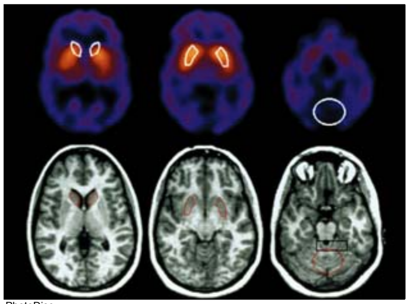
# Chapter Eleven Nuclear Chemistry



## How is brain-scans done?

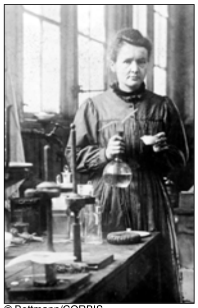
→ CO 11.1
Associated with brain-scan technology is the use of small amounts of radioactive substances.







## Marie Curie discovered radium





← Fig. 11.1
Marie Curie, one of the pioneers in the study of radioactivity, is the first person to have been awarded two Nobel Prizes for scientific work.



## Effect of electromagnetic fields on ionization radiation

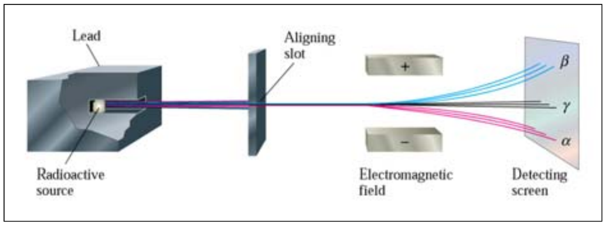
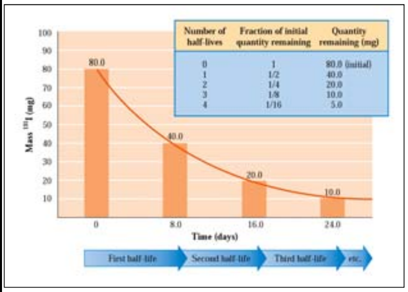



Fig. 11.2
The effect of an electromagnetic field on alpha, beta, and gamma radiation.

## What is half-life period?




← **Fig. 11.3**
**After each half-life period, the quantity of material present at the beginning of the period is reduced by half.**



# Half-life and decay

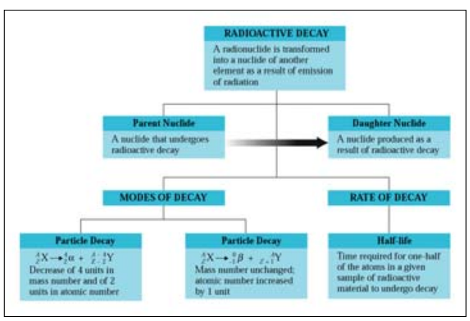
→ Table 11.1

| Element | Half-life ($t_{1/2}$) |
|---|---|
| vanadium-50 | $6 \times 10^{15}$ yr |
| platinum-190 | $6.9 \times 10^{11}$ yr |
| uranium-238 | $4.5 \times 10^{9}$ yr |
| uranium-235 | $7.1 \times 10^{8}$ yr |
| thorium-230 | $7.5 \times 10^{4}$ yr |
| lead-210 | 22 yr |
| bismuth-214 | 19.7 min |
| polonium-212 | $3.0 \times 10^{-7}$ sec |



# Radioactive decay

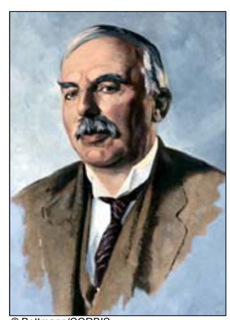
→ CAG 11.1






## Bombardment reaction

→ **Fig. 11.4**
**Ernest Rutherford was the first person to carry out a bombardment reaction.**



