A SourceBook Module

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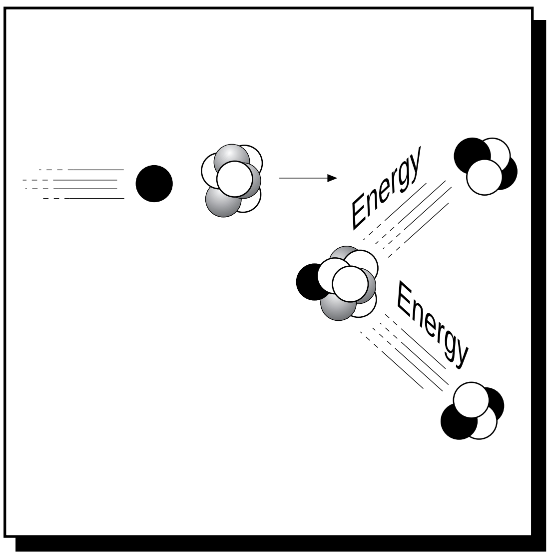
NUCLEAR CHEMISTRY



ChemSource

Instructional Resources for Preservice and Inservice Chemistry Teachers

Topic Overview

Content in a Nutshell

When the universe came into being, the elements formed by a coming together of protons and neutrons, accompanied by an enormous emission of energy. Our sun and other stars continue to fuel nuclear reactions and emit their associated energy.

The nuclei of atoms contain protons and neutrons held together by strong binding forces. Over one hundred kinds of subatomic particles of nuclear origin have been identified. The so-called fundamental particles, protons and neutrons, are made up of more basic particles called quarks.

Chemical reactions take place as a result of changes in the higher electron energy levels in the atom. If these changes are spontaneous they lead to greater stability of products with respect to reactants. Nuclear reactions are the result of changes within the nucleus of unstable atoms. An unstable nucleus, with a very high or very low neutron to proton ratio, may lead to natural radioactivity with alpha, beta, or gamma emission. This emission cannot be delayed or stopped by any external activity nor does it depend upon whether the element is free or in a compound. Radioactivity results in transmutation of an unstable nucleus to a stable nucleus. Stable nuclei with a favorable neutron to proton ratio do not spontaneously decay. (See Decay Pattern of $^{235}_{92}U$ in *Appendix*.)

The splitting of very heavy nuclei is called nuclear fission. When light nuclei combine, the reaction is referred to as nuclear fusion. These changes lead to more stable nuclei with the release of great amounts of energy. We make use of natural and induced nuclear reactions in power plants, nuclear weapons, medical treatment, and consumer products.

Central Concepts

1. The nucleus is composed of protons (with a +1 charge) and neutrons (no charge), which are in turn composed of smaller particles called quarks.
2. There is a critical relationship between the number of protons and neutrons in a nucleus, determining its stability.
3. An unstable nucleus commonly decays by one of several radioactive modes: alpha (α), beta (β), and/or gamma (γ) emission.
4. The positively charged particles are held together in the nucleus due to very strong binding energy.
5. The energy of nuclear reactions is significantly larger than that associated with physical change or chemical reactions.
6. The relative instability of a nucleus is indicated by a characteristic rate of decay, measured by its half-life.
7. There are many applications of radioisotopes in medicine, commercial processes and research.

Related Concepts

1. An understanding of the atomic model (see *Atomic Structure* module).
2. A qualitative understanding that energy changes are involved in all reactions.
3. Thermochemical calculations.

Related Skills

1. Ability to write and balance chemical equations.
2. Ability to perform stoichiometric calculations.

Performance Objectives

After completing their study of nuclear chemistry, students should be able to:

1. balance a nuclear equation.
2. compare the relative amounts of energy released from physical, chemical, and nuclear reactions.
3. calculate the quantity of material remaining after a specified number of half-lives.
4. identify the relative benefits and hazards of nuclear reactions.

Concept/Skills Development

Laboratory Activity and Demonstrations

This topic does not have any feasible, applicable laboratory activities associated with it. If, by some chance, your high school owns a Geiger counter (try the physics teacher) or cloud chamber and a source of α or β emission, these items can be used for demonstrations. A sealed β source can be used to expose Polaroid™ film. Half life can be demonstrated by starting out with a known number of candy corn or other object and diminishing by half each time. Dismissing a class by coin toss can simulate the decay process (probability).

Group and Discussion Activities

1. Relative energy calculations comparing the output of physical, chemical, and nuclear processes (see *Appendix*). Discuss the abundance of raw materials and compare that with the efficiency of energy conversion.
2. Have students understand the effects of a chain reaction. These effects can be illustrated by:
   a. generating a "picture in the mind" of a room full of mousetraps, each one with a ping-pong ball poised on the bait end of the trap. Now imagine tossing one ping-pong ball into the room and triggering the chain reaction.
   b. having students calculate how many cycles of letters it would take, in a high school of 1000 students, to make sure everyone received a chain letter.
3. Two excellent activities (half-life simulation and understanding isotopes) are included in the *ChemCom* unit on radioactive decay. (See *References* for publisher information.)

Tips for the Teacher

Language of Chemistry

1. **Glossary**

alpha particle (α, $^{4}_{2}$He) a nuclear particle containing two protons and two neutrons with a mass number of four (4.0026 u). An alpha particle is identical to a helium nucleus. Alpha particles are most often emitted from very heavy nuclei (*i.e.*, Z ≥ 83).

beta particle (β, $^{0}_{-1}$e) a nuclear particle of zero mass number (0.0005486 u) and unit negative charge. A beta particle is an electron of nuclear origin. Beta particles may be emitted from both heavy and light radioactive nuclei.

chain reaction a reaction in which one of the products can also serve as one of the reactants. Such a reaction is self-sustaining, once begun. In nuclear fission, the chain reaction is started with neutrons that split uranium nuclei, which, in turn release more neutrons to sustain the reaction.

control rods cylinders usually made of neutron-absorbing material, such as boron or cadmium, which may be lowered into a nuclear fission reactor to control the speed of the reaction by slowing, or halting the chain process.

critical mass the minimum mass of radioactive material needed to sustain fission.

fission the process whereby certain heavy nuclei (*e.g.*, $^{235}_{92}U$) break apart into two approximately equal smaller, more stable, nuclei called "daughters." Fission is usually initiated by bombarding heavy nuclei with slow moving neutrons. In the process, additional neutrons are released, which can cause the fission of yet more nuclei, thus sustaining a chain reaction. Fission processes release large quantities of energy.

fusion the process in which two small nuclei (usually H or He) combine to form a larger, more stable, nucleus. The heat and light of the sun are generated by the fusion of hydrogen isotopes to form helium nuclei.

gamma rays (γ) high energy electromagnetic radiation. The wavelength of gamma rays is approximately 10^{-12} m (refer to a standard chemistry textbook for electromagnetic spectrum diagram). Both alpha and beta decay are usually accompanied by gamma emission.

half-life ($t_{1/2}$) time required for one-half of a given amount of a radioactive substance to decay.

isotopes nuclei of an element having the same number of protons but different number of neutrons. For any given element, some isotopes may be unstable (and therefore undergo nuclear decay), while others may be stable.

moderator a substance that slows down neutrons in a fission reactor.

