33 Atomic Nucleus and Radioactivity

Photo openers show two instructors with different radiation counters: Stan Micklavzina with a Geiger counter, and Roger Rassool with a scintillation counter. The impressive photo in the center is the world famous hot springs in Pamukkale, Turkey. I took a dip in these springs in 1995 and found them most intriguing. Like hot springs all around the world, their source of energy is primarily radioactive decay in Earth's interior. The 4th photo is of Leilah McCarthy of CCSF lecturing on radioactive half-life.

The personality profile for this chapter is Marie Curie. Most appropriate!

The chapter begins with X-rays and presents a relatively extensive treatment of radioactivity and its applications. Formulas for decay reactions are illustrated with supporting sketches that enable better comprehension. The background for this material goes back to Chapter 11. This chapter is a prerequisite to Chapter 34.

Ask your students if they want to produce X-rays. To do so, simply unroll a roll of Scotch tape! This creates electrostatic charges that jump across the gap between the tape and the roll, which can produce X-rays. That's if the process is done in a vacuum. In air, the electrons are too slow to produce them. But try unrolling tape in a completely dark room and you'll notice a faint glow.

The energy of gamma-ray photons is more than 100 kilo-electron-volts (keV), which is some 100,000 times more than a photon of visible light. All photons emitted by atomic nuclei are classified as gamma rays, even the rare ones of less than 100 keV. The sunlight we enjoy began as energetic gamma rays in the Sun's core and degraded into visible light during its passage through overlaying layers of gas. If watching stars on a calm night seems a tranquil experience, gamma rays betray the true violence of the universe!

In the text it is stated that a couple of round-trip flights across country exposes one to as much radiation one receives in a normal chest X-ray. More specifically, a dose of 2 millirems is typically received in flying across the United States in a jet. This is the same dose received annually from those old luminous dial wristwatches. Cosmic radiation at sea level imparts 45 millirems annually, and radiation from the Earth's crust imparts about 80 millirems. Living in a concrete or brick house makes this figure slightly higher, for these materials contain more radioactive material than wood. The human body contains small amounts of carbon-14, potassium-40, and traces of uranium and thorium daughter products, which give an annual dose of 25 millirems. So the total natural background radiation annually is about 150 millirems. This makes up about 56% of the radiation the average person encounters, the rest being mainly medical and dental X-rays.

Before being retired, the former high-flying British-French SST, the Concorde, was equipped with radiation detectors that signaled the pilots when a level of 10 millirems per hour was reached (during a solar flare, for example). The pilots were required to descend to lower altitudes at 50 millirems per hour. According to a report by the British government after a year of Concorde operation, none of the alarms had ever gone off. Concorde pilots were limited to 500 hours flying time per year, compared to 1000 hours for crews on conventional aircraft.

Dentists routinely cover a patient with a leaded apron when making dental X-rays. Which airline will be first to provide similar protection to its airline personnel? I'm told by a seasoned pilot that life span for pilots is considerably below average. I find it incredible that being in the presence of cosmic days, day after day, doesn't cause a stir today. In my view, it's only a matter of time when leaded fabrics will be above the pilots in their cabin and the location where flight attendants spend much time. Perhaps the weight of such protection for passengers is considered prohibitive. In any event, most flying by the public is occasional and the danger is as tolerated as the dangers of being in automobiles, the number-one killer.

Common smoke detectors in the home make use of the very low dose of about 2 microcuries of americium-241, used to make the air in the detector's ionization chamber electrically conductive. When smoke enters the chamber it inhibits the flow of electricity, which activates the alarm. The lives saved each year by these devices number in the thousands (which dwarfs the numbers seriously harmed by radiation).

Computed tomography (CT) scans are created with the use of a 360-degree X-ray scan and computer assembly of the resulting images. These scans allow for cross-sectional views of body organs and tissues. Images are sharp, focused, and three-dimensional. X-ray exposure, however is many times that of standard X-rays. A single abdominal scan can expose a patient to 500 times more radiation than does a conventional chest X-ray. A similar looking machine is the MRI, which like the sonogram, provide images of the body with no radiation whatever. MRIs and sonograms involve no radiation.

