TOPIC 4.1: MEDICAL PHYSICS

S4P-4-1 Describe the nuclear model of the atom.

Include: proton, neutron, nucleus, nuclear forces, stability, isotope, mass number, electron, ion

S4P-4-2 Define radioactivity as a nuclear change that releases energy.

Include: Becquerel units, radioactive decay, half life

S4P-4-3 Perform decay calculations using integer numbers of half life.

S4P-4-4 Describe the following types of radiation: alpha, beta, and electromagnetic radiation.

Include: particle radiation, wave radiation, electromagnetic spectrum, linear energy transfer

S4P-4-5 Compare and contrast sources and characteristics of ionizing radiation and non-ionizing radiation.

Include: NORM (Naturally Occurring Radioactive Materials), radon, background radiation, incandescent light bulb, hot objects

S4P-4-6 Describe various applications of non-ionizing radiation.

Examples: communications, microwave oven, laser, tanning bed

S4P-4-7 Describe various applications of ionizing radiation.

Examples: food irradiation, sterilization, smoke alarm

S4P-4-8 Describe the effects of non-ionizing and ionizing radiation on the human body.

Include: equivalency of sievert (Sv) and rem units, solar erythema (sunburn)

S4P-4-9 Research, identify, and examine the application of radiation to diagnostic imaging and treatment techniques.

Examples: nuclear medicine imagery techniques such as MRI, ultrasound, endoscopy, X-ray, CT scanning, PET, heavy isotopes such as Ba; nuclear medicine therapies such as brachitherapy, external beam, gamma knife

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

SPECIFIC LEARNING OUTCOME

S4P-4-1: Describe the nuclear model of the atom.

Include: proton, neutron, nucleus, nuclear forces, stability, isotope, mass number, electron, ion

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

The Bohr model of the atom was introduced in Senior 1 Science. In addition, the four fundamental forces were introduced in Senior 3 Physics.

Notes to the Teacher

Atoms can be described as the building blocks of matter. Atoms contain a central region known as the **nucleus**, which contains most of the atom's mass, and all its positive charge. **Electrons** surround the nucleus, and carry a negative charge; each electron has a negative charge that exactly balances the positive charge of a proton in the nucleus. **Neutral atoms** contain a balance of protons and electrons, and so have no net charge. The term **ion** is used for an atom that is not neutral. Ions may be positive or negative, depending on which is greater, the number of protons or electrons.

The basic building blocks of the nucleus are two different types of particles: **protons** and **neutrons**, which are collectively referred to as **nucleons**. Protons and neutrons have masses that are nearly equal, but have different charge states: protons are positively charged and neutrons are uncharged. It is the number of protons in the nucleus that provide the nucleus with its elemental identity. This is referred to as the **atomic number**. As an example, any atom with 6 protons in the nucleus is identified as carbon.

The number of nucleons in an atom determines its **mass number**. It is important to note that elements generally have more than one possible mass number, as the number of neutrons can vary, even for atoms of the same element. Such variations of an element are referred to as **isotopes**. As an example, most carbon atoms have 6 neutrons. These atoms therefore have 12 nucleons, and make up one isotope of carbon: Carbon-12. A small number of naturally occurring carbon atoms have 5 neutrons, and so 11 nucleons. This is another isotope of carbon: Carbon-11.

SKILLS AND ATTITUDES OUTCOME

S4P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand the properties and structures of matter as well as various common manifestations and applications of the actions and interactions of matter (GLO D3)

SUGGESTIONS FOR INSTRUCTION

The particles within a nucleus continually exert forces on each other. The protons are all positive, and so repel each other by the electromagnetic force. The neutrons are neutral, and so are not affected by the electromagnetic force. Both protons and neutrons are subjected to another force: the strong nuclear force. This force is attractive, and stronger than the electromagnetic force, but has a very short effective range. The protons within a nucleus repel each other within one force, while they attract each other with another. These forces may result in an equilibrium state, in which case the particles remain in the nucleus. A nucleus that contains nucleons in a sustained equilibrium state is said to be **stable**.

Class Discussion

A brief historical review of the model of the atom will help set the context for the study of medical physics.

Demonstration

Students build models of different atoms using Styrofoam spheres and toothpicks.

SUGGESTIONS FOR ASSESSMENT

Visual Display

Students draw Bohr atoms of various elements using neutral atoms with atomic numbers from 1 to 20.

Students draw the Bohr model of an ion formed by the element.

Students draw the Bohr model of an isotope of the element.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Describe scientific and technological developments, past and present, and appreciate their impact on individuals, societies, and the environment, both locally and globally (GLO B1)

SPECIFIC LEARNING OUTCOMES

S4P-4-2: Define radioactivity as a nuclear change that releases energy.

Include: Becquerel units, radioactive decay, half life

S4P-4-3: Perform decay calculations using integer numbers of half life.

