Unit 3
Matter Energy Interface
Suggested Time: 24 Hours

Unit Overview

Introduction

The time period between 1890 and 1930 saw the development of concepts which are still referred to as "modern physics." At the same time, research was being carried out on the nature of electromagnetic phenomena, including the nature of light. It was in this period that these branches of research became linked.

In their daily lives, people are exposed to radiation from a variety of sources. Some radiation is harmless; other radiation is potentially harmful. Some kinds of radiation can be used in beneficial ways. Students should explore the full range of types of radiation, including natural and artificial sources, and assess the risks and benefits of exposure to each of them.

Focus and Context

This historical context provides students with a means to connect developments which occurred independently and seem, at first, to be unrelated. The objective should be for students to develop an integrated view of the achievements that form the essence of twentieth-century physics. By reading and writing about activities and investigations which occurred during this period, students will consolidate their knowledge and understanding.

Perhaps the most awesome achievement of the twentieth century was the development of fission and fusion technologies. Our world is still threatened by vast stockpiles of nuclear weapons. Their storage and their decommissioning present a challenge to our very existence. At the same time, our fission reactors are aging rapidly. Design flaws are becoming apparent and the technology has spread to countries whose motives are suspect and safety practices inadequate.

This unit presents an excellent STSE issue with which to end the course. Students can apply the knowledge they have gained to the problems of future development, storage and handling, and alternative energy sources for the new millennium. This investigation will help students become informed about political decisions our society must soon face.

Science Curriculum Links

In Physics 2204, students will have begun to compare the merits of wave and particle models in explaining the behaviour of light. In this unit, they will extend their understanding to the wider range of electromagnetic phenomena and make connections to theories relating to the structure of matter.

The structure of the atom was introduced in grade 9 Science. This unit helps to further develop skills in dealing with social issues in science.

Curriculum Outcomes

STSE

Students will be expected to

Nature of Science and Technology

115-3 explain how a photon momentum revolutionized thinking in the scientific community

115-5 analyse why and how a particular technology was developed and improved over time

115-7 explain how scientific knowledge evolves as new evidence comes to light and as laws and theories are tested and subsequently restricted, revised, or replaced

Relationships Between Science and Technology

116-4 analyse and describe examples where technologies were developed based on scientific understanding

116-6 describe and evaluate the design of technological solutions and the way they function, using scientific principles

Social and Environmental Contexts of Science and Technology

117-5 provide examples of how science and technology are an integral part of their lives and their community

117-11 analyse examples of Canadian contributions to science and technology

118-2 analyse from a variety of perspectives the risks and benefits to society and the environment of applying scientific knowledge or introducing a particular technology

118-4 evaluate the design of a technology and the way it functions on the basis of a variety of criteria that they have identified themselves

Skills

Students will be expected to

Performing and Recording

213-6 use library and electronic research tools to collect information on a given topic

213-7 select and integrate information from various print and electronic sources or from several parts of the same source

212-9 develop appropriate sampling procedures

213-8 select and use apparatus and materials safely

213-9 demonstrate a knowledge of WHMIS standards by selecting and applying proper techniques for handling and disposing of lab materials

Analysing and Interpreting

214-2 identify limitations of a given classification system and identify alternative ways of classifying to accommodate anomalies

214-6 apply and assess alternative theoretical models for interpreting knowledge in a given field

214-12 explain how data support or refuse the hypothesis or prediction

214-15 propose alternative solutions to a given practical problem, identify the potential strengths and weaknesses of each, and select one as the basis for a plan

Communication and Teamwork

215-4 identify multiple perspectives that influence a science-related decision or issue

215-5 develop, present, and defend a position or course of action, based on findings

Knowledge

Students will be expected to

326-9 apply quantitatively the law of conservation of mass and energy using Einstein's mass-energy equivalence

327-9 describe how the quantum energy concept explains black-body radiation and the photoelectric effect

327-10 explain qualitatively and quantitatively the photoelectric effect

327-11 summarize the evidence for the wave and particle models of light

329-1 explain quantitatively the Bohr atomic model as a synthesis of classical and quantum concepts

329-2 explain quantitatively the Bohr atomic model as a synthesis of classical and quantum concepts

329-3 explain the relationship among the energy levels in Bohr's model, the energy difference between levels, and the energy of the emitted photons

329-4 describe the products of radioactive decay, and the characteristics of alpha, beta, and gamma radiation

