THE CHEMICAL ELEMENTS AND ISOTOPES

A chemical element is made up of atoms having the same “atomic number” (i.e., number of protons in the nucleus of each atom) and hence having the same chemical properties. An atom is the smallest unit of a chemical element that has all the chemical properties of that element. All the atoms of a chemical element react with atoms of another chemical element in the same way. Some examples of chemical elements are hydrogen, oxygen, and carbon. Two hydrogen atoms react with one oxygen atom to form a molecule of water (H_2O); a carbon atom reacts with two oxygen atoms to form a molecule of carbon dioxide (CO_2); and so forth.

There are 92 naturally occurring chemical elements. An alphabetical list of the chemical elements and their symbols appear on the following pages.

A chart of the chemical elements called “The Periodic Table” is included. The periodic table is a chart that was originally devised by Dmitri Mendeleev in 1869. The table helps scientists understand the different relationships that elements have to one another. Each square in the periodic table gives information about a separate element.

As noted in the footnotes to the periodic table and earlier, the atomic number is equal to the number of protons in the nucleus of an atom of a chemical element. The number of protons in the nucleus of an atom determines the chemical properties of an atom. Atoms of a chemical element often have different atomic weights because, although the atomic nuclei have the same number of protons, the number of neutrons may differ. Atoms of an element having the same number of protons but different numbers of neutrons are called isotopes of that element.

For example, uranium has several isotopes, which all react in the same way chemically, but their nuclear reactions are different. Uranium-238 does not fission readily. For this reason, uranium-235, which fissions more readily, is used for reactor fuel.

THE CHEMICAL ELEMENTS AND THEIR SYMBOLS

actinium	Ac	hafnium	Hf	praseodymium	Pr
aluminum	Al	helium	He	promethium	Pm
americium	Am	holmium	Ho	protactinium	Pa
antimony	Sb	hydrogen	H	radium	Ra
argon	Ar	indium	In	radon	Rn
arsenic	As	iodine	I	rhenium	Re
astatine	At	iridium	Ir	rhodium	Rh
barium	Ba	iron	Fe	rubidium	Rb
berkelium	Bk	krypton	Kr	ruthenium	Ru
beryllium	Be	lanthanum	La	samarium	Sm
bismuth	Bi	lawrencium	Lr	scandium	Sc
boron	B	lead	Pb	selenium	Se
bromine	Br	lithium	Li	silicon	Si
cadmium	Cd	lutetium	Lu	silver	Ag
calcium	Ca	magnesium	Mg	sodium	Na
californium	Cf	manganese	Mn	strontium	Sr
carbon	C	mendelevium	Md	sulfur	S
cerium	Ce	mercury	Hg	tantalum	Ta
cesium	Cs	molybdenum	Mo	technetium	Tc
chlorine	Cl	neodymium	Nd	tellurium	Te
chromium	Cr	neon	Ne	terbium	Tb
cobalt	Co	neptunium	Np	thallium	Tl
copper	Cu	nickel	Ni	thorium	Th
curium	Cm	niobium	Nb	thulium	Tm
dysprosium	Dy	nitrogen	N	tin	Sn
einsteinium	Es	nobelium	No	titanium	Ti
erbium	Er	osmium	Os	tungsten	W
europium	Eu	oxygen	O	uranium	U
fermium	Fm	palladium	Pd	vanadium	V
fluorine	F	phosphorus	P	xenon	Xe
francium	Fr	platinum	Pt	ytterbium	Yb
gadolinium	Gd	plutonium	Pu	yttrium	Y
gallium	Ga	polonium	Po	zinc	Zn
germanium	Ge	potassium	K	zirconium	Zr
gold	Au				

Periodic Table

Atomic Number → 20 | Atomic Weight → 40.08 | **Ca**

1 **H** 1.00797																	2 **He** 4.0026
3 **Li** 6.939	4 **Be** 9.0122											5 **B** 10.811	6 **C** 12.01115	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984	10 **Ne** 20.183
11 **Na** 22.9898	12 **Mg** 24.312											13 **Al** 26.9815	14 **Si** 28.086	15 **P** 30.9738	16 **S** 32.064	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.102	20 **Ca** 40.08	21 **Sc** 44.956	22 **Ti** 47.90	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.71	29 **Cu** 63.546	30 **Zn** 65.37	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.909	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.905	40 **Zr** 91.22	41 **Nb** 92.906	42 **Mo** 95.94	43 **Tc** 97	44 **Ru** 101.07	45 **Rh** 102.905	46 **Pd** 106.4	47 **Ag** 107.868	48 **Cd** 112.40	49 **In** 114.82	50 **Sn** 118.69	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.9044	54 **Xe** 131.30
55 **Cs** 132.905	56 **Ba** 137.34	57 **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.948	74 **W** 183.85	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.09	79 **Au** 196.967	80 **Hg** 200.59	81 **Tl** 204.37	82 **Pb** 207.19	83 **Bi** 208.980	84 **Po** 210.05	85 **At** 210	86 **Rn** 222
87 **Fr** 223	88 **Ra** 226	89 **Ac** 227															
			58 **Ce** 140.12	59 **Pr** 140.907	60 **Nd** 144.24	61 **Pm** 145	62 **Sm** 150.35	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.924	66 **Dy** 162.50	67 **Ho** 164.930	68 **Er** 167.28	69 **Tm** 168.934	70 **Yb** 173.04	71 **Lu** 174.97	
			90 **Th** 232.038	91 **Pa** 231.10	92 **U** 238.03	93 **Np** 237	94 **Pu** 239.05	95 **Am** 243.13	96 **Cm** 247	97 **Bk** 248	98 **Cf** 251	99 **Es** 252	100 **Fm** 257	101 **Md** 258	102 **No** 255	103 **Lr** 256	

1. The capital letter or combination of a capital letter and lower case letter in the center of the box is the symbol for the element. For example, H stands for hydrogen, He for helium.

2. In the upper left corner of each box is the atomic number for the element. This number is equal to the number of protons in the nucleus of the element.

3. In the center of the box is the atomic weight, given in decimals. Atomic weight is the average weight of all isotopes of a particular element. Rounded off to the nearest whole number, the atomic weight is the number of protons and neutrons, of most common isotopes, added together.

CHEMICAL ELEMENT WORKTABLE

DIRECTIONS: Using the list of elements and symbols and the Periodic Table, fill in the chart below. The first example has been completed for you.

Element	Symbol	Atomic Number	Atomic Weight	Atomic Weight (rounded off)	No. of Protons	No. of Neutrons
Gold	Au	79	196.9670	197	79	118
Helium						
Carbon						
Uranium						
Radium						
Plutonium						
Oxygen						
Radon						
Nitrogen						
Calcium						

CHEMICAL ELEMENT WORKTABLE

DIRECTIONS: Name the isotopes by filling in all the blanks below.

Isotopes of a given element are atoms with nuclei that have the same number of protons, but different numbers of neutrons. An isotope is identified by the sum of the number of protons and neutrons in its nucleus. To find the symbol, use the list of elements and symbols. To find the correct number of protons, use the periodic table.

The first example has already been completed.

Element	Symbol	Number Protons	Number Neutrons	Name of Isotope
Uranium	U	92	143	Uranium-235
Uranium			146	
Carbon			8	
Iodine			78	
Strontium			52	
Cesium			82	
Thorium			142	

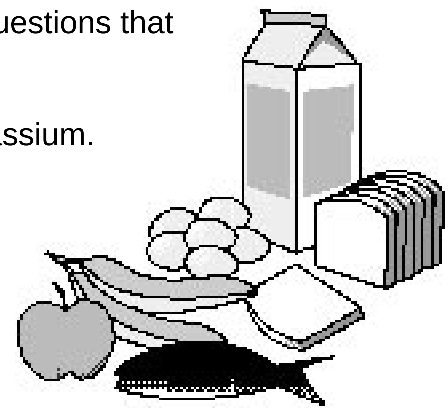
RADIOACTIVITY IN FOOD

Many of the foods that we eat contribute to our internal exposure to radiation. These foods are naturally radioactive. They contain elements like potassium and carbon that are essential for good health and cannot be eliminated from our diets.

Potassium-40

Potassium-40 is a radioactive isotope of naturally occurring potassium. Potassium-40 contributes 18 millirem to our average annual internal radiation exposure.

Directions: Use the chart entitled *Potassium Content and Potassium-40 Activity in Some Selected Foods* to answer the questions that follow.



1. List four foods you have eaten this week that contain potassium.

 ____

 ____

 ____

 ____

2. If the radioactivity of 1 gram of natural potassium is 30 disintegrations per second (d/sec) and a small banana contains about 0.4 grams of natural potassium, what is the number of disintegrations per second of this banana?

