APPENDIX C

NUCLIDES AND ISOTOPES

ACCOMPANYING THE CHART OF THE NUCLIDES
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INTRODUCTION

The earliest discussion 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 ν, 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:

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H.$$

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 nucleus)
d	deuteron	α	alpha particle
p	proton	γ	gamma ray
^{3}He	helium-3 nucleus		

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

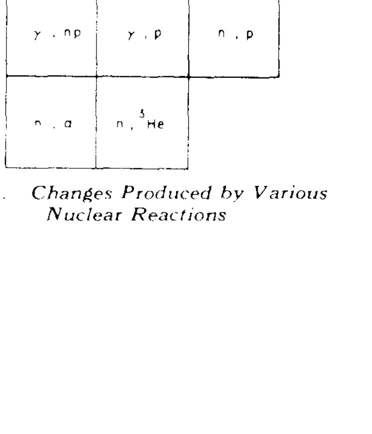


Fig. 1. Changes Produced by Various Nuclear Reactions

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 β^-) 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 ϵ.) 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 σ 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 σ_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^{-24} square centimeters). The most probable reaction (that is, the reaction with the largest cross section) is generally the neutron capture reaction (symbol σ_γ) 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 σ_p, σ_α, and σ_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 σ_γ 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 μb following the cross-section value indicates that the units of the cross section are millibarns per atom ($10^{-27}cm^2$/atom) or mircobarns per atom ($10^{-30}cm^2$/atom), respectively. When no mb or μb 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 h/2π, where h 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 h/2π, the nuclear spin (in units of h/2π) 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 +, 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 h/2π. 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_I, 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.

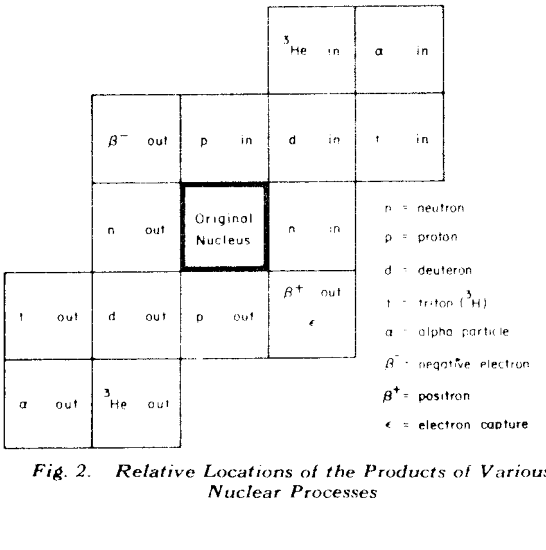


Fig. 2. Relative Locations of the Products of Various Nuclear Processes

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 σ_a .27 mb

Sodium σ_a .534

The atomic weight for praseodymium should read 140.908.

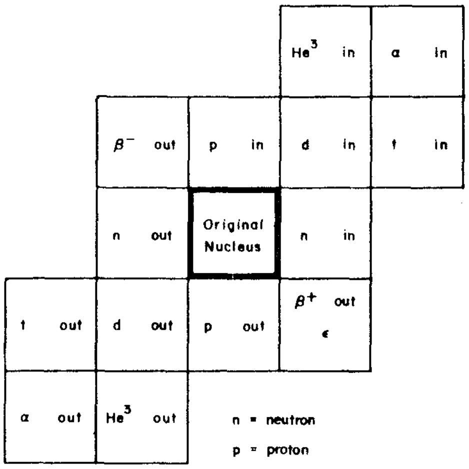
ACKNOWLEDGMENTS

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 Kernphysisch 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

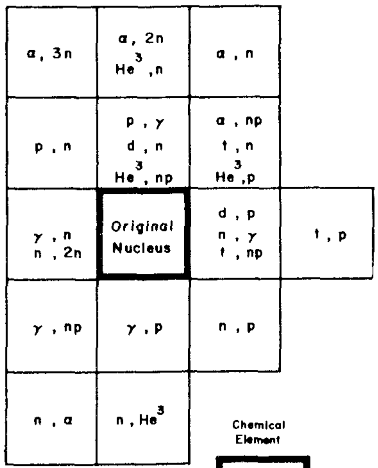
ATOMIC NUMBER	SYMBOL	NAME	ATOMIC WEIGHT	ATOMIC NUMBER	SYMBOL	NAME	ATOMIC WEIGHT
0	n	neutron	......	52	Te	tellurium	127.60
1	H	hydrogen	1.00797	53	I	iodine	126.9044
2	He	helium	4.0026	54	Xe	xenon	131.30
3	Li	lithium	6.940	55	Cs	cesium	132.905
4	Be	beryllium	9.0122	56	Ba	barium	137.34
5	B	boron	10.811	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	europium	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	......

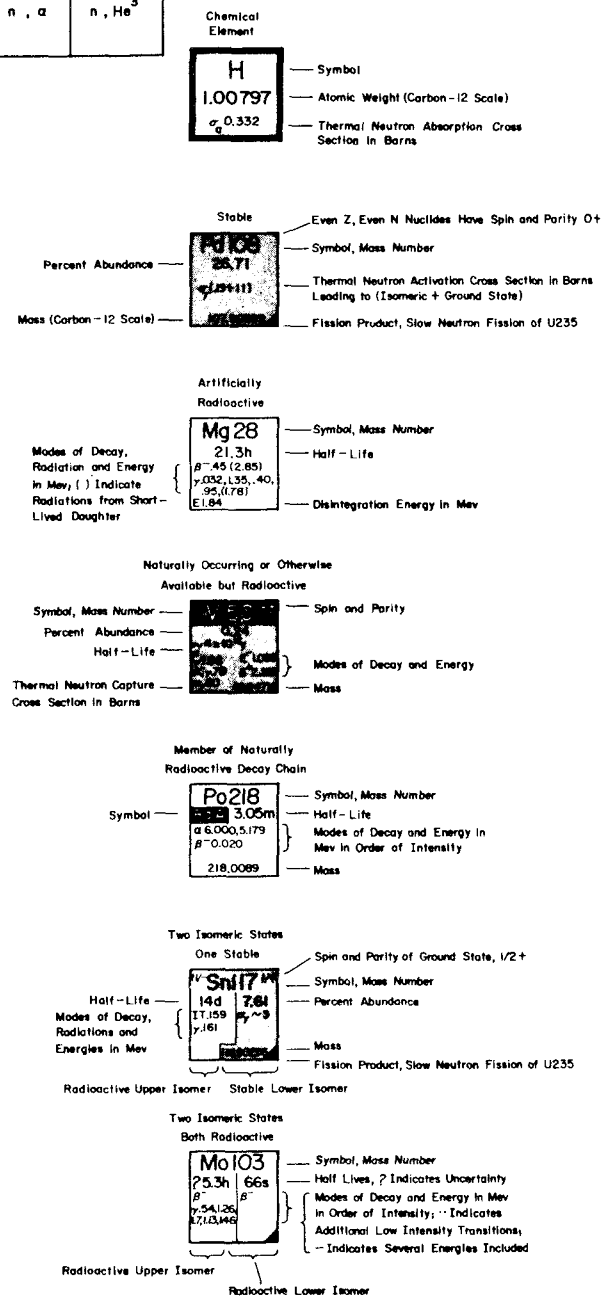
Relative Locations of the Products of Various Nuclear Processes



n = neutron
p = proton
d = deuteron
t = triton (H^3)
α = alpha particle
β^- = negative electron
β^+ = positron
ε = electron capture