nuclear decay the general term for any of several processes (alpha emission, beta emission, fission, *etc*.) that an unstable nucleus can undergo in order to achieve stability.

nuclear reactor vessel where controlled nuclear fission takes place.

positron (e^+, $^{0}_{+1}e$) positively charged particle with the same mass as an electron.

radioactivity the generic term for alpha, beta or gamma emission.

transuranium elements the elements heavier than uranium (U), therefore those elements with $Z > 92$.

units of radiation various types of units exist to characterize ionizing radiation (alpha, beta, and gamma). Each is a slightly different way to measure the radiation.

a. A **rad**, or **r**adiation **a**bsorbed **d**ose, corresponds to 10^{-5} J of energy absorbed per gram of body weight. Not all forms of ionizing radiation have the same biological effect, so the **RBE**, **r**adiation **b**iological **e**ffectiveness, is a correction factor. For instance, X-rays and gamma rays are assigned an RBE of 1, while alpha particles have an RBE of 10, which means alpha particles can cause more ionization and therefore more damage to the body. This term can be misleading because alpha particles external to the body are stopped by our skin, or even a piece of paper; they have little penetrating power. Gamma rays, on the other hand can penetrate soft body parts.

b. The **rem**, **r**oentgen **e**quivalent **m**an, is calculated by multiplying the absorbed dose in rads by the radiation biological effectiveness.

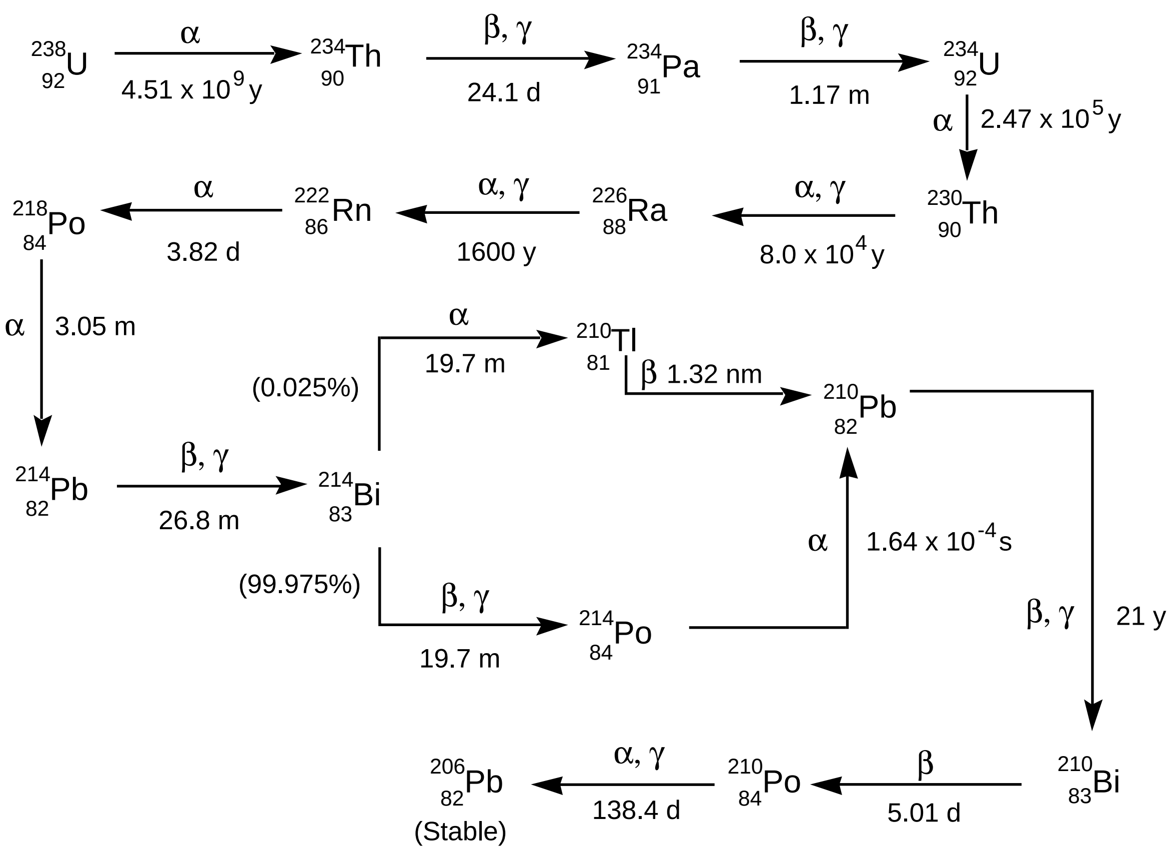
$$\text{rem} = \text{rad} \times \text{RBE}$$

c. The **activity** of a radioactive sample is usually measured in disintegrations per second, or in curies, where

$$1 \text{ curie (Ci)} = 3.7 \times 10^{10} \text{ disintegrations/s}$$

d. A **roentgen** is a unit of radiation dose that produces one electrostatic unit of electricity per cubic centimeter of dry air at 0 °C and 1 atm pressure.

2. Decay Pattern (of Uranium-238) and Half-Life:



y = years, d = days, m = minutes, s = seconds

Common Student Misconceptions

1. **“Irradiated food is radioactive.”**

   Although some foods have an extended shelf-life after radiation with gamma rays, irradiation only kills the microorganisms in the food. This process does not make the food radioactive.

2. **“All radiation is harmful.”**

   The physical harm caused by radiation varies greatly, depending on the quantity received, what type it is (gamma rays can be more harmful, in general, than alpha particles), whether the radiation is internal or external to the body, *etc.* (see the tables in the *Appendix* for additional comparisons).

3. **“All radiation is man-made.”**

   Most radiation to which humans are exposed is natural radiation from cosmic rays or from naturally occurring radioisotopes.

4. **"I can't be hurt by something I can't see or feel."**

   Too much radiation can indeed be harmful. Just because it isn't visible doesn't mean it isn't real.

5. **"All uranium can be used as nuclear fuel."**

   Only the ^{235}U isotope of uranium is fissionable; most uranium ore (>90%) is ^{238}U, which is not fissionable.

6. **"The number of counts from a Geiger counter is equal to the number of nuclei that decay."**

   The Geiger counter detects and records only a small fraction of particles emitted from decaying nuclei. Some reasons for this inability to count all disintegrations are:

   a. Window thickness of the Geiger tube. Not all particles will penetrate the tube.

   b. Geiger tube dead time. While the tube is busy reacting to a particle, other particles go undetected.

   c. Counter geometry. Radioisotopes emit radiation in all directions (4-π geometry). A typical Geiger tube can only monitor a small fraction or small angle of all the radiation direction angles.

   A typical counter only counts the relative number of disintegrations.

Pattern Recognition/Problem Solving

1. To balance nuclear equations, conservation of both mass number and charge on the nucleus must be achieved. **Mass number** (A) is the sum of the numbers of protons and neutrons in the nucleus. It is also the approximate mass of a particle or isotope to the nearest whole atomic mass unit, u. **Charge** is the positive or negative whole units of electrical charge. One unit equals 1.60×10^{-19} C (coulombs).