3. The activity of the radioactive potassium-40 in your body is about 60 disintegrations per second per kilogram (d/sec/kg) of body weight.

 a. How much do you weigh? (in pounds) ____________________

 b. If 1 kilogram (kg) = 2.2 lbs., how much do you weigh in kilograms?

c. Given the activity of potassium-40 above, what is the activity of potassium-40 in your body in disintegrations per second (d/sec)?

Carbon-14

The second largest contributor to our annual internal exposure is carbon-14, a naturally occurring radioactive isotope of carbon. It contributes about 1.2 millirem to our average annual internal radiation exposure.

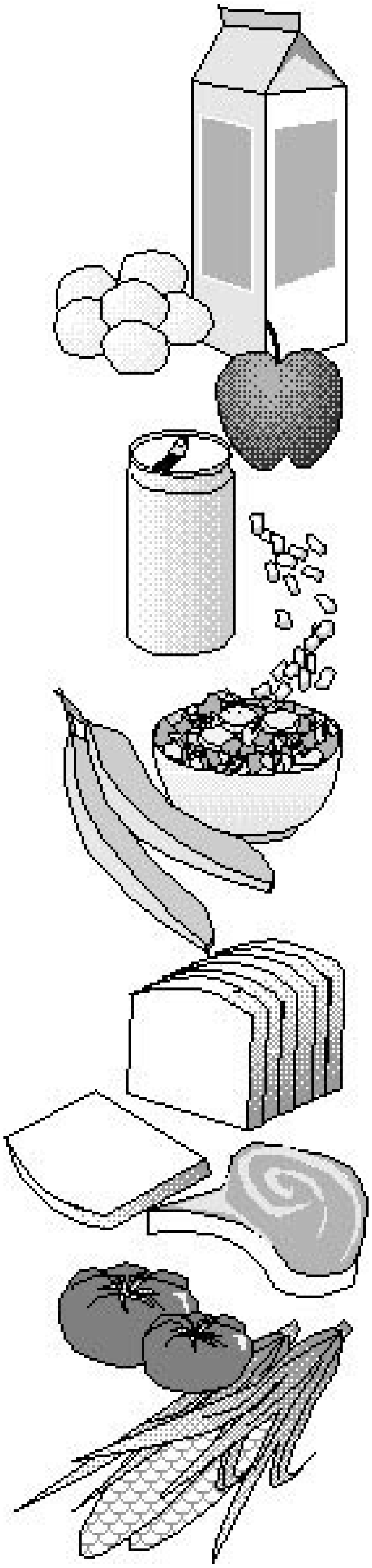
4. Our bodies are about 23 percent carbon by weight. Because it contains some carbon-14, the carbon in your body has an activity of 227 disintegrations per second per kilogram.

a. Based on your weight in kilograms (from question 3b), how much of your body is carbon? Express your answer in kilograms of carbon.

b. Given the activity of carbon-14 in the carbon of your body, what is the total activity of the carbon in your body?

Carbon, Potassium, and Your Health

5. Should you try to eliminate all potassium or carbon from your diet in an effort to reduce your annual internal exposure to ionizing radiation? Why or why not?



Potassium Content and Potassium-40 Activity in Some Selected Foods

Food	Portion	Potassium (Milligrams)	Potassium-40 (disintegration per second)
Meat, fish, poultry			
Hamburger	4 ounces	960	29
Salmon, canned	3.5 ounces	350	10.5
Tuna, canned	3.5 ounces	240	7
Chicken, fried	1/4 chicken	240	7
Hot dogs	2 regular	200	6
Bacon	1 strip	17	0.5
Vegetables			
Red kidney beans	1/2 cup	980	29
French fries	3.5 ounces	650	19.5
Potato, baked	1 average	500	15
Broccoli	1 stalk	270	6.6
Tomato	1 small	240	5.7
Corn	1 ear	200	6
Green beans	1/2 cup	100	3
Fruits and fruit juices			
Banana	1 small	370	9
Orange	1 medium	300	7
Orange juice, frozen	1/2 cup	230	7
Apple	1 medium	160	5
Lemonade, frozen	1/2 cup	18	0.5
Milk and milk products			
2%	1 cup	380	11.4
Whole	1 cup	370	11
Yogurt (skim milk)	1 cup	320	9.6
Ice cream	4 ounces	50	1.5
Other beverages			
Hot chocolate	1 packet	190	5.7
Pepsi Cola	12 ounces	13	0.4
Coca Cola	12 ounces	4	0.1
Sprite	12 ounces	0	0
Cereals			
Bran, flakes	1 ounce	140	4.2
Oatmeal	1 cup	130	4
Wheat, shredded	1 ounce	50	1.5
Corn, flakes	1 ounce	14	0.4
Rice, crisped	1 ounce	14	0.4
Bread, crackers, cookies			
Graham crackers (2)	1/2 ounce	50	1.5
Whole wheat, 1 slice	1 ounce	70	2.1
White, 1 slice	1 ounce	30	0.9
Vanilla wafers (5)	1/2 ounce	10	0.3
Miscellaneous			
Sunflower seeds	3.5 ounces	920	27.6
Peanuts	1/2 ounce	110	3.3
Peanut butter	1 tablespoon	100	3
Egg	1 large	65	2

Source: Potassium concentrations from U.S. Dietary Goals, *U.S. Department of Agriculture, 1977 and Natow, A.B. and J. Heslin,* Nutrition for the Prime of Your Life, *New York, McGraw, 1984.*

Jet Flight Exposure

Because the atmosphere gets less dense as the elevation increases, the cosmic radiation dose rises with increasing elevation. Therefore, passengers on a jet airplane receive an additional dose from cosmic rays during the flight. According to the National Council on Radiation Protection and Measurements, cosmic exposure at 11,887.20 meters (39,000 feet) is 0.5 millirem per hour.

Directions: Figure the radiation exposure from cosmic radiation for the jet flights listed below.

Flight	Round Trip Flight Time	Radiation Exposure
San Francisco to Washington, DC	12 hours	millirem
Atlanta to Chicago	4 hours	millirem
Dallas/Ft. Worth to Chicago	4 hours	millirem
Boston to Los Angeles	10 hours	millirem
Chicago to Honolulu	18 hours	millirem
New York to Las Vegas	10 hours	millirem

Cosmic Radiation

Cosmic rays originate outside the Earth's atmosphere and are composed of highly penetrating radiation of all sorts, both particles and rays. At sea level, the average annual exposure from cosmic rays is 26 millirem. The following table shows the effect of elevation on cosmic ray exposures.

Effect of Elevation, in Feet, on Cosmic Radiation Exposures (MREM/YR)
(exposures reflect 10% reduction for shielding from buildings/structures)

0 (sea level)	26	4,000	39
500	27	6,000	52
1,000	28	8,000	74
2,000	31	10,000	107

Directions: Using the data in the table above, calculate the cosmic ray exposure where you live and the exposure from cosmic rays for the cities listed below. (Check an atlas for the elevation above sea level of your area.)

Place	Elevation	Exposures from cosmic rays mrem/yr
Your home town		millirem
Atlanta, GA	1,050	millirem
Minneapolis, MN	815	millirem
Salt Lake City, UT	4,400	millirem
Spokane, WA	1,890	millirem

Apollo Flight Exposure

As previously mentioned, U.S. astronauts in Earth orbit or on Moon missions received increased radiation exposure from cosmic rays. The following table shows the estimated exposures by our astronauts on the various Apollo missions. The data are taken from a 1982 report of the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) entitled *Ionizing Radiation: Sources and Biological Effects*.

Directions: In the table below, calculate the average rate of exposure in millirem per hour for the various missions.

Estimated Doses Received by Astronauts on the Apollo Missions

Apollo Mission Number	Launch Date	Type of Orbit	Duration of Mission (Hours)	Exposure	
				Total (mrem)	Rate (mrem/hr)
VII	August 1968	Earth orbital	260	120	______
VIII	December 1968	Circumlunar	147	185	______
IX	February 1969	Earth orbital	241	210	______
X	May 1969	Circumlunar	192	470	______
XI	July 1969	Lunar landing	182	200	______
XII	November 1969	Lunar landing	236	~200	______
XIV	January 1971	Lunar landing	286	~500	______
XV	July 1971	Lunar landing	286	~200	______

MANMADE RADIATION SOURCES

1. True or False: In the blank before the sentence, write T if the statement is true and F if it is false. If the statement is false, correct it to make it true.

The following questions are based on the graph titled *Some Exposures from Manmade Sources Compared to the Average Natural Radiation Exposure.*

__ a. The exposures from manmade sources shown in the graph are based on the lowest exposures.

__ b. The highest exposure to manmade sources of radiation is from smoking cigarettes.

__ c. There is more exposure from building materials than from storage of low-level waste.

__ d. The only energy use that results in any exposure to radiation is related to nuclear powerplants.

2. List 3 consumer goods that are related to radiation exposure.

____

____

____

3. Write a sentence or two explaining what you think is the source of radioactivity at coal-fired powerplants, construction activities, and fertilizers.