Displacements Caused by Nuclear Bombardment Reactions





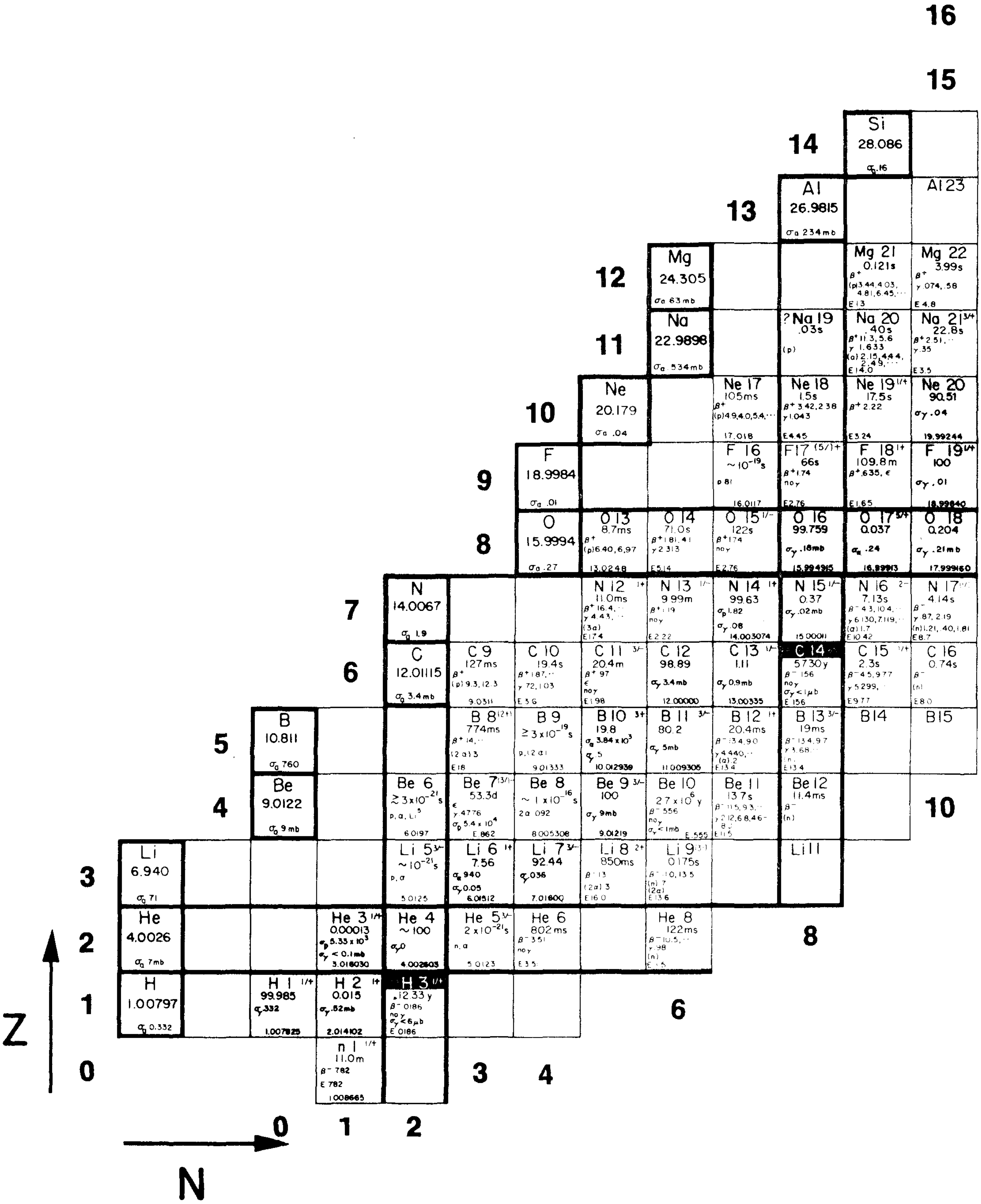
SYMBOLS

RADIATIONS AND DECAY

α	alpha particle
β^-	negative electron
β^+	positron
γ	gamma ray
n	neutron
p	proton
ε	electron capture
IT	isomeric transition
D	radiation delayed
SF	spontaneous fission
E	disintegration energy
e^-	conversion electron

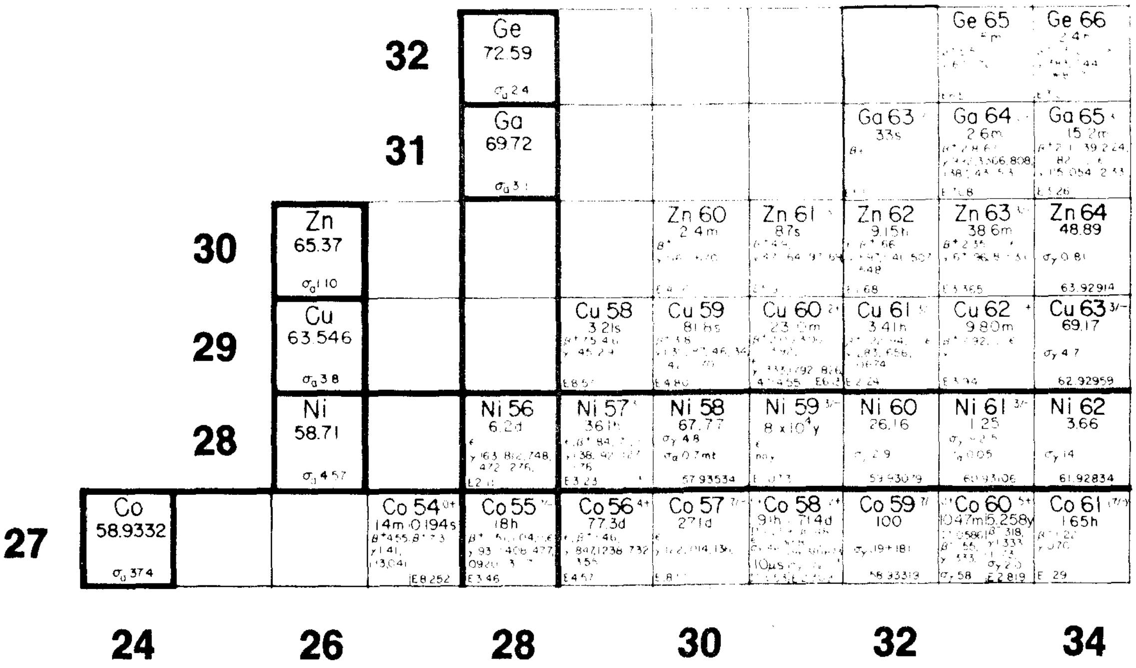
TIME

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



Z
N
H 1.00797
He 4.0026
Li 6.940
Be 9.0122
B 10.811
C 12.01115
N 14.0067
O 15.9994
F 18.9984
Ne 20.179
Na 22.9898
Mg 24.305
Al 26.9815
Si 28.086
n 1 11.0m
H 1 99.985
H 2 0.015
H 3 12.33 y
He 3 0.00013
He 4 ~100
He 5 2 x10⁻²¹s
He 6 802 ms
He 8 122ms
Li 5 ~10⁻²¹s
Li 6 7.56
Li 7 92.44
Li 8 850ms
Li 9 0.175s
Li 11
Be 6
Be 7 53.3d
Be 8
Be 9 100
Be 10
Be 11 13.7s
Be 12 11.4ms
B 8 774ms
B 9
B 10 19.8
B 11 80.2
B 12 20.4ms
B 13 19ms
B14
B15
C 9 127ms
C 10 19.4s
C 11 20.4m
C 12 98.89
C 13 1.11
C 14 5730 y
C 15 2.3s
C 16 0.74s
N 12 11.0ms
N 13 9.99m
N 14 99.63
N 15 0.37
N 16 7.13s
N 17 4.14s
O 13 8.7ms
O 14 71.0s
O 15 122s
O 16 99.759
O 17 0.037
O 18 0.204
F 16
F17 66s
F 18 109.8 m
F 19 100
Ne 17 105ms
Ne 18 1.5s
Ne 19 17.5s
Ne 20 90.51
?Na 19 .03s
Na 20 .40s
Na 21 22.8s
Mg 21 0.121s
Mg 22 3.99s
Al 23

