

APPENDIX C

# NUCLIDES AND ISOTOPES

ACCOMPANYING THE CHART OF THE NUCLIDES  
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## INTRODUCTION

The earliest discussor of the atomic hypothesis is attributed to the ancient Greek philosophers who speculated about the mysteries of nature. In the fifth century B.C., Democritus believed that elementary substances (earth, water, fire, and air) were formed by minute individual particles called atoms. This vague philosophical speculation was given reality when John Dalton, between 1803 and 1808, showed how to determine the weights of different atoms relative to one another.

In 1816, William Prout believed (based on the few atomic weights known) that all atomic weights were whole numbers and integral multiples of the atomic weight of hydrogen. He thought that all elements might be built up from hydrogen. His concept lost favor when elements such as chlorine were definitely shown to have noninteger atomic weights.

## PERIODIC PROPERTIES OF ELEMENTS

In 1869, Dmitri Mendeleev published a short note on the periodic regularity of chemical elements. He arranged the elements in rows according to the magnitude of their atomic weights, beginning with the smallest weight. Elements that appeared in the same vertical column showed a remarkable similarity in their chemical properties. Mendeleev hypothesized that deviations from the expected periodicity were due to chemists' failure to discover some elements in nature. He predicted the properties of gallium, scandium, and germanium, which were subsequently discovered. Pairs of elements (for example, nickel and cobalt) that did not fit the periodic properties of their columns were interchanged so that they would correspond. He argued that the atomic weight measurements for these elements must be in error. It is now known that the atomic number (see page 2), rather than the atomic weight, is the correct basis for the periodicity in the chemical properties of the elements. By coincidence, the list of elements ordered by atomic weight usually agrees with the list ordered by atomic number, except for the few cases observed by Mendeleev.

## NEW PHENOMENA

Toward the end of the nineteenth century, the successes in chemistry, together with those of classical mechanics and electromagnetic theory, convinced some individuals that classical physics was

a "closed book" and that workers in the field would henceforth merely advance existing knowledge to the next decimal place. This attitude changed in 1895 when Wilhelm Roentgen discovered X-rays and in 1896 when A. Henri Becquerel discovered natural radioactivity. Since such phenomena could not be explained by existing theories of matter, they created great interest.

In 1902, Ernest Rutherford and Frederick Soddy, in their theory of radioactive disintegration, proposed that radioactivity involves changes occurring within the atom. Their view met strong opposition because it was considered contrary to the established view on the permanency of the atom.

## EARLY MODELS OF ATOMIC STRUCTURE

Early experiments in the investigation of atomic structure disclosed three different types of radioactivity, called alpha, beta, and gamma radiation. Alpha rays were found to be positively charged helium ions; beta rays were found to be negatively charged electrons; and gamma rays were high-energy electromagnetic waves. In a magnetic field, the alpha rays were deflected in one direction, the beta rays deflected in the opposite direction, and the gamma rays not deflected at all.

The discovery of radioactivity and Sir Joseph Thomson's proof of the independent existence of the electron were the starting points for theories of atomic structure. Thomson proposed one of the first models of the atom. His "plum pudding" model of internal structure depicted the atom as a homogeneous sphere of positive electric fluid (the pudding) in which were imbedded the negatively charged electrons (the plums). In this model the negatively charged electrons, which repel each other and which are attracted to the positive charge, assume certain stable positions inside the atom. If the electron distribution is disturbed by an external force, e.g., the violent collisions between atoms in a hot gas, the electrons vibrate about their equilibrium positions and emit electromagnetic radiation.

The homogeneous-atom concept was proved incorrect when Rutherford performed a series of experiments with a beam of high-speed alpha particles fired at a very thin metal foil. Most of the alpha particles passed straight through the foil or were scattered or deflected only slightly from their original paths. A small percentage of alpha particles were significantly deflected, however, with some alphas reversing their directions.

The Thomson model, in which the positive charge was uniformly distributed throughout the atom, would never permit a sufficiently large concentration of this charge in one region to affect the alpha particles significantly. Rutherford thought that "it (the experimental result) was about as credible as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

To explain these results, Rutherford postulated that the atom does not consist of a uniform sphere of positive electrification, but that the positive charge is concentrated in a small region called the nucleus, at the center of the atom. In his dynamic planetary model, the nucleus plays the role of the sun and the electrons correspond to individual planets of the solar system revolving about the sun. This model, along with the classical physical laws of electricity and mechanics, provided an adequate explanation of the alpha particle's scattering. Subsequent experiments performed on seven different scattering materials and at different alpha energies verified Rutherford's theory.

Electromagnetic theory demands that an oscillating or revolving electric charge emit electromagnetic waves. Such emission results in the loss of energy by the emitting particle. Applied to Rutherford's electrons, this energy loss would cause a steady contraction of the system since the electrons would spiral into the central nucleus as their rotational energy was dissipated. This process would occur very rapidly and would directly contradict the permanent existence of atoms. Also, if the radiation pattern produced by the atom were related to the energy radiated by its moving electron, this radiant energy would be changing with the radius of curvature of the electron's path. The pattern would consist of a continuous range of wavelengths instead of the well-defined discrete wavelengths that are characteristic of each element.

### BOHR ATOM

Since the known stability of atomic systems could not be reconciled with classical principles of mechanics and electrodynamics, Niels Bohr in 1913 reasoned that classical physics laws must be wrong when applied to the motion of the electron in the atom. Max Planck revealed an essential limitation in the theories of classical physics in 1901 when he introduced the concept of discrete amounts of energy (the energy quantum) in his quantum theory of heat radiation. Albert Einstein had applied this concept to light in 1905, when he described the photoelectric effect. The quantum theory states that electromagnetic radiation (of which light is one form) must be emitted or absorbed in integral multiples of these energy quanta. Bohr coupled Rutherford's atom with the quantum theory to produce his quantum theory of atomic structure.

Since a body that spins about its own axis or revolves in an orbit about a central point possesses angular momentum, Bohr assumed that the electron's angular momentum was restricted to certain values (he quantized the angular momentum). Each of the restricted values, which was described by a principal quantum number,  $n$ , would specify a particular circular orbit. An atomic system, whose electrons were in given orbits, would not emit

electromagnetic radiation even though the particles were accelerating. The whole atom was said to be in a stationary state. Such an assumption is contrary to classical electrodynamics as mentioned earlier. Electromagnetic radiation would be emitted or absorbed only when an electron changed from one allowed orbit to another allowed orbit. The energy difference between the two states would be emitted or absorbed in the form of a single quantum of radiant energy, producing a radiation pattern of a definite frequency  $\nu$ , related to the energy  $E$  by the relation  $E = h\nu$  already postulated by Planck and Einstein.

### QUANTUM NUMBERS

The quantum theory was further refined in 1916 when Arnold Sommerfeld introduced an azimuthal quantum number,  $l$ , where  $l \leq n - 1$ , which permitted discrete elliptical orbits for electrons, in addition to the circular orbits. This change permitted the Bohr model to account for detailed structure in the pattern of radiation emitted by hydrogen and other atoms. To account for the change in the emitted radiation pattern when an atom is exposed to a magnetic field, a magnetic quantum number  $m$  (with permitted integral values from  $-l$  to  $+l$ ) was added. This quantum number designates different projections of the possible circular or elliptical orbits along the magnetic field direction in space. Finally, a spin quantum number for the electron was postulated by Samuel Goudsmit and George Uhlenbeck to account for the close grouping of two or more spectral lines. An electron was considered to have an angular momentum about its own axis; in mechanical terms, this motion can be thought of as spin. In a magnetic field, the spin axis can have two directions relative to the field.

The orbits in which the electrons move can be described by specifying a set of these four quantum numbers. All electrons with principal quantum number  $n = 1$  are in the innermost orbit, called the K shell. All electrons with  $n = 2$  fall into a second group, called the L shell. The total number of electrons in a shell is limited by the various possible combinations of the other three quantum numbers. When an electron shell is filled, the atom is in a stable configuration (the noble gas configuration) and does not easily undergo chemical reactions. If only one or two electrons are in the last unfilled shell, it is relatively easy for the atom to lose these electrons to another atom whose last unfilled shell has one or two vacancies. The first of these two atoms becomes positively charged (because of the loss of electrons); the second becomes negatively charged (because of the gain of electrons). These atoms can now attract each other and form a compound (ionic bonding).

The periodicity or repetitive structure of the Mendeleev chart is now understood to be due to the number of electrons in the atom. In a neutral atom the number of electrons is balanced by the equal number of protons (hydrogen nuclei with a positive charge and a mass of about 1836 electron masses) in the nucleus of the atom. Note that the atomic number of an element is equal to the number of unit positive charges carried by the nucleus and is not the same as the atomic weight. In 1913,

Henry G. J. Moseley determined the magnitude of the nuclear charge by comparing the characteristic X-ray wavelengths of elements. Identification of the atomic number of an element from its high-frequency spectrum provided a rule for fitting newly discovered elements into vacant places on the Mendeleev chart.

In 1923, Louis DeBroglie postulated that, in analogy with light having both a wave and a particle nature, matter should have a wave as well as a particle nature. The wavelength that he predicted for a particle was inversely proportional to the particles' momentum. Clinton J. Davisson and Lester H. Germer experimented with the scattering of electrons from a crystal. They showed that electrons definitely had wave properties with a wavelength corresponding to the value predicted by DeBroglie.

The mechanical picture offered for the classification of stationary states of atoms by the Bohr theory, and its subsequent modification, was handicapped by its reliance on many *ad hoc* postulates and by an inability to explain the intensities of radiation patterns emitted by atoms. A new departure was provided in 1926 by Erwin Schrödinger's establishment of wave-mechanics,\* in which stationary states are conceived as proper solutions of a fundamental wave equation. In advanced theories, the mechanical models are no longer used.

### ISOTOPES

Experimental investigations in nuclear physics began to require specialized instruments. One of the first of these instruments was the mass spectrograph developed by Francis W. Aston to measure the relative mass of the atoms of an element. This device directed positive ions of an ionized (electrically charged) gas at a photographic plate. The ions were deflected by electric and magnetic fields, working at right angles, so that all particles having the same mass were brought to a focus at a fine line. Heavier ions, having more inertia, were deflected less than were the lighter ions.

With the use of the mass spectrograph, it was discovered that some chemical elements have two or more components, each with its own mass. Natural chlorine, whose atomic weight is fractional (about 35.5), produced two lines on the photographic plate corresponding to masses very close to 35 and 37. No particle was found with a fractional mass (within the experimental error). Components of the same chemical element with different mass numbers are called isotopes. Most elements in their natural state consist of two or more isotopes, although 20 elements have only one isotope; for example, aluminum, cobalt, and gold. Modifying Prout's hypothesis, Aston proposed the whole-number rule which states that all atomic masses are close to integers and that fractional atomic weights are due to the presence of two or more isotopes, each of which has an approximately integral value. On the carbon-12 scale now used, where the atomic weight of carbon-12 is exactly 12 units, all other isotopes have atomic weights close to integers.

\* Wave-mechanics is equivalent to the matrix mechanics developed by Werner Heisenberg in 1925.

With the problem of fractional atomic weights solved, physicists at first believed that nuclei consisted of electrons and protons. A nucleus with an atomic number Z and an atomic mass A would consist of A protons, to account for the total mass, and A minus Z electrons to balance the excess positive charge of the protons. This view of the structure of the nucleus was altered in 1932 when James Chadwick discovered the neutron. This particle has no electric charge and has approximately the same mass as the proton.