The fact that the source of the Earth's heat is radioactive decay is not generally well known. More generally, people fear anything suggestive of radioactivity. When I was discussing this while driving through the volcano park in Hawaii with my guests, the Hopkinson family from Vancouver, physics teacher Peter Hopkinson replied that we have to be careful about using the *R* word. His daughter Jean humorously replied, "you mean r*adioactivity*?" The word *nuclear* also, is frightening to many people, which is the main reason why the name NMR (nuclear magnetic resonance) has been changed to MRI (magnetic resonance imaging)! The box on food irradiation in this chapter highlights another example of public distrust of anything "nuclear."

Being ignorant of radioactive decay, Lord Kelvin (1824 - 1907) made the extravagant claim that the age of Earth was between 20 to 400 million years. Penetration of Earth's crust by bore-holes and mines showed that temperature increases with depth. This means there is a flow of heat from the interior to the surface. Kelvin argued that this loss of heat meant Earth had been progressively hotter in the past. His premise was that the molten interior of Earth was the remnant of its hot birth. With this assumption and the rate at which Earth loses heat, Kelvin calculated the age of Earth. He allowed wide limits, due to uncertainties, and pronounced Earth's age as between 20 and 400 million years. This initiated a great controversy with geologists of Victorian times. Despite their protests, Kelvin felt justified by 1897 in narrowing his limits to 20 and 40 million years. It is interesting to note that with the superior data of the present day, the solution to Kelvin's problem, as he posed it, is between 25 and 30 million years. Although radioactivity had just been discovered (1896), Kelvin didn't acknowledge its role in heating Earth's interior. Sadly, when this was pointed out to him, he held to his previous hard earned but incorrect views. (How many people do you know who are comfortable in admitting when they're wrong?) Was it Bernard Shaw who said that human progress depends on finite lifetimes of people?

We don't say an electric heater is cooling because it is losing heat. From the moment when it is first switched on it is losing energy, as evidenced by the heated surroundings. The heater gets hotter until a balance is achieved between the heat electrically generated and the heat lost by radiation, conduction, and convection. Only when the current is reduced or switched off does cooling begin. Kelvin's treatment of his problem was concerned with the case of the current being turned off; when there was no internal source of heat at all. With the discovery of radioactivity and knowledge that Earth's interior has a source of energy, estimates of Earth's age based on the outward heat flow become valueless. Volcanic activity shows Earth has ample heat-generating resources.

The Practice Page for Chapter 17, *Our Earth's Hot Interior*, highlights this. If you didn't assign it earlier, do so now. A note of interest: The reason the Practice Page on the radioactivity in Earth's interior is in "an early" Chapter 17 in the Practicing Physics Book is because I feel the topic too important to place in this late chapter. Why? Because it is common to race through the end material of a physics book and to never get to radioactivity. As mentioned earlier, educated people can cite the acceleration due to Earth gravity, but very few can correctly answer the question, "What is the principle source of the Earth's internal heat?" I strongly feel radioactivity should be a part of a physics course.

Note the box on Food Irradiation in this chapter. Many people vigorously and actively oppose it, based on their perception of its dangers. Ironically, hundreds die of food poisoning in the U.S. each week—deaths that would have been averted if the food eaten had been irradiated. How many published photographs of the people who die daily would it take to re-channel the misplaced zeal of those who actively oppose food irradiation?