	17	Cl 35.453 σα 33.3		Cl 32 1+ 297ms β+ 9.47,4.7,· γ2.23,4.77,2.46,· (α) (p) E 12.8	Cl 33 3/+ 2.52s β+ 4.5 γ2.93 E 5.6	3+ Cl 34 0+ 32.2m ; 1.58s IT .146 ; β+ 4.5 β+ 2.5, 1.3, γ2.13, 3.30, 1.18,6.4–4 ; E 5.48	Cl 35 3/+ 75.77 σγ 43 σp .45, σα 0.1mb 34.96885	Cl 36 2+ 3.07x10^5 y β− .709, ε, β+ .12 no γ σγ <.10 E− .71 E+ 1.14	Cl 37 3/+ 24.23 σγ(.005+.43) 36.96590	Cl 38 2− 0.8s ; 37.2m IT .66 ; β− 4.91, 1.1, 2.8 γ2.167, 1.642,· E 4.92	Cl 39 3/+ 55.5m β− 1.91, 2.18, 3.44 γ1.27, .25, 1.52 E 3.44	Cl 40 (2−) 0.10s ; 1.42m β− ~3.2,~7.5, γ1.46, 3.3–5.9 E~8		
S 32.064 σα .52		S 29 0.19s β+ γ (p)5.59,3.86,3.60,· E 14	S 30 1.3s β+ 4.42, 5.08 γ .677 E 6.1	S 31 1/+ 2.64s β+ 4.4 γ1.27 E 5.4	S 32 95.0 σα .4mb σγ .53 31.97207	S 33 3/+ 0.76 σp 2mb σγ .02 σα .16 32.97146	S 34 4.22 σγ .22 33.96786	S 35 3/+ 87.2d β− .167 no γ E .167	S 36 0.014 σγ .14 35.9671	S 37 (7/)− 5.06m β− 1.64, 4.75, 1.04 γ3.11, 3.71 E 4.8	S 38 2.87h β− 1.1,··(4.91,··) γ1.88(2.167, 1.642,) E 3		24	
P 30.9738 σα .19		P 28 3+ 270ms β+ 11.5,··· γ1.780, 4.499, 2.84–7.50 E 14.3	P 29 1/+ 4.23s β+ 3.95, γ1.28, 2.43 E 4.9	P 30 1+ 2.50m β+ 3.24, γ2.23 E 4.2	P 31 1/+ 100 σγ .19 30.97376	P 32 1+ 14.31d β− 1.709 no γ E 1.71	P 33 (1/)+ 25.2d β− .248 no γ E .25	P 34 1+ 12.4s β− 5.1, 3.2,·· γ2.1, 4.0 E 5						
Si 25 0.22 s β+ (p)4.25, 1.95, 3.47, .82–5.90	Si 26 2.1s β+ 3.83,· γ .825 E 5.1	Si 27 5/+ 4.20s β+ 3.8,··· γ2.21 E 4.81	Si 28 92.21 σγ .16 27.97693	Si 29 1/+ 4.70 σγ .3 28.97650	Si 30 3.09 σγ .10 29.97376	Si 31 3/+ 2.62h β− 1.48,·· γ1.27 σγ ~.11 E 1.48	Si 32 ~650y β− .21(1.71) no γ E .21				22			
Al 24 4+ 0.129s ; 2.09s IT .44 ; β+ 4.4, β+ 3.3, 11.3, 8.76, 8, 9.0 ; γ1.37, 7.1 γ1.37, 2.75, (α)~2 E 4.4 ; E 14.0	Al 25 5/+ 7.23s β+ 3.24,· γ1.6,· E 4.26	0+ Al 26 5+ 6.4s ; 7.4x10^5 y β+ 3.21 ; β+ 1.16, ε no γ ; γ1.81, 1.12,· E 4.00	Al 27 5/+ 100 σγ 234mb 26.98154	Al 28 2.27m β− 2.85 γ1.779 E 4.63	Al 29 5/+ 6.52m β− 2.5, 1.4 γ1.28, 2.43 E 3.7	Al 30 7.3s ; 3.3s IT? ; β5.05,·· γ2.24, 3.52 ; γ2.24, 3.52 E 7.	18		20					
Mg 23 3/+ 12s β+ 3.1, γ .44 E 4.06	Mg 24 78.99 σγ .05 23.98504	Mg 25 5/+ 10.00 σγ .2 24.98584	Mg 26 11.01 σγ .03 25.98259	Mg 27 1/+ 9.5m β− 1.76, 1.59 γ .844, 1.015, .175 σγ <.04 E 2.61	Mg 28 21.3h β− .45, (2.85) γ .032, 1.35, .40, .95, (1.78) E 1.84									
Na 22 3+ 2.602y β+ .546, ε γ 1.2745 σγ 4x10^4 E 2.84	Na 23 3/+ 100 σγ(.40+.13) 22.98977	(1+) Na 24 4+ 19.9ms ; 15.00h IT .472 ; β− 1.39,·· γ2.75, 1.37,·· E 5.51	Na 25 5/+ 59s β− 3.8, 2.8, γ .98, .58, .40, 1.61,·· E 3.8	Na 26 1.04s β− 6.7, γ1.809,·· E 9.	Na 27									