It is now believed that neutral atoms consist of N neutrons, Z protons, and Z orbital electrons, with A = N + Z. Isotopes are nuclides with the same Z but different N. For example, natural hydrogen consists almost entirely of atoms that contain one proton and one electron. However, a small amount (about 0.015 percent) of deuterium (heavy hydrogen) is present in nature; deuterium consists of one proton, one neutron, and one electron. In general, the situation becomes more complex as the heavier elements are encountered. Natural tin, which has atomic number 50, consists of 10 isotopes of masses 112, 114, 115, 116, 117, 118, 119, 120, 122, and 124. These isotopes differ from one another because, although each has 50 protons and 50 electrons, each contains a different number of neutrons (ranging from 62 to 74).

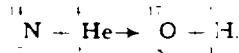
The nucleus is held together by attractive forces between the neutrons and protons. These attractive forces are not completely understood, but it is known that they must be strong enough to overcome the electrostatic repulsion between the protons. Because of this repulsion, however, the ratio of neutrons to protons increases for stable isotopes as the atomic number increases. Among light elements in nature, there is approximately one proton for every neutron. Among heavy stable isotopes, for every two protons there are approximately three neutrons.

As previously mentioned, Aston found that the atomic masses were approximately integers. More accurate measurements indicate that the total mass of a nucleus is always less than the sum of the proton and neutron masses of which the nucleus is composed. In 1905, Einstein had shown that mass, m, was another form of energy, E, expressed by his relationship  $E = mc^2$ , where c is the velocity of light. The mass deficiency of the nucleus is expressed as the nuclear binding energy. The binding energy represents the amount of energy required to break the nucleus into its constituent nucleons. The ratio of the binding energy to the number of particles in the nucleus varies among the stable elements. It is greater for elements with mass numbers between 30 and 120 than it is for very light or very heavy stable elements.

### ARTIFICIAL RADIOACTIVITY

In 1919, Rutherford's discovery of artificial radioactivity achieved the feat vainly sought by the ancient alchemists, that is, changing one element into another. Rutherford bombarded nitrogen gas with a stream of alpha particles. Some of the alpha particles were absorbed by the nitrogen, protons were emitted, and a different element, oxygen, was formed. The physicist uses symbolic language

to represent the transformation as follows:



The superscripts denote the total number of nucleons (number of protons plus neutrons), and the subscripts denote the atomic number (number of protons) in each element. Note that the superscripts on one side of the arrow balance those on the other side. The same is true for the subscripts. The balance represents the conservation of the number of protons and neutrons separately.

This initial discovery has been followed by the construction of large machines designed to accelerate charged particles such as protons and alpha particles to higher energies so that they may be used to bombard nuclei. Among these machines are the Van de Graaff generator, the cyclotron, the betatron, the linear accelerator (linac), and others. Beams of high-energy neutrons can also be produced. Since the neutron is electrically neutral, however, there is no electrostatic repulsion between bombarding neutrons and the positively charged target nuclei. Even thermal neutrons could be used for nuclear reaction studies (thermal neutrons have energies that correspond to the most probable energy for a group of neutrons at 68°F, that is, energies in the neighborhood of 0.025 eV).

## **NEUTRON FISSION**

During the investigation of neutron-produced reactions in various target elements, Enrico Fermi and his associates discovered different beta activities (distinguished by half-life) when uranium was used as a target. They assumed that a transuranium element had been produced (that is, an element whose atomic number was greater than 92). In 1938, Otto Hahn and Fritz Strassman, repeating the experiments, discovered part of the activity to be due to barium (atomic number 56). Lise Meitner and Otto Frisch suggested that the uranium nucleus had split into two roughly equal parts, barium and krypton (the latter, atomic number 36), when the uranium captured the incident neutron. This reaction Frisch termed "fission," after the term used to describe the division of cells in a living organism. Since the mass defect (or binding energy) per particle is greater for the residual nuclei, barium and krypton, than for the uranium, neutron fission is accompanied by a large energy release.

For nuclear reactions other than fission, Fig. 1 illustrates the many combinations of incident (or bombarding) and emitted particles, and how each combination changes the original nucleus. This figure is copied from the lower right corner of the chart. A special type of shorthand is used on this diagram to identify the data represented. An example is (p,n) which denotes a reaction in which the nucleus absorbs a proton and emits a neutron. The symbols used are:

n	neutron	t	triton (hydrogen-3)
d	deuteron		nu:leus)
p	proton	"	alpha particle
${}^3\text{He}$	helium-3 nucleus	"	gamma ray

Using these reactions, nuclear physicists have produced far more artificially radioactive isotopes than the stable or radioactive isotopes that occur

in nature. The term "nuclide" was proposed by Truman P. Kohman for a species of atom characterized by the number of neutrons and protons that the atom contains. The term is used in this booklet in this general sense to encompass both stable and radioactive species. At present, there are 1675 nuclides known, of which 264 are stable forms of the natural elements. In addition, 65 of the unstable nuclides are found in nature, mainly among the heaviest elements. Active nuclear research, which is conducted in many laboratories throughout the world, causes additions and changes in the list of nuclides. Since the last edition of the chart was published (1966), 8 nuclides, which had been misassigned, have been removed, and 180 new nuclides have been added.

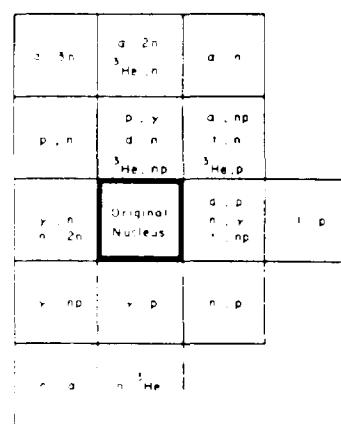
## **CHART OF THE NUCLIDES**

(Data revised to December 1968;  
occasional data to June 1969)

The general arrangement of the Chart is similar to that suggested by Emilio Segré and followed in previous editions. Because of its size, the Chart is presented in three overlapping sections. The numbers along the left-hand side, marking the horizontal rows, represent the atomic number  $Z$  (the number of protons in each nucleus of that row). Each horizontal row represents one element; the filled spaces indicate the known isotopes of that element. The numbers at the bottom of the vertical columns represent the number of neutrons in each nucleus of that column; the number is designated by  $N$ .

Heavy lines on the Chart occur for Z or N equal to 2, 8, 20, 28, 50, 82, and 126. These are the so-called "magic numbers", i.e., the numbers of neutrons (protons) present when a neutron (proton) shell is closed. In analogy with the electron shell model of the atom, a nuclear shell model has been developed for the neutrons and protons within a nucleus. Filled shells represent the most stable configurations. Nuclides having either a closed neutron shell, or a closed proton shell, or both, are most stable.

Spaces shaded in gray represent isotopes that occur in nature and that are generally considered stable. A black rectangular area at the top of a



*Fig. 1. Changes Produced by Various Nuclear Reactions*

white square indicates a radioactive isotope that is found in nature. Examples of such isotopes are (1) an unstable nuclide having a lifetime sufficiently long to have prevented the loss by disintegration of all atoms of that particular nuclide that were available at the time the elements were formed, and (2) a short-lived nuclide that is a disintegration product of such a long-lived nuclide. Occasionally one nuclide has both the gray shading and the black top. This indicates an isotope found in nature, such as rubidium-87, that is radioactive with a very long half-life. Squares with smaller black rectangular areas near the top represent members of one of the naturally radioactive decay chains (see page 8). The old symbolic name is inserted in this smaller black area. White squares represent artificially produced radioactive nuclides.

The heavily bordered space at the left side of each horizontal row gives properties of the element as found in nature, including the chemical atomic weight (on a mass scale where the neutral atom of carbon-12 = 12.00000) and the thermal neutron absorption cross section (see page 6).

Each of the other occupied spaces carries the chemical symbol (a list of these symbols is given on page 7 along with the atomic weights) and the mass number of the nuclide indicated. The mass number, designated by A, is the sum of the number of neutrons and protons in the nucleus. The number of neutrons N is equal to the difference between the mass number and the atomic number, that is, A minus Z.

### STABLE NUCLIDES

Classifying the 264 stable nuclides by the even- or oddness of Z and N gives four possible categories. The first category contains an even number of protons and an even number of neutrons (so called even-even nuclei). The other categories are even-odd, odd-even, and odd-odd. Table 1 shows the number of stable nuclides that fall in each category.

Table 1. Distribution of Stable Nuclides

A	Z	N	Number of Stable Nuclides
Even	Even	Even	157
Odd	Even	Odd	53
Odd	Odd	Even	50
Even	Odd	Odd	4
			264

Table 1 shows that for the odd A nuclides there are approximately as many nuclides with an even number of protons (even Z) as with an even number of neutrons (even N). This is evidence that the nuclear force between two nucleons is independent of whether the nucleons are protons or neutrons. Odd-odd stable nuclides are scarce, and they are found only among the lightest nuclides. Their scarcity is due to a "pairing energy" between particles in the same shell. The condition of being in the same shell increases the binding energy of these particles, making them more stable than particles in different shells. An odd-odd nuclide contains at least one unpaired proton and one unpaired neutron which are usually in different shells and hence contribute weakly to the binding. For the lightest nuclei, however, the unpaired neutron and proton are in the same shell.

Diagonals running from upper left to lower right connect nuclides of different elements, which have the same mass numbers. For example, one line could connect calcium-40, which has 20 protons and 20 neutrons, with argon-40, which has 18 protons and 22 neutrons. Nuclides of the same mass number are called isobars; nuclides with the same number of neutrons are called isotones.

### DATA DISPLAY

The manner of displaying data is explained in the lower right corner of the chart. For stable nuclides, the first line contains the chemical symbol and mass number; the second line presents the atom percent of the natural element that this isotope represents (known as the absolute isotopic abundance); the third line contains the thermal neutron cross section (see page 6); and the fourth line presents the isotopic mass of the neutral atom (the mass of the nucleus and its surrounding electrons). This mass is given in atomic mass units where carbon-12 is assigned a mass of 12.00000.

For long-lived, naturally occurring radioactive nuclides, the first line contains the chemical symbol and mass number, the second line presents the absolute isotopic abundance, and the third line contains the half-life. The half-life is the period of time in which half of the nuclei initially present in a given sample disintegrate. Additional lines present the decay modes (or types) and energies of decay, and the isotopic mass of the nuclide. Energies are given in millions of electron volts (MeV). When more than one mode of decay occurs, the most prominent mode appears first (above, or to the left of, the other modes). When gamma radiation is emitted in more than one decay mode, or if several gamma rays are emitted in one mode, the gamma rays are separated and presented below (or to the right of) their associated decay mode(s).

For radioactive nuclides that are not of the long-lived, naturally occurring type, the same information is presented except that the isotopic abundance is omitted and the last line of the pertinent square contains the beta-decay energy instead of the isotopic mass. For the heavy elements, where the major mode of decay is alpha-particle emission, the isotopic mass is retained in the last line. In many squares, a small black triangle appears in the lower right corner to indicate that the nuclide has been formed as a product in the thermal-neutron fission of uranium-235.

### METASTABLE STATES

Note that certain squares are divided, for example, the square for aluminum-26. Such divisions occur when a nuclide has one or more isomeric states, that is, when a nuclide has the same mass number and atomic number, but possesses different radioactive properties in different long-lived energy states. On the chart, a long-lived state is arbitrarily defined as a state whose half-life is one microsecond (one-millionth of a second) or longer. The lower energy state is generally referred to as the ground state, the higher state as the isomeric state. Frequently, the ground state is a stable nuclide. If one metastable state exists, it is shown on the left. If two exist, the higher energy state is shown on the

left, the lower below it or to the right of it, and the ground state to the right of both.

A mode of decay and the decay energy shown in parentheses indicate that the decay results from a short-lived daughter that accompanies its parent. (In a radioactive decay, the original nuclide is called the parent or precursor; the resultant nuclide is called the daughter.) For example, nitrogen-17, with a half-life of 4.14 seconds, decays by negative beta emission (symbol  $\beta^-$ ) into an exceedingly short-lived state of oxygen-17, which in turn emits a neutron. Thus, nitrogen-17 emits "delayed neutrons" with a half-life of 4.14 seconds.