329-5 describe sources of radioactivity in the natural and constructed environments

329-6 compare and contrast fission and fusion

329-7 use the quantum mechanical model to explain natural luminous phenomena

Quantum Physics

Outcomes

Students will be expected to

- explain how quantum physics evolved as new evidence came to light (115-7, 213-6)
  - define quantum theory
  - state the problems with the wave theory of light. Include:
    - (i) energy is quantified
    - (ii) light has momentum
    - (iii) atomic particles exhibit wave properties
    - (iv) neutral atoms are stable

Elaborations—Strategies for Learning and Teaching

At the end of the nineteenth century, physicists seemed poised to be able to present a complete explanation of this natural world. Newtonian mechanics (matter) and Maxwell's electro-magnetic theory (waves) had solved most of the problems related to the behaviour of matter and light.

They were overly optimistic. It took the introduction of two concepts in the early twentieth century to resolve outstanding issues: the theory of relativity and quantum theory. Students should learn what impact quantum theory had on the Newtonian model of the universe.

Students should be able to make connections with their previous study of light from Physics 2204. Specifically, students should review the electromagnetic spectrum (see p. 391 in textbook). In building on this, the students could be asked to research everyday experiences with things that produce light. For example, the metal wire in a light bulb glows white when electricity is passed through it. A piece of steel will first glow red then eventually white hot as it is heated. Some gases, like neon, glow with a characteristic colour when electricity is applied to the gas in an evacuated tube.

- describe how the quantum energy concept explains both black-body radiation and the photoelectric effect (327-9)

Students should describe black-body radiation. Students do not have to use Wien's formula or Rayleigh-Jeans Law. Students will not be expected to do quantitative analysis for black-body radiation.

  - define blackbody radiation

Students could research the sequence of events that led to Planck's prediction of "quanta". This model predicted the behaviour, but it did not explain why it happened.

Note, the observation of the distribution of energy radiated from warm objects (black body radiation) led to a major dilemna. Classical theory could not describe the distribution of energy released at high frequencies (the UV catastrophe). Planck came up with a mathematical model to describe the actual distribution by proposing that the energy emitted at any particular frequency is released in discrete packets he called "quanta". The energy of each packet was proportional to its frequency.

  - define qualitatively the photoelectric effect

Einstein took the next step with his analysis of the photoelectric effect. Einstein concluded that **all energy** is made of tiny "wavy" packets which he called "photons". These photons were similar to Planck's quanta, having energy proportional to their frequency.

$$E_{photon} = hf \quad \text{where } h \equiv \text{Planck's constant}$$

$$E_{Total} = nhf \quad \text{where } n = 1, 2, 3, \ldots$$

Quantum Physics

Suggested Assessment Strategies

Presentation

- Groups of students could be created in each class to give presentations on the historical development of quantum theory.

  One group is given the task of preparing a multimedia presentation on the breakdown of classical theory as it applies to the "ultraviolet catastrophe." Another group should research the historical context of the photoelectric effect and where that fits into the historical context following Planck's theory and present their findings. A third group should research Einstein's role in explaining the photoelectric effect and once again fit that into the historical context as it relates to his use of the "quanta" that Planck proposed. (115-7, 213-6, 327-9, 327-10)

Resources/Notes

www.gov.nl.ca/edu/science_ref/main.htm

Concepts and Connections

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pages 702-707

Quantum Physics *(continued)*

Outcomes

Students will be expected to

- explain qualitatively and apply the formula for the photoelectric effect (327-10)
  - state and solve problems using Planck's equation (E=hf)
  - define and calculate the stopping potential
  - convert energy terms from Joules (J) to electronvolts (eV) and vice versa
  - define and calculate the work function
  - relate the energy of the incident light (photon) to the work function
- explain how scientific knowledge evolves as new evidence comes to light and as laws and theories are tested and subsequently restricted, revised or replaced. (115-7)
- analyze and describe examples where technological solutions were developed based on scientific understanding. (116-4)
- analyze technological systems to interpret and explain their structure. (116-7)

Elaborations—Strategies for Learning and Teaching

Einstein proposed the photoelectric effect as a test of Planck's quantum hypothesis, i.e., $E \propto f$. He pictured light as photons (particle-like) of energy. The photon theory of light predicts that each incident photon can strike an electron in a material and eject it if it has sufficient energy. The maximum energy of the ejected electrons is then related to the frequency of the incident light. Students should be introduced to Einstein's photoelectric effect equation: $hf = KE + W$, and the concept of the work function. Students should be able to apply the photoelectric effect formula on simple examples.