Ne 21 3/+ 0.266 20.99386	Ne 22 9.22 σγ .04 21.99138	Ne 23 (5/)+ 37.6s β− 4.38, 3.95, γ .44, 1.64,··· E 4.38	Ne 24 3.38m β− 1.98, 1.10 γ .472, .88 E 2.5		16									
F 20 2+ 11.2s β− 5.4 γ1.633,... E 7.03	F 21 4.36s β− 5.4, 4.0,·· γ .35, 1.38 E 5.7	F 22 4.0s β− 9.1, 11.2 γ1.28, 2.06 E 12.5	14											
O 19 5/+ 26.8s β− 3.25, 4.6 γ .20, 1.36,· E 4.82	O 20 14s β− 2.7 γ1.06 E 3.8	O 21												
N 18 0.63s β− 9.4 γ1.98, 1.65, .82, 2.47 E 13.9	N 19													
C 17	12													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27
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Ga 69.72
Zn 65.37
Cu 63.546
Ni 58.71
Co 58.9332
Ge 65
Ge 66
Ga 63 33s
Ga 64 2.6m
Ga 65 15.2m
Zn 60 2.4m
Zn 61 87s
Zn 62 9.15h
Zn 63 38.6m
Zn 64 48.89
Cu 58 3.21s
Cu 59 81.6s
Cu 60 23.2m
Cu 61 3.41h
Cu 62 9.80m
Cu 63 69.17
Ni 56 6.2d
Ni 57 36h
Ni 58 67.77
Ni 59 8 x 10^4 y
Ni 60 26.16
Ni 61 1.25
Ni 62 3.66
Co 54 14m 0.194s
Co 55 18h
Co 56 77.3d
Co 57 271d
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Co 59 100
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Co 61 1.65h
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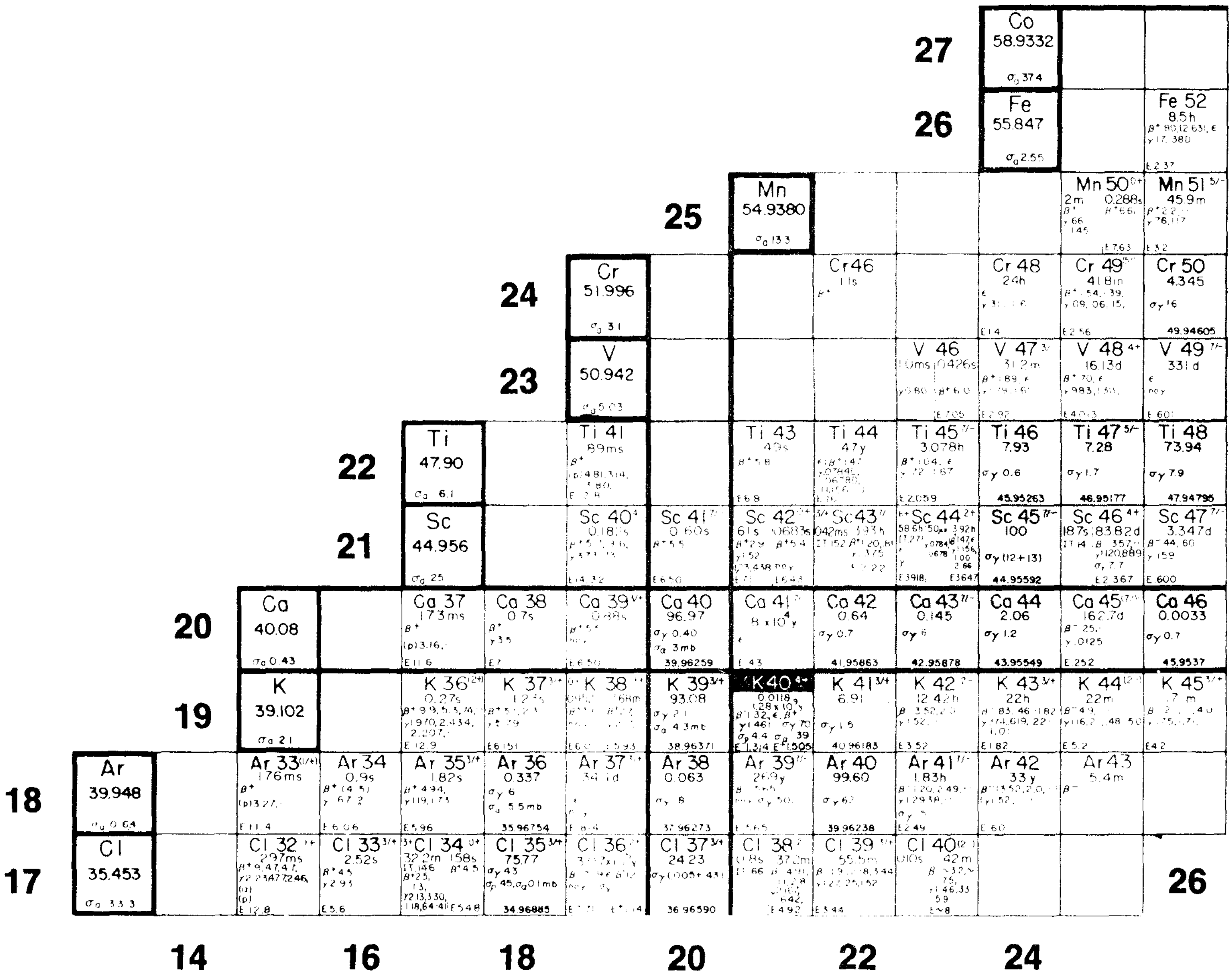
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Co 58.9332
Fe 55.847
Fe 52 8.5h
Mn 54.9380
Mn 50 2m 0.288s
Mn 51 45.9m
Cr 51.996
Cr 46 1.1s
Cr 48 24h
Cr 49 41.8m
Cr 50 4.345
V 50.942
V 46 10ms 0.426s
V 47 31.2m
V 48 16.13d
V 49 331d
Ti 47.90
Ti 41 89ms
Ti 43 0.5s
Ti 44 47y
Ti 45 3.078h
Ti 46 7.93
Ti 47 7.28
Ti 48 73.94
Sc 44.956
Sc 40 0.18s
Sc 41 0.60s
Sc 42 61s 0.683s
Sc 43
Sc 44
Sc 45 100
Sc 46 18.7s 83.82d
Sc 47 3.347d
Ca 40.08
Ca 37 173ms
Ca 38 0.7s
Ca 39 0.88s
Ca 40 96.97
Ca 41 8 x 10^4 y
Ca 42 0.64
Ca 43 0.145
Ca 44 2.06
Ca 45 162.7d
Ca 46 0.0033
K 39.102
K 36 0.27s
K 37 1.2s
K 38
K 39 93.08
K 40
K 41 6.91
K 42 12.42h
K 43 22h
K 44 22m
K 45
Ar 39.948
Ar 33 176ms
Ar 34 0.9s
Ar 35 1.82s
Ar 36 0.337
Ar 37 34.1d
Ar 38 0.063
Ar 39 269y
Ar 40 99.60
Ar 41 1.83h
Ar 42 33y
Ar 43 5.4m
Cl 35.453
Cl 32 297ms
Cl 33 2.52s
Cl 34 32.2m 1.58s
Cl 35 75.77
Cl 36
Cl 37 24.23
Cl 38 37.3m
Cl 39 55.5m
Cl 40 1.4m
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14
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18
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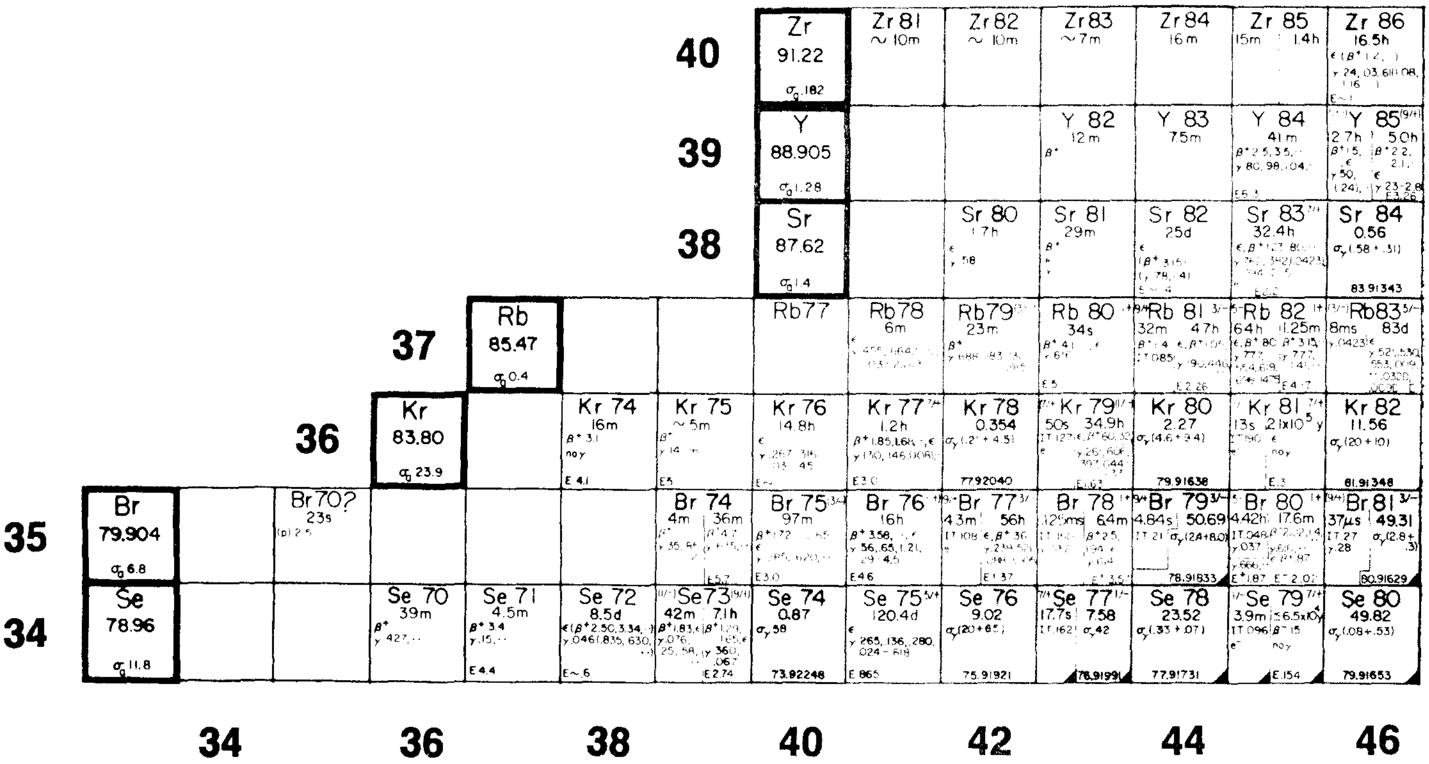
24