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Although this learning outcome limits the analysis to integer numbers of half life, students who have completed Senior 4 Pre-Calculus Mathematics or Senior 4 Applied Mathematics will have seen exponential functions, including radioactive decay.

Notes to the Teacher

The forces acting on the particles of the nucleus can result in a loss of equilibrium. A nucleus in such a state will undergo a change, which is referred to as **radioactive decay**. Nuclei that undergo radioactive decay spontaneously are said to be unstable. Radioactive decay releases energy, and may also change the composition of the nucleus. A sample of unstable nuclei is said to have an activity, measured in the unit of Becquerel (Bq), which is one decay per second. Although unstable nuclei will certainly decay, the timing of the decay cannot be predicted and so it is said to be random. As an example, a sample of material that undergoes 100 decays per second would be said to have an activity of 100 Becquerels.

As with the toss of a coin, the outcome of a single event is unknown, but large numbers of events can be described accurately. One measure of the longevity of an unstable isotope is that of a half life, which is the length of time needed for half of the nuclei in a large sample to decay. As an example, the half life of Iodine-131 is about 8 days. This means that if a sample consisted of 1 kg of Iodine-131, then after 8 days, only 0.5 kg of Iodine-131 would remain (note that the sample would still be nearly 1 kg, but the remaining 0.5 kg would no longer be Iodine-131). After 16 days (two half lives), the sample would contain about 0.25 kg of Iodine-131. Note that 1 kg of Iodine-131 consists of approximately 4.6 1024 atoms, which makes the statistical predictions quite accurate.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-2c: Formulate operational definitions of major variables or concepts.

S4P-0-2d: Estimate and measure accurately using SI units.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand the composition of the universe, the interactions within it, and the impacts of humankind's continued attempts to understand and explore it (GLO D6)

SUGGESTIONS FOR INSTRUCTION

Class Activity

Obtain about 200 (or more) pennies and distribute them among the students. Initially, each penny represents an unstable nucleus. Have the students each shake their pennies in a cup and then invert the cup so that each penny lies flat. A penny that comes up heads represents a nucleus that has decayed (and assumed to now be stable), and a penny that comes up tails represents a nucleus that has not yet decayed—it is still unstable. Obtain the total number of pennies that come up tails—this is the number of unstable nuclei—and place them back inside the cups. (Set aside the pennies that have come up heads. They have decayed, and so are "out of the game.") Repeat this several times until the number of pennies that remains in the game is less than 20, and graph the results: Number of unstable nuclei versus toss number. Statistically, we expect approximately half of the coins to "decay" each toss. The "half life" for the pennies is the amount of time to go through the process described above.

Student Activity

See "Get a Half Life" activity in Appendix 4.1.

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students graph sample data for radioactive decay.

Students solve a variety of half-life problems.

Laboratory Report

Students report on the penny simulation lab as if it were a radioactive example. Include safety considerations for radioactive materials.

SUGGESTED LEARNING RESOURCES

BLM 39-1: Conceptual-Development Practice, Radioactive Half Life, *Conceptual Physics,* Pearson, 2002

Appendix 4.1: "Get a Half Life"

The Best From Conceptual Physics Alive! DVD Series: Episode 33—Radioactivity, Call #6017

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand the composition of the universe, the interactions within it, and the impacts of humankind's continued attempts to understand and explore it (GLO D6)

SPECIFIC LEARNING OUTCOME

S4P-4-4: Describe the following types of radiation: alpha, beta, and electromagnetic radiation.

Include: particle radiation, wave radiation, electromagnetic spectrum, linear energy transfer

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

The Bohr model of the atom was introduced in Senior 1 Science. In addition, the four fundamental forces were introduced in Senior 3 Physics.

Notes to the Teacher

When a nucleus decays, it releases energy. This energy may be in the form of particles (which possess kinetic energy) or waves. Alpha particles are literally fragments of the nucleus, being made of two protons and two neutrons (they are, in fact, identical to the nucleus of a Helium-4 atom). An isotope that releases alpha particles is described as an **alpha emitter**, and the process of ejecting an alpha particle from the nucleus is **alpha decay**. The remainder of the original nucleus is referred to as the **daughter nucleus**, which has two fewer protons and two fewer neutrons (its elemental identity is therefore changed) compared to the parent nucleus, and may itself be unstable. As an example, Uranium-238 undergoes alpha decay, resulting in a daughter nucleus, which is Thorium-234.

Beta decay is the name given to the process of the nucleus ejecting a beta particle. Beta particles are identical to electrons. The complication that arises is that there were no electrons in the nucleus to begin with. The ejected beta particle is in fact created in the process in which a neutron in the nucleus is converted into a proton. This process may suggest that a neutron is merely a proton and an electron merged together, but this is not the case. In the subatomic realm, particle creation and particle annihilation are commonplace. As an example, Carbon-14 undergoes beta decay, resulting in a daughter nucleus, which is Nitrogen-14.