Practicing Physics Book:
- Radioactivity
- Natural Transmutation
- Nuclear Reactions

Problem Solving Book:
There are ample problems on radioactive processes

Laboratory Manual:
- Get a Half-Life *Radioactivity* (Activity)
- Radioactive Speed Dating *Radiometric Dating Simulation* (Tech Lab)

Next-Time Questions:
- Age of the Earth
- Radioactive Cookies
- Child's Balloon
- Radioactive Chromium
- Hot Spring
- Radioactive Gasoline
- Ancient Axe
- Geiger Counter

Hewitt-Drew-It! Screencasts: •*Radioactivity* •*The Strong Force* •*Radioactive Half-Life* •*Transmutation* •*Carbon Dating*

SUGGESTED LECTURE PRESENTATION

Begin by commenting on young William's statement about the warmth of the hot spring in the Part 7 opener—that radioactivity is nothing new and is as natural as hot springs and geysers. It in fact powers them. When electricity was first harnessed, people were fearful of it and its effects on life forms. Now it is commonplace, because its dangers are well understood. We are at a similar stage with regard to anything called nuclear. Even the very beneficial medical science *nuclear magnetic resonance* (*NMR*) has undergone a name change to *magnetic resonant imaging* (*MRI*). Why? "I don't want *my* Aunt Minnie near any *nuclear* machine!" The events of Fukushima add to the negativity concerning anything nuclear.

Hundreds of thousands of Americans live in houses that have a yearly radiation dose from radon in the ground equal to the dose residents living in the vicinity of Chernobyl received in 1986 when one of its reactors exploded and released radioactive materials into the environment (Go back to *Scientific American*, May, 1988). This is not to say it is unharmful to live in the vicinity of radon emission, but to say that radioactivity is not a modern problem and not a byproduct of science per se. It's been with us since day 1.

X-Rays and Radioactivity

Begin by comparing the emission of x-rays with the emission of light, showing that x-rays are emitted when the innermost electrons of heavy elements are excited. Then discuss medical and dental applications of X-rays, citing the newer photographic films now available that permit very short exposures of low intensity, and therefore safer dosages. Cite also the fact that the eye is the part of the body most prone to radiation damage—something that seems to be ignored by many dentists when making exposures of the teeth (and inadvertently, the eyes). (Why not eye masks as well as chest masks?)

Alpha, Beta, and Gamma Rays

Distinguish between alpha, beta, and gamma rays. If you've covered electricity and magnetism, ask if the rays could be separated by an electric field, rather than the magnetic field depicted in Figure 33.3.

Environmental Radiation

Radiation is not good for anybody, but we can't escape it. It is everywhere. However, we can take steps to avoid unnecessary radiation. Radiation, like everything else that is both damaging and little understood, is usually seen to be worse than it is. You can alleviate a sense of hopelessness about the dangers of radiation by pointing out that radiation is nothing new. It not only goes back before science and technology but before Earth came to be. It goes back to day 1. It is a part of nature that must be lived with. Good sense simply dictates that we avoid unnecessary concentrations of radiation.

Units and Doses of Radiation

There is much data here that may take more effort to learn than is worthwhile. Go easy on this. The general idea and comparisons are sufficient.

The Atomic Nucleus and the Strong Force

With no strong force in the atomic nucleus there would be no elements other than hydrogen. Everybody is interested in quarks. Discuss quarks—briefly.

Make the point that although neutrons provide a sort of nuclear cement, too many of them separate the protons and lead to instability. The nuclear fragments of fission (Chapter 34) are radioactive because of their preponderance of neutrons.

Radioactive Half-Life

Talk of jumping halfway to the wall, then halfway again, then halfway again and so on, and ask how many jumps will get you to the wall. Similarly with radioactivity. Of course, with a sample of radioactivity, there is a time when all the atoms undergo decay. But measuring decay rate in terms of this occurrence is a poor idea if only because of the small sample of atoms one deals with as the process nears the end of its course. Insurance companies can make accurate predictions of car accidents and the like with large numbers, but not so for small numbers. Dealing with radioactive half-life at least insures half the large number of atoms you start with.

> CHECK QUESTIONS: If the half-life of a certain isotope is one day, how much of the original isotope in a sample will still exist at the end of two days? Three days? Four days?

Pose the Check Yourself question on page 632 about the archaeologist finding an ancient axe handle in a cave. It makes a good lecture skit, after explaining the nitrogen-carbon-nitrogen cycle. Note that the screencast *Carbon Dating* treats this topic.