Ge 67 19.0m β⁺3.1, 2.3, ..., ε γ 17, .34 - 3.4 E 4.4	Ge 68 287d ε γ (1.077...) E ~.5	Ge 69 5/- 51μs | 39.2h γ .085 | ε, β⁺1.21, .63, ... γ 1.107, .574, .872, .235 - 2.04 E 2.227	Ge 70 20.5 σγ (.3+3.0) 69.92425	Ge 71 1/- 200ms | 11d IT .023 | ε γ .175 | no γ E .235	Ge 72 27.4 σγ 1.1 71.92208	Ge 73 9/+ 40μs | 7.8 IT .0135 53s | σγ 16 IT .0533 γ .0135 72.92346	Ge 74 36.5 σγ (.15+.31) 73.92118	Ge 75 (1/-) 46s | 82.8m IT .139 e⁻ | β⁻1.20, .92, ... γ .265, .066 - .618 E 1.20	Ge 76 7.8 σγ (.10+.05) 75.92141	Ge 77 (7/+) 55s | 11.30h β⁻2.9, 2.7, ... | β⁻2.2, 1.6, 2.3, 1.2, ... γ .215, IT .159 | γ .264, .211, .416, .12 - 2.34 E 2.95 | E 2.79	Ge 78 1.45h β⁻.70 γ .278, .294 E .98	Ge 79 < 1m β⁻
Ga 66 (0+) 9.5h β⁺4.153, ... ε γ 1.039, 2.752, .834 - 4.806 E 5.175	Ga 67 3/- 78.2h ε γ .09330, .185, .300, .0913 - .888 E 1.000	Ga 68 1+ 68.2m β⁺1.90, ... ε γ 1.077, ... .578 - 2.34 E 2.920	Ga 69 3/- 60.16 σγ 1.9 68.92557	Ga 70 1+ 21.1m β⁻1.66, ... γ 1.040, .173 E 1.66, E⁺.654	Ga 71 3/- 39.84 σγ (.2+4.8) 70.92471	Ga 72 3- 37ms | 14.1h IT .100 | β⁻.97, ... E 4.10 | .166 - 3.16 γ .835, 2.20, .630, .290 - 3.34 E 4.00	Ga 73 (3/-) 4.8h β⁻1.19, ... γ .296, .325, .742, (.0533, .0135) E 1.55	Ga 74 7.9m β⁻2.6, 4.3 γ .596, 2.35, .38 - 3.6 E 5.5	Ga 75 1.9m β⁻3.3 γ .58, .36 E 3.3	Ga 76 (3-) 32s β⁻~6 γ .56, 1.12, ... E ~7	Ga 77 17s	Ga 78 ~4s
Zn 65 5/- 243.7d ε, β⁺.325 γ 1.115, ... E 1.349	Zn 66 27.81 σγ 1 65.92605	Zn 67 5/- 9.3μs | 4.11 γ .0933 | σγ 6.7 66.92714	Zn 68 18.57 σγ (0.075+0.80) 67.92486	Zn 69 1/- 13.7h | 58m IT .439 | β⁻.93, no γ E .93	Zn 70 0.62 σγ (8.2mb + 86mb) 69.92534	Zn 71 (1/-) 3.97h | 2.4m β⁻1.45 | β⁻2.61, 2.1, ... γ .387, .488, .610, ... | γ .512, ... .12 - 1.48 E 2.95 | E 2.61	Zn 72 46.5h β⁻.30, ... γ .145, .191, .016 - .112 (.100) e⁻ E .46				46	
Cu 64 1+ 12.75h ε | γ 1.348 β⁻.573 β⁺.654 E .573, E⁺1.677	Cu 65 3/- 30.83 σγ 1.9 64.92779	Cu 66 1+ 5.10m β⁻2.63, 1.59, ... γ 1.039, .834 σγ 160 E 2.63	Cu 67 (3/-) 61.6h β⁻.40, .48, .58 γ .185, .090, .0930, ... E .58	Cu 68 (1+) 31s β⁻3.50, 2.26, ... γ 1.08, .81, 1.88, 1.24, ... E 4.6	Cu 69 (3/-) 3.0m β⁻2.66, ... γ 1.007, .898, .17 - 2.03 E 2.66				44			
Ni 63 1/- 92y β⁻.0659 no γ E .0659	Ni 64 1.16 σγ 1.7 63.92796	Ni 65 5/- 2.55h β⁻2.14, .610, ... γ 1.481, 1.115, .366, ... σγ 20 E 2.14	Ni 66 54.6h β⁻.20 no γ E .20	Ni 67 50s β⁻4.1, 2.3, 3.2 γ .90, .89, 1.26 E 4.1								
Co 62 1.6m | 13.9m β⁻ | β⁻.88, .88 γ | γ 1.17, .147, 1.74, 2.03, ... E 5.22	Co 63 52s β⁻3.6 γ .088 ? E 3.6	Co 64 (1+) 28s | < 28s γ .095 | β⁻~3.5					42					
	36		38		40							