Another possibility is that the particles of the nucleus do not change in terms of their actual makeup, but rather settle into a lower energy state, releasing the energy as electromagnetic radiation (i.e., **gamma rays**). Gamma rays are essentially a higher energy form of visible light, and are parts of what is generally referred to as **electromagnetic waves**. The electromagnetic spectrum is the family of all electromagnetic waves, which are identified by frequency and wavelength. The constituents of the electromagnetic spectrum in order of increasing energy, increasing frequency, and decreasing wavelength, are: radio waves, microwaves, infrared, visible light, ultraviolet light, X-rays, and gamma rays.

At this point, inclusion of a diagram of the electromagnetic spectrum, followed by a discussion with students, would be appropriate.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-2c: Formulate operational definitions of major variables or concepts.

S4P-0-4b: Work co-operatively with a group to identify prior knowledge, initiate and exchange ideas, propose problems and their solution, and carry out investigations.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand the composition of the universe, the interactions within it, and the impacts of humankind's continued attempts to understand and explore it (GLO D6)

SUGGESTIONS FOR INSTRUCTION

Prior Knowledge Activity

Students collaborate and enter into their science journal real-life stories of medical treatments using radiation.

Student Activity

Students use Three-Point Approach concept frames (SYSTH) to detail the characteristics of alpha, beta, and gamma radiation.

SUGGESTIONS FOR ASSESSMENT

Students use compare/contrast frames (SYSTH) to compare different forms of radiation.

SUGGESTED LEARNING RESOURCES

BLM 68-1: The Bohr Atom, *Physics: Concepts and Connections*, Irwin Publishing Ltd., 2003

BLM 39-2: Conceptual-Development Practice, Nuclear Reactions, *Conceptual Physics,* Pearson, 2002

Appendix 4.2: Alpha Decay

Appendix 4.3: Beta Decay

Appendix 4.4: Gamma Radiation

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand the properties and structures of matter as well as various common manifestations and applications of the actions and interactions of matter (GLO D3)

SPECIFIC LEARNING OUTCOME

S4P-4-5: Compare and contrast sources and characteristics of ionizing radiation and non-ionizing radiation.

Include: NORM (Naturally Occurring Radioactive Materials), radon, background radiation, incandescent light bulb, hot objects

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

None.

Notes to the Teacher

Some students may have the belief that "radiation" is dangerous and should be avoided. While radiation can be dangerous, it is impossible to avoid and is not necessarily dangerous. Many common materials in our environment are naturally radioactive—they contain isotopes that are unstable. Everything from the air we breathe, to the foods we eat, to the Earth we live on is radioactive. In addition to these terrestrial sources, we are constantly bathed in radiation that comes from space, including from our own Sun.

Radiation of all forms can be generally described as ionizing or non-ionizing. After it has been released from the nucleus, the various forms of radiation can interact with matter. In particular, the radiation can interact with the electrons that surround a neutral atom. If the radiation has sufficient energy, it can remove the electron from its parent nucleus, leaving a charged ion and a free electron—in which case the radiation is identified as **ionizing**. If the radiation does not have sufficient energy to cause the ionizing, it is identified as **non-ionizing**.

If the term **radiation** is used in the most general sense, virtually everything is a source of radiation. In particular, all objects emit electromagnetic radiation of a type and amount that depend on the temperature of the object. At room temperature, objects mostly emit infrared (non-ionizing) radiation. At higher temperatures, they additionally emit visible light (non-ionizing) radiation. For example, the filament of an incandescent light bulb is designed to emit visible light by reaching a sufficiently high temperature.

One source of radiation of particular concern is that of radon. Uranium is found in very small amounts in virtually all soil. Uranium undergoes a series of decay events, with one of the eventual isotopes produced being Radon-222. Radon is a noble gas, and so does not react chemically. Being a gas, it seeps out of the soil and enters the atmosphere, at which point it can be inhaled. While in the lungs, it may decay (it is an alpha emitter), subjecting the lungs to alpha radiation. Furthermore, the daughter products of this decay are also radioactive, not inert, and can interact with the lining of the lung, where they will remain.

Demonstration

Thomas A. Walkiewicz, Collection of Radon Daughter Products, *Physics Teacher* 33 (1995): 345.

Summary

Ionizing radiation is radiation consisting of particles (such as α or β particles, fast-moving neutrons) or high-energy electromagnetic waves (such as γ-rays, X-rays, high-energy UV rays) that have sufficient energy to knock electrons out of atoms and molecules, and create ions.

There are several sources of radiation in our environment. These include background radiation from cosmic rays, radioactive nuclei in our own bodies, radioactive particles in the Earth and in the air around us, and radon found in the soil and rocks.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-2i: Select and integrate information obtained from a variety of sources.