Another example is 17-day palladium-103, which decays by K-electron capture mainly to the 57-minute rhodium-103 and, statistically less often, to stable rhodium-103. (K-electron capture occurs when the nucleus captures an electron from the K shell; the symbol is  $e^-$ .) The 57-minute rhodium emits a gamma ray or an internal-conversion electron that corresponds to an isomeric transition of 0.040 MeV. (An internal-conversion process involves the direct transfer of energy from the nucleus to one of the orbital electrons, and the electron is ejected from the atom; the symbol used is  $e^-$ .) On the chart, the delayed gamma ray is assigned to the parent; inclusion of the energy in parentheses indicates that the gamma ray comes from the daughter, but continues to last as long as the disintegrating parent is still present.

A further example is provided by a standard laboratory radionuclide, 30.2-year cesium-137. This long-lived parent decays directly to a short-lived daughter, 2.551-minute barium-137, by negative beta emission. The 6.616-MeV gamma ray which is emitted by the barium is included in parentheses on the cesium square.

#### THERMAL NEUTRON CROSS SECTIONS

The Greek letter  $\sigma$  with various subscripts is used to identify the thermal neutron cross sections. The neutron cross section measures the probability of interaction of a neutron with matter. The cross section can be most easily visualized as a cross-sectional target area presented to the neutron by the nucleus. The cross section depends upon the type of interaction involved and the energy of the neutron. At thermal energies, a number of reaction types are possible. The thermal neutron absorption cross section (symbol  $\sigma_a$ ) is the sum of the cross sections for all reactions except scattering of the neutron. Cross sections are usually measured in units of barns per atom. A barn is the area of a square a millionth of a millionth of a centimeter on each side ( $10^{-44}$  square centimeters). The most probable reaction (that is, the reaction with the largest cross section) is generally the neutron capture reaction (symbol  $\sigma_c$ ) in which the absorption of the neutron by the nucleus is accompanied by high-energy gamma-ray emission. Occasionally, a proton or an alpha particle may be emitted, or the nucleus may fission upon neutron absorption (symbols  $\sigma_p$ ,  $\sigma_{\alpha}$ , and  $\sigma_f$ ). Examples of these cross sections are found on the squares of beryllium-7, boron-10, and thorium-227, respectively.

A given nuclide might undergo two or more interactions, and its square would then contain

two or more of these cross-section values. When neutron capture can lead to a metastable state as well as to the ground state, more than one value will appear beside the capture cross section for that nuclide. The cross-section value for metastable state formation is listed on the left and that for direct ground state formation on the right. For two metastable states, the higher of the two states is on the left. For example, indium-113 has an indicated capture cross section  $\sigma_c$  of (2.8 + 5.0 + 3), which means that the cross section for formation of 44-millisecond indium-114 is 2.8 barns, the cross section for the direct formation of 50.0-day indium-114 is 5.0 barns, and the cross section for formation of 71.9-second indium-114 is 3 barns.

The designation mb or  $\mu b$  following the cross-section value indicates that the units of the cross section are millibarns per atom ( $10^{-24}$  cm<sup>2</sup>/atom) or microbarns per atom ( $10^{-26}$  cm<sup>2</sup>/atom), respectively. When no mb or  $\mu b$  appears on the chart square, the units of the cross section are barns per atom.

#### SPINS AND PARITIES

In the upper right corner of the square for the ground state of a nuclide, and in the upper left corner of the isomeric state, are shown the spin and parity of the corresponding energy level. Each neutron and proton has an intrinsic angular momentum of  $\frac{1}{2}$  (in units of  $\hbar/2\pi$ , where  $\hbar$  is Planck's constant), similar to that of the electron, which combines with their orbital angular momentum to produce a resultant angular momentum called the nuclear spin. Since the orbital angular momentum is always zero or an integral multiple of  $\hbar/2\pi$ , the nuclear spin (in units of  $\hbar/2\pi$ ) is always integer or half-odd-integer, depending upon whether the nucleus has an even or an odd number of nucleons. The concept of parity was introduced by the mathematical formalism of quantum theory and has no classical analogue. A system in a given state may have even parity (symbol  $+/-$ ) or odd parity (symbol  $-/+$ ). For aluminum-27 the spin and parity are shown as  $5/2+$ , where the 2 in the denominator of  $5/2$  has been removed to improve the readability of the chart. The ground states of all even-even nuclides are known to have spin and parity  $0+/-$ ; so  $0+$  has been omitted.

The arguments for the assignment of spin and parity to nuclear states can be divided into two classes: strong arguments such as measuring values directly, and weak arguments such as inferring values indirectly. On the chart, the absence of parentheses indicates spins and/or parities based on strong arguments; the presence of parentheses indicates spins and/or parities based on weak arguments. When the spins of both the ground state and an isomeric state are given for a particular nuclide, it is interesting to observe that these spins usually differ by two or more units of  $\hbar/2\pi$ . The large angular momentum (spin) change is required for the gamma-ray transition between the states. Combining this spin change with the small energy differences (a few hundred keV) leads to a relatively long lifetime (metastable state).

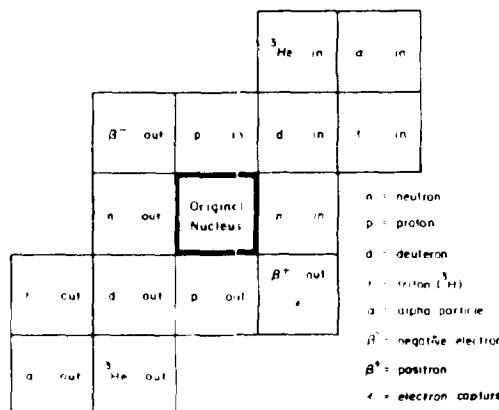
## RADIOACTIVE DECAY CHAINS

As nuclear processes occur, whether in natural radioactivity or under artificially induced conditions, the nuclides change in accordance with the scheme shown in Fig. 2. To understand the use of this scheme more fully, consider the uranium-238 decay chain (one of three such chains found in nature). On the chart we start with the parent uranium-238 which emits an alpha particle. The daughter nucleus is in the second space diagonally down to the left (see Fig. 2). This square represents the isotope thorium-234. (This nuclide is also identified by the old symbol uranium  $X_1$ , which is the historic name given it before it was identified as thorium.)

Thorium-234 in turn emits a negative electron; so the loss of mass is not appreciable. However, there is a loss of one negative charge, which means that the atomic number  $Z$  increases by one. In effect, one neutron has changed into a proton. The move one space up and one space to the left (see Fig. 2) leads to protactinium-234 which has isomeric states. Each of these states undergoes negative beta emission; so another move diagonally upward to the left leads to uranium-234.

Uranium-234 emits an alpha particle ending at thorium-230. Another alpha decay yields radium-226. Three further alpha decays result first in radon-222, then in polonium-218, and finally in lead-214. However, this isotope of lead is unstable and emits a negative electron producing bismuth-214. A beta decay to polonium-214 is followed by an alpha decay to lead-210. An alternate route from bismuth-214 to lead-210 is taken in a small fraction of the disintegrations since bismuth-214 can also emit an alpha particle and the resulting thallium-210 beta-decays to lead-210.

In either case, lead-210 beta-decays to bismuth-210. Another beta decay produces polonium-210 which alpha-decays to the stable isotope lead-206. At this point the chain ends. Incidentally, in many of the above steps, gamma rays and conversion electrons are also emitted.



*Fig. 2. Relative Locations of the Products of Various Nuclear Processes*

Similarly, the two other natural radioactive sequences may be traced. One is the actinium series which starts with uranium-235 and ends with lead-207. The other is the thorium series, which goes from thorium-232 to lead-208. A fourth, or neptunium, series is also known. However, the half-life of the parent, neptunium-237, is only about two million years. Since the age of the earth is five or ten billion years, most of the neptunium-237 present when the earth was younger has already decayed, and the series is not found in nature.

Since the naturally radioactive decay chains end at stable isotopes of lead, the isotopic composition of lead ore will be variable depending upon its source and its past history. Elements such as lithium and boron also have variable compositions that are affected by reactions that their samples have previously undergone. In a similar manner, scientists examining the isotopic compositions of samples recently brought back from the moon have already obtained an estimate of the age of the samples from the relative amounts of potassium and argon-40 present. A comparison of the isotopic composition of elements on the moon with those on earth might provide scientists with some solutions to the problem of the origin of the universe.

Errata

(Chart of the Nuclides, Tenth Edition)

The absorption cross sections for oxygen and sodium should read as follows:

### Oxygen $\sigma_0$ , 27 mb

### Sodium $\sigma_0$ .534

The atomic weight for praseodymium should read 140.908.

## ACKNOWLEDGMENTS

The authors thank the large number of persons who by correspondence and in discussions contributed generously of their time and information. It is not possible to acknowledge specifically in this limited space everyone who sent his experimental results in advance of publication and whose assistance was needed in the comparison of the various experimental data. Special thanks are due to John R. Stehn of the Brookhaven National Laboratory, Geoffrey C. Hanna of the Chalk River Laboratory, David T. Goldman of the National Bureau of Standards, Earl K. Hyde and Albert Ghiorso of the Lawrence Radiation Laboratory, Arve Kjelberg of CERN, Jere D. Knight of Los Alamos Scientific Laboratory, W. Bruce Ewbank of the Nuclear Data Project at Oak Ridge National Laboratory, R. Van Lieshout of the Instituut Voor Kernfysisch Onderzoek, and T. Leo Collins, Jr., and the mass spectrometry group at KAPL, for their assistance in various stages of the preparation of the accompanying Chart of the Nuclides.

## LIST OF ELEMENTS

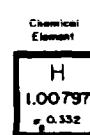
ATOMIC NUMBER	SYMBOL	NAME	ATOMIC WEIGHT	ATOMIC NUMBER	SYMBOL	NAME	ATOMIC WEIGHT
0	n	neutron	.....	52	Te	tellurium	127.60
1	H	hydrogen	1.00797	53	I	iodine	126.9044
2	He	helium	4.0026	54	Xe	xenon	131.30
3	Li	lithium	6.940	55	Cs	cesium	132.905
4	Be	beryllium	9.0122	56	Ba	barium	137.34
5	B	boron	10.811	57	La	lanthanum	138.91
6	C	carbon	12.01115	58	Ce	cerium	140.12
7	N	nitrogen	14.0067	59	Pr	praseodymium	140.908
8	O	oxygen	15.9994	60	Nd	neodymium	144.24
9	F	fluorine	18.9984	61	Pm	promethium	.....
10	Ne	neon	20.179	62	Sm	samarium	150.35
11	Na	sodium	22.9898	63	Eu	euroium	151.96
12	Mg	magnesium	24.305	64	Gd	gadolinium	157.25
13	Al	aluminum	26.9815	65	Tb	terbium	158.924
14	Si	silicon	28.086	66	Dy	dysprosium	162.50
15	P	phosphorus	30.9738	67	Ho	holmium	164.930
16	S	sulfur	32.064	68	Er	erbium	167.26
17	Cl	chlorine	35.453	69	Tm	thulium	168.934
18	Ar	argon	39.948	70	Yb	ytterbium	173.04
19	K	potassium	39.102	71	Lu	lutetium	174.97
20	Ca	calcium	40.08	72	Hf	hafnium	178.49
21	Sc	scandium	44.956	73	Ta	tantalum	180.948
22	Ti	titanium	47.90	74	W	tungsten	183.85
23	V	vanadium	50.942	75	Re	rhenium	186.2
24	Cr	chromium	51.996	76	Os	osmium	190.2
25	Mn	manganese	54.9380	77	Ir	iridium	192.2
26	Fe	iron	55.847	78	Pt	platinum	195.09
27	Co	cobalt	58.9332	79	Au	gold	196.967
28	Ni	nickel	58.71	80	Hg	mercury	200.59
29	Cu	copper	63.546	81	Tl	thallium	204.37
30	Zn	zinc	65.37	82	Pb	lead	207.19
31	Ga	gallium	69.72	83	Bi	bismuth	208.980
32	Ge	germanium	72.59	84	Po	polonium	.....
33	As	arsenic	74.9216	85	At	astatine	.....
34	Se	selenium	78.96	86	Rn	radon	.....
35	Br	bromine	79.904	87	Fr	francium	.....
36	Kr	krypton	83.80	88	Ra	radium	.....
37	Rb	rubidium	85.47	89	Ac	actinium	.....
38	Sr	strontium	87.62	90	Th	thorium	232.038
39	Y	yttrium	88.905	91	Pa	protactinium	.....
40	Zr	zirconium	91.22	92	U	uranium	238.03
41	Nb	niobium	92.906	93	Np	neptunium	.....
42	Mo	molybdenum	95.94	94	Pu	plutonium	.....
43	Tc	technetium	.....	95	Am	americium	.....
44	Ru	ruthenium	101.07	96	Cm	curium	.....
45	Rh	rhodium	102.905	97	Bk	berkelium	.....
46	Pd	palladium	106.4	98	Cf	californium	.....
47	Ag	silver	107.868	99	Es	einsteinium	.....
48	Cd	cadmium	112.40	100	Fm	fermium	.....
49	In	indium	114.82	101	Md	mendelevium	.....
50	Sn	tin	118.69	102	No	nobelium	.....
51	Sb	antimony	121.75	103	Lr	lawrencium	.....