Co 54 0+ 1.4m | 0.194s β⁺4.55 | β⁺7.3 γ 1.41, ... 3.04, ... E 8.252	Co 55 7/- 18h β⁺1.51, 1.04, ... ε γ .931, 1.408, .477, .0920 - 3.17 E 3.46	Co 56 4+ 77.3d ε, β⁺1.46, ... γ .847, 1.238, .732 - 3.55 E 4.57	Co 57 7/- 271d ε γ .122, .014, .136, ... E .837	Co 58 2+ 9.1h | 71.4d IT .025 | ε, β⁺.48, ... e⁻ | γ .811, ... σγ (4×10⁴) | .8638, 1.675 10μs | σγ 1.7×10³ IT .053 | E 2.309	Co 59 7/- 100 σγ (19+18) 58.93319	Co 60 5+ 10.47m | 5.258y IT .0586 | β⁻.318, ... β⁻1.55, ... | γ 1.333, 1.173, ... γ 1.333, ... | σγ 2.0 σγ 58 | E 2.819	Co 61 (7/-) 1.65h β⁻1.22 γ .070 E 1.29	Co 62 1.6m | 13.9m β⁻ | β⁻2.88, .88 γ | γ 1.17, .147, 1.74, 2.03, ... E 5.22	Co 63 52s β⁻3.6 γ .088 ? E 3.6	Co 64 (1+) 28s | < 28s γ .095 | β⁻~3.5				
Fe 53 (7/-) 2.53m | 8.53m γ .702, 1.011, 1.329, 2.340 | β⁺2.8, 2.4, ... ε γ .38, ... E 3.98	Fe 54 5.82 σγ 2.3 53.93962	Fe 55 3/- 2.7y ε no γ E .232	Fe 56 91.66 σγ 2.6 55.93494	Fe 57 1/- 2.19 σγ 2.5 56.93540	Fe 58 0.33 σγ 1.2 57.9333	Fe 59 3/- 45d β⁻.467, .273, 1.573 γ 1.099, 1.292, .192, ... E 1.573	Fe 60 ~10⁵y β⁻.135, .37, ... γ .0586, .0272 (1.332, 1.173, ...) E .19	Fe 61 3/(-) 6.06m β⁻2.6, 2.5, 2.8, ... γ 1.20, 1.02, .30, .12 - 2.7 E 3.8						40
Mn 52 6+ 21.4m | 5.63d β⁺2.63, ε | β⁺.575 IT .38 | γ 1.434, .936, .744 γ 1.43 E 4.7	Mn 53 7/- 2×10⁶y ε no γ σγ ~8×10² E .598	Mn 54 3+ 313d ε γ .8348 σγ < 10 E 1.379	Mn 55 5/- 100 σγ 13.3 54.93805	Mn 56 3+ 2.582h β⁻2.85, 1.04, .73, ... γ .8467, 1.811, 2.113 E 3.702	Mn 57 1.7m β⁻2.6, ... γ .122, .014, .136, .22 - .71 E 2.7	Mn 58 1.1m β⁻ γ .36 - 2.8 E 7							38	
Cr 51 7/- 27.8d ε γ .320, ... E .75	Cr 52 83.79 σγ 0.8 51.94051	Cr 53 3/- 9.50 σγ 18 52.94065	Cr 54 2.365 σγ 0.38 53.93888	Cr 55 3/- 3.53m β⁻2.5 γ 1.52, 2.24 E 2.59	Cr 56 5.9m β⁻1.5 γ .083, .026 E 1.6					36				
V 50 6+ 0.24 ~4×10¹⁴y γ 1.56 | E⁻1.038 γ .78 | E⁺2.218 σγ 60 49.94716	V 51 7/- 99.76 σγ 4.9 50.94396	V 52 3+ 3.75m β⁻2.5, ... γ 1.434, ... E 3.97	V 53 2.0m β⁻2.5 γ 1.00 E 3.4	V 54 55s β⁻3.3 γ .835, .99, 2.2, ... E 7										
Ti 49 7/- 5.51 σγ 1.9 48.94787	Ti 50 5.34 σγ < 0.2 49.94479	Ti 51 7/- 5.76m β⁻2.14, 1.5 γ .320, .93, .61 E 2.46	Ti 52 1.7m | 49m β⁻1.8 | β⁻ γ .125, .017 | γ (1.43) E 1.97				34							
Sc 48 6+ 1.82d β⁻.65, .48 γ 1.311, .983, 1.037, .175 - 1.212 E 3.98	Sc 49 (7/-) 57.5m β⁻2.01, ... γ 1.78 E 2.008	Sc 50 0.4s | 1.73m IT .258 | β⁻3.6 γ 1.12, 1.56, .52 E 6.8	Sc 51 12s β⁻~5, ... γ 1.44, 2.16 E 6.52		32									
Ca 47 7/- 4.53d β⁻.68, 1.98, ... γ 1.297, .489, .808 E 1.98	Ca 48 0.18 σγ 1.1 47.9525	Ca 49 3/- 8.70m β⁻2.1, 1, ... γ 3.08, 4.07, ... E 5.26	Ca 50 11s β⁻ γ .072, (.26) E 5.4											