2. Nuclear Symbols. — $^{A}_{Z}X$

   A = mass number, and Z = positive charge on nucleus or
   A = sum of the protons and neutrons, and Z = number of protons

   e.g., for $^{238}_{92}U$ 238 = mass number, and 92 = charge on nucleus or
   238 = protons + neutrons, and 92 = protons

other:

proton: $^{1}_{1}H$ electron: $^{0}_{-1}e$ neutron: $^{1}_{0}n$

alpha (α) particle: $^{4}_{2}He$ beta (β or β⁻) particle: $^{0}_{-1}e$ positron (β^{+}): $^{0}_{+1}e$

3. Balancing Nuclear Equations. — In a nuclear equation charge and mass must be conserved.

   Examples:

   a. **Alpha radiation** ($^{4}_{2}He$ emitted from nucleus)

$$^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{A}_{Z}X$$

   238 = (4 + A) A must be 234 (conservation of mass number)
   92 = (2 + Z) Z must be 90 (conservation of charge)

The new isotope produced is ${}^{234}_{90}\text{Th}$ (by finding the symbol for Z = 90 in the Periodic Table).

b. **Beta radiation** (${}^{0}_{-1}\text{e}$ emitted from nucleus):

$${}^{210}_{82}\text{Pb} \rightarrow {}^{0}_{-1}\text{e} + {}^{A}_{Z}\text{X}$$

210 = (0 + A) A must be 210
82 = (–1 + Z) Z must be 83

The new isotope produced is ${}^{210}_{83}\text{Bi}$.

c. **Fission** (see *Language of Chemistry*):

$${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{139}_{56}\text{Ba} + {}^{94}_{36}\text{Kr} + 3\,{}^{1}_{0}\text{n} + \text{Energy}$$

235 + 1 = 139 + 94 + 3(1) (conservation of mass number)
92 + 0 = 56 + 36 + 3(0) (conservation of charge)

NOTE: Many other products of uranium fission in addition to barium and krypton are formed.

d. **Fusion** (see *Language of Chemistry*):

$$4\,{}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + 2\,{}^{0}_{1}\text{e} + \text{Energy}$$

4(1) = 4 + 2(0) (conservation of mass number)
4(1) = 2 + 2(1) (conservation of charge)

4. Student Worksheet: Writing Nuclear Equations

Part A. Complete each of the following by identifying ${}^{A}_{Z}\text{X}$.

1. ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{A}_{Z}\text{X}$
2. ${}^{222}_{88}\text{Ra} \rightarrow {}^{4}_{2}\text{He} + {}^{A}_{Z}\text{X}$
3. ${}^{A}_{Z}\text{X} + {}^{0}_{-1}\text{e} \rightarrow {}^{54}_{24}\text{Cr}$
4. ${}^{54}_{26}\text{Fe} + {}^{1}_{0}\text{n} \rightarrow {}^{1}_{1}\text{H} + {}^{A}_{Z}\text{X}$
5. ${}^{238}_{92}\text{U} + {}^{12}_{6}\text{C} \rightarrow {}^{246}_{98}\text{Cf} + 4\,{}^{A}_{Z}\text{X}$
6. ${}^{A}_{Z}\text{X} + {}^{4}_{2}\text{He} \rightarrow {}^{245}_{97}\text{Bk} + {}^{1}_{1}\text{H} + 2\,{}^{1}_{0}\text{n}$
7. ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{139}_{56}\text{Ba} + {}^{A}_{Z}\text{X} + 3\,{}^{1}_{0}\text{n}$
8. ${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{A}_{Z}\text{X} + {}^{1}_{0}\text{n}$

Part B. Write balanced equations for each of these reactions:

1. Alpha emission of $^{214}_{84}Po$
2. Beta emission of $^{210}_{83}Bi$
3. Neutron emission of $^{107}_{47}Ag$
4. Positron emission of $^{70}_{33}As$
5. Neutron emission of $^{88}_{35}Br$
6. Electron absorption by $^{116}_{51}Sb$
7. Proton emission of $^{41}_{19}K$
8. Alpha absorption by $^{14}_{7}N$ with neutron emission

Worksheet Answers

Part A

1. $^{236}_{92}U$
2. $^{218}_{86}Rn$
3. $^{54}_{25}Mn$
4. $^{54}_{25}Mn$
5. $^{1}_{0}n$
6. $^{244}_{96}Cm$
7. $^{94}_{36}Kr$
8. $^{4}_{2}He$

Part B

1. $^{214}_{84}Po \rightarrow {}^{4}_{2}He + {}^{210}_{82}Pb$
2. $^{210}_{83}Bi \rightarrow {}^{0}_{-1}e + {}^{210}_{84}Po$
3. $^{107}_{47}Ag \rightarrow {}^{106}_{47}Ag + {}^{1}_{0}n$
4. $^{70}_{33}As \rightarrow {}^{0}_{+1}e + {}^{70}_{32}Ge$
5. $^{88}_{35}Br \rightarrow {}^{1}_{0}n + {}^{87}_{35}Br$
6. $^{116}_{51}Sb + {}^{0}_{-1}e \rightarrow {}^{116}_{50}Sn$
7. $^{41}_{19}K \rightarrow {}^{1}_{1}H + {}^{40}_{18}Ar$
8. $^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{9}F + {}^{1}_{0}n$

5. Half-Life of Radon (see *Appendix*).

HISTORY: ON THE HUMAN SIDE

1834 Michael Faraday—electrolysis experiments suggested electrical nature of matter.

1895 Wilhelm Roentgen—discovered X-rays when cathode rays strike the anode.

1896 Henri Becquerel—discovered "uranic rays" and radioactivity.

1896 Marie (Marya Sklodowska) and Pierre Curie—discovered that radiation is a property of the atom, and not due to chemical reaction. (Marie named this property *radioactivity*.)

1897 Joseph J. Thomson—discovered the electron through Crookes tube experiments.

1898 Marie and Pierre Curie—discovered the radioactive elements polonium and radium.

1899 Ernest Rutherford—discovered alpha and beta particles.

1900 Paul Villard—discovered gamma rays.

1903 Ernest Rutherford and Frederick Soddy—established the laws of radioactive decay and transformation.

1910 Frederick Soddy—proposed the isotope concept to explain the existence of more than one atomic weight of radioelements.

1911 Ernest Rutherford—used alpha particles to explore gold foil; discovered the nucleus and the proton; proposed the nuclear theory of the atom.

1919 Ernest Rutherford—announced the first artificial transmutation of atoms.

1932 James Chadwick—discovered the neutron by alpha particle bombardment of Beryllium.

1934 Frederic Joliot and Irene Joliot Curie—produced the first artificial radioisotope.

1938 Otto Hahn, Fritz Strassmann, Lise Meitner, and Otto Frisch—discovered nuclear fission of uranium-235 by neutron bombardment.

1940 Edwin M. McMillan and Philip H. Abelson—discovered the first transuranium element, neptunium, by neutron irradiation of uranium in a cyclotron.

1941 Glenn T. Seaborg, Edwin M. McMillan, Joseph W. Kennedy and Arthur C. Wahl—announced discovery of plutonium from beta particle emission of neptunium.

1942 Enrico Fermi—produced the first nuclear fission chain-reaction.

1944 Glenn T. Seaborg—proposed a new format for the periodic table to show that a new actinide series of 14 elements would fall below and be analogous to the 14 lanthanide-series elements.