Include: print, electronic, specialists, or other resource people

S4P-0-4e: Demonstrate a continuing and more informed interest in science and science-related issues.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand the properties and structures of matter as well as various common manifestations and applications of the actions and interactions of matter (GLO D3)

SUGGESTIONS FOR INSTRUCTION

There are several man-made sources of radiation. Examples are radioactive sources in consumer products like the mantle of gas lanterns, smoke detectors, and the radiation we may be exposed to through medical procedures.

Radiation can damage the cells of biological organisms. The ions produced during ionization can interfere with chemical reactions in the cell. Ionization can break apart molecules in the cell so it cannot function in a normal way, or it may be completely destroyed. If the DNA of a cell is damaged, the materials of the cell cannot be properly produced. This may cause the cell to die or defective cells may be produced, leading to cancer. High doses of radiation may lead to radiation sickness (nausea, fever, loss of body hair, etc.). Damage to the DNA in reproductive cells may lead to mutations that are transmitted to future generations.

Non-ionizing electromagnetic radiation has several uses: low-frequency radio and television waves are used in communication; microwaves are used in satellite communication, radio astronomy, microwave ovens, and diathermy machines; and infrared radiation is used in remote control units, motion detectors, heat lamps, satellites for examining crop diseases and detecting missile launchers, thermographs for the detection of brain tumours and cancers, and infrared telescopes.

Visible light is used to expose photographic film and to treat premature infants who may have developed jaundice. It is needed for photosynthesis to occur. Because visible light may be energetic enough to break apart some delicate chemical bonds, some substances are stored in dark bottles.

Ultraviolet light causes tanning and sunburn, and prolonged exposure can cause wrinkles, liver spots, actinic keratosis, and cancer. It can inhibit the immune system and can kill micro-organisms. Ultraviolet light is largely filtered out as it passes through our atmosphere.

SUGGESTIONS FOR ASSESSMENT

Students use compare/contrast frames (SYSTH) to compare ionizing and non-ionizing forms of radiation.

SUGGESTED LEARNING RESOURCES

<www.eco-usa.net/toxics/index.shtml> (Look under “Other compounds” for Radon)

General Learning Outcome Connection

Students will…

Recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena (GLO A1)

Specific Learning Outcome

S4P-4-6: Describe various applications of non-ionizing radiation.

Examples: communications, microwave oven, laser, tanning bed

Suggestions for Instruction

Notes to the Teacher

Radiation plays an important and varied role in our everyday lives. Some applications of radiation, such as communications and microwave ovens, are perceived as useful. Other applications, such as food irradiation, are controversial, and others, such as sunburn and radiation therapy, have major medical consequences. These outcomes are ideal for independent student research. Students should be able to explain the basic physics from their research, identify both sides of controversial issues, and address societal concerns.

Non-ionizing Radiation: Radio Waves to Infrared Waves

Electromagnetic (EM) radiation with a high energy (γ-rays, X-rays, high-energy UV rays) has the ability to ionize atoms and molecules, but EM waves with a low energy do not. The electromagnetic spectrum has traditionally been divided into seven or so regions that tend to overlap. The EM waves with the longest wavelength, the lowest frequency, and the lowest energy are the radio waves. In order of increasing energy, the spectrum continues with microwaves, infrared, visible light, ultraviolet light, X-rays, and finally γ-rays. The low-energy EM waves have various applications.

The lowest-frequency electromagnetic waves of practical importance are radio and television waves. The radios we listen to are most often either AM (amplitude modulation) or FM (frequency modulation). The frequency range for AM waves is 545 kHz to 1605 kHz. The frequencies of FM radio waves lie between 88 MHz and 108 MHz. Television channels 2 to 6 utilize electromagnetic waves with frequencies between 54 and 88 MHz, while channels 7 to 13 use frequencies between 174 and 216 MHz.

The frequency region from about 109 Hz, 1 gigahertz (1 GHz) up to roughly 3×10^{11} Hz is in the domain of microwaves. Microwaves can penetrate the Earth's atmosphere and this makes them especially useful for space-vehicle communications and radio astronomy. Microwaves are used to communicate through the use of satellites, and therefore are useful in telephone or cell phone technology. Airplanes communicate with each other and with ground stations using microwaves. Television stations that communicate with each other do so through microwaves.

Water molecules absorb microwave radiation, causing them to vibrate back and forth. This vibrational energy is rapidly converted to thermal energy, and the water heats up. This is what happens in a microwave oven. The object to be heated must contain water, so a dry paper plate will remain quite cool. In a similar way, the diathermy machine can be used to warm muscles and joints to relieve soreness.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-2d: Estimate and measure accurately using SI units.