K 46 115s β⁻6.3, ... γ 1.35, 3.70, ... E 7.72	K 47 17.5s β⁻4.1, ~6, γ 2.0, 2.6 E 6.65		30											
	28													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Zr 81 ~10m
Zr 82 ~10m
Zr 83 ~7m
Zr 84 16m
Zr 85 15m 1.4h
Zr 86 16.5h
Y 88.905
Y 82 12m
Y 83 7.5m
Y 84 41m
Y 85
Sr 87.62
Sr 80
Sr 81 29m
Sr 82 25d
Sr 83 32.4h
Sr 84 0.56
Rb 85.47
Rb77
Rb78 6m
Rb79 23m
Rb 80 34s
Rb 81
Rb 82
Rb83 83d
Kr 83.80
Kr 74 16m
Kr 75 ~5m
Kr 76 14.8h
Kr 77 1.2h
Kr 78 0.354
Kr 79 50s 34.9h
Kr 80 2.27
Kr 81 13s
Kr 82 11.56
Br 79.904
Br70? 23s
Br 74 4m 36m
Br 75 97m
Br 76 16h
Br 77 4.3m 56h
Br 78 6.4m
Br 79 4.84s 50.69
Br 80 4.42h 17.6m
Br 81 37μs 49.31
Se 78.96
Se 70 39m
Se 71 4.5m
Se 72 8.5d
Se73 42m 7.1h
Se 74 0.87
Se 75 120.4d
Se 76 9.02
Se 77 17.7s 7.58
Se 78 23.52
Se 79 3.9m
Se 80 49.82
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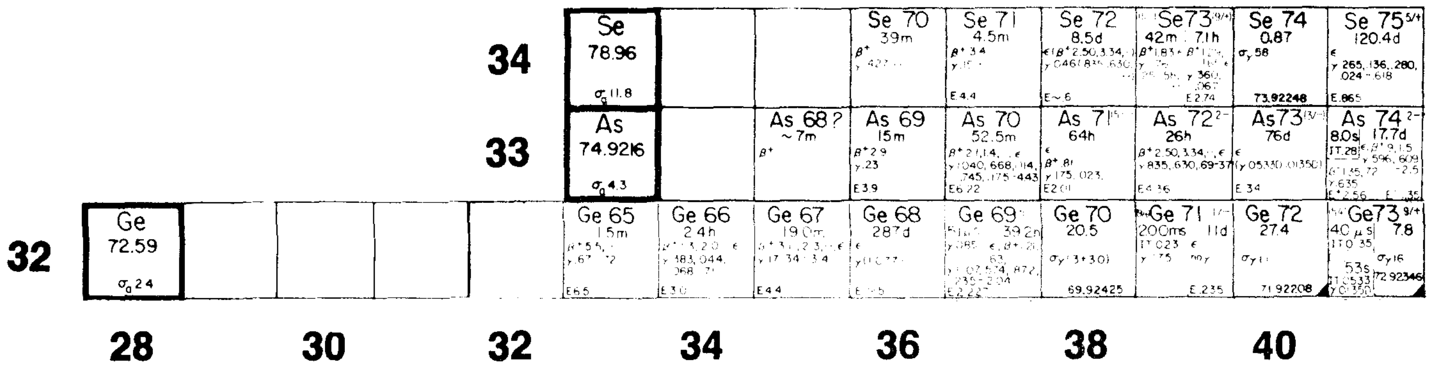
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Se 71 4.5m
Se 72 8.5d
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Se 74 0.87
Se 75 120.4d
As 74.9216
As 68? ~7m
As 69 15m
As 70 52.5m
As 71 64h
As 72 26h
As73 76d
As 74 8.0s 17.7d
Ge 72.59
Ge 65 1.5m
Ge 66 2.4h
Ge 67 19.0m
Ge 68 287d
Ge 69
Ge 70 20.5
Ge 71 11d
Ge 72 27.4
Ge73 7.8
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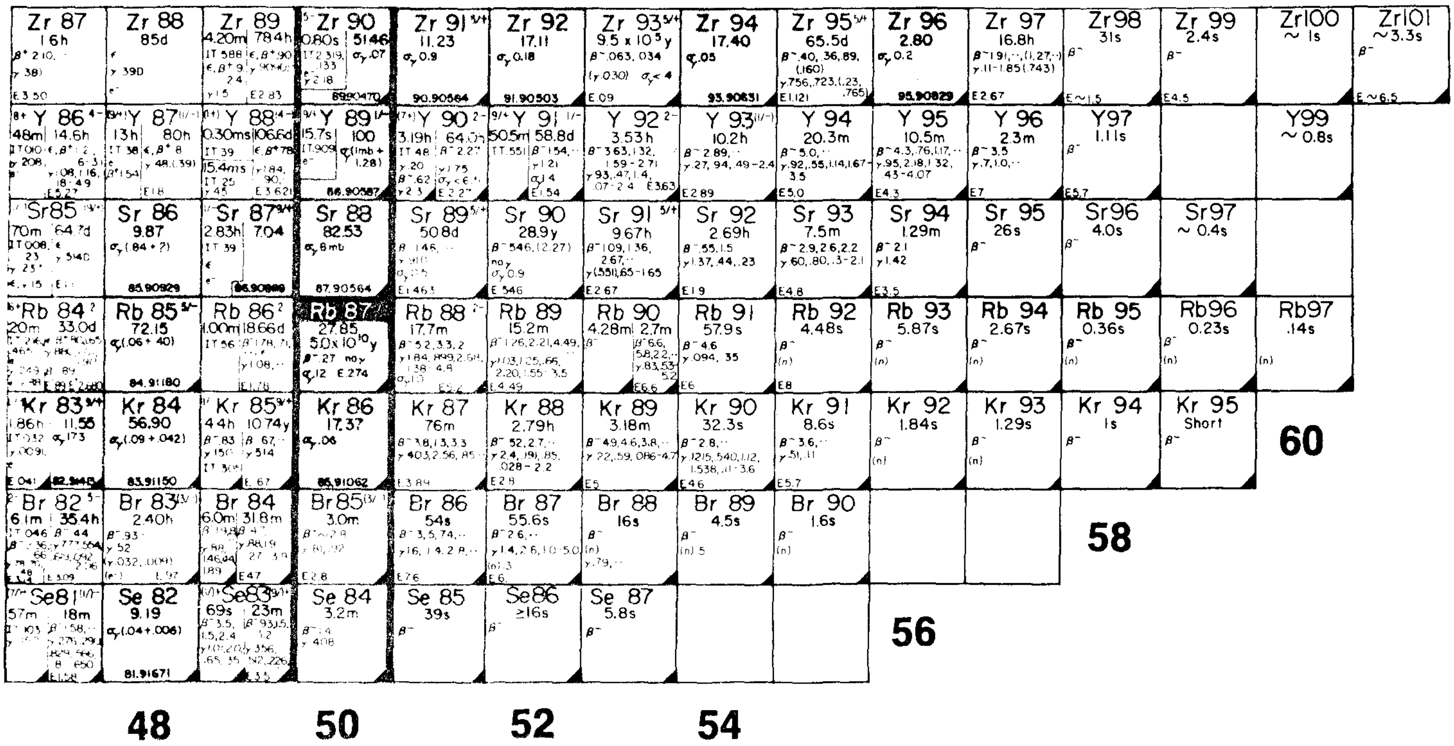
Zr 87 1.6h
Zr 88 85d
Zr 89 4.20m 78.4h
Zr 90 0.80s 51.46
Zr 91 11.23
Zr 92 17.11
Zr 93 9.5 x 10^5y
Zr 94 17.40
Zr 95 65.5d
Zr 96 2.80
Zr 97 16.8h
Zr98 31s
Zr 99 2.4s
Zr100 ~ 1s
Zr101 ~3.3s
Y 86 48m 14.6h
Y 87 13h 80h
Y 88 0.30ms 106.6d
Y 89 15.7s 100
Y 90 3.19h 64.0h
Y 91 50.5m 58.8d
Y 92 3.53h
Y 93 10.2h
Y 94 20.3m
Y 95 10.5m
Y 96 2.3m
Y97 1.11s
Y99 ~ 0.8s
Sr85 70m 64.7d
Sr 86 9.87
Sr 87 2.83h 7.04
Sr 88 82.53
Sr 89 50.8d
Sr 90 28.9y
Sr 91 9.67h
Sr 92 2.69h
Sr 93 7.5m
Sr 94 1.29m
Sr 95 26s
Sr96 4.0s
Sr97 ~ 0.4s
Rb 84 20m 33.0d
Rb 85 72.15
Rb 86 1.00m 18.66d
Rb 87 27.85 5.0x10^10y
Rb 88 17.7m
Rb 89 15.2m
Rb 90 4.28m 2.7m
Rb 91 57.9s
Rb 92 4.48s
Rb 93 5.87s
Rb 94 2.67s
Rb 95 0.36s
Rb96 0.23s
Rb97 .14s
Kr 83 1.86h 11.55
Kr 84 56.90
Kr 85 4.4h 10.74y
Kr 86 17.37
Kr 87 76m
Kr 88 2.79h
Kr 89 3.18m
Kr 90 32.3s
Kr 91 8.6s
Kr 92 1.84s
Kr 93 1.29s
Kr 94 1s
Kr 95 Short
Br 82 6.1m 35.4h
Br 83 2.40h
Br 84 6.0m 31.8m
Br85 3.0m
Br 86 54s
Br 87 55.6s
Br 88 16s
Br 89 4.5s
Br 90 1.6s
Se81 57m 18m
Se 82 9.19
Se83 69s 23m
Se 84 3.2m
Se 85 39s
Se86 ≥16s
Se 87 5.8s
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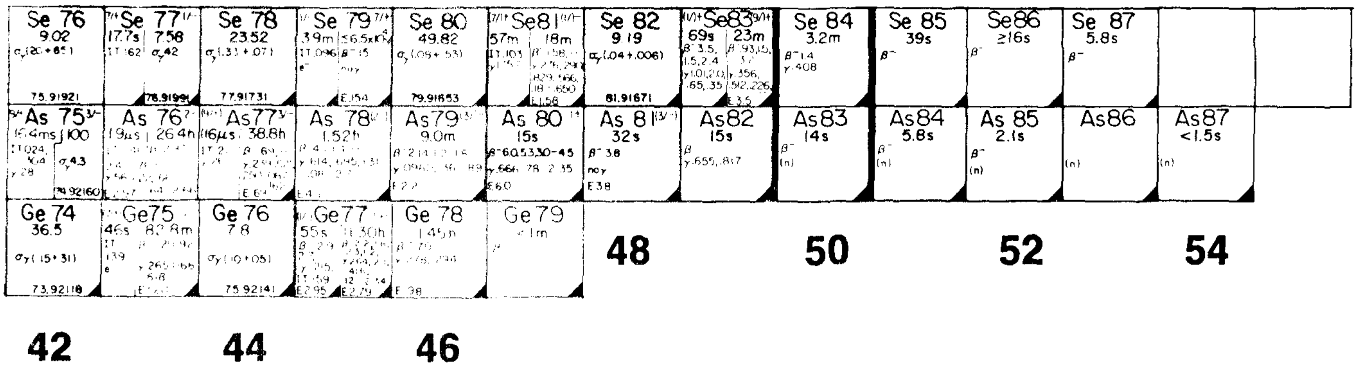
58
56
48
50
52
54