1964 Murray Gell-Mann hypothesized that quarks are the fundamental particles that make up all known subatomic particles except leptons.

HUMOR: ON THE FUN SIDE

1. **ELEMENTARY GOSPEL** *(CHEM 13 NEWS, November 1975, p. 977)*

   And the Lord said unto uranium, "You shall lead a degenerate life," and it was lead.

2. Word search (see *Appendix* for master copy)

F	J	V	F	C	M	O	D	E	R	A	T	O	R	R	M	N
C	U	B	F	Q	W	Z	Q	E	L	V	Z	A	A	N	A	S
D	Y	S	E	Y	Q	S	B	S	F	Z	D	P	C	I	Q	S
H	B	I	I	H	P	K	D	K	U	I	P	Y	K	S	Z	A
B	O	R	F	O	C	R	J	P	O	V	L	V	X	Z	H	M
W	C	C	Y	Q	N	I	Q	A	N	A	B	F	X	P	E	L
T	A	T	E	B	L	P	C	H	O	V	U	U	L	D	W	A
F	Z	Y	M	K	G	T	P	G	I	J	V	A	U	A	G	C
D	C	M	S	J	I	A	K	C	S	G	A	V	B	V	H	I
B	I	S	D	V	G	H	G	I	S	O	T	O	P	E	S	T
M	D	C	I	W	T	I	E	O	I	W	V	M	V	T	V	I
X	C	T	X	D	A	R	O	A	F	N	L	B	N	T	E	R
Z	Y	Z	D	T	O	B	W	O	E	T	A	V	L	U	T	C

   Words about the concepts in this module can be obtained from the clues given. Find these words in the block of letters:

   1. Nuclear particle containing two neutrons and two protons.
   2. Particle that is an electron of nuclear origin.
   3. Process of heavy nuclei breaking down into smaller nuclei called "daughters."
   4. Process wherein two small nuclei combine to form a larger, more stable, nucleus.
   5. Time required for one-half of a given amount of a radioactive substance to decay. (2 words)
   6. Nuclei of an element having the same number of protons but different numbers of neutrons.
   7. Generic term for the emission of alpha, beta, or gamma rays.
   8. Radiation absorbed dose, 10^{-5} joules/gram of body mass. (Abbrev.)
   9. Describing the minimum mass of radioactive material needed to sustain fission.
   10. Substance that slows down neutrons in a fission reactor.

   Answers: 1. ALPHA 2. BETA 3. FISSION 4. FUSION 5. HALF-LIFE 6. ISOTOPES 7. RADIOACTIVITY 8. RAD 9. CRITICAL 10. MODERATOR

3. See cartoons at end of module.

MEDIA

1. CHEMStudy Film *Transuranium Elements*, available from Ward's Natural Science Establishment, Inc., P.O. Box 92912, Rochester, NY 14692-9978, (716) 334-6174.

2. *The Discovery of Radioactivity*, International Film Bureau, Inc., 332 South Michigan Avenue, Chicago, IL 60604-4382.
3. *Ring of Truth*, episode on energy is pertinent to this topic. Videotapes are available from PBS Home Video (Phone: 1-800-424-7963).
4. *Nova*, PBS series on the Chernobyl nuclear accident. PBS Video, 1320 Bradford Place, Alexandria, VA 22314, (703) 734-5010.
5. *Radiation and Your Environment*, from EME, P.O. Box 2805, Danbury, CT 06813-2805.
6. Software published by Project SERAPHIM, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue. Madison, Wl 53706-1396: (608) 263-2837 (voice) or (608) 262-0381 (FAX).

   a. For the Apple II computer: AP 1001, AP 1002.

   c. For IBM PCs and PC-compatibles: PC 3801.

EQUIPMENT AND INSTRUMENTATION

If your school already owns a Geiger counter you may elect to show your students the radiation from a smoke detector, a lantern mantle, some watch dials, rock samples, *etc.*

Links/Connections

WITHIN CHEMISTRY

1. The number of protons and neutrons determine variations in physical properties of elements observed in isotopes. Naturally radioactive elements decay spontaneously. X-rays can be produced when metallic anodes are bombarded with electrons in a cathode ray tube. (*Nuclear Chemistry* topics may be included with the study of *Atomic Structure*.) The discovery of fundamental particles may be used to develop the atomic model. Radioactive decay and half-life may be used in kinetics to illustrate first-order rate reactions (see *Rates of Reactions* module).
2. Tritium is a naturally occurring radioactive isotope of hydrogen. It has two neutrons and one proton in its nucleus, exists in the diatomic state, and constitutes a very small percentage of the hydrogen content of water. Since it has a half-life of 12.3 years, it can be used for dating rather "young" samples. For example, after a wine is bottled, it becomes a closed system; it can no longer exchange substances with the outside world, and its tritium content will decay at the rate dictated by its half-life. Meanwhile, the naturally occurring level of tritium worldwide remains relatively constant. The tritium level of the wine can be compared to that of ordinary water to determine the wine's age. For example, if a port wine is tested for tritium content along with ordinary water, and it is found that its tritium level is only 30.6% of that of the tritium activity of water, then one can infer that the wine is 21 years old.

BETWEEN CHEMISTRY AND OTHER DISCIPLINES

Nuclear physicists concentrate on the study and expansion of knowledge of subatomic particles, their structure, and models for the nuclear atom. Therefore, nuclear chemistry is an area with strong overlap with a general physics course. Radioactivity, fission, fusion, and nuclear reactors are also important areas to the nonscientist.

TO THE CONTEMPORARY WORLD

Community

Field trips to: nearby nuclear power plant; nuclear medicine center at most large hospitals.

Societal

1. Americium (Am) is the ionizing source in smoke detectors.
2. Nuclear medicine.
3. Carbon-14 is used to date objects made of wood or other formerly living material. Examples include the Shroud of Turin, Native American artifacts, bones, *etc.*
4. The current clamor over radon gas risks in well-insulated homes built over uranium-rich bedrock.
5. Camping lanterns have a mantle containing some radioactive thorium.
6. At one time, watch dials were painted with a paint containing radium in order to make them glow in the dark. The radium was harmful to the health of the factory workers—in particular the women who hand-painted the dials, frequently licking their small paint brushes. Now, tritium (^{3}H) is used, but due to its much shorter half-life, the face may visibly dim during the life of the watch.
7. Some *EXIT* signs are illuminated by tritium rather than by electricity. Can you think why this is an advantage? *[In a power failure, an electrically powered EXIT sign would not remain lighted.]*

Extensions

Nuclear Chemistry is an excellent section for special topics or term papers. Examples of possible subjects are:

1. Linear accelerators.
2. Radon in homes: kits to measure radon gas can be purchased from Central Scientific Co., 11222 Melrose Avenue, Franklin Park, IL 60131-1364 (1-800-262-3626).
3. Any nuclear medical technique. You might contact a local oncologist.
4. Have students consider the pros and cons of generating electricity by nuclear power as opposed to coal-burning plants, or using wood to heat homes. Consider the bumper sticker *Split Wood, Not Atoms.* You might contact your local power company. Most have a technical public relations office that can provide written information or a guest speaker for your class.

References

Module developed by Joseph Baron, Marvin Blevins, and Barbara Sawrey, the California team.