Note, at the atomic level, energy is commonly measured in electronvolts (eV). The origin of the conversion to Joules is from

$$\begin{aligned} V &= E/Q \\ \therefore\ E &= VQ \\ 1J &= 1V \times 1C \\ 1eV &= 1V \times 1e \\ &= leV \end{aligned} \qquad \text{OR} \qquad \begin{aligned} 1eV &= 1V \times 1.6 \times 10^{-19}C \\ &= 1J/C \times 1.6 \times 10^{-19}C \\ 1eV &= 1.6 \times 10^{-19}C \\ &= 1.6 \times 10^{-19}C \end{aligned}$$

Teachers should highlight that Planck used data from blackbody radiation experiments and then "fit" the formula $E = hf$ to match the data! This led the scientific community to quantum theory. The photoelectric effect was Einstein's test of the theory, which turned out to validate Planck's work.

Students could be asked to research the electrical devices that use the principle of the photoelectric effect, including such things as solar cells in calculators and infra-red remote control devices.

Using a high energy ultraviolet light source, a piece of polished zinc and a gold leaf electroscope, the teacher could demonstrate the photoelectric effect. A solar cell could be used to demonstrate the photoelectric effect as well.

The CORE STSE component of this unit, *The Physics of Movie Sound*, incorporates a broad range of Physics 3204 outcomes. More specifically it targets (in whole or in part) 327-9, 327-10, 115-7, 327-11, 116-4, and 116-7. The STSE component, *The Physics of Movie Sound,* can be found in Appendix B.

Quantum Physics *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- When electromagnetic radiation with a wavelength of 352 nm falls on a metal, the maximum kinetic energy of the ejected electrons is 1.20 eV. What is the work function of the metal? (327-10)
- What is the energy of a photon that has a wave length of 461 nm? (327-10)
- What is the stopping voltage of an electron that has 7.4 x 10^{-19} J of kinetic energy? (327-10)
- Light, with a frequency of 5.0 x 10^{14} Hz illuminates a photo electric surface that ahs a work funciton of 2.3 x 10^{-19} J. What is the maximum energy of the ejected electrons? (327-10)

Journal

- Research how the photoelectric circuit could be used in:
  - (a) a burglar alarm
  - (b) a smoke detector
  - (c) a potographic light meter (327-10)

Resources/Notes

Concepts and Connections

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Core STSE #3: *"The Physics of Movie Sound"*, Appendix B

Quantum Physics *(continued)*

Outcomes

Students will be expected to

- explain qualitatively the Compton effect and the de Broglie hypothesis, using the laws of mechanics, the conservation of momentum, and the nature of light (329-1)
  - do calculations using $p = \frac{h}{\lambda}$, Compton's photon momentum equation
- explain how photon momentum changed scientific thinking on the properties of light (waves) (115-3)
- explain how deBroglie's matter waves changed scientific thinking on the properties of particles (115-3)
  - do calculations using deBroglie's Wave Equation $\lambda = \frac{h}{mv}$

Elaborations—Strategies for Learning and Teaching

Students should make the connection between the photoelectric effect and the work of Compton with X-ray scattering that led to the concept of photon momentum.

Students should be aware of the scattering results of Compton. Emphasis here would be on the idea that this effect is connected to conservation of momentum and conservation of energy.

Photon momentum calculations should be limited to 1- dimensional problems only.

Students could reflect on the changes to the model of light that have arisen since the discovery of the photoelectric effect. The need to think differently, or "outside the box" about light under certain conditions should be emphasized.

Students should begin with a summary of the successes and shortcomings of the Newtonian particle model and the Huygen's wave model in exploring common light phenomena. In the early years Newton was an advocate of the particle model of light, whereas Huygen supported the wave model of light. They should discuss the impact of the photoelectric effect on the credibility of the two models. Finally, they should explain the need to synthesize elements of both theories in the form of the modern wave–particle duality model.

When investigating de Broglie (pronounced "de Broy") wavelengths, the students could calculate de Broglie wavelengths for real world-sized objects such as a basketball to help them develop an understanding of why we do not see the wave nature of objects of that scale.