Relative Locations of the Products  
of Various Nuclear Processes

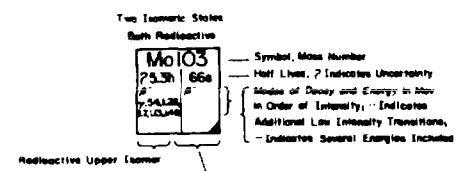
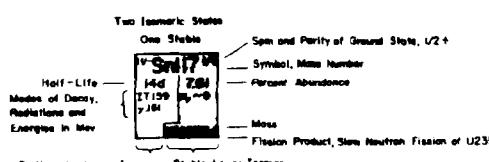
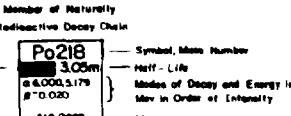
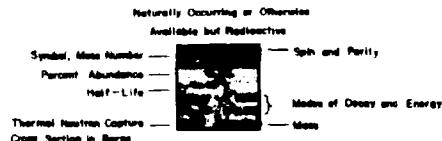
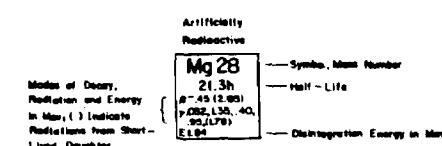
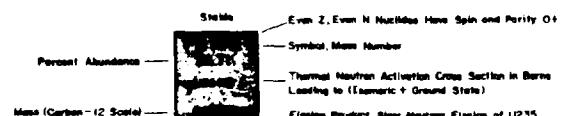
		$\text{He}^3$ in	$\alpha$ in
$\beta^-$ out	p in	d in	t in
n out	Original Nucleus	r in	
t out	d out	p out	$\beta^+$ out
$\alpha$ out	$\text{He}^3$ out	n = neutron p = proton d = deuteron t = triton ( $\text{H}^3$ ) $\alpha$ = alpha particle $\beta^-$ = negative electron $\beta^+$ = positron $\epsilon$ = electron capture	

Displacements Caused by Nuclear  
Bombardment Reactions

$\alpha$ , 3n	$\alpha$ , 2n $\text{He}^3, n$	$\alpha$ , n
p, n	$p + \gamma$ $d, n$ $\text{He}^3, np$	$\alpha, np$ $t, n$ $\text{He}^3, p$
$\gamma, n$ $n, \text{Zn}$	Original Nucleus	$d, p$ $n + \gamma$ $t, np$
$\gamma, np$	$\gamma, p$	$n, p$
n, s	$n, \text{He}^3$	



— Symbol  
— Atomic Weight (Carbon-12 Scale)  
— Thermal Neutron Absorption Cross Section in Barns



## SYMBOLS

## RADIATIONS AND DECAY

- $\alpha$  alpha particle
- $\beta^-$  negative electron
- $\beta^+$  positron
- $\gamma$  gamma ray
- n neutron
- p proton
- $\epsilon$  electron capture
- IT isomeric transition
- D radiation delayed
- SF spontaneous fission
- E disintegration energy
- $\epsilon^-$  conversion electron

## TIME

- ms milliseconds ( $10^{-3}$  s)
- $\mu\text{s}$  microseconds ( $10^{-6}$  s)
- s seconds
- m minutes
- h hours
- d days
- y years

16

15

Z

**0**

1 2

- 10 -

17	C1 35.453	C1 32	C1 33 <sup>34</sup>	C1 34 <sup>35</sup>	C1 35 <sup>36</sup>	C1 36 <sup>37</sup>	C1 37 <sup>38</sup>	C1 38 <sup>39</sup>	C1 39 <sup>40</sup>	C1 40 <sup>41</sup>	
S 32.064	$\sigma_{\gamma}$ 42	S 29 0.15	S 30 1.15	S 31 <sup>32</sup> 0.65	S 32 0.76	S 33 <sup>34</sup> 0.76	S 34 0.22	S 35 <sup>36</sup> 0.014	S 36 0.06	S 37 <sup>38</sup> 2.47	
P 30.9738	$\sigma_{\gamma}$ 19	P 28 <sup>29</sup> 2.70ms 4.23s	P 29 <sup>30</sup> 4.23s	P 30 <sup>31</sup> 2.50m 4.12s	P 31 <sup>32</sup> 100	P 32 <sup>33</sup> 14.31d	P 33 <sup>34</sup> 25.2d	P 34 <sup>35</sup> 12.4s	P 35 <sup>36</sup> 1.67	P 36 <sup>37</sup> 1.49	24
Si 25 0.220s	Si 26 0.23s	Si 27 <sup>28</sup> 4.20s	Si 28 9.21	Si 29 <sup>30</sup> 7.3	Si 30 0.016	Si 31 <sup>32</sup> 3.09	Si 32 0.22h	Si 33 <sup>34</sup> ~6.50v	Si 34 <sup>35</sup> ~6.50v	Si 35 <sup>36</sup> ~6.50v	22
Al 24 <sup>25</sup> 0.129s	Al 25 <sup>26</sup> 7.23s	Al 26 <sup>27</sup> 6.45s	Al 27 <sup>28</sup> 100	Al 28 1.76s	Al 29 <sup>30</sup> 2.27m	Al 30 <sup>31</sup> 6.52m	Al 31 <sup>32</sup> 1.75s	Al 32 <sup>33</sup> 1.24s	Al 33 <sup>34</sup> 2.24s	Al 34 <sup>35</sup> 3.52	18
Mg 23 <sup>24</sup> 12s	Mg 24 7.99s	Mg 25 <sup>26</sup> 10.00	Mg 26 11.01	Mg 27 <sup>28</sup> 9.5m	Mg 28 11.76s	Mg 29 <sup>30</sup> 1.45(2.85)	Mg 30 <sup>31</sup> 1.45(2.85)	Mg 31 <sup>32</sup> 1.45(2.85)	Mg 32 <sup>33</sup> 1.45(2.85)	Mg 33 <sup>34</sup> 1.45(2.85)	20
Na 22 <sup>23</sup> 2602y	Na 23 <sup>24</sup> 100	Na 24 <sup>25</sup> 15.00h	Na 25 <sup>26</sup> 17.42s	Na 26 <sup>27</sup> 59s	Na 27 1.67	Na 28 <sup>29</sup> 1.67	Na 29 <sup>30</sup> 1.67	Na 30 <sup>31</sup> 1.67	Na 31 <sup>32</sup> 1.67	Na 32 <sup>33</sup> 1.67	
Ne 21 <sup>22</sup> 0.266	Ne 22 9.22	Ne 23 <sup>24</sup> 37.6s	Ne 24 4.0s	Ne 25 <sup>26</sup> 3.38m	Ne 26 1.04s	Ne 27 <sup>28</sup> 1.04s	Ne 28 <sup>29</sup> 1.04s	Ne 29 <sup>30</sup> 1.04s	Ne 30 <sup>31</sup> 1.04s	Ne 31 <sup>32</sup> 1.04s	16
F 20 <sup>21</sup> 11.2s	F 21 4.36s	F 22 4.0s	F 23 <sup>24</sup> 4.34s	F 24 <sup>25</sup> 4.34s	F 25 <sup>26</sup> 4.34s	F 26 <sup>27</sup> 4.34s	F 27 <sup>28</sup> 4.34s	F 28 <sup>29</sup> 4.34s	F 29 <sup>30</sup> 4.34s	F 30 <sup>31</sup> 4.34s	14
O 19 <sup>20</sup> 26.8s	O 20 14s	O 21 4.0s	O 22 <sup>23</sup> 32.4s	O 23 <sup>24</sup> 7.06	O 24 <sup>25</sup> 7.06	O 25 <sup>26</sup> 7.06	O 26 <sup>27</sup> 7.06	O 27 <sup>28</sup> 7.06	O 28 <sup>29</sup> 7.06	O 29 <sup>30</sup> 7.06	
N 18 0.63s	N 19 0.64s										12

- 12 -

Ge 67 19.0m $\mu^+ 31.23$ $\gamma^- 17.34, 1.4$	Ge 68 287d $\mu_{1.5} 39.27$ $\gamma^- 0.077, 1$	Ge 69 6.5 $\mu_{1.5} 6.5$ $\gamma^- 107.574, 872$ $\gamma^- 2.227$	Ge 70 20.5 200ms $\sigma_{\gamma} 13.301$	Ge 71 11d $\mu_{1.023} 11d$ $\gamma^- 1.75$ $\sigma_{\gamma} 11$	Ge 72 274 40.4 $\mu_{1.030}$	Ge 73 78 36.5 $\mu_{1.35}$ $\sigma_{\gamma} 16$	Ge 74 36.5 $\mu_{1.35}$ $\sigma_{\gamma} 15.31$	Ge 75 46.5 1.82.8m $\mu_{1.130h}$ $\sigma_{\gamma} 1.29$	Ge 76 7.8 1.45h $\mu_{1.29}$ $\sigma_{\gamma} 1.00.051$	Ge 77 55.5 11.30h $\mu_{1.29}$ $\sigma_{\gamma} 1.29$	Ge 78 1.45h $\mu_{1.29}$ $\sigma_{\gamma} 1.29$	Ge 79 < 1m $\mu_{1.29}$
Ga 66 9.5h $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 67 7.82h $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 68 6.82m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 69 60.16 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 70 21.1m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 71 39.84 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 72 1.41h $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 73 3.19 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 74 4.6h $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 75 7.9m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 76 3.23 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 77 1.7s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ga 78 ~4s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$
Zn 65 243.7d $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Zn 66 2781 $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Zn 67 18.57 $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Zn 68 18.57 $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Zn 69 17.71 $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Zn 70 0.62 $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Zn 71 3.79h 2.4m $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Zn 72 46.5h $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$					46
Cu 64 12.75h $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Cu 65 30.83 $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Cu 66 5.10m $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Cu 67 6.16h $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Cu 68 31s $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Cu 69 3.0m $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$							44
Ni 63 9.2y $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ni 64 11.6 $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Ni 65 2.55h $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Ni 66 5.46h $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$	Ni 67 5.05s $\mu_{1.5} 4.0$ $\sigma_{\gamma} 1$								
Co 62 16ml 159m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Co 63 52s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Co 64 28s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$										42