American Chemical Society. (1993). Nuclear chemistry in our world. *ChemCom*. Kendall/Hunt Publishing, pp. 270-337.

An excellent source of material for this topic.

Cline, B. (1989). *The men who made the new physics.* University of Chicago Press.

This is an easy-to-read historical and personal overview of the chemistry and physics that led to the atomic age. Good level for students.

Gamow, G. (1985). *Thirty years that shook physics.* New York: Dover Publications.

Journal of Chemical Education. (1989). *66,* 362-393.

This issue devoted space to seven articles about the history of nuclear fission, the atomic bomb, and using nuclear chemistry in the curriculum.

Tausta, J. (1989, February). Shrouded in mystery. *ChemMatters,* 8-11.

An article specifically for high school students in which C-14 dating of the Shroud of Turin is discussed.

Zuror, P. (1986, May 5). Food irradiation. *Chemical & Engineering News*, *64*(18), 46-56.

Discusses the how and why of food irradiation.

Other written information for educators can be obtained from:

The Nucleus, Inc., 761 Emory Valley Road, P.O. Box 2561, Oak Ridge, TN 37830-2561.

To join the American Nuclear Science Teachers Association, write:

American Nuclear Society, 555 North Kensington Avenue, La Grange Park, IL 60525.

Appendix

- **Transparency Masters**
  1. Student Worksheet: Writing Nuclear Equations
  2. Half-Life of Radon
  3. Common Subatomic Species
  4. Word Search
- **Humor**

Student Worksheet: Writing Nuclear Equations

Part A. Complete each of the following by identifying . ${}^{A}_{Z}X$

1. ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{A}_{Z}X$
2. ${}^{222}_{88}Ra \rightarrow {}^{4}_{2}He + {}^{A}_{Z}X$
3. ${}^{A}_{Z}X + {}^{0}_{-1}e \rightarrow {}^{54}_{24}Cr$
4. ${}^{54}_{26}Fe + {}^{1}_{0}n \rightarrow {}^{1}_{1}H + {}^{A}_{Z}X$
5. ${}^{238}_{92}U + {}^{12}_{6}C \rightarrow {}^{246}_{98}Cf + 4\,{}^{A}_{Z}X$
6. ${}^{A}_{Z}X + {}^{4}_{2}He \rightarrow {}^{245}_{97}Bk + {}^{1}_{1}H + 2\,{}^{1}_{0}n$
7. ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{139}_{56}Ba + {}^{A}_{Z}X + 3\,{}^{1}_{0}n$
8. ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{A}_{Z}X + {}^{1}_{0}n$

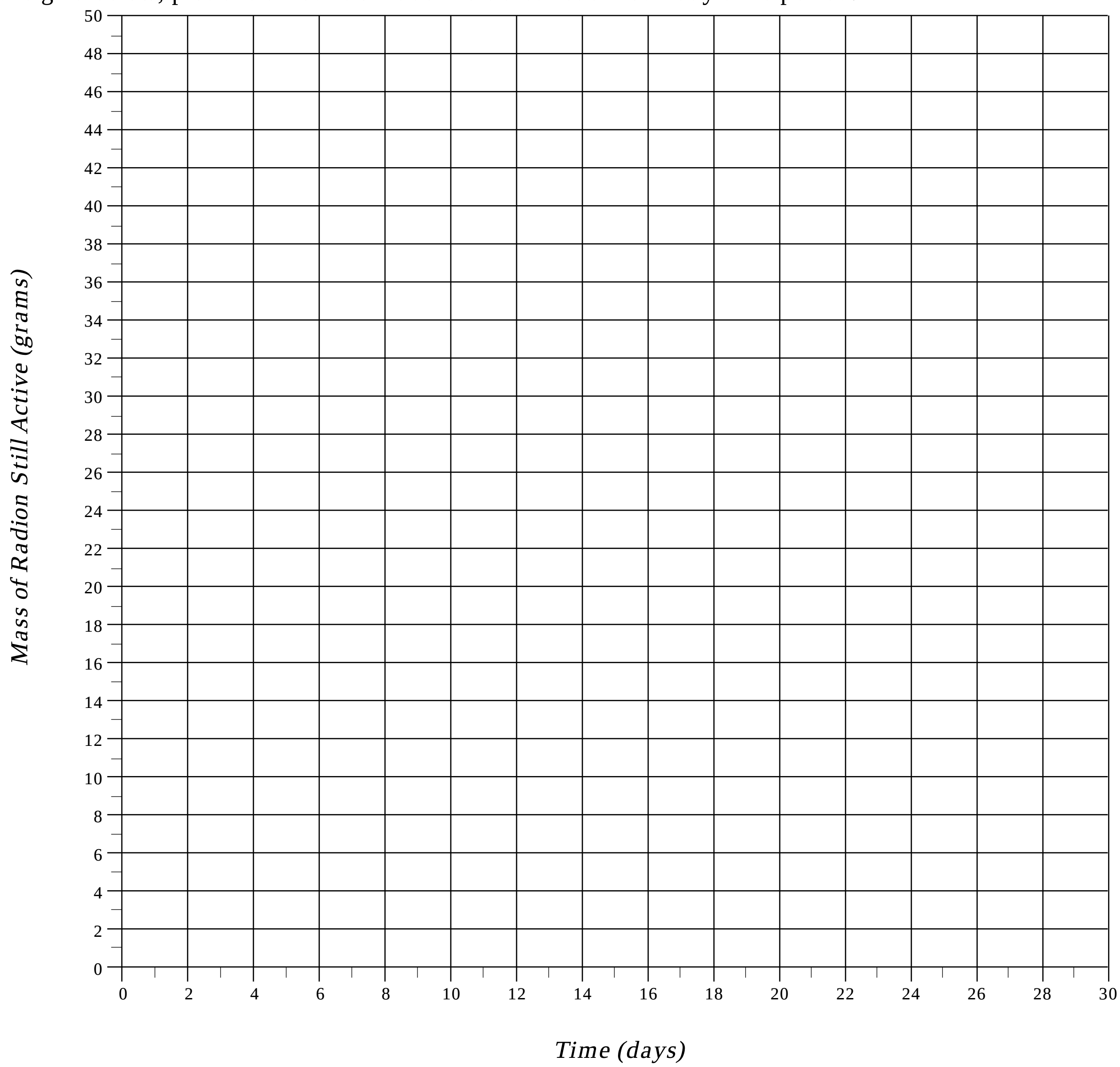
Part B. Write balanced equations for each of these reactions:

1. Alpha emission of ${}^{214}_{84}Po$
2. Beta emission of ${}^{210}_{83}Bi$
3. Neutron emission of ${}^{107}_{47}Ag$
4. Positron emission of ${}^{70}_{33}As$
5. Neutron emission of ${}^{88}_{35}Br$
6. Electron absorption by ${}^{116}_{51}Sb$
7. Proton emission of ${}^{41}_{19}K$
8. Alpha absorption by ${}^{14}_{7}N$ with neutron emission