In discussing the exponential nature of radioactive half-life you may wish to cite the exponential nature of growth and doubling time. This is treated in Appendix E, a very timely topic. If the only ultimate check on growth of human populations is misery, the population will likely grow until it is miserable enough to stop its growth.

Radiation Detectors

Discuss and compare the various radiation detectors, beginning with the Geiger and scintillation counters shown in Figure 33.17. Figure 33.20 shows tracks left by streams of charged particles traveling through liquid hydrogen. Ask your class to hypothesize why the spiral shapes instead of the circular or helical shapes that a magnetic field would produce. (The track is there only because of an interaction with the liquid hydrogen, slowing by friction of sorts.) The conceptually nice bubble chamber is fading fast and arrays of fine wires in concert with fast computers have replaced them.

DEMONSTRATION: Show a cloud chamber in action (such as a simple one shown by my dear late friend Walt Steiger in Figure 33.19).

Natural and Artificial Transmutation of Elements
Introduce the symbolic way of writing atomic equations. Write some transmutation formulas on the board while your students follow along with their books opened to the periodic table in Chapter 11. A repetition and explanation of the reactions shown in Figure 33.22 is in order, if you follow up with one or two new ones as Check Questions. Be sure that your class can comfortably write equations for alpha decay before writing equations for beta decay, which are more complex because of the negative charge. Your treatment is the same for both natural and artificial transmutations.

Radioactive Isotopes
Acknowledge the use of these in so many common devices. One is the ionization smoke detectors where particles of smoke are ionized as they drift by a beta emitter to complete an electric circuit to sound an alarm. Ironically while many people fear anything associated with *nuclear* or *radioactivity*, these devices save thousands of lives each year.

The box on Food Irradiation can elicit class discussion.

NEXT-TIME QUESTION: With the aid of the periodic table, consider a decay-scheme diagram similar to the one shown in Figure 33.22 but beginning with U-235 and ending with an isotope of lead. Use the following steps and identify each element in the series with its chemical symbol. What isotope does this produce? [Pb-207]

1. Alpha
2. Beta
3. Alpha
4. Alpha
5. Beta
6. Alpha
7. Alpha
8. Alpha
9. Beta
10. Alpha
11. Beta
12. Stable

Answers and Solutions for Chapter 33

Reading Check Questions

1. Roentgen discovered the emission of “new kind of rays.”
2. X-rays are high-frequency electromagnetic radiation.
3. Becquerel discovered that uranium emitted a new kind of penetrating radiation.
4. The Curies discovered polonium and radium.
5. Gamma rays have no electric charge.
6. Gamma rays are higher in frequency than X-rays.
7. A rad is a unit of absorbed energy. A rem is a measure of radiation based on potential damage (roentgen equivalent man).
8. Humans receive more radiation from natural sources than artificial sources.
9. Yes, the human body *is* radioactive. Radioactive potassium is in all humans.
10. Radioactive tracers are radioactive isotopes used to trace pathways in living things.
11. Protons and neutrons are two different nucleons.
12. The presence of a strong attractive force between nucleons in the nucleus prevents protons from repelling out of the nucleus.
13. Because the strong force is short range, protons in a large nucleus are farther apart on average than in a small nucleus, and the strong force is less effective between wide-apart protons.
14. Neutrons play the role of a nuclear cement in nuclei and also act to space protons apart.
15. Larger nuclei contain a larger percentage of neutrons.
16. Rate of decay is greater for elements with short half-lives.
17. The half-life of Ra-226 is 1620 years.
18. A trail in the tube is composed of freed electrons and positive ions.
19. A Geiger counter senses radiation by ionization.
20. A scintillation counter senses radiation by flashes of light.
21. A transmutation is the changing of an element to another element.
22. The transmutation of thorium by alpha emission produces an element with 2 less protons in the nucleus, to atomic number 88.
23. When thorium emits a beta particle, it transmutes to an element with atomic number increased by 1, to atomic number 91.
24. There is a mass reduction of 4 for alpha emission, and no change in mass for beta emission.
25. When an element emits an alpha particle, atomic number decreases by 2. For emission of a beta particle, atomic number increases by 1. For gamma emission, no change in atomic number.
26. Uranium ultimately transmutes to lead.
27. Ernest Rutherford in 1919 was the first to intentionally transmute elements.
28. When nitrogen captures a neutron it transmutes to carbon-14.
29. Most of the carbon we ingest is carbon-12.
30. Uranium is continually transmuting to lead, so deposits of uranium also contain lead.