36

38

40

Co 54 14m O(1945) $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Co 55 18h $\mu_{1.5} 1.04$ $\sigma_{\gamma} 1$	Co 56 7.73d $\mu_{1.5} 1.04$ $\sigma_{\gamma} 1$	Co 57 271d $\mu_{1.5} 1.04$ $\sigma_{\gamma} 1$	Co 58 9.1h 7.14d $\mu_{1.5} 1.04$ $\sigma_{\gamma} 1$	Co 59 100 $\mu_{1.5} 1.04$ $\sigma_{\gamma} 1$	Co 60 100 $\mu_{1.5} 1.04$ $\sigma_{\gamma} 1$	Co 61 165h $\mu_{1.5} 1.04$ $\sigma_{\gamma} 1$	Co 62 16ml 159m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Co 63 2.25s 28s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Co 64 28s 28s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$			
Fe 53 2.53m 65.3m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Fe 54 5.82 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Fe 55 2.7 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Fe 56 9.16 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Fe 57 2.19 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Fe 58 0.33 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Fe 59 0.33 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Fe 60 ~10y $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Fe 61 6.05m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$				40	
Mn 52 2.14h 5.63d $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Mn 53 2.10e $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Mn 54 3.15d $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Mn 55 100 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Mn 56 2.582h 7m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Mn 57 1.7m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Mn 58 1.1m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$					38		
Cr 51 2.78d $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Cr 52 83.79 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Cr 53 9.50 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Cr 54 2.365 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Cr 55 3.53m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Cr 56 5.9m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$							36	
V 50 0.24 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	V 51 99.76 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	V 52 3.75m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	V 53 2.0m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	V 54 5.5s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$								34	
Ti 49 3.81 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ti 50 9.34 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ti 51 5.76m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Ti 52 1.7m 49m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$									32	
Sc 48 1.82d $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Sc 49 57.5m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Sc 50 0.45 1.73m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Sc 51 12s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Sc 52 1.1s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$								30	
Co 47 4.53d $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Co 48 0.18 $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Co 49 8.70m $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	Co 50 11s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$										
K 46 115s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$	K 47 17.5s $\mu^+ 1.1$ $\gamma^- 1.59, 2.52$ $\gamma^- 4.54, 4.616$ $\gamma^- 1.57$												

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40	Zr 81 9122 $\sigma_1 162$	Zr 82 ~ 1 Km $\sigma_1$	Zr 83 ~ 2 m $\sigma_1$	Zr 84 15 m $\sigma_1$	Zr 85 14 h $\sigma_1$	Zr 86 16 h $\sigma_1$	Zr 87 16 h $\sigma_1$	Zr 88 85 d $\sigma_1$	Zr 89 784 h 0.80 x 51.46 1.58 x 8.90 4.37 x 1.99 1.23 x 0.07 0.06 x 0.04 0.03 x 0.02 0.02 x 0.01	Zr 90 51.46 1.99 1.99 0.07 0.04 0.03 0.02 0.01	Zr 91 51.46 1.23 0.07 0.04 0.02 0.01	Zr 92 17 h $\sigma_1 0.16$	Zr 93 9.55 h 0.063 x 0.04 0.030 x 0.04 0.020 x 0.04 0.009 x 0.04	
42	Nb 92.906 $\sigma_1 115$													
44	Mo 95.94 $\sigma_2 68$	Mo 88 27 m $\sigma_1 2.25$ $\sigma_2 2.69$	Mo 89.7 7 m $\sigma_1 4.05 \times 4.95$	Mo 90 5.7 h $\sigma_1 1.14 \times 1.11$ $\sigma_2 2.51 \times 4.82$	Mo 91 65.5 x 154.9 m $\sigma_1 1.65 \times 1.44$ $\sigma_2 3.73 \times 7.65$	Mo 92 4.4 m $\sigma_1 1.14 \times 1.11$ $\sigma_2 2.51 \times 4.82$	Tc 92 4.4 m $\sigma_1 1.14 \times 1.11$ $\sigma_2 2.51 \times 4.82$	Tc 93 4.3 m 2.73 h $\sigma_1 1.14 \times 1.11$ $\sigma_2 2.51 \times 4.82$	Tc 94 52 m 4.8 h 61 d 200 h $\sigma_1 1.14 \times 1.11$ $\sigma_2 2.51 \times 4.82$	Tc 95 52 m 4.8 h 61 d 200 h $\sigma_1 1.14 \times 1.11$ $\sigma_2 2.51 \times 4.82$	Tc 96 52 m 4.8 h 61 d 200 h $\sigma_1 1.14 \times 1.11$ $\sigma_2 2.51 \times 4.82$			
46	41													
48	45	Rh 102.905 $\sigma_1 148$	Rh 95 4.8 m $\sigma_1 1.5 m \sim 9 m$ $\sigma_2 1.5 m$	Rh 96 3.3 m $\sigma_1 0.82 \times 0.82$ $\sigma_2 1.24 \times 2.29$	Rh 97 3.3 m $\sigma_1 0.82 \times 0.82$ $\sigma_2 1.24 \times 2.29$	Rh 98 4.7 h 15.0 d $\sigma_1 0.74 \times 4.87$ $\sigma_2 1.35 \times 6.27$	Rh 99 2.1 h $\sigma_1 0.74 \times 4.87$ $\sigma_2 1.35 \times 6.27$	Rh 100 4.47 d 1.3 y $\sigma_1 0.74 \times 4.87$ $\sigma_2 1.35 \times 6.27$	Rh 101 1.2 h 20.7 d $\sigma_1 0.74 \times 4.87$ $\sigma_2 1.35 \times 6.27$	Rh 102 55 m 100 17.040 x 111.1 $\sigma_1 1.37$ $\sigma_2 1.37$	Rh 103 1.2 h 22.23 $\sigma_1 0.74 \times 4.87$ $\sigma_2 1.35 \times 6.27$	Rh 104 10.97 $\sigma_1 0.74 \times 4.87$ $\sigma_2 1.35 \times 6.27$	Rh 105 27.33 $\sigma_1 0.013 \times 28$ $\sigma_2 0.013 \times 28$	Rh 106 27.33 $\sigma_1 0.013 \times 28$ $\sigma_2 0.013 \times 28$
48	46	Pd 106.4 $\sigma_1 8$		Pd 98 17.5 m $\sigma_1 8.3 m$ $\sigma_2 8.3 m$	Pd 99 3.7 d $\sigma_1 0.84 \times 0.84$ $\sigma_2 1.18$	Pd 100 3.7 d $\sigma_1 0.84 \times 0.84$ $\sigma_2 1.18$	Pd 101 8.3 h $\sigma_1 0.24 \times 2.96$ $\sigma_2 1.21 \times 3.13$	Pd 102 0.96 $\sigma_1 0.5$	Pd 103 1.7 d $\sigma_1 0.040 \times 0.51$ $\sigma_2 1.56$	Pd 104 10.97 $\sigma_1 0.040 \times 0.51$ $\sigma_2 1.56$	Pd 105 16.6 s 22.23 $\sigma_1 0.040 \times 0.51$ $\sigma_2 1.56$	Pd 106 27.33 $\sigma_1 0.040 \times 0.51$ $\sigma_2 1.56$	Pd 107 10.9348 $\sigma_1 0.040 \times 0.51$ $\sigma_2 1.56$	Pd 108 0.88 $\sigma_1 0.040 \times 0.51$ $\sigma_2 1.56$
48	47	Ag 107.868 $\sigma_1 3.63$		Ag 99 1.8 m $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$	Ag 100 8 m $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$	Ag 101 10.8 m $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$	Ag 102 5.8 s 1.7 m $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$	Ag 103 2.9 m 5.7 m $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$	Ag 104 4.1 Cd $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$	Ag 105 4.1 Cd $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$	Ag 106 4.4 s 24.1 m $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$	Ag 107 4.4 s 51.62 $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$	Ag 108 10.7 90419 $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$	Ag 109 0.88 $\sigma_1 0.41 \times 1.11$ $\sigma_2 0.41 \times 1.11$

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Cs 134 <sup>**</sup>	Cs 135 <sup>**</sup>	Cs 136 <sup>*</sup>	Cs 137 <sup>*</sup>	Cs 138 <sup>*</sup>	Cs 139 <sup>*</sup>	Cs 140 <sup>*</sup>	Cs 141 <sup>*</sup>	Cs 142 <sup>*</sup>	Cs 143 <sup>*</sup>	Cs 144 <sup>*</sup>				
2.90h 2.26d 0.27d (2.23) 0.346 0.080 0.190 0.428	2.06y 53m 2.8x10 <sup>5</sup> y 17.23 10.44 0.016 0.000 0.000	13d 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	30.2y R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	32.2m R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	9.3m R 4.22m 0.42-0.46 0.44-0.46 0.44-0.46 0.44-0.46 0.44-0.46	6.38s R 4.22m 0.42-0.46 0.44-0.46 0.44-0.46 0.44-0.46 0.44-0.46	24.7s R 4.22m 0.42-0.46 0.44-0.46 0.44-0.46 0.44-0.46 0.44-0.46	1.7s R 4.22s 0.42-0.46 0.44-0.46 0.44-0.46 0.44-0.46 0.44-0.46	1.7s R 4.22s 0.42-0.46 0.44-0.46 0.44-0.46 0.44-0.46 0.44-0.46	1.1s R 4.22s 0.42-0.46 0.44-0.46 0.44-0.46 0.44-0.46 0.44-0.46				
Xe 133 <sup>v*</sup>	Xe 134 <sup>*</sup>	Xe 135 <sup>*</sup>	Xe 136 <sup>*</sup>	Xe 137 <sup>*</sup>	Xe 138 <sup>*</sup>	Xe 139 <sup>*</sup>	Xe 140 <sup>*</sup>	Xe 141 <sup>*</sup>	Xe 142 <sup>*</sup>	Xe 143 <sup>*</sup>	Xe 144 <sup>*</sup>			
2.28d 0.27d 0.80 0.77 0.77 0.428	2.26d 0.27d 0.80 0.77 0.77 0.428	10.44 17.23 0.016 0.000 0.000	15.7m R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	15.7m R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	3.82m R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	14.2m R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	40s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	13.6s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	12.2s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	9.6s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	9.5s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14			
I 132 <sup>**</sup>	I 133 <sup>**</sup>	I 134 <sup>*</sup>	I 135 <sup>*</sup>	I 136 <sup>*</sup>	I 137 <sup>*</sup>	I 138 <sup>*</sup>	I 139 <sup>*</sup>	I 140 <sup>*</sup>	I 141 <sup>*</sup>	I 142 <sup>*</sup>	I 143 <sup>*</sup>	I 144 <sup>*</sup>		
2.28d 0.27d 0.80 0.77 0.77 0.428	2.28d 0.27d 0.80 0.77 0.77 0.428	20.8m R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	22.3m R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	6.7m R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	10.5m R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	22.3s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	6.0s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	20s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	15s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	12.2s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	9.6s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14	9.5s R 1.44m 0.05-0.64 0.7-2.5 2.1-14 2.1-14 2.1-14		
Tel 31 <sup>*</sup>	Tel 32 <sup>*</sup>	Tel 33 <sup>*</sup>	Tel 34 <sup>*</sup>	Tel 35 <sup>*</sup>	Tel 36 <sup>*</sup>									
30h 25.0m R 4.22m 0.211 0.211 0.211 0.211	7.8m R 4.22m 0.211 0.211 0.211 0.211	53m 2.5m R 4.22m 0.211 0.211 0.211 0.211	4.5m R 4.22m 0.211 0.211 0.211 0.211	4.5m R 4.22m 0.211 0.211 0.211 0.211	11s R 4.22m 0.211 0.211 0.211 0.211									
Sb 130 <sup>*</sup>	Sb 131 <sup>*</sup>	Sb 132 <sup>*</sup>	Sb 133 <sup>*</sup>	Sb 134 <sup>*</sup>	Sb 135 <sup>*</sup>									
8m 37m R 4.22m 0.211 0.211 0.211	23.0m R 4.22m 0.211 0.211 0.211	45.1 31m R 4.22m 0.211 0.211 0.211	23.0m R 4.22m 0.211 0.211 0.211	3.8m R 4.22m 0.211 0.211 0.211	11.5s R 4.22m 0.211 0.211 0.211									
Sn 129 <sup>*</sup>	Sn 130 <sup>*</sup>	Sn 131 <sup>*</sup>	Sn 132 <sup>*</sup>	Sn 133 <sup>*</sup>										
~2m 2.5m R 4.22m 0.211	2.6m R 4.22m 0.211	1.3m R 4.22m 0.211	1.0m R 4.22m 0.211	~5s R 4.22m 0.211										