Half-Life of Radon

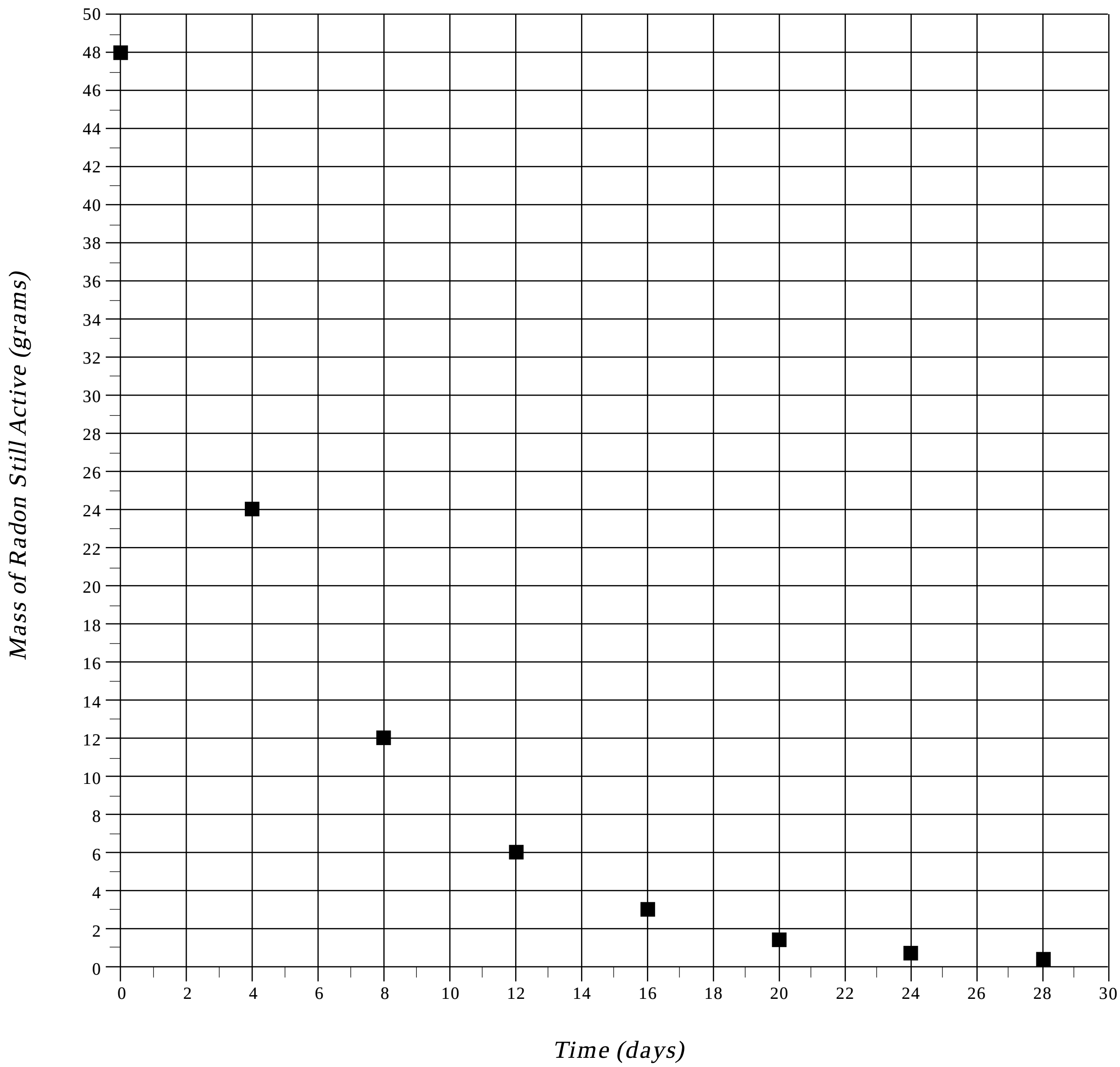
$^{222}_{86}\text{Rn}$ is the first decay product of $^{226}_{88}\text{Ra}$. Radon's activity is much greater than that of its parent. It is the heaviest of all gases (atomic mass = 222), with a density of almost 10 g/L. Like radium, it is hazardous to handle and should be used with adequate protective shielding.

Assume you have an initial sample of radon with a mass of 48 g. Assume the half-life of radon is about four days. On the grid below, plot the amount of radon left after each four-day time period.



Questions

1. How many grams of radon would be present after 4 days?
2. How many grams of radon would be present after 12 days?
3. How many grams of radon would be present after 24 days?
4. If 8 g of radon are left, what is the time elapsed?
5. How many grams of radon would be present after 6 days?



Answers

1. 24 g
2. 6 g
3. 0.75 g
4. 10 days
5. 16 g

Common Subatomic Species

Name	Symbol	Mass(g)	Mass (u)	Mass Number	Charge
electron or beta particle	e^-, β	9.109×10^{-28}	0.0005486	0	–1
proton	p	1.674×10^{-24}	1.0079	1	+1
neutron	n	1.675×10^{-24}	1.0087	1	0
alpha particle or helium nucleus	$^{4}_{2}\alpha$, $^{4}_{2}He$	6.647×10^{-24}	4.0026	4	+2
gamma	γ	0	0	0	0
positron	e^+, β^+	9.109×10^{-28}	0.0005486	0	–1