Quantum Physics *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- What is the momentum of a photon whose wavelength is 451 nm? (329-1)
- Find the speed of an electron having the same momentum as a photon having a wavelength of 0.80 nm. (329-1)
- What is the de Broglie wavelength of an electron that has been accelerated from rest to a velocity of 4.8×10^6 m/s? (329-1)
- Calculate the de Broglie wavelength of a 1.0×10^3 kg car moving at 90.0 km/h. (329-1)

Presentation

- This is a continuation of the project from quantum physics on p. 89. One group of students should research and prepare multimedia presentations on Compton's scattering and its historical connection to the photoelectric effect as well as its consequences. Another group should research and prepare a presentation on the consequences of the photoelectric effect and Compton's scattering experiment to the wave model of light. A third group should research the work of de Broglie and his prediction of a particle wavelength. (115-3, 214-6, 329-1)

Resources/Notes

Concepts and Connections

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Compton and de Broglie

Outcomes

Students will be expected to

- explain that qualitatively the Bohr atomic model is a synthesis of classical and quantum concepts (329-2)
  - describe qualitatively how the Bohr model of the atom explains emission and absorption spectra
  - describe qualitatively and quantitatively Bohr's radius
  - define qualitatively and quantitatively the energy of an electron in Bohr's atom

Elaborations—Strategies for Learning and Teaching

As an optional extension, teachers could lead the students through the derivation of the energy level equation developed by Bohr to explain the hydrogen atom. The derivation should emphasize how Bohr connected this concept to the quanta of energy they were introduced to when they looked at Planck's work.

When observing light emitted from excited gases, it was discovered that only certain set frequencies or wavelengths of light were given off (bright line emission spectra). Balmer, Paschen and Lyman found mathematical patterns in the values of the wavelength of light released given by:

$$\frac{1}{\lambda} = \frac{1}{R}\left(\frac{1}{n_{lower}^{2}} - \frac{1}{n_{higher}^{2}}\right) \quad \text{when } n_{higher} = 2, 3, \ldots \text{ and } n_{lower} = 1, 2, 3, 4, \ldots$$

where $R = 1.10 \text{ x } 10^{7}\ \text{m}^{-1}$

Bohr's model of the atom equates the centripetal force required to keep the electron in circular atomic orbits, with the Coulomb's electric attraction between electron and proton. A model is then derived in which the energy of the photon emitted is a result of the change in energy of the electrons in its orbit.

$$\varepsilon_{photon} = \Delta\varepsilon \text{ electron}$$

$$\varepsilon_{photon} = \varepsilon_{\text{higher}} - \varepsilon_{\text{lower}}$$

$$\frac{\text{hc}}{\lambda} = \frac{-13.6 \text{ eV}}{\text{n}_{\text{higher}}^{2}} - \frac{-13.6 \text{ eV}}{\text{n}_{\text{lower}}^{2}}$$

$$\frac{\text{hc}}{\lambda} = 13.6 \text{ eV}\left(\frac{-1}{\text{n}_{\text{lower}}^{2}} + \frac{1}{\text{n}_{\text{higher}}^{2}}\right)$$

$$\frac{1}{\lambda} = \left(\frac{13.6 \text{ eV}}{\text{hc}}\right)\left(\frac{1}{\text{n}_{\text{lower}}^{2}} - \frac{1}{\text{n}_{\text{higher}}^{2}}\right)$$

↓

R = Rydberg's constant above.

Compton and de Broglie

Suggested Assessment Strategies

Journal

- Write a memo that explains how Bohr integrated ideas from classical and quantum physics. (329-2)

Paper and Pencil

- Find the energy of the second allowed orbit in the hydrogen atom. (329-2, 329-3)
- Determine the wavelength of the light given off when an electron in hydrogen moves from the n = 4 to the n = 2 orbit. (329-2, 329-3)
- Determine the energy required to cause an electron's transition from n = 1 to n = 4 in the hydrogen atom. (329-3)

Resources/Notes

Concepts and Connections

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Bohr Atoms and Quantum Atoms

Outcomes

Students will be expected to

- explain the relationship among the energy levels in Bohr's model, the energy difference between levels, and the energy of the emitted photons (329-3)
  - do calculations to determine energy lost/gained of an electron as it jumps up or down various orbits
  - do calculations to determine the wavelength of electromagnetic radiation released/required when an electron jumps various orbits
  - compare the calculated wavelengths of electromagnetic energy (for electrons moving into a lower n) to the emission spectra for hydrogen

