

Since the ISS usually orbits approximately 407 km (252 mi) above the surface of the Earth, it is well below the inner Van Allen radiation belt. Occasionally, however, the ISS must orbit through the South Atlantic Anomaly, where the inner belt dips closer to the Earth (approximately 200 km, or 124 miles, from the Earth's surface). Here, the ISS encounters protons greater than 10 mega-electronvolts (MeV).

A. What is the momentum of a proton with a kinetic energy of 11.2 MeV?

The mass, m, of a proton is known: $m_p = 1.67 \times 10^{-27}\ kg$. *In order to find momentum of the proton, the velocity is needed. This can be determined using the equation for kinetic energy.*

$$K = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{2K}{m}}$$
$$v = \sqrt{\frac{2\cdot\left(11.2\times10^6 eV\right)\cdot\frac{1.6\times10^{-19} J}{1 eV}}{1.67\times10^{-27} kg}}$$
$$v = 4.6326103\times10^7 \tfrac{m}{s}$$

$$p = mv$$
$$p = \left(1.67\times10^{-27}\ kg\right)\cdot\left(4.6326103\times10^7\ \tfrac{m}{s}\right)$$
$$p = 7.74\times10^{-20}\ \tfrac{kg\cdot m}{s}$$

B. Ignoring relativistic speeds, what is the deBroglie wavelength of this proton?

$$\lambda = \frac{h}{p}$$
$$\lambda = \frac{6.63\times10^{-34}\ J\cdot s}{7.74\times10^{-20}\ kg\cdot\frac{m}{s}}$$
$$\lambda = 8.57\times10^{-15}\ m$$

C. Photons are massless. Their energy does not depend upon their speed and mass, but upon their frequency.

I. What is the wavelength of a photon that has the same 11.2 MeV of energy?

$$E = hf \text{ or } E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E}$$
$$\lambda = \frac{1.24\times10^{-6} eV\cdot m}{11.2\times10^6 eV}$$
$$\lambda = 1.11\times10^{-13} m$$

II. Does this correspond to a frequency that is lower than, inside of, or higher than the visible light spectrum? Explain.

Higher. The smaller the wavelength, the higher the frequency. Visible light ranges from about 400 to 700 nm. The wavelength in part I is smaller than that, so the frequency is high (and therefore, the energy is high). A photon of energy this high corresponds to an energy that is higher than visible light.

Scoring Guide

Suggested 10 points total to be given.

Question		Distribution of points
A	*4 points*	1 point for substitution of the mass of the proton into the correct expression for kinetic energy 1 point for correct answer for the speed of the proton 1 point for correct substitution into the momentum equation 1 point for correct answer with units
B	*3 points*	1 point for correct substitution of Planck's constant 1 point for correct substitution of the momentum from question A 1 point for correct answer with units
C	*3 points*	1 point for correct equation relating energy and wavelength, and correct substitutions 1 point for correct answer with units 1 point for correct answer with explanation to part II

Contributors

This problem was developed by the Human Research Program Education and Outreach (HRPEO) team with the help of NASA subject matter experts and high school AP Physics instructors.

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