S4P-0-2i: Select and integrate information obtained from a variety of sources.
Include: print, electronic, specialists, or other resource people

S4P-0-3a: Analyze, from a variety of perspectives, the risks and benefits to society and the environment when applying scientific knowledge or introducing technology.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that scientific and technological endeavours have been and continue to be influenced by human needs and the societal context of the time (GLO B2)

SUGGESTIONS FOR INSTRUCTION

The infrared band merges with microwaves at around 300 GHz (10^9 Hz, 1.0 mm wavelength) and extends to about 385 THz (10^{12} Hz, 780 mm wavelength). Infrared radiation is really heat radiation. One application of infrared radiation in the communications field is its use as a television remote control unit. Infrared devices can also be used as motion detectors and therefore as security devices. Another application of infrared radiation is in the use of heat lamps that can be used in physical therapy to treat sore muscles. Photographic films that are sensitive to infrared radiation can produce pictures, known as thermographs, which show temperature distribution in a part of the body and therefore any abnormal blood flow. They can help in the detection of brain tumours and breast cancer. Satellites that can detect infrared radiation can look out for crop diseases and rocket launchers. Infrared telescopes are used to scan the sky.

Student Research

Students use a jigsaw approach to investigate the applications and effects of radiation. Divide the class into “expert” groups. The expert groups each research a different topic. Groups are re-formed with an “expert” from each of the groups. The “expert” presents his or her research to the rest of the group in a collaborative exchange of ideas.

Students interview medical technologists, doctors, dentists, and research scientists about the use of radiation in their careers.

SUGGESTIONS FOR ASSESSMENT

Visual Display

Students create posters on the applications and effects of radiation. Students prepare a Gallery Walk for other students, teachers, and parents.

Research Report/Presentation

Students can work in small groups to prepare a report on the applications of non-ionizing and ionizing radiation. Students can include an analysis of the benefits to, and possible harmful effects on, humans.

Students can research and report on each type of medical technology (imaging and/or treatment).

Rubrics/Checklists

Develop a rubric/checklist in collaboration with the students to guide students during the research and presentation of their reports.

SUGGESTED LEARNING RESOURCES

Appendix 4.5: Radioisotopes and Their Use in the Diagnosis or Treatment of Illness

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Describe scientific and technological developments, past and present, and appreciate their impact on individuals, societies, and the environment, both locally and globally (GLO B1)

SPECIFIC LEARNING OUTCOME

S4P-4-7: Describe various applications of ionizing radiation.

Examples: food irradiation, sterilization, smoke alarm

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

Applications of Ionizing Radiation

One of the practical applications of the use of ionizing radiation is in a smoke detector. The detector makes use of the alpha decay of the artificial radioactive isotope $^{241}_{95}Am$. In this type of smoke detector, a minute quantity of $^{241}_{95}Am$ is placed between two metal plates connected to a battery or other source of emf. The α particles emitted by the source ionize the air, allowing a measurable electric current to flow between the plates. As long as this current flows, the smoke detector remains silent. When smoke enters the detector, however, the ionized air molecules tend to stick to the smoke particles and become neutralized. This reduces the current and triggers the alarm. These "ionization" smoke detectors are more sensitive than the "photoelectric" detectors that rely on the thickness of smoke to dim a beam of light.

Ionizing radiation can also be use to irradiate food. The radiation can destroy insects and parasites in grains, dried beans, dried fruits and vegetables, and meat and seafood. It can decrease the numbers of micro-organisms in foods. Hence, the incidence of food-borne illness and disease can be decreased. The radiation can also be used to increase the shelf life of food by inhibiting sprouting in crops such as potatoes and onions, and delay the ripening of fresh fruits and vegetables. The sources of the radiation can be isotopes of cobalt, $^{60}_{27}Co$, or cesium $^{137}_{55}Cs$, or from particle accelerators that produce controlled amounts of beta rays or X-rays on food.

Because ionizing radiation can destroy micro-organisms, it can also be used to sterilize medical equipment. Cobalt or cesium isotopes or particle accelerators are used for this purpose.

Skills and Attitudes Outcomes

S4P-0-3b: Describe examples of how technology has evolved in response to scientific advances and how scientific knowledge has evolved as the result of new innovations in technology.

S4P-0-3c: Identify social issues related to science and technology, taking into account human and environmental needs and ethical considerations.

General Learning Outcome Connection

Students will…

Recognize safety symbols and practices related to scientific and technological activities and to their daily lives, and apply this knowledge in appropriate situations (GLO C1)

Suggestions for Instruction

Teaching Notes

Suggestions for Assessment

Students use compare/contrast frames (SYSTH) to compare ionizing and non-ionizing forms of radiation.

Suggested Learning Resources

<www.eco-usa.net/toxics/index.shtml> (Look under “Other compounds” for Radon)

General Learning Outcome Connection

Students will…

Identify the factors that affect health and explain the relationships among personal habits, lifestyle choices, and human health, both individual and social (GLO B3)

Specific Learning Outcome

S4P-4-8: Describe the effects of non-ionizing and ionizing radiation on the human body.

Include: equivalency of sievert (Sv) and rem units, solar erythema (sunburn)

Suggestions for Instruction

Notes to the Teacher

Radiation Damage in Biological Organisms

Radiation can damage the cells of biological organisms. There are various ways in which this damage can occur.