# Details of radioactive nuclides

→ Table 11.2

| Name | Symbol | Atomic Number | Mass Number of Most Stable Nuclide | Half-life of Most Stable Nuclide | Discovery Year for First Isotope |
|---|---|---|---|---|---|
| neptunium | Np | 93 | 237 | $2.14 \times 10^6$ yr | 1940 |
| plutonium | Pu | 94 | 244 | $7.6 \times 10^7$ yr | 1940 |
| americium | Am | 95 | 243 | $8.0 \times 10^3$ yr | 1944 |
| curium | Cm | 96 | 247 | $1.6 \times 10^7$ yr | 1944 |
| berkelium | Bk | 97 | 247 | 1400 yr | 1950 |
| californium | Cf | 98 | 251 | 900 yr | 1950 |
| einsteinium | Es | 99 | 252 | 472 days | 1952 |
| fermium | Fm | 100 | 257 | 100 days | 1953 |
| mendelevium | Md | 101 | 258 | 52 days | 1955 |
| nobelium | No | 102 | 259 | 58 min | 1958 |
| lawrencium | Lr | 103 | 262 | 3.6 hr | 1961 |
| rutherfordium | Rf | 104 | 263 | 10 min | 1969 |
| dubnium | Db | 105 | 262 | 34 sec | 1970 |
| seaborgium | Sg | 106 | 266 | 20 sec | 1974 |
| bohrium | Bh | 107 | 267 | 17 sec | 1980 |
| hassium | Hs | 108 | 277 | 11 min | 1984 |
| meitnerium | Mt | 109 | 276 | 0.72 sec | 1982 |
| darmstadtium | Ds | 110 | 271 | 1.6 min | 1994 |
| roentgenium | Rg | 111 | 272 | 0.002 sec | 1994 |
| element 112 | — | 112 | 285 | 15.4 min | 1996 |
| element 113 | — | 113 | 284 | 0.48 sec | 2004 |
| element 114 | — | 114 | 289 | 30.4 sec | 1999 |
| element 115 | — | 115 | 288 | 0.0087 sec | 2004 |



# Smoking, lung-cancer & radiation

The adverse health effects from cigarette smoking account for 440,000 deaths, or nearly 1 in 5 deaths, each year in the United States. Approximately one-third of these deaths are from lung cancer and an almost equal number from cardiovascular disease. The risk of dying from lung cancer is 22 times higher among men who smoke cigarettes compared with nonsmokers. Cigarette smokers are 2–4 times more likely to develop coronary heart disease than nonsmokers. Cigarette smoking approximately doubles a person's risk of stroke. One's life is shortened 14 minutes for every cigarette smoked. A 30- to 40-year cigarette smoker who smokes two packs of cigarettes per day loses an estimated 8 years of life.

The link between cigarette smoke and cancer is definitely established. The causative agents for the cancer involve many of the more than 2000 compounds identified in cigarette tar. And radioactivity has also been implicated.

The link between radioactivity and tobacco involves the following sequence of events. The soil in which tobacco is grown is heavily treated with phosphate fertilizers. The source for phosphate fertilizers is ultimately phosphate rock. Nearly all phosphate rock contains small amounts of uranium and its decay products as impurities. Hence small amounts of radioactive nuclides are present in fertilized tobacco-growing soil (as well as in many other crop soils).

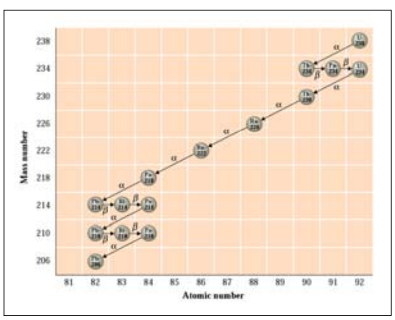
Radon-222, one of the intermediate products from the uranium-238 decay series (Section 11.6), is present at relatively high concentrations in soil gas and in the surface air layer under the vegetation canopy provided by a field of growing tobacco plants. The decay products from radon-222 (see Figure 11.6), which include the solids polonium-218 and bismuth-214, often become firmly attached to the surface and interior of tobacco leaves. These short-lived isotopes decay further to lead-210, which has a half-life of 20.4 years. Gradually, lead-210 levels build in tobacco leaves.

During the burning of a cigarette, small particles (particulates) are produced in addition to gaseous products. Many of these particulates, some of which have a lead-210 content, are inhaled and deposited in the respiratory tract of the smoker and are eventually transported to storage sites in the liver, spleen, and bone marrow. With time (years of smoking), lead-210 concentrations (and decay products) continue to build within the body. The results are constant added exposure of organs and bone marrow to alpha and beta particles and an increased probability of cancer development in the smoker as compared with the nonsmoker.



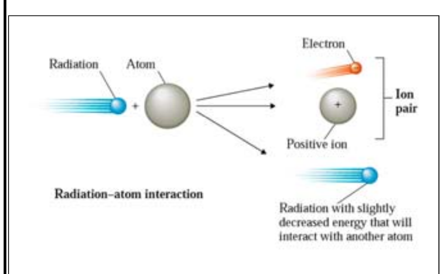
# Nuclear decay series-uranium-235

→ Fig. 11.6
In the U-238 decay series, each nuclide is unstable except Pb-206.





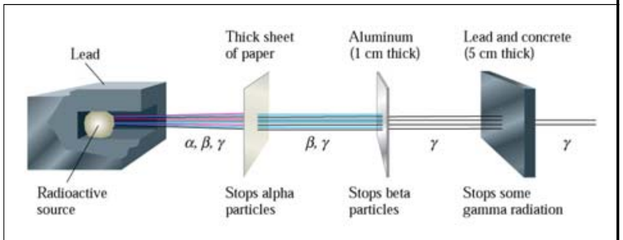

# Ionizing radiation




← Fig. 11.7
Ion pair formation.