____

____

____

BIOLOGICAL EFFECTS OF IONIZING RADIATION

Refer to the reading entitled *Biological Effects of Ionizing Radiation* to answer the questions below.

1. The principal factors that determine the biological effect of ionizing radiation are ____________

   ____

   ____

2. The possibility of injury from ionizing radiation ________________ with increasing exposure.

3. Increasing the volume of tissue exposed ____________________ the severity of radiation injury.

4. Alpha particles deposit all their energy in a ____________________ path.

5. X-rays and gamma rays deposit their energy over a _______________ path.

6. The two main categories of biological effects are ______________________________ effects

   and ______________________________ effects.

7. Of the two main types of effects in question 6, which applies to the exposed individual and which applies to future generations?

   _______________ effects apply to the exposed individual

   _______________ effects apply to future generations

8. Background radiation accounts for only ___________to ___________ percent of the spontaneous incidence of cancer.

9. The _______________ and ______________ are particularly sensitive to radiation exposure.

10. For any radiation exposure greater than zero, there is some _______________ .

USING HALF-LIVES

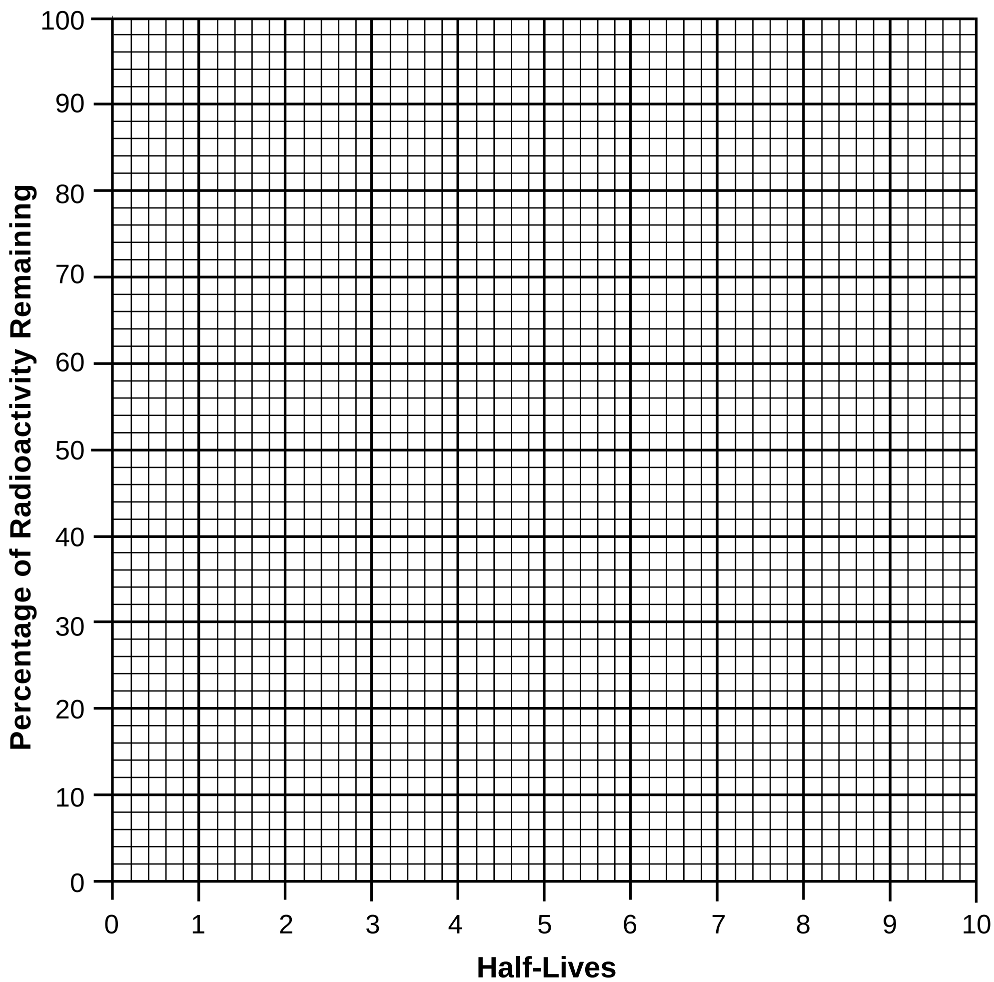
Radioactive materials spontaneously emit ionizing radiation during the process of radioactive decay and become less radioactive over time as a result of this process. The time required for a quantity of a radioactive substance to lose half its radioactivity by radioactive decay is the half-life of that substance. Half-life is a unique characteristic of each radioisotope.

Directions: Answer the following questions by applying the information about half-life given above. Read carefully and think before answering.

1. What percentage of the original radioactivity of a quantity of a radioactive material remains after each half-life?

0	**1**	**2**	**3**	**4**	**5**
_____	_____	_____	_____	_____	_____

2. Plot the radioactive decay curve from data in Question 1. On the x-axis plot half-lives and on the y-axis the percentage of radioactivity remaining. Connect each point with straight line segments.



3. Radium has a half-life of 1600 years. Approximately, how long does it take for 1 percent of a sample of radium to decay?

4. Radon has a half-life of 3.8 days. Approximately, how long does it take for 1 percent of a sample of radon to decay? Express your answer in hours.

5. Scientists believe the Earth is 4.6 billion years old.

   a. Approximately what percentage of the uranium-238 originally present is here now if the half-life of uranium-238 is 4.5 billion years?

   b. Calculate a more exact percentage.

6. Calculate approximately what percent of the original thorium-232 is left if it has a half-life of 14 billion years.

7. Uranium-235 has a half-life of 0.7 billion years and also was present when the Earth was formed.

   a. How many U-235 half-lives have occurred since the beginning of the Earth?

   b. Approximately what percent of the original uranium-235 is left?
   (Hint: Make a table of half-lives and calculate the fraction remaining after each half-life)

Half-lives	1	2	3	4	5	6	7
Fraction Remaining	___	___	___	___	___	___	___

8. All natural uranium contains both U-235 and U-238. Each decays at a different rate but both are always present in any quantity of natural uranium. We must consider changes in both U-235 and U-238 to calculate the concentration of either at any given time. Keep in mind that natural uranium = U-235 + U-238.

   a. Today, natural uranium contains about 0.7% U-235. How much U-2338 does natural uranium contain today?

   b. The percentages from (a.) are true for any unit of natural uranium. Consider one gram of natural uranium today. What fractional portion of U-235 and of U-238 would comprise that one gram of natural uranium?

   (The choice of one gram as a measure of mass is completely arbitrary. Any mass—one pound, two ounces, etc.—would produce the same answer.)

c. How much U-235 was required 4.6 billion years ago to produce 0.007 grams of U-235 in every gram of natural uranium today? Remember that 1.1% of the total amount of U-235 remains undecayed today. (Question 7b)

d. How much U-238 was required 4.6 billion years ago to produce 0.993 grams of U-238 in every gram of natural uranium today? Remember that 49.45% of the total amount of U-238 remains undecayed today. (Question 5b)

e. Keeping in mind that natural uranium = U-235 + U-238, what percent of U-235 existed in natural uranium 4.6 billion years ago?

9. Based on evidence discovered in 1972, scientists believe that about 2.0 billion years ago, a fission chain reaction occurred spontaneously at Oklo, Gabon, in Africa. Remember that natural uranium = U-235 + U-238 and that U-235 at some concentration was necessary for this reaction to occur. Answer the following to determine the concentration of U-235 in natural uranium 2.0 billion years ago.

a. How much time had elapsed since the formation of the Earth 4.6 billion years ago when the reaction at Oklo occurred?

b. At the time of the Oklo reaction, how many half-lives of U-235 and of U-238 had elapsed?

c. What percentage of the original amount of U-235 and U-238 remained at the time of the nuclear reaction in Oklo, Gabon?

d. 4.6 billion years ago natural uranium was 24.05% U-235. (Question 8). What percent of natural uranium was U-238?