When the atoms and molecules are ionized, ions (also called radicals) are produced. These ions are highly reactive and take part in chemical reactions that interfere with the normal operation of the cell. Also, when electrons are knocked out of molecules, it may cause the molecule to break apart. The structure of the molecule may be altered so that it does not perform its normal function, or it may perform a harmful function. In the case of proteins, the loss of one molecule is not serious if there are other copies of that particular one in the cell, and the cell can make additional ones. However, large doses of radiation may damage so many molecules that new copies cannot be made quickly enough and the cell dies.

Ionizing radiation may also damage the DNA in the cell. It is the DNA that provides a code that allows the production of proteins and other materials for the cell. If the DNA is damaged, these materials may not be made at all and the cell may die. In most cases, the death of a single cell is not a problem, since the body can replace it with a new one. (There are some exceptions, such as neurons, which may not be replaceable, so their loss is serious.) But if many cells die, the organism may not be able to recover. On the other hand, the cell may survive but be defective. It may go on dividing and produce more defective cells to the detriment of the whole organism. Cancer is caused when defective cells are rapidly produced.

Radiation damage to biological organisms is often divided into categories according to its location in the body: "somatic" and "genetic." Somatic damage refers to any part of the body except the reproductive organs. Somatic damage affects that organism and may cause cancer. At high doses, radiation may cause radiation sickness. Nausea, vomiting, fever, diarrhea, fatigue, a loss of body hair, or even death characterize radiation sickness. The severity of radiation sickness is related to the dose received. Genetic damage refers to damage to reproductive cells and so affects the individual's offspring. Damage to the DNA and the genetics of the reproductive cells results in mutations, the majority of which are harmful. These mutations are transmitted to future generations.

Visible Light to Ultraviolet Light: Non-ionizing and Ionizing Effects in Humans

Visible light ranges in wavelength from approximately 400 nm for violet light to 700 nm for red light. Some white light is energetic enough to produce chemical reactions. Light can break up delicate chemical bonds, so dark bottles protect substances like aspirin and wine. Light-sensitive photographic films are commonplace. Premature infants may develop jaundice, due to an excess of bilirubin in the blood. This condition can be successfully treated by exposing them to light, since blue-light has enough energy to dissociate the bilirubin molecule. The process of photosynthesis requires light. Photosynthesis removes 200 thousand

SKILLS AND ATTITUDES OUTCOMES

S4P-0-4b: Work co-operatively with a group to identify prior knowledge, initiate and exchange ideas, propose problems and their solution, and carry out investigations.

S4P-0-4c: Demonstrate confidence in their ability to carry out investigations in science and to address STSE issues.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize safety symbols and practices related to scientific and technological activities and to their daily lives, and apply this knowledge in appropriate situations (GLO C1)

SUGGESTIONS FOR INSTRUCTION

million tons of carbon yearly from the atmosphere and produces many complex organic molecules.

Ultraviolet rays have a wavelength range of approximately 400 nm to 12.5 nm. UV light controls some dermatological conditions, such as tanning, activating the synthesis of Vitamin D. At wavelengths of approximately 300 nm and below, UV rays can cause sunburn as well as tanning. Interestingly, UV rays at this wavelength have the energy needed to break carbon-carbon bonds. Much of this radiation is filtered out as it passes through the atmosphere, especially in the higher latitudes and at low-sun angles that occur in winter and in the early and late parts of the day. The ozone layer (O_3 molecules) helps to absorb some of the UV radiation. UV radiation below 300 nm can damage or destroy nucleic acids and proteins, both of which are strong absorbers of UV rays. Extended exposure to UV rays can, in time, cause wrinkles, liver spots, actinic keratosis (pre-cancerous dark blotches), and finally cancer. UV rays can also inhibit the immune system, which may explain why some viral diseases, such as fever blisters and chicken pox, get more severe when the person is exposed to sunshine. Some materials reflect UV light as much as they reflect visible light, so long exposure while near snow or water can be hazardous. The same is true for lying about on a beach on a totally overcast summer day, since water vapour passes a good deal of UV rays. In contrast, ordinary window glass can stop the passage of UV rays. For UV rays at wavelengths less than 290 nm, the energy can ionize an atom or break apart a chemical bond. These kinds of UV rays are germicidal—that is, they kill microorganisms.

SUGGESTIONS FOR ASSESSMENT

Students use compare/contrast frames (SYSTH) to compare ionizing and non-ionizing forms of radiation.

SUGGESTED LEARNING RESOURCES

<www.eco-usa.net/toxics/index.shtml> (Look under “Other compounds” for Radon)

General Learning Outcome Connection

Students will…

Identify and appreciate contributions made by women and men from many societies and cultural backgrounds toward increasing our understanding of the world and in bringing about technological innovations (GLO A4)

Specific Learning Outcome

S4P-4-9: Research, identify, and examine the application of radiation to diagnostic imaging and treatment techniques.