Elaborations—Strategies for Learning and Teaching

Students should calculate specific energy levels and the difference between any two energy levels of the Bohr atom.

$$\Delta\varepsilon = \varepsilon_{higher} - \varepsilon_{lower}$$

$$\Delta\varepsilon = \frac{-13.6}{6^2} - \frac{-13.6}{2^2}$$

$$= 3.4 \text{ eV} + 0.38 \text{ eV}$$
$$= 3.02 \text{ eV}$$

Since $\lambda = \frac{c}{f}$ and $\Delta\varepsilon = hf$

$$f = \frac{\Delta\varepsilon}{h} = \frac{\varepsilon_{higher} - \varepsilon_{lower}}{h}$$

$$\lambda = \frac{hc}{\Delta\varepsilon} = \frac{hc}{3.02 \text{ eV}}$$

$$f = 4.1 \times 10^{-7} \text{ m}$$

Note that when doing $\Delta\varepsilon$ calculations for absorption or emission, we take the absolute value of $\Delta\varepsilon$. Students should know however, that absorption spectra involve a gain in energy, while emission spectra involve a loss in energy.

Students should observe the spectra of various gases, particularly hydrogen, with a spectroscope by using an animated internet version. Emphasis should be placed on the production of light by the excitation of electrons from one permitted energy level to another and returning to ground state. These "jumps" then must agree with known spectral lines produced by hydrogen and Bohr's calculation of the constant E_n.

Bohr Atoms and Quantum Atoms

Suggested Assessment Strategies

Resources/Notes

Concepts and Connections

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Bohr Atoms and Quantum Atoms (continued)

Outcomes

Students will be expected to

- use the quantum-mechanical model to explain naturally luminous phenomena (329-7)
- summarize the evidence for the wave and particle models of light (327-11)
  - describe phosphorescence and fluorescence
  - define wave-particle duality

Elaborations—Strategies for Learning and Teaching

Students should make connections between the Bohr model of the atom and examples of natural luminosity such as phosphorescence and fluorescence.

Teachers should note that naturally luminous phenomena is not discussed in the textbook, and will, therefore, need to be supplemented. The fundamental ideas are:

i) Phosphorescence
An example of phosphorescence is a luminous watch dial. Atoms are excited by absorption of a photon to an energy level said to be metastable. When an atom is raised to a normal excited state, it drops back down in about 10^{-8}s. Metastable states last a few seconds or longer. In a collection of atoms, many of these atoms will remain in the excited state for over an hour. Hence light will be emitted even after long periods.

ii) Fluorescence
Examples of fluorescence include trail marker tape used in hiking and road signs. When an atom is excited from one energy state to a higher one by the absorption of a photon, it may return to the lower level in a series of two or more jumps. The emitted photons will have lower energy and frequency than the absorbed photon. When the absorbed photon is in the UV and the emitted photons are in the visible region of the spectrum, the phenomenon is called fluorescence.

- give evidence of light being both a wave: behaviour of long wavelengths, interference and diffraction, or a particle: behaviour of short wavelengths, photoelectric effect, Compton effect, line spectra, blackbody radiation

A good overview is available on page 718 of the textbook.

Bohr Atoms and Quantum Atoms (continued)

Suggested Assessment Strategies

Journal

- Summarize your understanding of the conditions under which light can be thought of as a wave and when it is better to think of light as a particle. (327-11)
- Write a note that explains how to relate the energy levels identified by Bohr to natural luminous phenomena. (329-7)

Presentation

- Organize a debate among teams of students and debate the following: Be it resolved that the particle model is a superior explanation of the behaviour of light. (327-11)

Resources/Notes

Concepts and Connections

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Particles and Waves

Outcomes

Students will be expected to

- describe sources of radioactivity in the natural and constructed environments (329-5)

Elaborations—Strategies for Learning and Teaching

Students should explore geological sources (ores, radon gas), cosmic and atmospheric sources (background radiation, solar wind, airborne contaminants), and human-made sources (radium dials, imaging technology, cancer therapy). Students could begin the radioactivity unit with an individual research project. It is important that students realize that radiation is a fact of everyday life. This research could be assigned a week ahead of beginning the topic in class. The research would then form the context for initial classroom discussion.