Think and Do

31. The point is that radioactivity is not something new, but is part of nature.

Think and Solve

32. At the end of the second year 1/4 of the original sample will be left; at the end of the third year, 1/8 will be left; and at the end of the fourth year, 1/16 will be left.

33. The half-life of the material is two hours. A little thought will show that 160 halved 4 times equals 10. So there have been four half-life periods in the 8 hours. And 8 hours/4 = 2 hours.

34. One-sixteenth will remain after 4 half-lives, so $4 \times 30 = 120$ years.

35. Nine hours have elapsed at 3:00 p.m. That’s 9/1.8 = 5 half-lives. So $(1/2) \times (1/2) \times (1/2) \times (1/2) \times (1/2) = 1/32$ the original amount, 0.0313 milligram. At midnight, 18 hours later, 18/1.8 = 10 half lives have elapsed. $(1/2)^{10}$ is about 1/1000 of the original, about 0.001 milligram. If the hospital needs F-18 the next day, it should produce it the next morning.

36. The intensity is down by a factor of 16.7 (from 100% to 6%). How many factors of two is this? About 4, since $2^4 = 16$. So the age of the artifact is about 4×5730 years or about 23,000 years.

37. There are 500 gallons in the tank since, after mixing, the gallon you withdraw has 10/5000 = 1/500 of the original radioactive particles in it.

Think and Rank

38. C, B, A.

39. a. B=C, A.
b. C, A=B**.**
c. B=C, A.

40. a. B, C, A.
b. C, A, B.

Think and Explain

41. Kelvin was not aware of radioactive decay, a source of energy to keep Earth warm for billions of years.

42. X-rays are high-frequency electromagnetic waves, and are therefore most similar to even higher-frequency electromagnetic waves—gamma rays. Alpha and beta rays, in contrast, are streams of material particles.

43. Gamma radiation is in the form of electromagnetic waves, while alpha and beta radiations consist of particles having mass.

44. A radioactive sample is always a little warmer than its surroundings because the radiating alpha or beta particles impart internal energy to the sample. (Interestingly, the heat energy of the Earth originates with radioactive decay in the Earth's interior.)

45. It is impossible for a hydrogen atom to eject an alpha particle, for an alpha particle is composed of four nucleons—two protons and two neutrons. It is equally impossible for a 1-kg melon to disintegrate into four 1-kg melons.

46. Alpha and beta rays are deflected in opposite directions in a magnetic field because they are oppositely charged—alphas are positive and betas negative. Gamma rays have no electric charge and are therefore undeflected.

47. The alpha particle has twice the charge, but almost 8000 times the inertia (since each of the four nucleons has nearly 2000 times the mass of an electron). So the much-greater mass of the alphas more than compensates for their double charge and lower speed.

48. Alpha and beta particles are pushed oppositely by an electric field; gamma rays are unaffected. If the particles move across (rather than along) the field lines, the paths of alpha and beta particles are bent oppositely, similar to what happens in a magnetic field. Gamma rays, in any case, traverse the field undeflected.

49. Alpha radiation decreases the atomic number of the emitting element by 2 and the atomic mass number by 4. Beta radiation increases the atomic number of an element by 1 and does not affect the atomic mass number. Gamma radiation does not affect the atomic number or the atomic mass number. So alpha radiation results in the greatest change in both atomic number and mass number.

50. Gamma and beta radiation both produce *no* change in mass number. Only gamma radiation produces no change in atomic number. Whereas beta radiation changes only atomic number, alpha radiation changes both mass number and atomic number.

51. Gamma predominates inside the enclosed elevator because the structure of the elevator shields against alpha and beta particles better than against gamma-ray photons.