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Cs 121 <sup>*</sup>	Cs 122 <sup>*</sup>	Cs 123 <sup>*</sup>	Cs 124 <sup>*</sup>	Cs 125 <sup>*</sup>	Cs 126 <sup>*</sup>	Cs 127 <sup>*</sup>	Cs 128 <sup>*</sup>	Cs 129 <sup>*</sup>	Cs 130 <sup>*</sup>	Cs 131 <sup>*</sup>	Cs 132 <sup>*</sup>	Cs 133 <sup>*</sup>
~m	0.5s	5.6m										
Xe 120 <sup>*</sup>	Xe 121 <sup>*</sup>	Xe 122 <sup>*</sup>	Xe 123 <sup>*</sup>	Xe 124 <sup>*</sup>	Xe 125 <sup>*</sup>	Xe 126 <sup>*</sup>	Xe 127 <sup>*</sup>	Xe 128 <sup>*</sup>	Xe 129 <sup>*</sup>	Xe 130 <sup>*</sup>	Xe 131 <sup>*</sup>	Xe 132 <sup>*</sup>
4.0m	3.9m	10.0m	2.0h	0.096	5.7s	7h	0.090	7.3s	36.41d	8d	26.44	4.08
I 119 <sup>*</sup>	I 120 <sup>*</sup>	I 121 <sup>*</sup>	I 122 <sup>*</sup>	I 123 <sup>*</sup>	I 124 <sup>*</sup>	I 125 <sup>*</sup>	I 126 <sup>*</sup>	I 127 <sup>*</sup>	I 128 <sup>*</sup>	I 129 <sup>*</sup>	I 130 <sup>*</sup>	I 131 <sup>*</sup>
~m	~m	1.5m	1.5m	3.5m	13.1h	4.17d	5.97d	13.0d	1.92	1.92	4.08	4.08
Te 118 <sup>*</sup>	Te 119 <sup>*</sup>	Te 120 <sup>*</sup>	Te 121 <sup>*</sup>	Te 122 <sup>*</sup>	Te 123 <sup>*</sup>	Te 124 <sup>*</sup>	Te 125 <sup>*</sup>	Te 126 <sup>*</sup>	Te 127 <sup>*</sup>	Te 128 <sup>*</sup>	Te 129 <sup>*</sup>	Te 130 <sup>*</sup>
6.0d	6.0d	0.089	0.089	2.46	11.0d	0.87	4.61	10.9d	31.79	31.79	34.48	34.48
St 117 <sup>*</sup>	St 118 <sup>*</sup>	St 119 <sup>*</sup>	St 120 <sup>*</sup>	St 121 <sup>*</sup>	St 122 <sup>*</sup>	St 123 <sup>*</sup>	St 124 <sup>*</sup>	St 125 <sup>*</sup>	St 126 <sup>*</sup>	St 127 <sup>*</sup>	St 128 <sup>*</sup>	St 129 <sup>*</sup>
~H	~H	~H	5.6d 16.0m	5.725	4.2m 2.74d	42.75	20.3m 60.2d	2.75	19.0m 12.4d	3.80d	10.4m 9.0h	4.34h
Sn 116 <sup>*</sup>	Sn 117 <sup>*</sup>	Sn 118 <sup>*</sup>	Sn 119 <sup>*</sup>	Sn 120 <sup>*</sup>	Sn 121 <sup>*</sup>	Sn 122 <sup>*</sup>	Sn 123 <sup>*</sup>	Sn 124 <sup>*</sup>	Sn 125 <sup>*</sup>	Sn 126 <sup>*</sup>	Sn 127 <sup>*</sup>	Sn 128 <sup>*</sup>
14.30	14.20	2.76	24.03	32.85	~7.5y 26.2h	4.72	40.3m 29.6d	5.94	~6.6m 9.0h	4.2m 12.2h	5.9m	5.9m
In 115 <sup>*</sup>	In 116 <sup>*</sup>	In 117 <sup>*</sup>	In 118 <sup>*</sup>	In 119 <sup>*</sup>	In 120 <sup>*</sup>	In 121 <sup>*</sup>	In 122 <sup>*</sup>	In 123 <sup>*</sup>	In 124 <sup>*</sup>	In 125 <sup>*</sup>	In 126 <sup>*</sup>	In 127 <sup>*</sup>
14.30	14.20	2.76	4.4m 4.5m	8.5s	3.2m 4.8s	3.2m 4.8s	3.2m 5.0s	4.72	4.72	4.72	4.72	4.72
Cd 114 <sup>*</sup>	Cd 115 <sup>*</sup>	Cd 116 <sup>*</sup>	Cd 117 <sup>*</sup>	Cd 118 <sup>*</sup>	Cd 119 <sup>*</sup>	Cd 120 <sup>*</sup>	Cd 121 <sup>*</sup>	Cd 122 <sup>*</sup>	Cd 123 <sup>*</sup>	Cd 124 <sup>*</sup>	Cd 125 <sup>*</sup>	Cd 126 <sup>*</sup>
28.86	44.11 35.5h	7.58	3.2h 2.5h	4.9m	2.7m 1.0m	1.15	1.15	1.15	1.15	1.15	1.15	1.15

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Pm 149 <sup>+</sup> 53h $\mu$ 107.78 + 28.45 - 11.50 + 1.07	Pm 150 <sup>+</sup> 268h $\mu$ 251.14-1.51 + 33.17-33.83 - 7.41-7.11 + 1.91	Pm 151 <sup>3/2</sup> 284h $\mu$ 252.4-17 + 340.02-96 - 7.19-7.00	Pm 152 <sup>+</sup> 42m $\mu$ 22.34 + 122.245 - 125.10	Pm 153 <sup>+</sup> 4.2m $\mu$ -1.65 + 1.0	Pm 154 <sup>+</sup> 5.5m $\mu$ -2.25 + 1.0			
Nd 148 <sup>+</sup> 5.73 $\mu$ 28 + 147.8100	Nd 149 <sup>+</sup> 8.42-1.02-11.5 + 9.28 - 1.40-24.05-65 + 1.17	Nd 150 <sup>+</sup> 5.62 $\mu$ 13 + 149.9208	Nd 151 <sup>+</sup> 12.4m $\mu$ 7.1 + 118.256.09 - 2.2 + 2.4	Nd 152 <sup>+</sup> 11.7m $\mu$ 2.4				96
Pr 147 <sup>+</sup> 12m $\mu$ 2.045- + 0.78-1.5 - 2.27	Pr 148 <sup>+</sup> 2.0m $\mu$ 4.2 + .30 - 6.65	Pr 149 <sup>+</sup> 2.3m $\mu$ 2.822 + 1.14-16.74 - 2.9					94	
Ce 146 <sup>+</sup> 14.2m $\mu$ 8.73 + 51.023-503 - 1.1	Ce 147 <sup>+</sup> 7.0s $\mu$ -	Ce 148 <sup>+</sup> ~ 43s $\mu$ -						
Ba 144 <sup>+</sup> 11.9s $\mu$ -								
Cs 143 <sup>+</sup> 1.7s $\mu$ -	Cs 144 <sup>+</sup> 1.1s $\mu$ -							92

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		Tm153 158s a.s.	Tm154 298s 5s 2504 a.496							Tm161 30m t.046 373	Tm162 79m 22m 1.8 7.24 8.23 10.9 10.4 24.2 32.2 1.80 1.49 1.22	Tm163 19m 1.8 8.23 8.24 10.4 24.2 32.2 8.23 8.24 1.80	Tm164 19m 1.8 8.23 8.24 10.4 24.2 32.2 8.23 8.24 1.80		
69	Tm168 934 a.s.	Er152 11s a.480 8s	Er153 16s a.467 8s	Er154 5m a.419	Er155 53m a.419	Er156 4m a.419	Er157 24m a.419	Er158 24m a.419	Er159 36m a.419	Er160 29m a.419	Er161 31m a.419	Er162 31m a.136	Er163 75m a.419		
68	Er 167.26 7.16s	Ho150 42s a.461 8s	Ho151 36s a.461 8s	Ho152 52s 2m a.445 8s	Ho153 65m 9.3m a.400 8s	Ho154 32.5m 8m a.355 8s	Ho155 21.6m 4.7m a.355 8s	Ho156 23m a.355	Ho157 15m a.355	Ho158 23m a.355	Ho159 23m a.355	Ho160 23m a.355	Ho161 23m a.160		
67	Ho 164.930 7.16s	Ho150 42s a.461 8s	Ho151 36s a.461 8s	Ho152 52s 2m a.445 8s	Ho153 65m 9.3m a.400 8s	Ho154 32.5m 8m a.355 8s	Ho155 21.6m 4.7m a.355 8s	Ho156 23m a.355	Ho157 15m a.355	Ho158 23m a.355	Ho159 23m a.355	Ho160 23m a.355	Ho161 23m a.160		
		82	84	86	88	90				92		94			
		67	Ho 164.930 7.16s	Ho150 20s a.461 8s	Ho151 42s a.461 8s	Ho152 52s 2m a.445 8s	Ho153 65m 9.3m a.400 8s	Ho154 32.5m 8m a.355 8s	Ho155 21.6m 4.7m a.355 8s	Ho156 23m a.355	Ho157 15m a.355	Ho158 23m a.355	Ho159 23m a.355		
		66	Dy 162.50 7.16s		Dy149 ~15m a.419	Dy150 7.1m a.419	Dy151 8m a.419	Dy152 3.8h a.419	Dy153 3h a.419	Dy154 ~10s a.419	Dy155 3h a.419	Dy156 3h a.419	Dy157 3h a.419		
		65	Tb 158.924 7.16s		Tb147 40m 24m a.419	Tb148 70m a.419	Tb149 41m 17m a.419	Tb150 31m a.419	Tb151 21m a.419	Tb152 4m 1.8h a.419	Tb153 4.1h 4.1h a.419	Tb154 4.1h 4.1h a.419	Tb155 4.1h 4.1h a.419		
		64	Gd 157.25 7.16s		Gd145 22.9m a.419	Gd146 22.9m a.419	Gd147 22.9m a.419	Gd148 9.5s a.419	Gd149 9.5s a.419	Gd150 18.80s a.419	Gd151 120d a.20	Gd152 0.20 a.419	Gd153 215 a.419		
		63	Eu 151.96 7.16s	Eu142 2.8m a.419	Eu143 2.8m a.419	Eu144 10s a.419	Eu145 5.96s a.419	Eu146 4.6d a.419	Eu147 24.3s a.419	Eu148 54.5s a.419	Eu149 14.9s a.419	Eu150 60.8s a.419	Eu151 47.82s a.419	Eu152 47.82s a.419	
		62	Sm 150.35 7.16s	Sm140 14m a.419	Sm141 2.8m a.419	Sm142 22.5m a.419	Sm143 6.3s 8.83s a.419	Sm144 3.09s a.419	Sm145 34.0d a.419	Sm146 0.10s a.419	Sm147 14.9s a.419	Sm148 11.24s a.419	Sm149 13.83s a.419	Sm150 7.44s a.419	
		61	Pm 151.96 7.16s	Pm139 5.8m a.419	Pm140 5.8m a.419	Pm141 10.9m a.419	Pm142 3.5s a.419	Pm143 26.5d a.419	Pm144 3.63d a.419	Pm145 18y a.419	Pm146 15.5s a.419	Pm147 17.45s a.419	Pm148 2.6234s a.419	Pm149 53.1h a.419	Pm150 2.66h a.419
		78	80	82	84	86				88		90			