- describe the products of radioactive decay, and the characteristics of alpha, beta, and gamma radiation (329-4)
  - define the following: electrons, neutrons, protons, nucleus, atomic number, atomic mass number and isotope
  - define transmutations and radioactivity

Students should become familiar with the symbolism used to describe radioisotopes and the products of decay. They should be able to interpret a decay equation such as the following: ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He + \gamma$

Students should explore uses of radiation. From agriculture to medicine, applications of our understanding of radiation abound. Potatoes are irradiated to control sprouting, tracer isotopes are used in medical diagnosis, the Cobalt "bomb" is used in cancer therapy. Students could work in pairs or small groups to prepare a large poster presenting what they have learned about any one radiation technology/application. A guest speaker could help students focus on actual cases. For example, an engineer could speak about radon gas accumulation in basements, or a person from the agrifood industry could explain the uses of radiation from seeds to preserving produce.

  - define alpha decay, beta minus decay and beta positive decay, electron capture and gamma decay
  - identify reaction type and balance nuclear reactions with one reactant or product missing

Before discussing nuclear reactions, teachers should briefly discuss the different forces within the nuclei of an atom (i.e., the strong nuclear force and electrical proton-proton repulsion). Students should have some idea of how stable nuclei can become unstable.

  - define and calculate mass defect using atomic mass units (u) or kg
  - calculate the energy released in nuclear reactions using mass defect

Students should be able to convert from atomic mass units to kg and vice versa.

Note, the greater the mass defect of an isotope's nucleus, the greater the energy which holds or binds it, therefore, the more stable it is. (It is the difference in mass which provides this binding energy as described by the formula $\varepsilon = \Delta mc^2$. This is why some isotopes of elements are radioactive. Their mass defect is so small that some of the nuclei in the sample will be ready to spontaneously decay).

Note, students are not required to calculate binding energy of particular nuclei.

Particles and Waves

Suggested Assessment Strategies

Presentation

- Prepare a class prestation summarizing your research and present a brief oral elaboration. (329-5)
- Organize posters as a cafeteria display, or display them elsewhere in the school or community. (116-4, 116-6, 117-5, 117-7)

Journal

- Research the medical and industrial uses of radioactivity. (329-5)

Paper and Pencil

- Uranium-232 $\left({}^{232}_{92}U\right)$ undergoes α- decay. Write the nuclear reaction showing reactants and products. (329-4)
- Write the reaction equations for:

  a) the β^- decay of ${}^{90}_{38}Sr$.

  b) the α decay of ${}^{226}_{88}Ra$.

  c) the β^+ decay of ${}^{64}_{29}Cu$.

  d) electron capture for the isotope argon-38. (329-4)
- Calculate the energy emitted in eV when an atom of ${}^{23}_{10}Ne$ decays into ${}^{23}_{11}Na$ and a β^- particle.

  Mass: ${}^{23}_{10}Ne = 22.9945\ \mu$

  ${}^{23}_{11}Na = 22.9898\ \mu$

  ${}^{0}_{-1}e = 0.00055\ \mu$ (329-4)
- Fill in the missing particle or nucleus:

  (a) ${}^{45}_{20}Ca \rightarrow ? + e^- + \gamma$

  (b) ${}^{58}_{29}Cu \rightarrow ? + \gamma$

  (c) ${}^{46}_{24}Cr \rightarrow {}^{46}_{23}V + ?$

  (d) ${}^{234}_{94}Pu \rightarrow ? + \alpha$

  (e) ${}^{239}_{93}Np \rightarrow {}^{239}_{92}U + ?$ (329-4)

Resources/Notes

Concepts and Connections

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Natural and Artificial Sources of Radiation

Outcomes

Students will be expected to

- analyze data on radioactive decay to predict half-life (214-2)
  - define half-life
  - complete half-life calculations using $$A = A_o\left(\frac{1}{2}\right)^{\frac{t}{T_{\frac{1}{2}}}}$$

Elaborations—Strategies for Learning and Teaching

Students should interpret radioactive decay graphs and determine the half-life from the graph. Mathematical problem-solving is expected. Students will be expected to use logarithms to solve half-life problems.