Word Search

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F J V F C M O D E R A T O R R M N
C U B F Q W Z Q E L V Z A A N A S
D Y S E Y Q S B S F Z D P C I Q S
H B I I H P K D K U I P Y K S Z A
B O R F O C R J P O V L V X Z H M
W C C Y Q N I Q A N A B F X P E L
T A T E B L P C H O V U U L D W A
F Z Y M K G T P G I J V A U A G C
D C M S J I A K C S G A V B V H I
B I S D V G H G I S O T O P E S T
M D C I W T I E O I W V M V T V I
X C T X D A R O A F N L B N T E R
Z Y Z D T O B W O E T A V L U T C
```

Words about the concepts in this module can be obtained from the clues given. Find these words in the block of letters:

1. Nuclear particle containing two neutrons and two protons.
2. Particle that is an electron of nuclear origin.
3. Process of heavy nuclei breaking down into smaller nuclei called "daughters."
4. Process wherein two small nuclei combine to form a larger, more stable, nucleus.
5. Time required for one-half of a given amount of a radioactive substance to decay. (2 words)
6. Nuclei of an element having the same number of protons but different numbers of neutrons.
7. Generic term for the emission of alpha, beta, or gamma rays.
8. Radiation absorbed dose, 10^{-5} joules/gram of body mass. (Abbrev.)
9. Describing the minimum mass of radioactive material needed to sustain fission.
10. Substance that slows down neutrons in a fission reactor.

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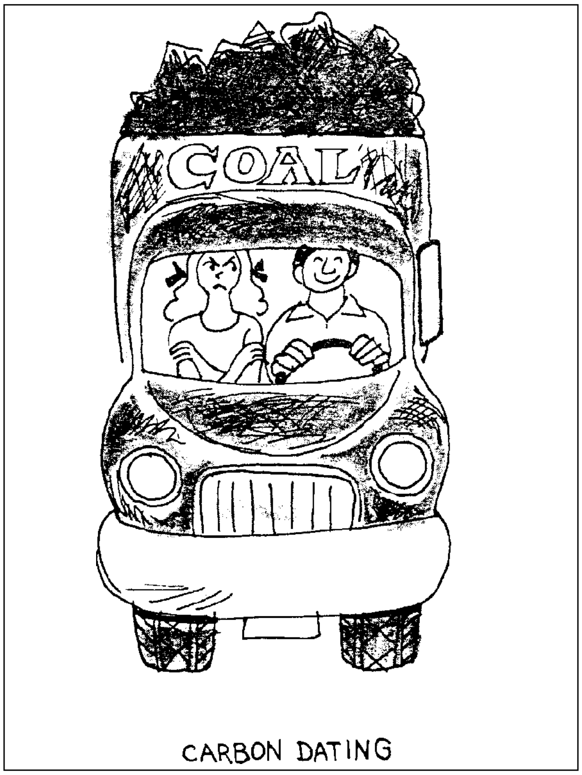

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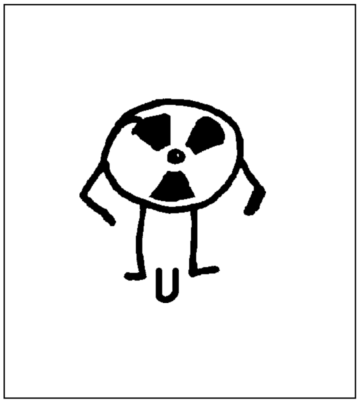

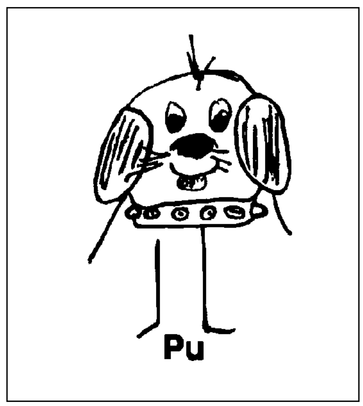

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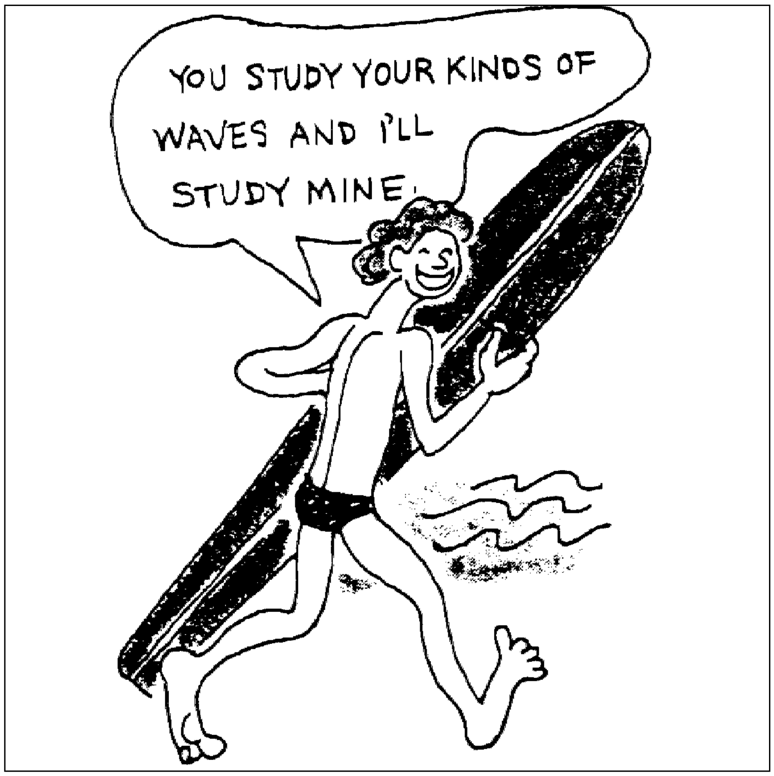

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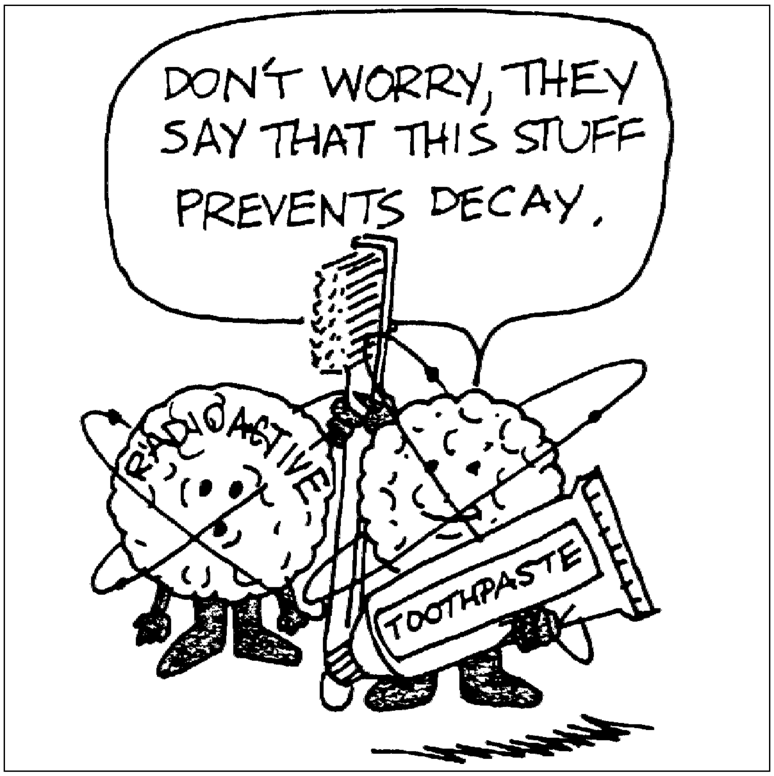

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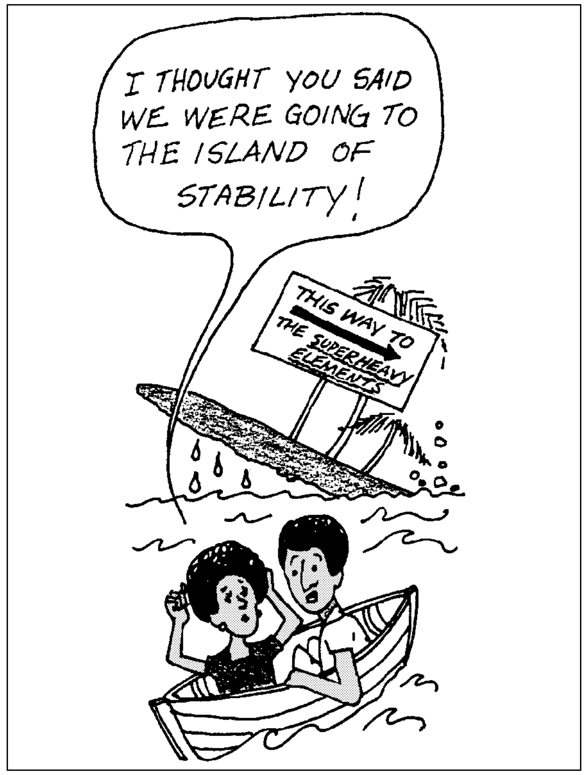

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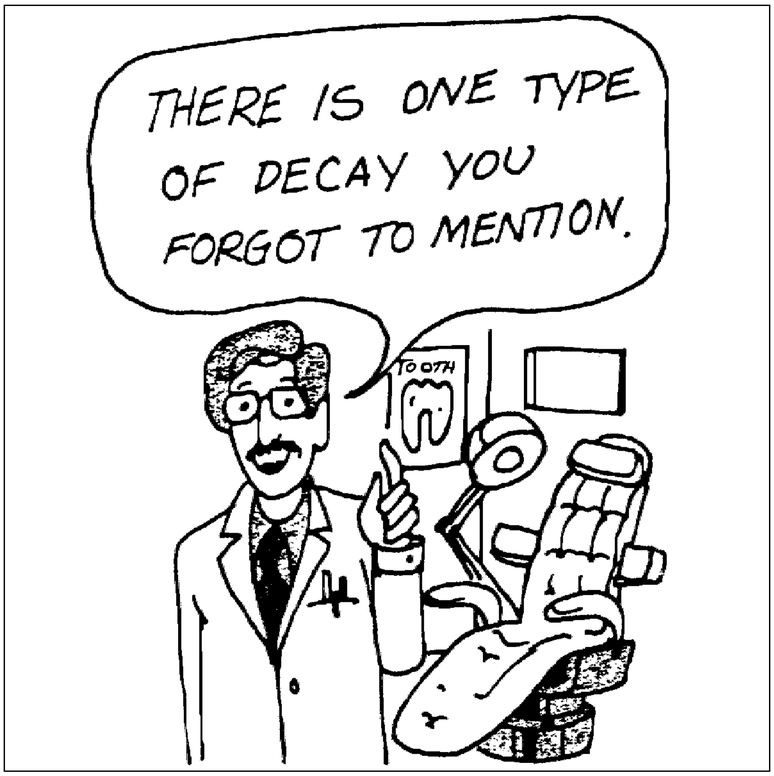

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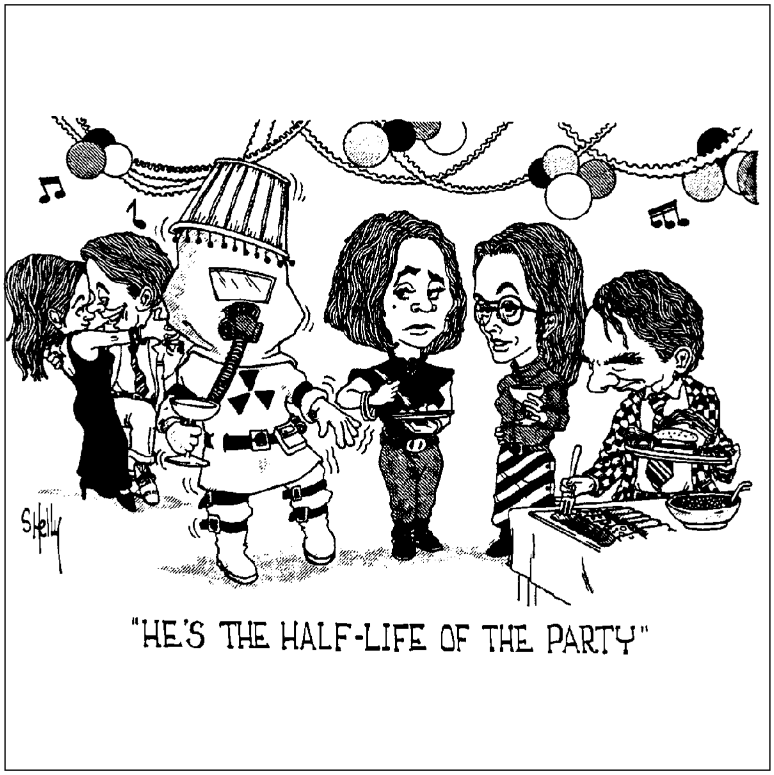

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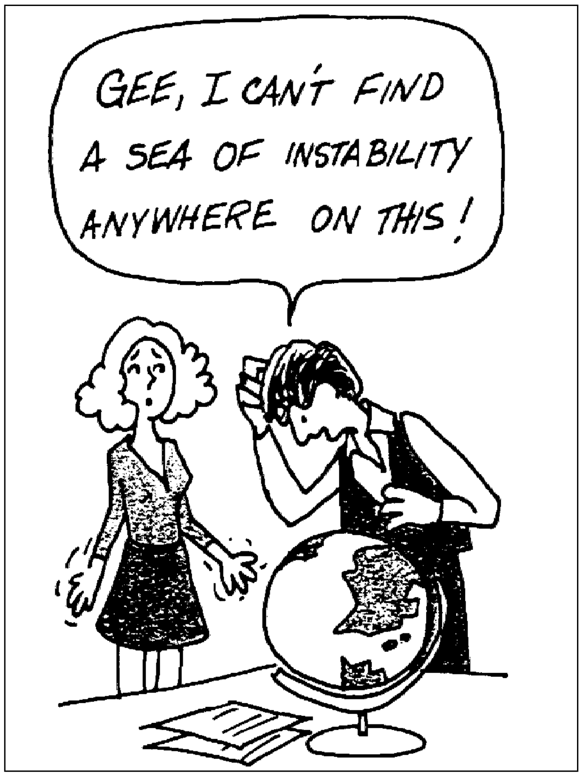

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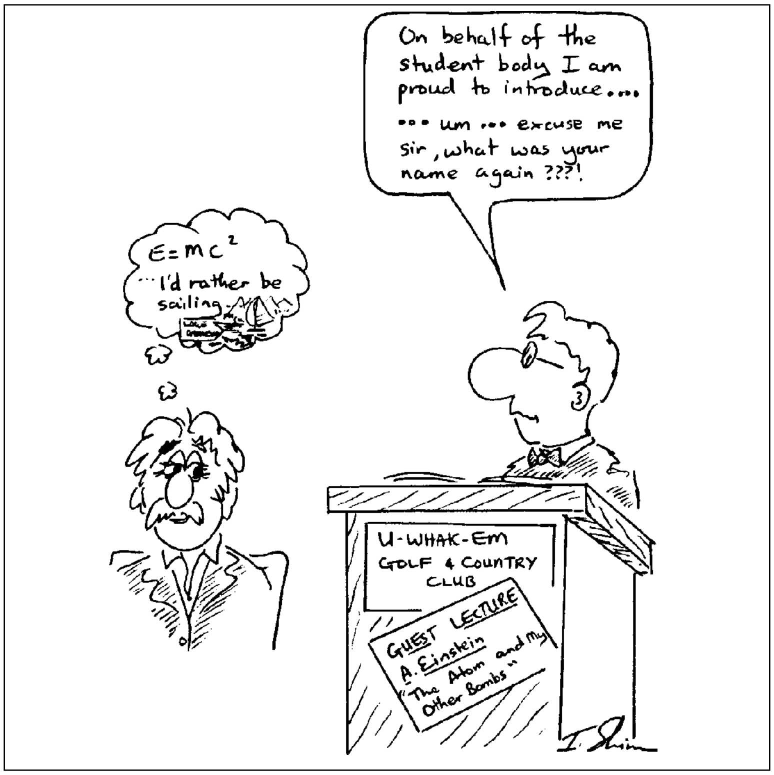

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