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Os 187- 23.15.1 1.64 T.O.157	Os 188 13.3	W Os 189 5.9h 16.1 49m 15.15.1 1.64 T.O.157	Os 190 26.4 15.6h 15.15.1 1.64 T.O.157	Os 191 15.6d 15.15.1 1.64 T.O.157	Os 192 41.0 11h 2.0	Os 193 11h 6.0y 1.461 54.574 281 105.104 T.O.157	Os 194 6.0y 1.461 54.574 281 105.104 T.O.157	Os 195 6.5m 1.043		
Re 186(1) 70.45. 9.17 10.13. 1.15. 1.37. 1.17. 4.16. 1.12. 1.2. 7.21. E.0025	Re 187 62.93 1.10.7 1.10.7 1.10.7 E.0025	Re 188 18.6m 6.8m 1.10.2. 2.13. 3.6. 3.6. 1.6. 1.6. 0.92. E.2.13.	Re 189 15.6d 1.10.2. 2.13. 3.6. 3.6. 1.6. 1.6. 0.92. E.2.13.	Re 190 1.7.8m 3.3m 1.10.5. 1.17. 0.91. 0.91. 0.91. 0.91. 1.10.	Re 191	Re 192 6.5 2.5 2.0 - 5.7				
W185 1.6m 7.5c 1.13. 1.42. 1.75. 1.22. 0.62. 0.52. 1.00. 1.42.3	W186 28.41 1.13. 1.42. 0.36	W187 23.9h 1.13. 1.42.11 1.606. 134.016 0.64	W188 8.9d 1.13. 1.42.11 1.290. 227. 0.64	W189 11.1m 1.20.2.5 1.35. 4.7. 0.94. 0.95						
Ta 184 8.7h 1.19.14. 1.42. 1.33. 0.12. 1.18. 0.69. 1.12. 1.23	Ta 185 1.75. 1.15. 0.073. 1.24	Ta 186 10.6m 1.21. 2.56 1.10. 1.10. 0.90. 0.95								
Hf 183 9.1d 6.51. 1.19. 1.12. 2.2. 1.05. 1.14. 1.93.										
112	114	116	118	120	122					

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Tl 201	Tl 202	Tl 203 <sup>m</sup>	Tl 204 <sup>m</sup>	Tl 205 <sup>m</sup>	Tl 206	Tl 207 <sup>m</sup>	Tl 208 <sup>m</sup>	Tl 209 <sup>m</sup>	Tl 210		
19ms 1.5m 1.2m 1.1m 1.0m 0.9m 0.8m 0.7m 0.6m 0.5m 0.4m 0.3m 0.2m 0.1m 0.05m	73h 0.58m 0.2d 0.1d 0.05d	29.50 62μs 3.00y 0.410	29.50 62μs 3.00y 0.410	70.50 0.410 0.21m 0.17	70.50 0.410 0.21m 0.17	70.50 0.410 0.21m 0.17	70.50 0.410 0.21m 0.17	70.50 0.410 0.21m 0.17	70.50 0.410 0.21m 0.17		
Hg 200	Hg 201 <sup>m</sup>	Hg 202	Hg 203 <sup>m</sup>	Hg 204	Hg 205 <sup>m</sup>	Hg 206	Hg 207 <sup>m</sup>	Hg 208 <sup>m</sup>	Hg 209 <sup>m</sup>	Hg 210	
23.13 9.80	94.43 13.22 11.53 10.40	23.80 21.46 19.88	46.60 13.56 12.19	6.85 5.5m 2.00	6.85 5.5m 2.00	6.2m 3.05					
Au 199 <sup>m</sup>	Au 200	Au 201	Au 202	Au 203	Au 204						
44ms 3.15d 1.75d 1.43d 1.13d 0.94d 0.74d 0.54d 0.34d 0.14d	19.49 14.84m 11.72 8.53 7.22 6.12	26m 0.35 0.32 0.29 0.26 0.23	26m 0.35 0.32 0.29 0.26 0.23	55s 0.35 0.32 0.29 0.26 0.23	4.43 0.43 0.43						
Pt 198	Pt 199 <sup>m</sup>	Pt 200	Pt 201								
7.21 2.76m + 4.01	14.1s 17.95s 17.7 10.32s 16.7 14.3.05s 1.29	31m 0.22 0.16 0.16	12h 0.25 0.16	2.5m 0.16 0.16							
Ir 197											
7m 2.01s 1.10 1.20											

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Tl 19	Tl 190	Tl 192 <sup>m</sup>	Tl 193 <sup>m</sup>	Tl 194	Tl 195 <sup>m</sup>	Tl 196 <sup>m</sup>	Tl 197 <sup>m</sup>	Tl 198 <sup>m</sup>	Tl 199 <sup>m</sup>	Tl 200 <sup>m</sup>	
1.0m e	1.0m e	1.0m e	32m 0.29s	34m 0.30s	1.17s 0.37s	1.17s 0.37s	1.17s 0.37s	1.17s 0.37s	1.17s 0.37s	1.17s 0.37s	
Hg 187	Hg 188	Hg 189	Hg 190	Hg 191	Hg 192	Hg 193 <sup>m</sup>	Hg 194	Hg 195 <sup>m</sup>	Hg 196	Hg 197 <sup>m</sup>	Hg 198 <sup>m</sup>
3m 0.40 0.31d	3m 0.42	8.7m 0.29-1.20	20m 0.29-1.20	56m 0.5h	5h 0.22-157.03s	1.4h 0.22-157.03s	0.40s~1.5s	0.40s~1.5s	0.16s	0.06s	0.02s
Au 186	Au 187	Au 188	Au 189	Au 190	Au 191 <sup>m</sup>	Au 192 <sup>m</sup>	Au 193 <sup>m</sup>	Au 194 <sup>m</sup>	Au 195 <sup>m</sup>	Au 196 <sup>m</sup>	Au 197 <sup>m</sup>
12m 0.14s 0.11s	8m 0.46s	8m 0.27-0.41s	46m 0.27-0.41s	42m 0.27-0.41s	32h 0.27-0.41s	4.7h 0.27-2.49.2s	39h 0.27-10.24s	97h 0.27-10.24s	97h 0.27-10.24s	97h 0.27-10.24s	97h 0.27-10.24s
Pt 185	Pt 186	Pt 187	Pt 188	Pt 189	Pt 190	Pt 191 <sup>m</sup>	Pt 192	Pt 193 <sup>m</sup>	Pt 194	Pt 195 <sup>m</sup>	Pt 196 <sup>m</sup>
11h 0.23s 0.15s	2.5h 0.14s	2.5h 0.14s	10.2d 0.14s	10.2d 0.14s	10.2d 0.14s	10.2d 0.14s	0.78 0.2d-500y	0.78 0.2d-500y	4.1d 0.2d-100y	7.5s 0.2d-100y	10.0s 0.2d-100y
Ir 184	Ir 185	Ir 186	Ir 187	Ir 188	Ir 189	Ir 190	Ir 191 <sup>m</sup>	Ir 192 <sup>m</sup>	Ir 193 <sup>m</sup>	Ir 194 <sup>m</sup>	Ir 195 <sup>m</sup>
32h 0.24-0.24	14h 0.24	14h 0.24	29ms 0.24	11.2h 0.24	4.1h 0.24	4.9h 0.24	3.75s 0.24	11.4m 0.24	12d 0.24	62.7	1.16
Os 183 <sup>m</sup>	Os 184 <sup>m</sup>	Os 185 <sup>m</sup>	Os 186	Os 187 <sup>m</sup>	Os 188	Os 189 <sup>m</sup>	Os 190	Os 191 <sup>m</sup>	Os 192	Os 193	Os 194
3.9h 0.11s	0.01s	9.4d 0.20s	9.4d 0.20s	1.6s 0.07	1.6s 0.07	13.3 0.07	9.9m 0.07	28.4 0.07	41.0	31.0	6.0y

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Rn205 28m	Rn 206 63m	Rn 207 11m	Rn 208 <sup>a</sup> 22m	Rn 209 30m	Rn 210 24h	Rn 211 15h	Rn 212 25m	Rn213 19ms	Rn214 Short	Rn 215 ~1μs	Rn 216 0.5ms
14.26	0.62%	1.61%	2.61%	3.61%	4.60%	5.60%	6.60%	7.60%	8.60%	9.60%	10.60%
204.93	205.19	205.45	205.71	205.97	206.23	206.49	206.75	207.01	207.27	207.53	207.79
A1 204 91m	A1 205 26m	A1 206 27h	A1 207 1.79h	A1 208 62h	A1 209 <sup>b</sup> 5.5h	A1 210 <sup>c</sup> 8.3h	A1 211 <sup>d</sup> 7.2h	A1 212 <sup>e</sup> 0.22s	A1 213 Short	A1 214 ~2μs	A1 215 ~0.76s
6.05%	0.29%	1.5%	2.5%	3.5%	4.5%	5.5%	6.5%	7.5%	8.5%	9.5%	10.5%
1.71	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49
Po 203 80m	Po 204 4.5h	Po 205 <sup>f</sup> 64ms <sup>g</sup>	Po 206 <sup>h</sup> Ind	Po 207 <sup>i</sup> 1.4h	Po 208 1.896y	Po 209 <sup>j</sup> 10.3y	Po 210 Ref 154.04d	Po 211 <sup>k</sup> 2.57s	Po 212 <sup>l</sup> 45s	Po 213 <sup>m</sup> 4.4s	Po 214 <sup>n</sup> 164s
1.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%
1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
B- 202 <sup>o</sup> 95m	Bi 203 <sup>p</sup> 11Bh	Bi 204 <sup>q</sup> 11.3h	Bi 205 <sup>r</sup> 1.53d	Bi 206 <sup>s</sup> 1.68s	Bi 207 <sup>t</sup> 0.77ms	Bi 208 <sup>u</sup> 2.57ms	Bi 209 <sup>v</sup> 100y	Bi 210 <sup>w</sup> 5.01d	Bi 211 <sup>x</sup> 2.14m	Bi 212 <sup>y</sup> 60.60m	Bi 213 <sup>z</sup> 46m
1.42%	1.42%	1.42%	1.42%	1.42%	1.42%	1.42%	1.42%	1.42%	1.42%	1.42%	1.42%
1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42
*Pb201 <sup>aa</sup>	Pb 202 <sup>ab</sup> 3.8h	Pb 203 <sup>ac</sup> 14h	Pb 204 <sup>ad</sup> 1.4h	Pb 205 <sup>ae</sup> 14ms	Pb 206 <sup>af</sup> 1.26ns	Pb 207 <sup>ag</sup> 3.10y	Pb 208 <sup>ah</sup> 523	Pb 209 <sup>ai</sup> 3.31h	Pb 210 <sup>aj</sup> 22y	Pb 211 <sup>ak</sup> 36m	Pb 212 <sup>al</sup> 1064h
6.1%	5.1%	4.1%	3.1%	2.1%	1.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Tl200 <sup>am</sup> 34ms	Tl 201 <sup>an</sup> 20th	Tl 202 <sup>ao</sup> 1.9ms	Tl 202 <sup>ap</sup> 7.3h	Tl 203 <sup>aq</sup> 0.58ms	Tl 204 <sup>ar</sup> 12.2d	Tl 205 <sup>as</sup> 2.95h	Tl 206 <sup>at</sup> 70.50	Tl 207 <sup>au</sup> 4.21m	Tl 208 <sup>av</sup> 4.77m	Tl 209 <sup>aw</sup> 3.06m	Tl 210 <sup>ax</sup> 2.2m
1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Mg204 <sup>ay</sup> 1.4%	Ca205 <sup>az</sup> 1.4%	Ca206 <sup>ba</sup> 1.4%	Ca207 <sup>bb</sup> 1.4%	Ca208 <sup>bc</sup> 1.4%	Ca209 <sup>bd</sup> 1.4%	Ca210 <sup>be</sup> 1.4%	Ca211 <sup>bf</sup> 1.4%	Ca212 <sup>bg</sup> 1.4%	Ca213 <sup>bh</sup> 1.4%	Ca214 <sup>bi</sup> 1.4%	Ca215 <sup>bj</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bk</sup> 1.4%	Eu205 <sup>bl</sup> 1.4%	Eu206 <sup>bm</sup> 1.4%	Eu207 <sup>bn</sup> 1.4%	Eu208 <sup>bo</sup> 1.4%	Eu209 <sup>bp</sup> 1.4%	Eu210 <sup>br</sup> 1.4%	Eu211 <sup>bs</sup> 1.4%	Eu212 <sup>bt</sup> 1.4%	Eu213 <sup>bu</sup> 1.4%	Eu214 <sup>bv</sup> 1.4%	Eu215 <sup>bw</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>bz</sup> 1.4%	Eu207 <sup>ca</sup> 1.4%	Eu208 <sup>cb</sup> 1.4%	Eu209 <sup>cc</sup> 1.4%	Eu210 <sup>cd</sup> 1.4%	Eu211 <sup>ce</sup> 1.4%	Eu212 <sup>cf</sup> 1.4%	Eu213 <sup>cg</sup> 1.4%	Eu214 <sup>ch</sup> 1.4%	Eu215 <sup>ci</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%
1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Eu204 <sup>bx</sup> 1.4%	Eu205 <sup>by</sup> 1.4%	Eu206 <sup>cz</sup> 1.4%	Eu207 <sup>da</sup> 1.4%	Eu208 <sup>db</sup> 1.4%	Eu209 <sup>dc</sup> 1.4%	Eu210 <sup>de</sup> 1.4%	Eu211 <sup>df</sup> 1.4%	Eu212 <sup>dg</sup> 1.4%	Eu213 <sup>dh</sup> 1.4%	Eu214 <sup>di</sup> 1.4%	Eu215 <sup>ej</sup> 1.4%