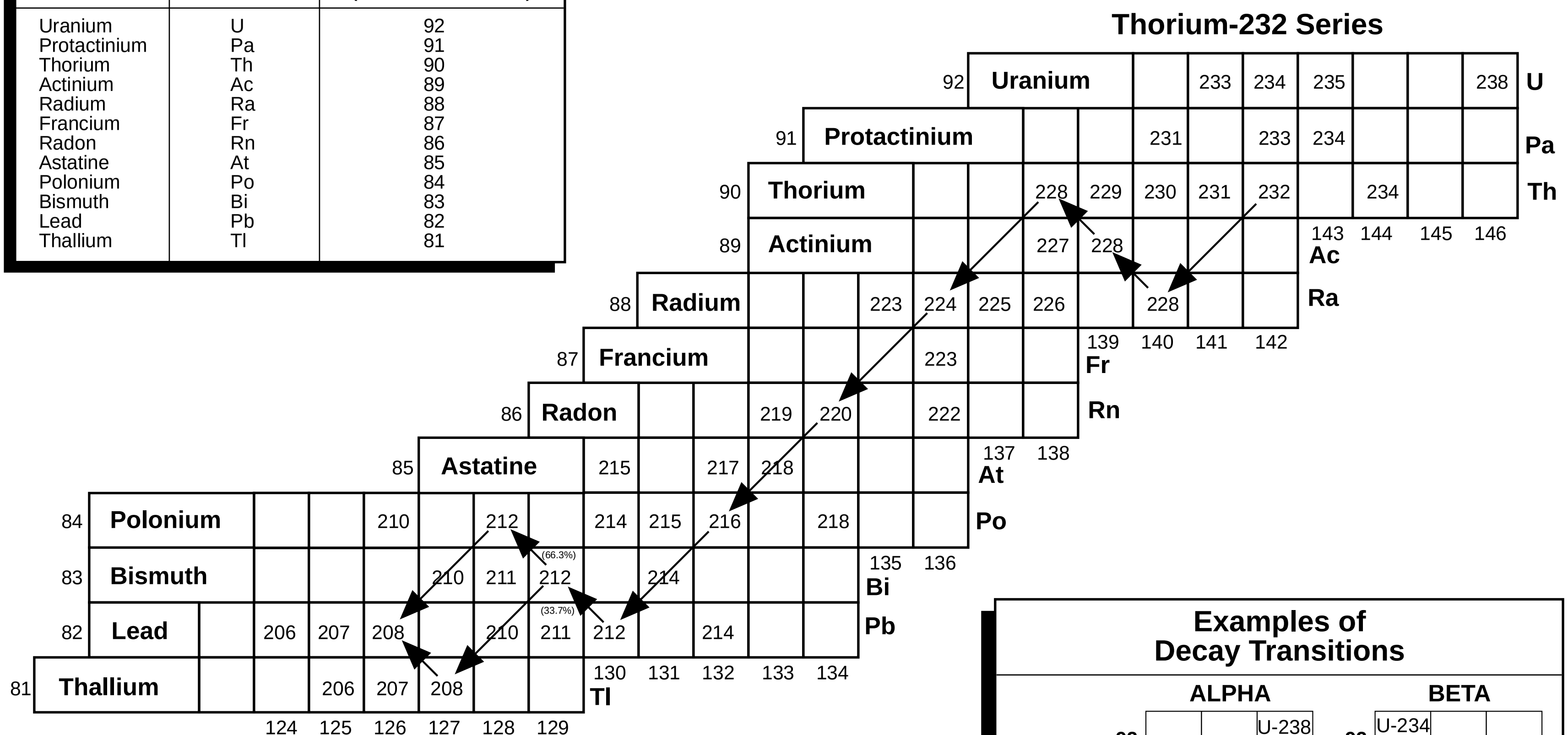
e. Consider one gram of natural uranium 4.6 billion years ago. What fractional portion of U-235 and U-238 would comprise that one gram?

f. If the one gram of natural uranium from (e.) were to decay until the time of the Oklo reaction, how many grams of U-235 and U-238 would remain?

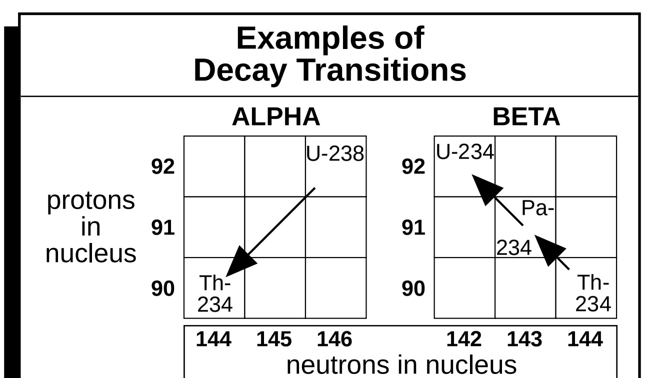
g. Keeping in mind that natural uranium = U-235 + U-238, what percent of U-235 existed in natural uranium at the time of the Oklo reaction?

CHART OF THE ISOTOPES IN THE U-238, U-235, AND Th-232 DECAY SERIES

Element	Symbol	Number of Protons in Nucleus (Atomic Number)
Uranium	U	92
Protactinium	Pa	91
Thorium	Th	90
Actinium	Ac	89
Radium	Ra	88
Francium	Fr	87
Radon	Rn	86
Astatine	At	85
Polonium	Po	84
Bismuth	Bi	83
Lead	Pb	82
Thallium	Tl	81



Adapted from The Chart of the Nuclides, Knolls Atomic Power Laboratory, Schenectady, New York, Operated by General Electric Company for Naval Reactors, the United States Department of Energy



ATOMIC TRANSITIONS IN THE NATURAL RADIOACTIVE DECAY SERIES

Directions:

1. Using the table of atomic transitions, trace the thorium-232 decay series on the chart of the isotopes.
2. Using the information provided in the table of atomic transitions, plot the transitions in the uranium-235 decay series on the chart of the isotopes.
3. Using the plot of the transitions in the uranium-238 series given on the chart of the isotopes, fill in the blanks on the table of atomic transitions.

Thorium-232			Uranium-235			Uranium-238		
Number of Protons in Nucleus (Atomic Number)	**Isotope**	**Decay**	**Number of Protons in Nucleus (Atomic Number)**	**Isotope**	**Decay**	**Number of Protons in Nucleus (Atomic Number)**	**Isotope**	**Decay**
90	Th-232	Alpha	92	U-235	Alpha	92	U-238	Alpha
88	Ra-228	Beta	90	Th-231	Beta	______	______	______
89	Ac-228	Beta	91	Pa-231	Alpha	______	______	______
90	Th-228	Alpha	89	Ac-227	Alpha	______	______	______
88	Ra-224	Alpha	87	Fr-223	Beta	______	______	______
86	Rn-220	Alpha	88	Ra-223	Alpha	______	______	______
84	Po-216	Alpha	86	Rn-219	Alpha	______	______	______
82	Pb-212	Beta	84	Po-215	Alpha	______	______	______
83	Bi-212	{ 33.7% Alpha	82	Pb-211	Beta	______	______	______
		66.3% Beta	83	Bi-211	Alpha	______	______	______
84	Po-212	Alpha	81	Tl-207	Beta	______	______	______
81	Tl-208	Beta	82	Pb-207	Stable	______	______	______
82	Pb-208	Stable				______	______	______
						______	______	______
						82	Pb-206	Stable

CHART OF THE ISOTOPES IN THE U-238, U-235, AND Th-232 DECAY SERIES

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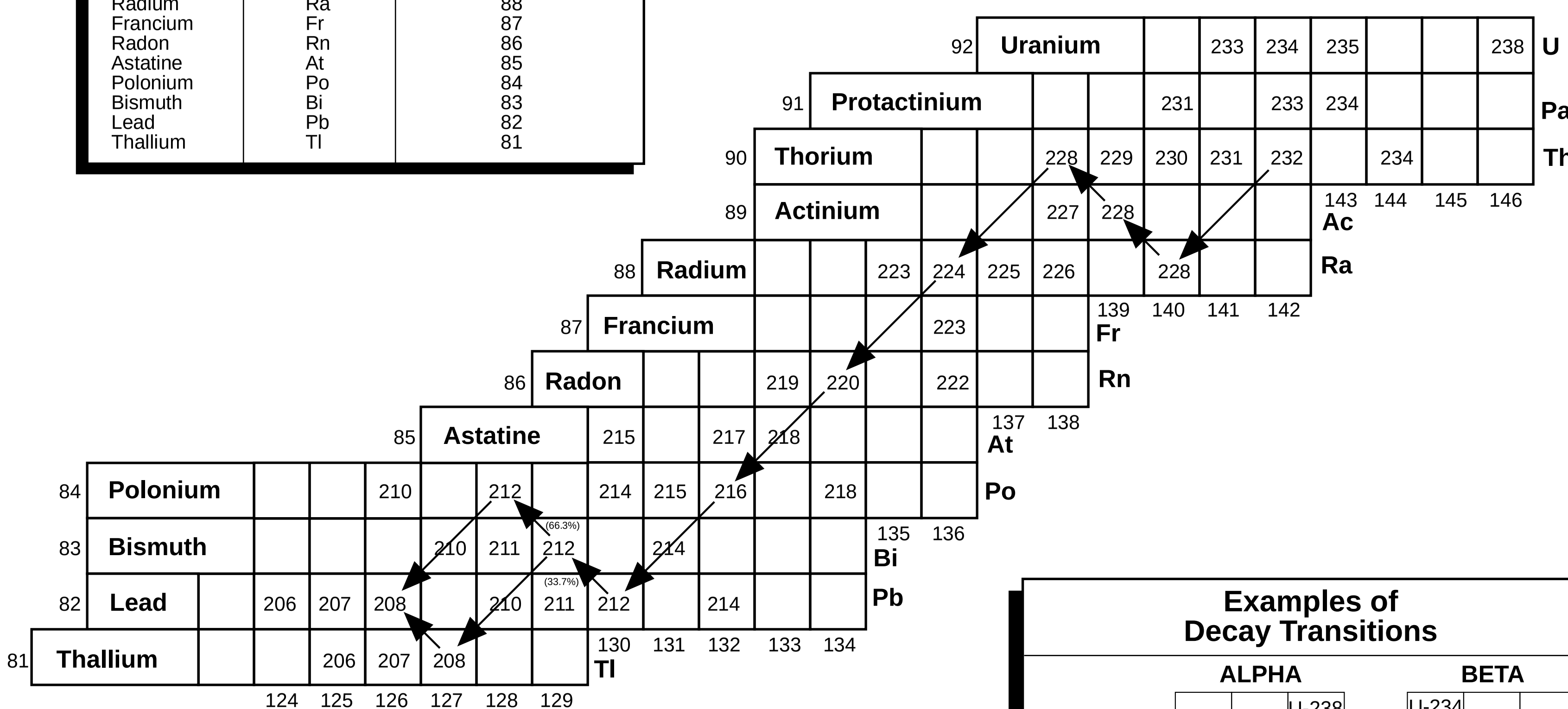