52. Because of the fact that like charges repel, and that protons have the same sign of charge (positive) as the target atomic nuclei, the protons must be driven into the target area with enormous energies if they are to bombard the nuclei. Lower-energy protons would be easily electrically repelled by any nuclei they approach.

53. An alpha particle undergoes an acceleration due to mutual electric repulsion as soon as it is out of the nucleus and away from the attracting nuclear force. This is because it has the same sign of charge as the nucleus. Like charges repel.

54. All isotopes have the same number of protons, but different number of neutrons.

55. Because it has twice as much charge as a beta particle, an alpha particle interacts more strongly with atomic electrons and loses energy more rapidly by ionizing the atoms. (The slower speed of the alpha particle also contributes to its ability to ionize atoms more effectively.)

56. They repel by the electric force, and attract each other by the strong nuclear force. With the help of neutrons, the strong force predominates. (If it didn't, there would be no atoms beyond hydrogen!) If the protons are separated to where the longer-range electric force overcomes the shorter-range strong force, they fly apart.

57. Within the atomic nucleus, it is the strong nuclear force that holds the nucleons together, and the electric force that mutually repels protons and pushes them apart.

58. The existence of atomic nuclei containing many protons is evidence that something stronger than electric repulsion is occurring in the nucleus. If there were not a stronger attractive nuclear force to keep the repelling electrical force from driving protons apart, the nucleus as we know it wouldn't exist.

59. Yes, indeed!

60. A positively charged hydrogen atom, an ion, is the nucleus of the atom, since no electron remains. It is usually a proton, but could be a deuteron or triton, one of the nuclei of heavier hydrogen isotopes.

61. Chemical properties have to do with electron structure, which is determined by the number of protons in the nucleus, not the number of neutrons.

62. In accord with the inverse-square law, at 2 m, double the distance, the count rate will be 1/4 of 360 or 90 counts/minute; at 3 m, the count rate will be 1/9 of 360, or 40 counts/minute.

63. The spiral path of charged particles in a bubble chamber is the result of a slowing of the particles due to collisions with atoms, usually hydrogen, in the chamber. The slower-moving charged particles bend more in the magnetic field of the chamber and their paths become spirals. If the charged particles moved without resistance, their paths would be circles or helixes.

64. Number of nucleons and electric charge.

65. The mass of the element is 157 + 100 = 257. Its atomic number is 100, the transuranic element named fermium, after Enrico Fermi.

66. When a nucleus of radium (atomic number 88) emits an alpha particle, its atomic number reduces by 2 and it becomes the nucleus of the element radon (atomic number 86). The resulting atomic mass number is reduced by 4. If the radium was of the most common isotope 226, then the radon isotope would have atomic mass number 222.

67. After the polonium nucleus emits a beta particle, the atomic number increases by 1 to become 85, and the atomic mass number is unchanged at 218.

68. When an alpha particle is emitted by polonium-218, the atomic number decreases by 2 to become 82, and the atomic mass number decreases by 4, becoming 214.

69. Both have 92 protons, but U-238 has more neutrons than U-235.

70. The deuterium nucleus contains 1 proton and 1 neutron; the carbon nucleus, 6 protons and 6 neutrons; the iron nucleus, 26 protons and 30 neutrons; the gold nucleus, 79 protons and 118 neutrons; the strontium nucleus, 38 protons and 52 neutrons; and the uranium nucleus, 92 protons and 146 neutrons.

71. An element can decay to an element of greater atomic number by emitting electrons (beta rays). When this happens, a neutron in the nucleus becomes a proton and the atomic number increases by one.

72. If it emits two beta particles for each alpha particle, the same element results.

73. When a phosphorus nucleus (atomic number 15) emits a positron (a positively-charged electron) the charge of the atomic nucleus decreases by 1, converting it to the nucleus of the element silicon (atomic number 14).

74. If strontium-90 (atomic number 38) emits betas, it should become the element yttrium (atomic number 39); hence the physicist can test a sample of strontium for traces of yttrium by spectrographic means or other techniques. To verify that it is a “pure” beta emitter, the physicist can check to make sure that the sample is emitting no alphas or gammas.