Activity can be expressed in Becquerels (Bq). In addition to activity, students will also be expected to deal with problems involving mass or number of nuclei: $\frac{A}{A_o} = \frac{N}{N_o} = \frac{M}{M_o} = \left(\frac{1}{2}\right)^{t/T_{½}}$

- compare and contrast fission and fusion (329-6)
  - describe the processes involved in a fission reaction. Include:
    - (i) chain reaction
    - (ii) moderator
    - (iii) products as compared to reactants
    - (iv) energy released

Students should look for answers to questions such as the following: What technological challenges have led society to question the practicality of fission reactors? How is the Candu reactor different from other reactor designs? What factors make fusion reactors seem to be an attractive alternative to fission reactors? What problems need to be solved before fusion reactors become a reality?

  - describe the processes involved in a fusion reaction. Include:
    - (i) conditions necessary for fusion
    - (ii) products as compared to reactants
    - (iii) energy released
    - (iv) harmful products

In a fusion reaction, two relatively light nuclei come close enough for the strong nuclear force to bind them into a single, larger nucleus. For this to happen, the nuclei must collide at very high speed. Otherwise their positive electrical charges would keep them too far apart for the nuclear binding force to act. Thus fusion reactions require very high temperatures.

- apply quantitatively the law of conservation of mass and energy using Einstein's mass-energy equivalence (326-9)
  - predict the atomic number and/or atomic mass number of reactants or products for fission and fusion reactions
  - solve problems using $E=mc^2$

Einstein's famous equation, $E = mc^2$, may well be the most often quoted and least understood expressions in physics. Students should learn the context in which it has meaning. They should be able to determine mass defect and use the equivalence equation to calculate the energy released in a decay or fusion reaction.

Natural and Artificial Sources of Radiation

Suggested Assessment Strategies

Paper and Pencil

- An experiment was performed to determine the half-life of Tc-99. The activity was measured over a 24-hour period, and students recorded the results below.

Time (h)	0.0	3.0	6.0	9.0	12	15	18	21
Activity (kBq)	17.0	12.2	8.9	6.5	4.5	3.2	2.3	1.5

  Plot a graph of activity versus time. Using the graph, determine the half-life of Tc-99. Predict the activity for 7.0 hours and 26 hours. (214-12)

- Solve problems such as the following:
  - In a fission reaction, the loss of mass was 0.0075 g. How much energy would have been released in this event?
  - 150 atoms were split in a fission reaction. If each atom releases 2.5 x 10^{-8} J, what mass was converted into energy? (326-9)
  - A radioactive material produces 1280 decays per minute at one time and 6.0 h later produces 320 decays per minute. What is its half-life. (214-2)
  - A 10.0 g sample of the radioactive tracer iodine-123 is stored on a hospital shelf for 5.0 days. If its half-life is 13 h how much is left? (214-2)
  - Calculate the energy released in the fusion of two deuterium nuclei:
    $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n$ (329-6)

- Write a note that shows you understand what we mean when we say mass and energy are equivalent. (326-9)

Presentation

- Prepare a page-sized poster that displays and explains the complete decay chain of a specific radioisotope. (329-6)

Resources/Notes

Concepts and Connections

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Nuclear Power

Outcomes

Students will be expected to

- analyze examples of Canadian contribution to a particular development of science and technology (115-5, 117-11)
  - describe the 3 features and safety systems of the CANDU reactor
- develop, present, and defend a position or course of action based on identifying multiple perspectives that influence the issue, and on interpreting data and the relationship among variables (214-15, 215-4, 215-5)
  - describe the pros and cons of nuclear energy. Include:
    (i) demand for electricity
    (ii) fuel availability
    (iii) safety
    (iv) environment
    (v) cost

Elaborations—Strategies for Learning and Teaching

A good overview is available on page 769 of the *Concepts and Connections* textbook.

Teachers could also discuss the general operation and main features of the CANDU reactor.

Nuclear Power

Suggested Assessment Strategies

Journal

- Reflect and comment on the statement that all nuclear reactions are detrimental to human life. (Hint: Do not forget our sun.) (118-2, 118-4)

Presentation

- Research and prepare for a panel discussion on the topic: Canada should abandon the fission technology currently in use at the end of its productive life and devote national resources to the development of fusion reactors. Panel members could include members of the community with relevant expertise. Presentation topics could include economic viability, long-term reliability, and risk/benefit analysis. (329-6, 115-5, 117-11, 214-15, 215-4, 215-5, 118-2, 118-4)

Performance

- Organize a debate on the pros and cons of building a nuclear power plant near a community.

Resources/Notes

Concepts and Connections

pages 763 - 765

pages 768 - 769