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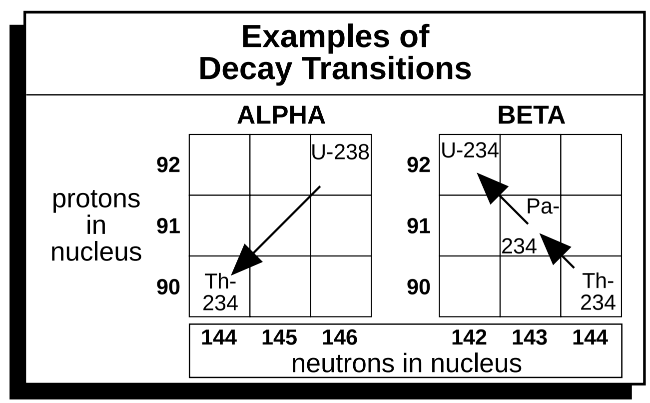

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Thorium	Th	90
Actinium	Ac	89
Radium	Ra	88
Francium	Fr	87
Radon	Rn	86
Astatine	At	85
Polonium	Po	84
Bismuth	Bi	83
Lead	Pb	82
Thallium	Tl	81

Uranium-235 Series

	Element	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	
92	Uranium																		233	234	235			238	U
91	Protactinium																	231		233	234				Pa
90	Thorium															228	229	230	231	232		234			Th
89	Actinium															227	228								Ac
88	Radium												223	224	225	226		228							Ra
87	Francium													223											Fr
86	Radon										219	220		222											Rn
85	Astatine							215		217	218														At
84	Polonium			210		212		214	215	216		218													Po
83	Bismuth				210	211	(66.3%) 212		214																Bi
82	Lead	206	207	208		210	(33.7%) 211	212		214															Pb
81	Thallium		206	207	208																				Tl

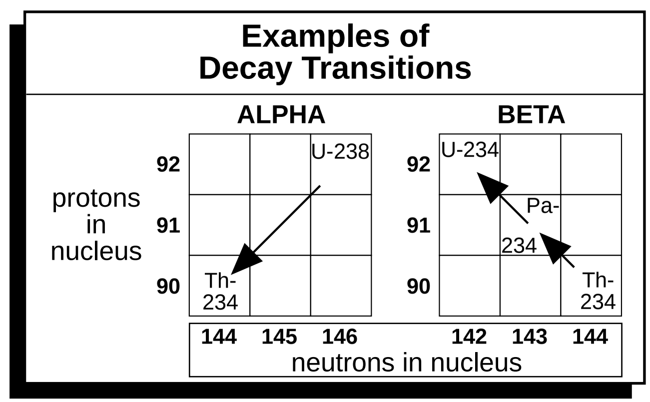
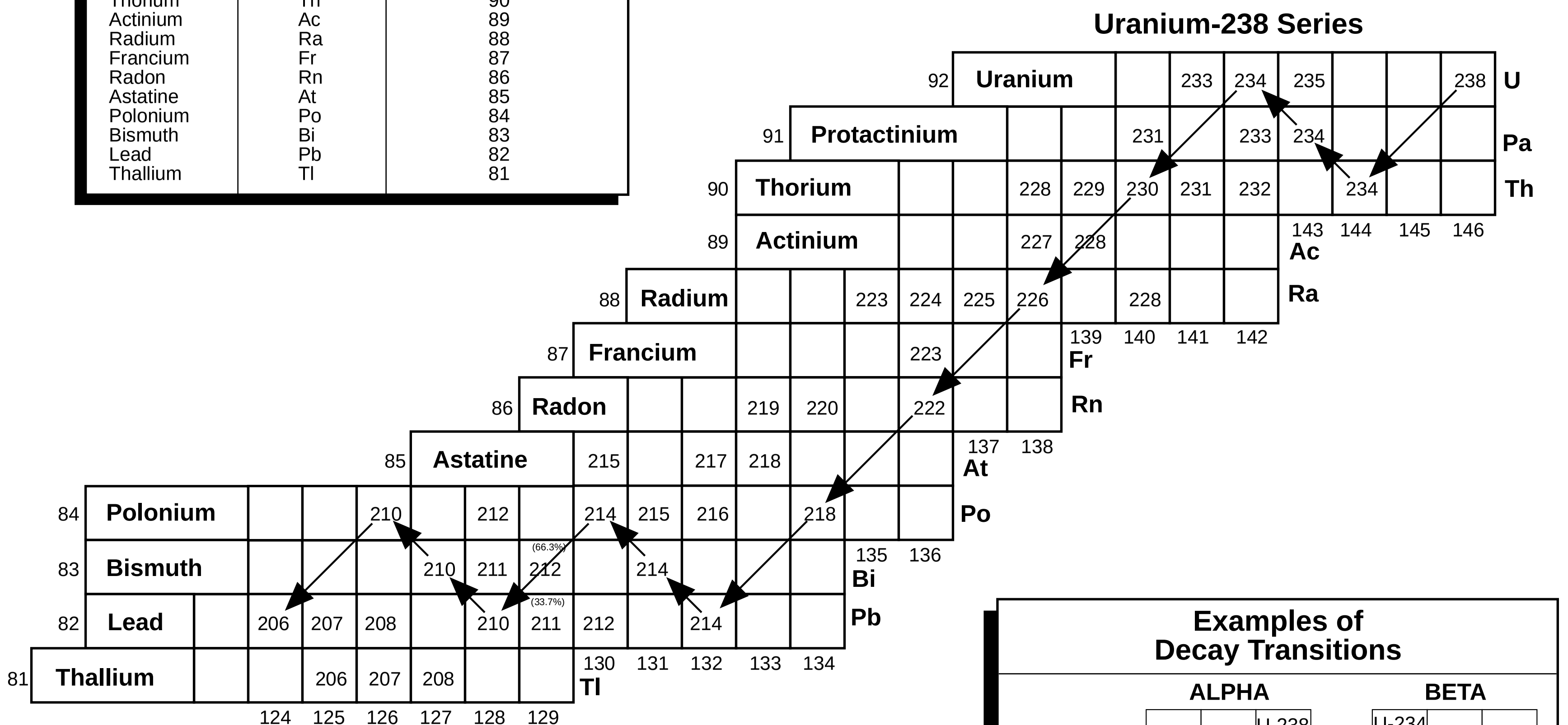


CHART OF THE ISOTOPES IN THE U-238, U-235, AND Th-232 DECAY SERIES

Element	Symbol	Number of Protons in Nucleus (Atomic Number)
Uranium	U	92
Protactinium	Pa	91
Thorium	Th	90
Actinium	Ac	89
Radium	Ra	88
Francium	Fr	87
Radon	Rn	86
Astatine	At	85
Polonium	Po	84
Bismuth	Bi	83
Lead	Pb	82
Thallium	Tl	81