Examples: nuclear medicine imagery techniques such as MRI, ultrasound, endoscopy, X-ray, CT scanning, PET, heavy isotopes such as Ba; nuclear medicine therapies such as brachitherapy, external beam, gamma knife

Suggestions for Instruction

Notes to the Teacher

Ultrasound and Medical Imaging

Ultrasonic sound waves (frequency range from 1 megahertz to 10 megahertz) can be used in medicine for both diagnosis and treatment. In diagnosis, the technique works as follows. A transducer emits a brief pulse of ultrasound. A transducer is a device that transforms an electrical pulse into a mechanical vibration that produces the sound wave. Part of the pulse is reflected at various interface surfaces in the body, and most continue on through the body. The detection of the pulse is done by the same transducer, which transforms the sound pulses into electrical pulses. These pulses can then be displayed on the screen of a cathode-ray tube, such as a display terminal or TV monitor. As an example, consider a sound pulse passing through the abdomen. At various interfaces in the body, part of the pulse is reflected. The time elapsed from when the pulse is emitted to when its reflection (echo) is received is proportional to the distance from the reflecting surface. The strength of a reflected pulse depends mainly on the difference in density of the two materials on either side of the interface. At interfaces involving bones or the lungs, most of the sound pulse is reflected so ultrasound cannot be used as a probe beyond such surfaces.

In the diagnostic use of ultrasound a **pulse-echo technique** is applied. A high-frequency sound pulse is directed into the body, and its reflections from boundaries or interfaces between organs and other structures and lesions in the body are then detected. By using this technique, tumours and other abnormal growths, or pockets of fluid, can be distinguished. The action of heart valves and the development of a foetus can be examined. Information about various organs of the body, such as the brain, heart, liver, and kidneys can be obtained. Although ultrasound does not replace X-rays, for certain kinds of diagnoses, it is more helpful. Some kinds of tissue or fluid are not detected in X-ray photographs, but ultrasound waves are reflected from their boundaries. It is also possible to produce “real-time” ultrasound images as if one were watching a movie of a section of the interior of the body. Furthermore, at low levels of intensity, no adverse effects have been reported, so ultrasound is considered a non-invasive method for probing the body.

Another use of ultrasound in medical diagnosis involves the **Doppler effect**, the change observed in the frequency with which a wave from a given source reaches an observer when the source and the observer are in relative motion. For example, ultrasonic waves reflected from red blood cells can be used to determine the velocity of blood flow. The Doppler flow meter can be used to locate regions where blood vessels have narrowed. The Doppler effect can also be used to determine the movement of the chest of a young foetus and to monitor its heartbeat.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-4d: Develop a sense of personal and shared responsibility for the impact of humans on the environment, and demonstrate concern for social and environmental consequences of proposed actions.

S4P-0-4e: Demonstrate continuing and more informed interest in science and science-related issues.

GENERAL LEARNING OUTCOMES CONNECTION

Students will…

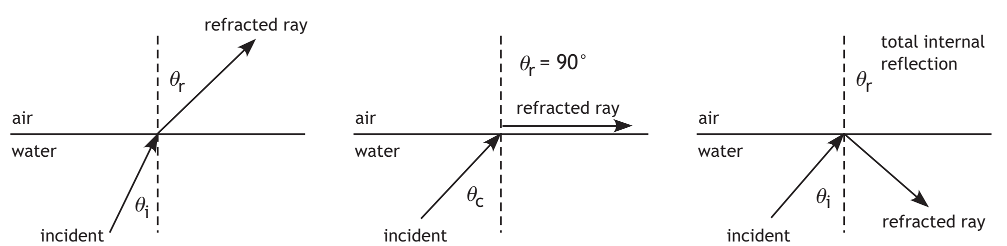
Describe scientific and technological developments, past and present, and appreciate their impact on individuals, societies, and the environment, both locally and globally (GLO B1)

Demonstrate a knowledge of, and personal consideration for, a range of possible science- and technology-related interests, hobbies, and careers (GLO B4)

SUGGESTIONS FOR INSTRUCTION

Endoscopy and Arthroscopic Surgery

An **endoscope** is a device used to peer the inside of the body, and **endoscopy** is the practice of using such a device. To understand how an endoscope functions, let us briefly review what total internal reflection is. When light passes from a medium with a larger index of refraction into a smaller index of refraction (such as water to air), the refracted light bends away from the normal. The angle of refraction, θ_r is greater than the angle of incidence, θ_i. As the angle of incidence increases, the angle of refraction also increases. When the angle of incidence reaches a certain angle called the **critical angle**, $\boldsymbol{\theta_c}$, the angle of refraction is 90°. Then the refracted angle points along the surface. When the angle of incidence exceeds the critical angle, there is no refracted light. All the incident light is reflected back into the medium from which it came, a phenomenon called **total internal reflection**.