# Relative penetrability of radiation

**Fig. 11.8**
**Alpha, beta, and gamma radiation differ in penetrating ability.**






# Radiation doses: rems

→ **Table 11.3**

| Dose (rems)* | Effects |
|---|---|
| 0–25 | No detectable clinical effects. |
| 25–100 | Slight short-term reduction in number of some blood cells; disabling sickness not common. |
| 100–200 | Nausea and fatigue, vomiting if dose is greater than 125 rems; longer-term reduction in number of some blood cells. |
| 200–300 | Nausea and vomiting first day of exposure; up to a 2-week latent period followed by appetite loss, general malaise, sore throat, pallor, diarrhea, and moderate emaciation. Recovery in about 3 months, unless complicated by infection or injury. |
| 300–600 | Nausea, vomiting, and diarrhea in first few hours. Up to a 1-week latent period followed by loss of appetite, fever, and general malaise in the second week, followed by hemorrhage, inflammation of mouth and throat, diarrhea, and emaciation. Some deaths in 2 to 6 weeks. Eventual death for 50% if exposure is above 450 rems; others recover in about 6 months. |
| 600 or more | Nausea, vomiting, and diarrhea in first few hours. Rapid emaciation and death as early as second week. Eventual death of nearly 100%. |

*A rem is the quantity of ionizing radiation that must be absorbed by a human to produce the same biological effect as 1 roentgen of high-penetration X rays. A roentgen is the quantity of high-penetration X rays that produces approximately $2 \times 10^9$ ion pairs per cubic centimeter of dry air at 0°C and 1 atm.



# Irradiated food safe to eat?

→ **CC 11.2**
**Irridated and nonradiated mushrooms**






# Radiation exposure

Doug Plummer/Photo Researchers

← **Fig. 11.9**
**Film badges are used to determine a person's exposure to radiation.**

## Radiation detection

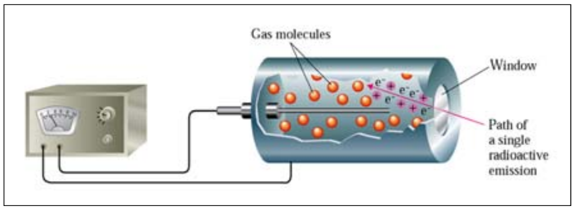
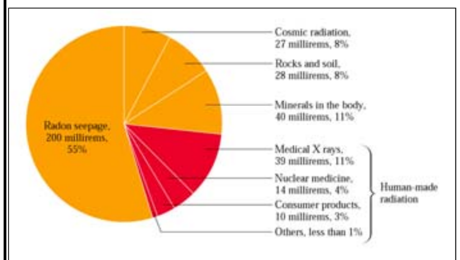



**Fig. 11.10**
Radiation passing through a Geiger counter ionizes one or more gas atoms, producing ion pairs.



## What causes radiation exposure?

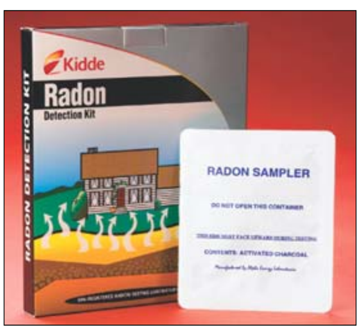



← **Fig. 11.11**
**Components of the estimated annual radiation of an average American.**



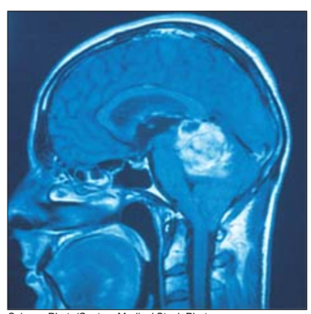
## Testing radon gas

→ **CC. 11.3**
**A commercially available kit to test for radon gas in the home.**






## Technetium-99 used as radiation source



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← **Fig. 11.12**
**Brain scans are obtained using radioactive technetium-99, a laboratory-produced radionuclide.**

# Radionuclide used in medicine

Table 11.4

| Nuclide | Half-life | Part of Body Affected | Use in Diagnosis |
|---|---|---|---|
| barium-131 | 11.6 days | bone | detection of bone tumors |
| chromium-51 | 27.8 days | blood | determination of blood volume and red blood cell lifetime |
| | | kidney | assessment of kidney activity |
| iodine-131 | 8.05 days | brain | detection of fluid buildup in the brain |
| | | kidney | location of cysts |
| | | lung | location of blood clots |
| | | thyroid | assessment of iodine uptake by thyroid |
| iron-59 | 45 days | blood | evaluation of iron metabolism in blood |
| phosphorus-32 | 14.3 days | blood | blood studies |
| | | breast | assessment of breast carcinoma |
| potassium-42 | 12.4 hours | tissue | determination of intercellular spaces in fluids |
| sodium-24 | 15.0 hours | blood | detection of circulatory problems; assessment of peripheral vascular disease |
| technetium-99 | 6.0 hours | brain | detection of brain tumors, hemorrhages, or blood clots |
| | | spleen | measurement of size and shape of spleen |
| | | thyroid | measurement of size and shape of thyroid |
| | | lung | location of blood clots |