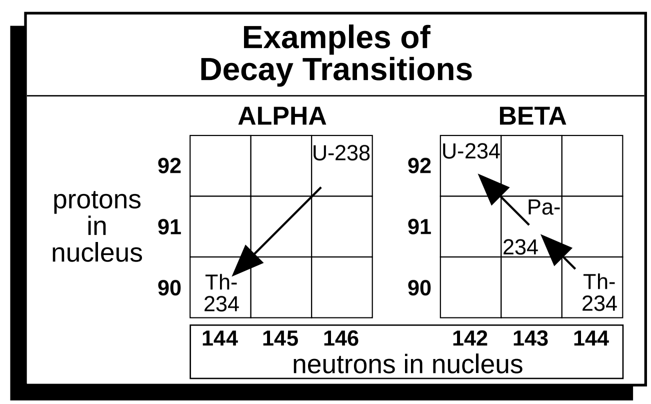


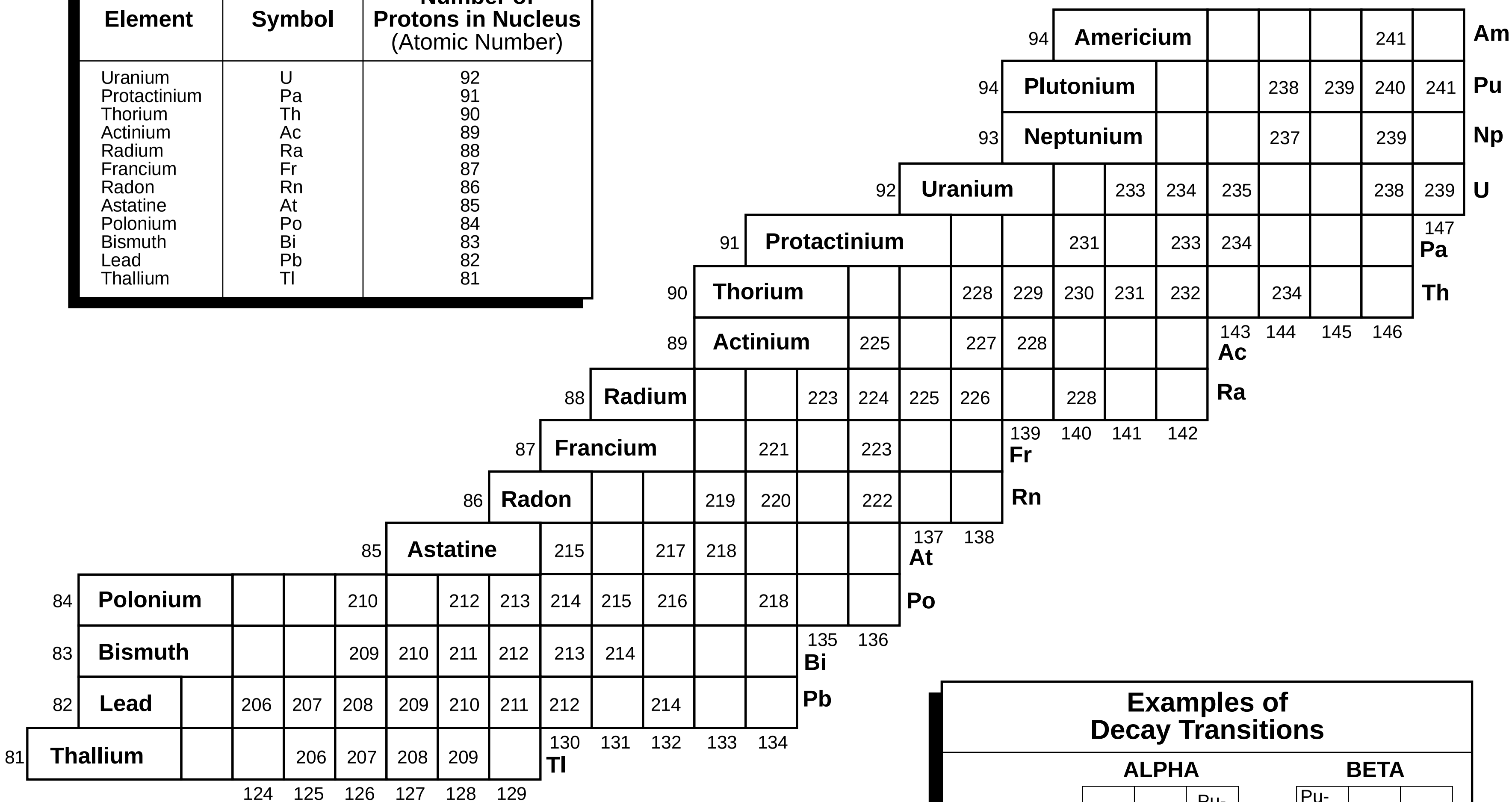
TABLE OF SOME IMPORTANT ATOMIC TRANSITIONS IN SPENT FUEL

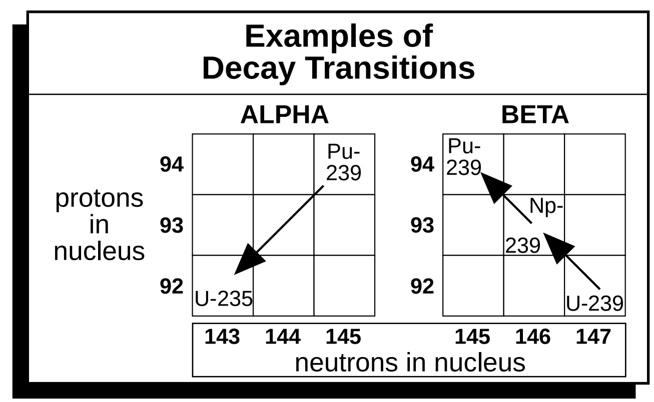
Directions: Using the information presented in the table below trace some important transitions in spent fuel on the Chart of Some Important Isotopes in Spent fuel.

Number of Protons in Nucleus (Atomic Number)	Isotope	Half-Life	Decay
94	Pu-241	13.2 years	Beta
95	Am-241	458 years	Alpha
93	Np-237	2,140,000 years	Alpha
91	Pa-233	27 days	Beta
92	U-233	162,000 years	Alpha
90	Th-229	7,340 years	Alpha
88	Ra-225	14.8 days	Beta
89	Ac-225	10.0 days	Alpha
87	Fr-221	4.8 minutes	Alpha
85	At-217	0.03 seconds	Alpha
83	Bi-213	47 minutes	{ 98% Alpha 2% Beta
84	Po-213	0.0000042 seconds	Alpha
81	Tl-209	2.20 minutes	Beta
82	Pb-209	3.3 hours	beta
83	Bi-209	Stable	Stable

CHART OF SOME IMPORTANT ISOTOPES IN SPENT FUEL

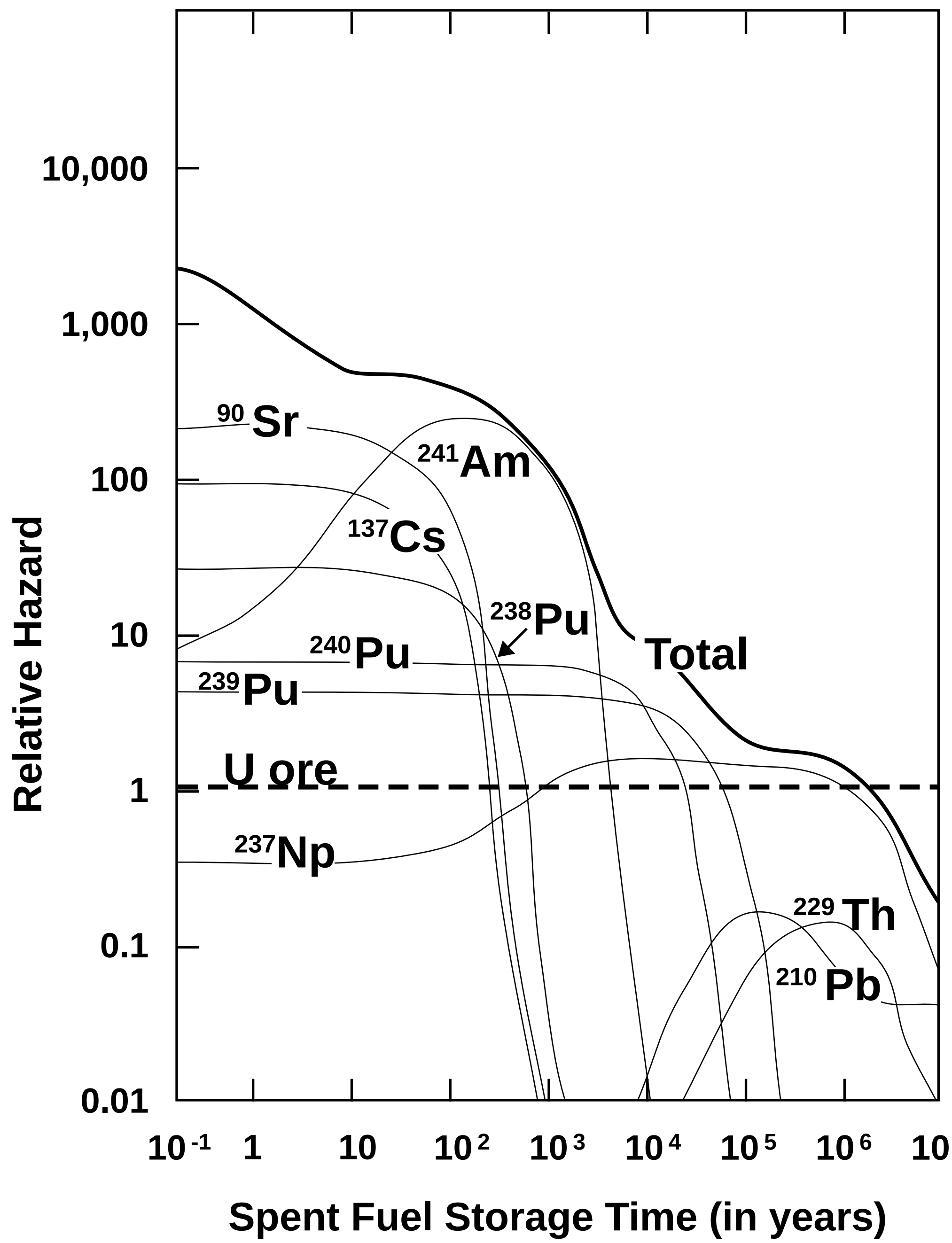
Element	Symbol	Number of Protons in Nucleus (Atomic Number)
Uranium	U	92
Protactinium	Pa	91
Thorium	Th	90
Actinium	Ac	89
Radium	Ra	88
Francium	Fr	87
Radon	Rn	86
Astatine	At	85
Polonium	Po	84
Bismuth	Bi	83
Lead	Pb	82
Thallium	Tl	81