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86	Rn	Rn200? 3s 3s 3s	Rn201 1s 1s 1s	Rn202 2s 2s 2s	Rn203 2s 2s 2s	Rn204 7s 7s 7s	Rn205 2m 2m 2m	Rn 206 6.3m 6.3m 6.3m	Rn 207 11m 11m 11m	Rn 208 22m 22m 22m	Rn 209 30m 30m 30m	Rn 210 2.4h 2.4h 2.4h	Rn 211 15h 15h 15h
87	Fr	Fr203 0.7s 2.2s 2.2s	Fr 204 3.3s 3.3s 3.3s	Fr 205 3.7s 3.7s 3.7s	Fr 206 15.7s 15.7s 15.7s	Fr 207 15s 15s 15s	Fr 208 38s 38s 38s	Fr 209 54s 54s 54s	Fr 210 3.0m 3.0m 3.0m	Fr 211 3.08m 3.08m 3.08m	Fr 212 19m 19m 19m		
88	Ra	Ra206 0.4s a 7.27	Ra207 1.3s a 7.13	Ra208 1.2s a 7.13	Ra209 4.7s a 7.01	Ra210 3.8s a 7.02	Ra211 1.5s a 6.91	Ra212 1.3s a 6.87	Ra213 1.3s a 6.87	Ra214 8.2s a 7.36			
89	Ac	Ac209 0.1s a 7.58	Ac210 ~0.35s a 7.46	Ac211 ~0.25s a 7.46	Ac212 ~0.93s a 7.38	Ac213 0.8s a 7.36	Ac214 8.2s a 7.36	Ac215 1.2s a 7.36					
90	Th	Th 232.038 a 7.4	Th213 15s a 7.63	Th214 13s a 7.63	Th215 12s a 7.39, 7.52, 7.33								
112	114	116	118	120	122	124							

Pa230	Pa231	Pa232	Pa233	Pa234	Pa235	Pa236	Pa237				
Th229	Th230	Th231	Th232	Th233	Th234	Th235	Th236				
Ac229	Ac229	Ac230	Ac231								
Ra227	Ra228	Ra229	Ra230								
Fr226											
Rn225	Rn226										

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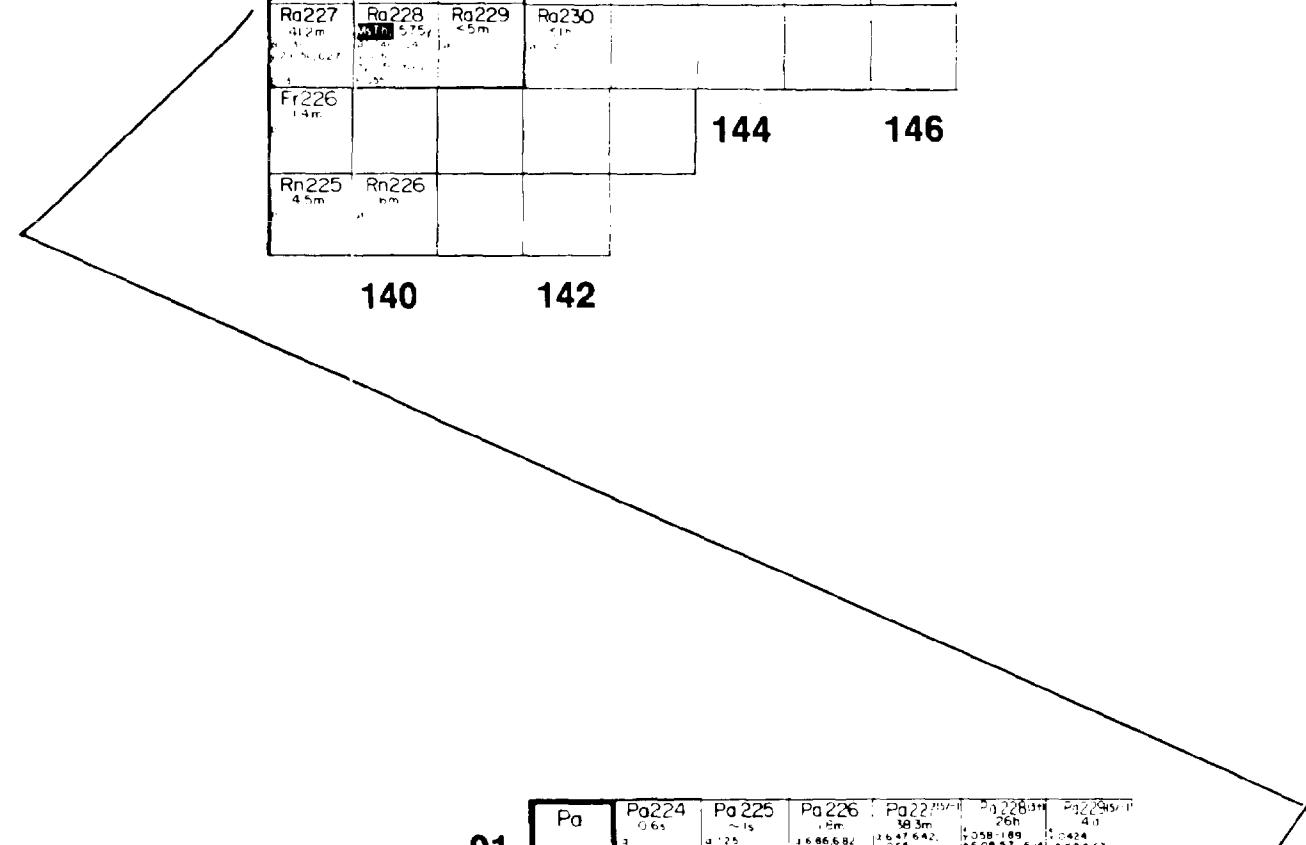
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Th216	Th217		Th220	Th221	Th222	Th223	Th224	Pa	Pa224	Pa225	Pa226	Pa227	Pa228	Pa229	Pa230
Ac215	Ac216		Ac218	Ac219	Ac220	Ac221	Ac222		Pa224	Pa225	Pa226	Pa227	Pa228	Pa229	Pa230
Ra214	Ra215	Ra216	Ra217	Ra218	Ra219	Ra220	Ra221		Th224	Th225	Th226	Th227	Th228	Th229	Th230
Fr213	Fr214	Fr215	Fr216	Fr217	Fr218	Fr219	Fr220		Th225	Th226	Th227	Th228	Th229	Th230	Th231
Rn212	Rn213	Rn214	Rn215	Rn216	Rn217	Rn218	Rn219		Pa225	Pa226	Pa227	Pa228	Pa229	Pa230	Pa231

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## LIST OF ATOMIC ELEMENTS

Actinium	Ac	89	Mercury	Hg	80
Aluminum	Al	13	Molybdenum	Mo	42
Americium	Am	95	Neodymium	Nd	60
Antimony	Sb	51	Neon	Ne	10
Argon	Ar	18	Neptunium	Np	93
Arsenic	As	33	Nickel	Ni	28
Astatine	At	85	Niobium	Nb	41
Barium	Ba	56	Nitrogen	N	7
Berkelium	Bk	97	Nobelium	No	102
Beryllium	Be	4	Osmium	Os	76
Bismuth	Bi	83	Oxygen	O	8
Boron	B	5	Palladium	Pd	46
Bromine	Br	35	Phosphorus	P	15
Cadmium	Cd	48	Platinum	Pt	78
Calcium	Ca	20	Plutonium	Pu	94
Californium	Cf	98	Polonium	Po	84
Carbon	C	6	Potassium	K	19
Cerium	Ce	58	Praseodymium	Pr	59
Cesium	Cs	55	Promethium	Pm	61
Chlorine	Cl	17	Protactinium	Pa	91
Chromium	Cr	24	Radium	Ra	88
Cobalt	Co	27	Radon	Rn	86
Copper	Cu	29	Rhenium	Re	75
Curium	Cm	96	Rhodium	Rh	45
Dysprosium	Dy	66	Rubidium	Rb	37
Einsteinium	Es	99	Ruthenium	Ru	44
Erbium	Er	68	Samarium	Sm	62
Europium	Eu	63	Scandium	Sc	21
Fermium	Fm	100	Selenium	Se	34
Fluorine	F	9	Silicon	Si	14
Francium	Fr	87	Silver	Ag	47
Gadolinium	Gd	64	Sodium	Na	11
Gallium	Ga	31	Strontium	Sr	38
Germanium	Ge	32	Sulfur	S	16
Gold	Au	79	Tantalum	Ta	73
Hafnium	Hf	72	Technetium	Tc	43
Helium	He	2	Tellurium	Te	52
Holmium	Ho	67	Terbium	Tb	65
Hydrogen	H	1	Thallium	Tl	81
Indium	In	49	Thorium	Th	90
Iodine	I	53	Thulium	Tm	69
Iridium	Ir	77	Tin	Sn	50
Iron	Fe	26	Titanium	Ti	22
Krypton	Kr	36	Tungsten	W	74
Lanthanum	La	57	Uranium	U	92
Lawrencium	Lw	103	Vanadium	V	23
Lead	Pb	82	Xenon	Xe	54
Lithium	Li	3	Ytterbium	Yb	70
Lutetium	Lu	71	Yttrium	Y	39
Magnesium	Mg	12	Zinc	Zn	30
Manganese	Mn	25	Zirconium	Zr	40
Mendelevium	Md	101			