# Radionuclide used in medicine

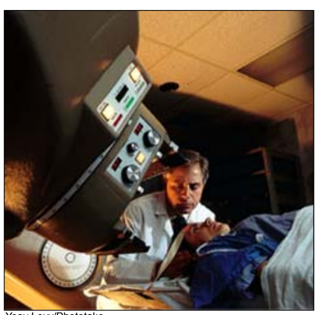
Table 11.5

| Nuclide | Half-life | Type of Emitter | Use in Therapy |
|---|---|---|---|
| cobalt-60 | 5.3 years | gamma | external source of radiation in treatment of cancer |
| iodine-131 | 8 days | beta, gamma | cancer of thyroid |
| phosphorus-32 | 14.3 days | beta, gamma | treatment of some types of leukemia and widespread carcinomas |
| radium-226 | 1620 years | alpha, gamma | used in implantation cancer therapy |
| radon-222 | 3.8 days | alpha, gamma | used in treatment of uterine, cervical, oral, and bladder cancers |
| yttrium-90 | 64 hours | beta, gamma | implantation therapy |



# Cobalt-60 as gamma source

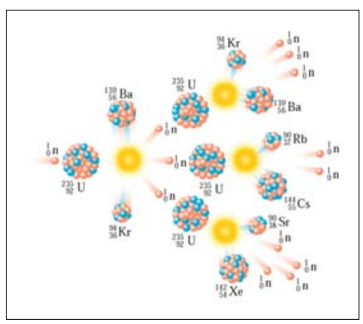
→ **Fig. 11.13**
**Cobalt-60 is used as a source of gamma radiation in radiation therapy.**



Yoav Levy/Phototake



## Fission chain reaction of uranium-235



← **Fig. 11.14**
**A fission chain reaction is caused by further reaction of the neutrons produced during fission.**

## Fission bomb

→ **Fig. 11.15**
**Enormous amounts of energy are released in the explosion of a nuclear fission bomb.**

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## Nuclear reactors for energy

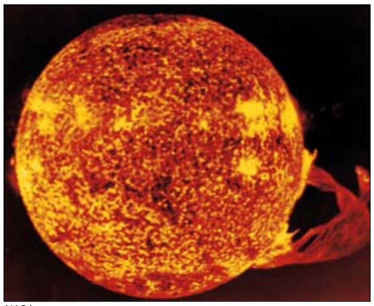
© Albert J. Copley/Visuals Unlimited

← **Fig. 11.16**
**The cooling tower at the Trojan nuclear power plant dominates the landscape. The nuclear reactor is housed in the dome-shaped enclosure.**



## Fusion energy: Ultimate source of energy

→ **Fig. 11.17**
**The process of nuclear fusion maintains the interior of the sun at the temperature of approximately 15 million degrees.**

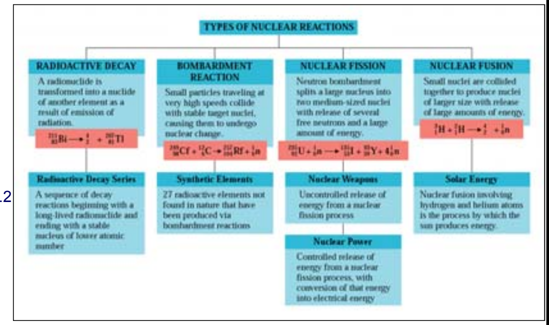


NASA



## Types of nuclear reactions

→ CAG 11.2



## Comparing chemical and nuclear reactions

→ **Table 11.6**

| Chemical Reaction | Nuclear Reaction |
| --- | --- |
| 1. Different isotopes of an element have identical chemical properties. | 1. Different isotopes of an element have different nuclear properties. |
| 2. The chemical reactivity of an element depends on the element's state of combination (free element, compound, etc.). | 2. The nuclear reactivity of an element is independent of the state of chemical combination. |
| 3. Elements retain their identity in chemical reactions. | 3. Elements may be changed into other elements during nuclear reactions. |
| 4. Energy changes that accompany chemical reactions are relatively small. | 4. Energy changes that accompany nuclear reactions are a number of orders of magnitude larger than those in chemical reactions. |
| 5. Reaction rates are influenced by temperature, pressure, catalysts, and reactant concentrations. | 5. Reaction rates are independent of temperature, pressure, catalysts, and reactant concentrations. |