Adapted from The Chart of the Nuclides, Knolls Atomic Power Laboratory, Schenectady, New York, Operated by General Electric Company for Naval Reactors, the United States Department of Energy.

HAZARDS OF SOME ISOTOPES IN SPENT FUEL COMPARED TO THE HAZARD OF URANIUM ORE



HAZARDS OF SOME ISOTOPES IN SPENT FUEL COMPARED TO THE HAZARD OF URANIUM ORE

Directions: Use the graph entitled *Hazards of Some Isotopes in Spent Fuel Compared to the Hazard of Uranium Ore* to answer the questions below.

Part I

1. Identify the isotopes. (If necessary, refer to the periodic table of the elements.)

^{90}Sr ______________	^{241}Am ______________	^{137}Cs ______________
^{238}Pu ______________	^{240}Pu ______________	^{241}Pu ______________
^{237}Np ______________	^{229}Th ______________	^{210}Pb ______________

2. Identify the information on each axis.

X axis (horizontal):

The x axis uses a logarithmic scale (exponential notation) to represent the years of spent fuel storage. How many years are represented by each of the following:

10^{-1} _________ 1 _________ 10 _________ 10^2 _________ 10^3 _________

10^4 _________ 10^5 _________ 10^6 _________ 10^7 _________

Y axis (vertical):

Relative hazard is one of many ways to compare the potential hazards of radioactive elements. The y axis measures the "relative hazard" of each isotope compared to the hazard of uranium ore, which is naturally radioactive. Although all the isotopes in spent fuel are not shown, the hazard from all isotopes present in spent fuel, considered as a whole, is shown as "Total."

Like the x axis, the y axis is a logarithmic scale. From the relative hazard list given below, insert the correct term in sentences a-f.

one tenth	one hundredth	ten times
one hundred times	one thousand times	ten thousand times

a. A substance located at 0.01 represents _________________ the hazard of uranium ore.

b. A substance located at 0.1 represents _________________ the hazard of uranium ore.

c. A substance located at 10 represents _________________ the hazard of uranium ore.

d. A substance located at 100 represents _________________ the hazard of uranium ore.

e. A substance located at 1,000 represents _________________ the hazard of uranium ore.

f. A substance located at 10,000 represents _________________ the hazard of uranium ore.

Part II

1. When spent fuel is first placed in storage, what is the hazard of the isotopes in the spent fuel in comparison to the hazard of uranium ore?

Sr-90 between _______ and _______ times (more? less?) hazardous than uranium ore

Cs-137 between _______ and _______ times (more? less?) hazardous than uranium ore

Pu-238 between _______ and _______ times (more? less?) hazardous than uranium ore

Am-241 between _______ and _______ times (more? less?) hazardous than uranium ore

Pu-240 between _______ and _______ times (more? less?) hazardous than uranium ore

Pu-239 between _______ and _______ times (more? less?) hazardous than uranium ore

Np-237 between _______ and _______ times (more? less?) hazardous than uranium ore

2. Between what years does each of the following isotopes reach the level of hazard of uranium ore? (The first answer is done as an example.)

Element	Storage Time (Exponential Notation)	Storage Time (Years)
Sr-90	Between 10^2 and 10^3 years	Between 100 and 1,000
Am-241	____________________	____________________
Cs-137	____________________	____________________
Pu-238	____________________	____________________
Pu-239	____________________	____________________
Pu-240	____________________	____________________
Np-237 (first)	____________________	____________________
Np-237 (second)	____________________	____________________

Between what years does the hazard of the spent fuel considered as a whole reach the level of hazard of uranium ore?

Total ____________________ ____________________

3. Does the relative hazard for an isotope decrease over the long term? Explain.

4. Does the relative hazard for an isotope always decrease over shorter time periods? Explain your answer.

5. When the spent fuel is first placed in storage, the relative hazard of neptunium-237 is (less?) than that of uranium ore. After 10^3 years, the hazard has (increased?). Then at about 10^6 years, it (decreases?) to that of uranium ore and continues to (decrease?). Explain how this is possible.

6. Look at the graphs of relative hazard for Th-229 and Pb-210. Notice that their graphs do not even begin until approximately 10,000 years. Where do you think these isotopes come from? How hazardous are they compared to uranium-238?

7. In the graph, the hazard for uranium ore is shown as a constant for comparative purposes. In reality, the hazard for uranium changes over time. Do you think the hazard for uranium would increase or decrease over time? Why?

8. The canister in which spent fuel will be stored is being designed to provide isolation for a minimum of 300 years. The repository itself must provide isolation of spent fuel from the accessible environment for 10,000 years. Using the information in the graph, explain why 300 years and 10,000 years are reasonable periods of time.

____

____

Part III

1. The period of time represented on the x axis is very long. To get some perspective of exactly how long, a timeline is shown below that goes back in time. Put the following items on the timeline in the appropriate place by making a tick mark and labeling it. The first item is done as an example. (If necessary, refer back to Part I for the conversions from exponential notations.)

   a. Average lifespan of US citizen—70-72 years

   b. The oldest known living plant (in 1990), a bristle cone pine, which is growing in the Sierra Nevada Mountain sprouts in the area of the Nevada/California border—4,900 years ago

   c. End of last Ice Age—10,000 years ago

   d. Meteor strikes Arizona and creates Meteor Crater—150,000 years ago

   e. Beginning of last Ice Age—2,500,000 years ago

   f. Earliest primate hominid remains deposited—5,000,000 years ago

10^7	10^6	10^5	10^4	10^3	10^2	10	1	10^{-1}

Time (Years Before Present)

2. Despite the length of time represented above, it is not very long in comparison to time spans used to describe the whole history of the Earth. To illustrate this point, several other important dates that geologists have established are given below. What are those dates in years?

   a. Years since the last dinosaurs died: 6.5×10^7 = ______________________________

   b. Years since the formation of the Earth: 4.6×10^9 = ______________________________

   c. How many years elapsed between the formation of the Earth and the end of the dinosaurs?

____

d. How many years elapsed between the formation of the Earth and the beginning of the last Ice Age? ______________________________

e. How many years elapsed between the end of the dinosaurs and the beginning of the last Ice Age? ______________________________

Across the <u>top</u> of the graph entitled “Relative Hazard of Some Isotopes in Spent Fuel Compared to Hazard of Uranium Ore” are tick marks. Label them to match the timeline for time before the present. Then add points along the top to represent the correct location for items a through f in question 1. This will help you to understand the length of time for storage of spent fuel that is represented by the graph.

Then answer the questions on the next page.

3. Suppose you live in St. Louis and have a time machine and decide to check the figures on this graph. You travel back in time 10^4 years ago. Would you need to take a coat? Why or why not?

____

____

4. Then you travel into the future. After 5,100 years of travel, a little longer than the length of time the bristle cone pine has lived, you stop to think about the spent fuel in storage.

a. What is the relative hazard of strontium-90 when you check it compared to what its hazard was in the present?