75. If nuclei were composed of equal numbers of protons and electrons, nuclei would have no net charge. They wouldn’t hold electrons in orbit. The fact that atoms do have a positive nucleus and orbiting electrons contradicts your friend’s assertion.

76. Radium is a “daughter” element, the result of the radioactive decay of long-live uranium. So as long as uranium exists, radium will exist.

77. Agree with your friend that sees helium gas as being alpha particles. It’s true, alpha particles emitted by radioactive isotopes in the ground slow down and stop, capture two electrons, and become helium atoms. Our supplies of helium come from underground. Any helium in the atmosphere is soon dissipated into space.

78. Your friend will encounter more radioactivity from the granite outcroppings than he or she will in the same time near a nuclear power plant. Plus, at high altitude your friend will be treated to increased cosmic radiation. But the radiations encountered in the vicinity of the plant, on the granite outcropping, or at high altitude are not appreciably different than the radiation one encounters in the “safest” of situations. Advise your friend to enjoy life anyway!

79. The Earth’s natural energy that heats the water in the hot spring is the energy of radioactive decay. Just as a piece of radioactive material is warmer than its surroundings due to thermal agitation from radioactive decay, the interior of the Earth is similarly warmed. The great radioactivity in the Earth’s interior therefore heats the water, but doesn’t make the water itself radioactive. The warmth of hot springs is one of the “nicer effects” of radioactive decay.

80. You can tell your friend who is fearful of the radiation measured by the Geiger counter that his attempt to avoid the radiation by avoiding the instrument that measures it is useless. Your friend might as well avoid thermometers on a hot day in effort to escape the heat. If it will console your fearful friend, tell him or her that ancestors from time zero have endured about the same level of radiation he or she receives whether or not standing near the Geiger counter. There have been no better options. Make the best of the years available anyway!

81. Dinosaur bones are simply much too old for carbon dating because too little carbon-14 is left in the bones after that long a time.

82. (a) No, not a few years old. Too small a fraction of the carbon-14 has decayed. You couldn’t tell the difference between an age of a few years and a few dozen or even a hundred years.
(b) Yes, in a few thousand years a significant fraction of the carbon-14 has decayed. The method gives best results for ages not so very different from the half-life of the isotope.
(c) No, not a few million years old. Essentially all of the carbon-14 will have decayed. There will be none left to detect. You wouldn’t be able to distinguish between an age of a million or ten million or a hundred million years.

83. Stone tablets cannot be dated by the carbon dating technique. Nonliving stone does not ingest carbon and transform that carbon by radioactive decay. Carbon dating works for organic materials.

84. Open-ended.

Think and Discuss

85. Starting from birth, a human population has a certain half-life, the time until half have died, but this doesn't mean that half of those still living will die in the next equal interval of time. For radioactive atoms, the chance of "dying" (undergoing decay) is always the same, regardless of the age of the atom. A young atom and an old atom of the same type have exactly the same chance to decay in the next equal interval of time. This is not so for humans, for whom the chance of dying increases with age.
86. Eight alpha particles and six beta particles are emitted in the decay chain from U-238 to Pb-206. The numbers are the same for the alternate routes.
87. The elements below uranium in atomic number with short half-lives exist as the product of the radioactive decay of uranium or another very long-lived element, thorium. For the billions of years that the uranium and thorium last, the lighter elements will be steadily replenished.
88. Although there is significantly more radioactivity in a nuclear power plant than in a coal-fired power plant, almost none of it escapes from the nuclear plant, whereas most of the radioactivity existing in a coal-fired plant escapes through the stacks. As a result, a typical coal plant injects more radioactivity into the environment than does a typical nuclear plant.
89. The irradiated food does not become radioactive as a result of being zapped with gamma rays. This is because the gamma rays lack the energy to initiate the nuclear reactions in atoms in the food that could make them radioactive.
90. The reading would be the same! With a half-life of billions of years, its decreased rate is negligible in a 60-year span.