SUGGESTIONS FOR ASSESSMENT

Students use compare/contrast frames (SYSTH) to compare ionizing and non-ionizing forms of radiation.

SUGGESTED LEARNING RESOURCES

<www.eco-usa.net/toxics/index.shtml> (Look under “Other compounds” for Radon)

General Learning Outcome Connection

Students will…

Identify and appreciate contributions made by women and men from many societies and cultural backgrounds toward increasing our understanding of the world and in bringing about technological innovations (GLO A4)

Specific Learning Outcome

S4P-4-9: Research, identify, and examine the application of radiation to diagnostic imaging and treatment techniques.

Examples: nuclear medicine imagery techniques such as MRI, ultrasound, endoscopy, X-ray, CT scanning, PET, heavy isotopes such as Ba; nuclear medicine therapies such as brachitherapy, external beam, gamma knife

Suggestions for Instruction

An important application of total internal reflection occurs in fibre optics, where hair-thin threads of glass or plastic, called optical fibres, "pipe" light from one place to another. An optical fibre consists of a cylindrical optical *core* that carries the light, and an outer concentric shell, the *cladding*. The core is made from transparent glass or plastic that has a relatively high index of refraction. The cladding is also made of glass, but of a type that has a relatively low index of refraction. Light enters one end of the core, strikes the core/cladding interface at an angle of incidence greater than the critical angle, and therefore, is reflected back into the core. Light, then, travels inside the optical fibre along a zigzag path.

Summary of Imaging Techniques

Ultrasound is a high-frequency sound wave produced when a transducer transforms an electrical pulse into a mechanical vibration and then detects the same wave after it has been reflected from interfaces between organs and other structures in the body. In the **pulse-echo technique**, several forms of diagnosis can take place, including the detection of tumours and abnormal growths, pockets of fluid, the action of heart valves, the development of a foetus, and information about various organs in the body. Ultrasound can detect some kinds of tissue and fluid that X-rays cannot. Ultrasound is a non-invasive form of probing the body and has no adverse effects. By using the **Doppler effect**, it is possible to locate regions where blood vessels have narrowed, and to monitor a foetus. Ultrasonic waves of high intensity can be used to destroy tumours and kidney stones.

Endoscopy is the practice of using an **endoscope**, a device used to peer inside the body. The endoscope consists of very thin threads of glass and plastic called **optical fibres**. The fibres are able to pipe light from one place to another through the process of **total internal reflection** which occurs when incident light is reflected back into the medium it came from when the angle of incidence exceeds the **critical angle**. Endoscopes such as the bronchoscope or colonoscope can be inserted into the body to diagnose disease. Optical fibres can also be used in arthroscopic surgery where only a tiny incision is needed, resulting in minimal damage to surrounding tissue.

A **laser** light is produced when excited atoms give off photons that in turn excite other atoms. For every one photon absorbed by an atom, two are emitted. The emitted photons travel in the same direction as the incident photon, and the light waves produced are in phase with each other and the output beam is monochromatic. One of the uses of laser light is a process called **photorefractive keratectomy (PRK)**, where tissues can be removed from the cornea to correct nearsightedness or farsightedness. A **pulsed dye laser** can be used in the treatment of congenital capillary malformations. **Photodynamic therapy** uses lasers to activate drugs that kill cancer cells.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-4d: Develop a sense of personal and shared responsibility for the impact of humans on the environment, and demonstrate concern for social and environmental consequences of proposed actions.

S4P-0-4e: Demonstrate continuing and more informed interest, in science and science-related issues.

GENERAL LEARNING OUTCOMES CONNECTION

Students will…

Describe scientific and technological developments, past and present, and appreciate their impact on individuals, societies, and the environment, both locally and globally (GLO B1)

Demonstrate a knowledge of, and personal consideration for, a range of possible science- and technology-related interests, hobbies, and careers (GLO B4)

SUGGESTIONS FOR INSTRUCTION

X-rays are a form of electromagnetic radiation produced when electrons are accelerated through a large potential difference and then made to collide with a metal target. When X-rays are directed toward a body, the denser tissue, like bones, absorb more of the radiation, leaving a lighter image on a photographic film or fluorescent screen. **Computerized axial tomography (CAT)**, also called **computerized tomography (CT)** uses collimated X-rays, detectors, and computer analysis to produce images of body structures and lesions that have a higher resolution than X-rays. Two-dimensional slices or three-dimensional images may be produced.

Magnetic resonance imaging (MRI) uses a strong magnetic field to align the nuclei of hydrogen atoms inside the body. Radiofrequency coils produce RF waves that excite the hydrogen nuclei. When the nuclei fall back down to ground state, the RF coils detect the energy and a computer analyzes the signals to produce remarkably detailed images of the human body that can be used in medical diagnosis.

SUGGESTIONS FOR ASSESSMENT

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