____

____

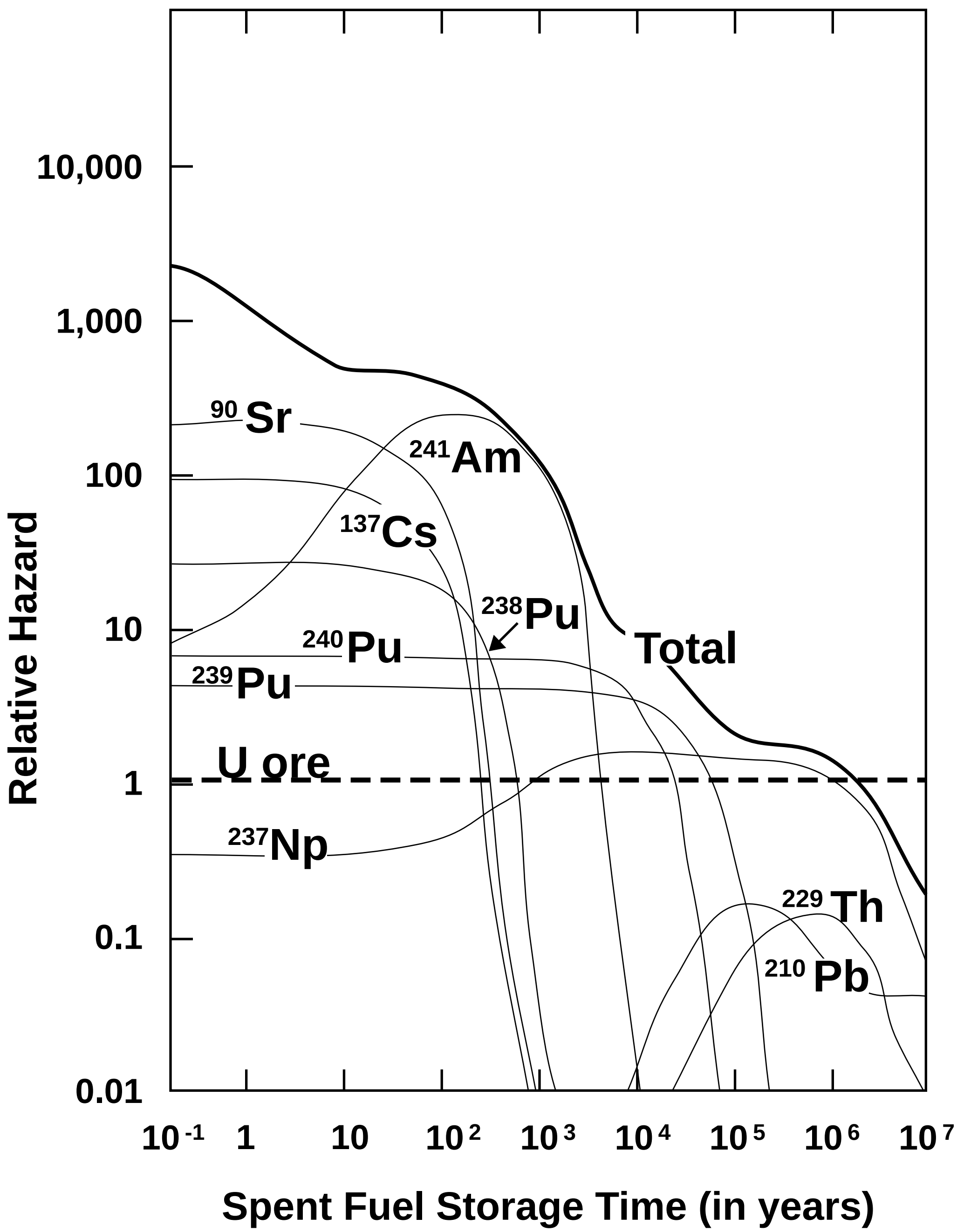
b. What is the relative hazard of Americium-241 in comparison to the hazard of uranium ore? Has the relative hazard changed at all during the 5,100 years? Why or why not?

____

____

c. At 5,100 years, what isotopes are still more hazardous than the standard for uranium ore?

HAZARDS OF SOME ISOTOPES IN SPENT FUEL COMPARED TO THE HAZARD OF URANIUM ORE



METRIC AND U.S. UNIT CONVERSIONS

Both American and metric units have been used in the curriculum, as appropriate to the issues being discussed. For example, inventories of spent fuel are routinely reported in the United States in terms of metric tons (1,000 kilograms) even though most Americans are familiar with the short ton (2,000 pounds). Classroom experiments are usually conducted using metric units as well. Yet the standards and tests for spent fuel transportation casks are written using temperature in degrees Fahrenheit, miles per hour, and other similar units.

To familiarize yourself with potentially unfamiliar metric units, a conversion chart has been prepared. To convert a given unit into its metric or U.S. equivalent, multiply the quantity by the number in the right hand column. For example, to convert 1,000 kilograms into its equivalent in pounds, multiply by 2.205 to get 2,205 pounds (1,000 kg x 2,205 lb/kg = 2,205 lb). Alternately, 2,000 pounds is equivalent to 2,000 lb x 0.4536 kg/lb or 907.2 kilograms.

People vary in their comprehension of metric units and unfamiliar U.S. units. Consider using this chart as an aid if you are confused or if you are especially interested in unit conversions.

Table 1. Approximate Conversions from Metric to English Units

If you know...

Length →	**multiply by** →	**to get**
millimeters (mm)	0.03937	inches (in)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.3937	inches (in)
meters (m)	39.37	inches (in)
meters (m)	3.281	feet (ft)
meters (m)	1.094	yards (yd)
kilometers (km)	3,281.0	feet (ft)
kilometers (km)	0.5396	nautical miles (mi)
kilometers (km)	0.6214	statute miles (mi)
Area		
hectares (ha)	2.471	acres
hectares (ha)	1.076 X 105	square ft (ft^2)
Weight (mass)		
grams (gm)	0.03527	ounces (oz)
grams (gm)	0.002205	pounds (lb)
kilograms (kg)	2.205	pounds (lb)
metric tons (t)	1.102	short tons
metric tons (t)	0.984	long tons
Pressure		
kilopascals (kPa)	6.9	pounds/square inch (lb/in^2)
Volume		
cubic centimeters (cm^3)	0.06202	cubic inches (in^3)
cubic meters (m^3)	3.531	cubic feet (ft^3)
cubic meters (m^3)	1.307	cubic yards (yd^3)
liters (L)	2.113	pints* (pt)
liters(L)	0.2642	gallons* (gal)
Temperature		
Celsius	9/5, [then add 32]	Fahrenheit
Electric Current		
ampere (A)	1	ampere (A)
Energy, Work, Heat		
joule (J)	9.480×10^{-4}	BTU
Power		
watt (W)	1	watt (W)
watt (W)	3.4129	BTU per hour
watt (W)	1.341×10^{-3}	horsepower

Common Prefixes for Metric Units:

mega = million = 10^6	deci = one-tenth
kilo = thousand	centi = one-hundredth
hecto = hundred	milli = one-thousandth
deka = ten	micro = one-millionth
Examples:	kilogram = 1,000 grams milliliter = 1/1,000 liter

*liquid measure

Table 2. Approximate Conversions from English to Metric Units

If you know...

Length	multiply by	to get
inches (in)	2.54	centimeters (cm)
feet (ft)	30.48	centimeters (cm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
yards (yd)	0.9144	meters (m)
Area		
square inches (in^2)	6.5	square centimeters (cm^2)
square feet (ft^2)	0.09	square meters (m^2)
square yards (yd^2)	0.8	square meters (m^2)
acres	0.4047	hectares (ha)
square miles (mi^2)	2.6	square kilometers (k^2)
Weight (mass)		
ounces (oz)	28.349527	grams (gm)
pounds (lb)	0.4536	kilograms (kg)
tons (long)	1.016	metric ton (t)
Pressure		
pounds per square inch	70.31	grams per square centimeter
pounds per square inch	0.145	kilopascals
Volume		
cubic feet (ft^3)	0.02832	cubic meters (m^3)
cubic inches (in^3)	16.387	cubic centimeters (cm^3)
cubic yards (yd^3)	0.765	cubic meters (m^3)
gallons* (gal)	3.785	liters (L)
pints* (pt)	0.473	liters (L)
quarts* (qt)	0.946	liters (L)
Temperature		
Fahrenheit	[subtract 32, then multiply by 5/9]	Celsius
Electric Current		
ampere (A)	1	ampere (A)
Energy, Work, Heat		
BTU	1,055	joules (J)
Power		
watt (W)	1	watt (W)
BTU per hour	0.293	watt (W)
horsepower	745.712	watt (W)

*liquid measure

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