Se 76 9.02
Se 77 17.7s 7.58
Se 78 23.52
Se 79 3.9m
Se 80 49.82
Se81 57m 18m
Se 82 9.19
Se83 69s 23m
Se 84 3.2m
Se 85 39s
Se86 ≥16s
Se 87 5.8s
As 75 16.4ms 100
As 76 26.4h
As77 38.8h
As 78 1.52h
As79 9.0m
As 80 15s
As 81 32s
As82 15s
As83 14s
As84 5.8s
As 85 2.1s
As86
As87 <1.5s
Ge 74 36.5
Ge75 46s 82.8m
Ge 76 7.8
Ge77 55s 11.30h
Ge 78 1.45h
Ge 79 <1m
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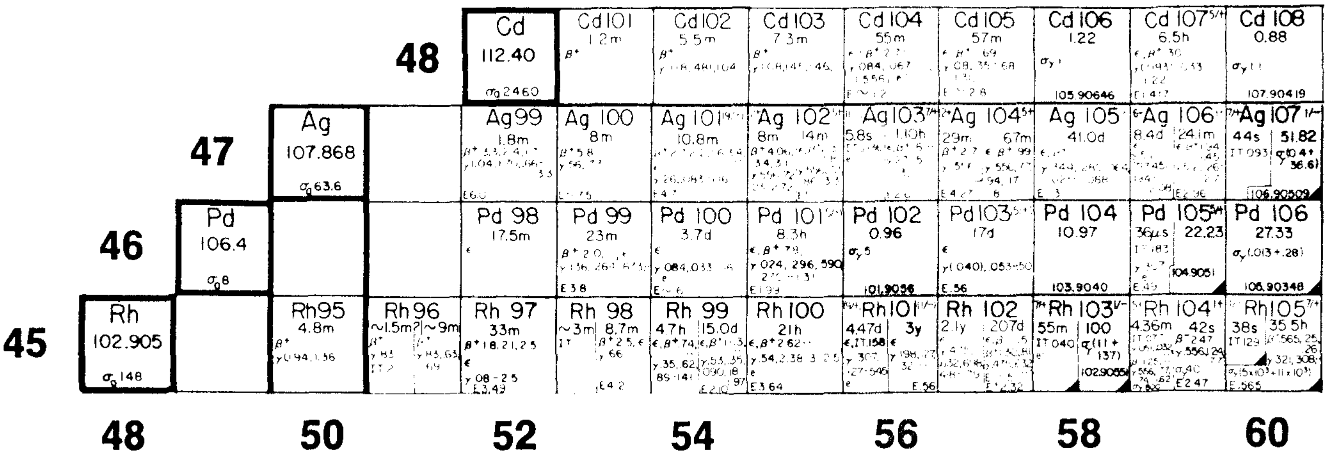
46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Pd
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Cd 104
Cd 105
Cd 106
Cd 107
Cd 108
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Ag 100
Ag 101
Ag 102
Ag 103
Ag 104
Ag 105
Ag 106
Ag 107
Pd 98
Pd 99
Pd 100
Pd 101
Pd 102
Pd 103
Pd 104
Pd 105
Pd 106
Rh 95
Rh 96
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Rh 99
Rh 100
Rh 101
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Rh 103
Rh 104
Rh 105
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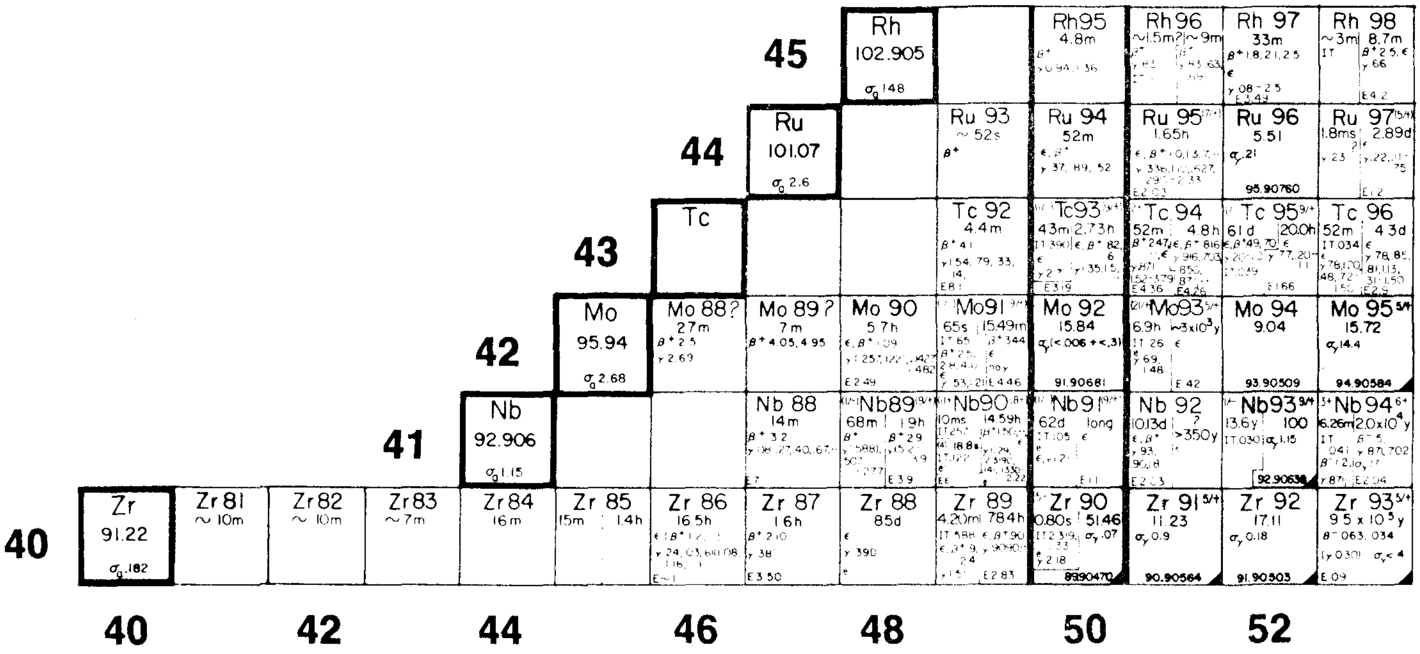
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Rh
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44
Ru
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Tc
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Mo
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Nb
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Rh 95
Rh 96
Rh 97
Rh 98
Ru 93
Ru 94
Ru 95
Ru 96
Ru 97
Tc 92
Tc 93
Tc 94
Tc 95
Tc 96
Mo 88?
Mo 89?
Mo 90
Mo 91
Mo 92
Mo 93
Mo 94
Mo 95
Nb 88
Nb 89
Nb 90
Nb 91
Nb 92
Nb 93
Nb 94
Zr 81
Zr 82
Zr 83
Zr 84
Zr 85
Zr 86
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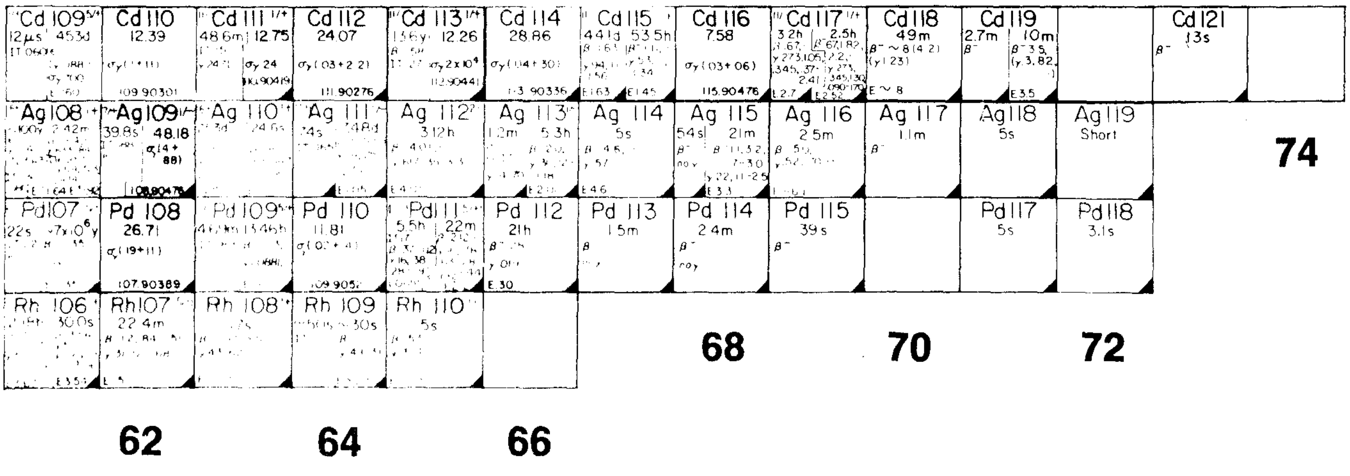
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Ag 111
Ag 112
Ag 113
Ag 114
Ag 115
Ag 116
Ag 117
Ag 118
Ag 119
Short
Pd 107
Pd 108
Pd 109
Pd 110
Pd 111
Pd 112
Pd 113
Pd 114
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Rh 107
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Rh 110
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64
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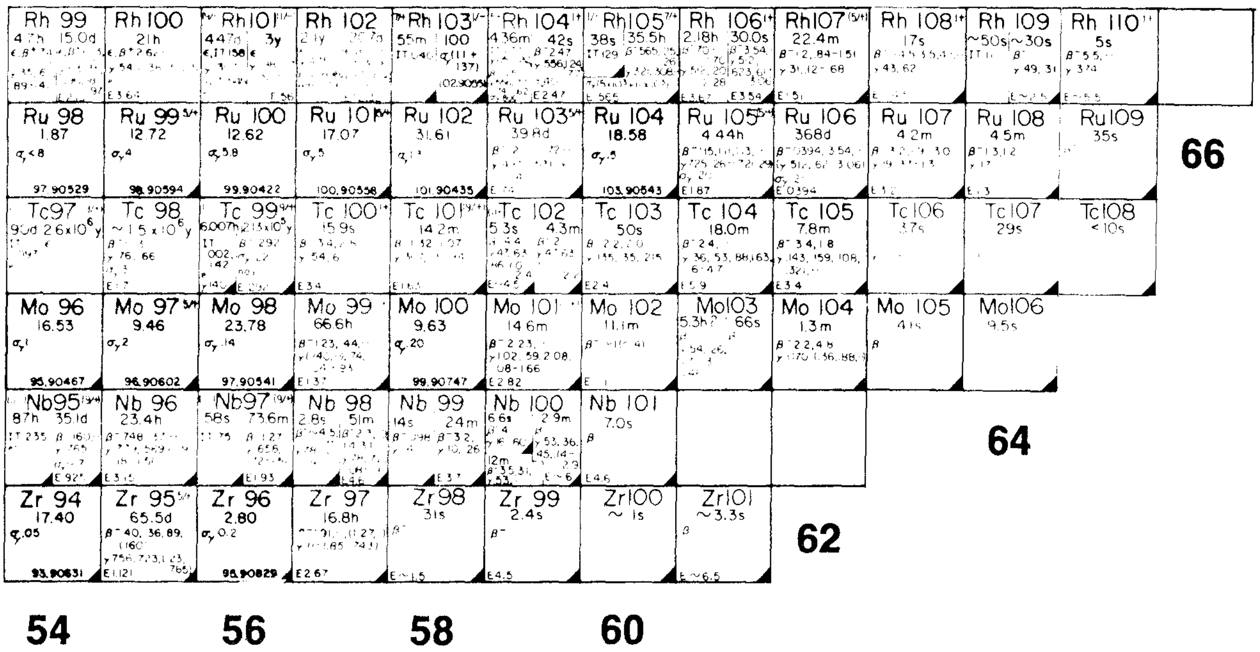
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Ru 102
Ru 103
Ru 104
Ru 105
Ru 106
Ru 107
Ru 108
Ru 109
66
Tc 97
Tc 98
Tc 99
Tc 100
Tc 101
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Tc 103
Tc 104
Tc 105
Tc 106
Tc 107
Tc 108
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Mo 97
Mo 98
Mo 99
Mo 100
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Mo 102
Mo 103
Mo 104
Mo 105
Mo 106
Nb 95
Nb 96
Nb 97
Nb 98
Nb 99
Nb 100
Nb 101
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Zr 100
Zr 101
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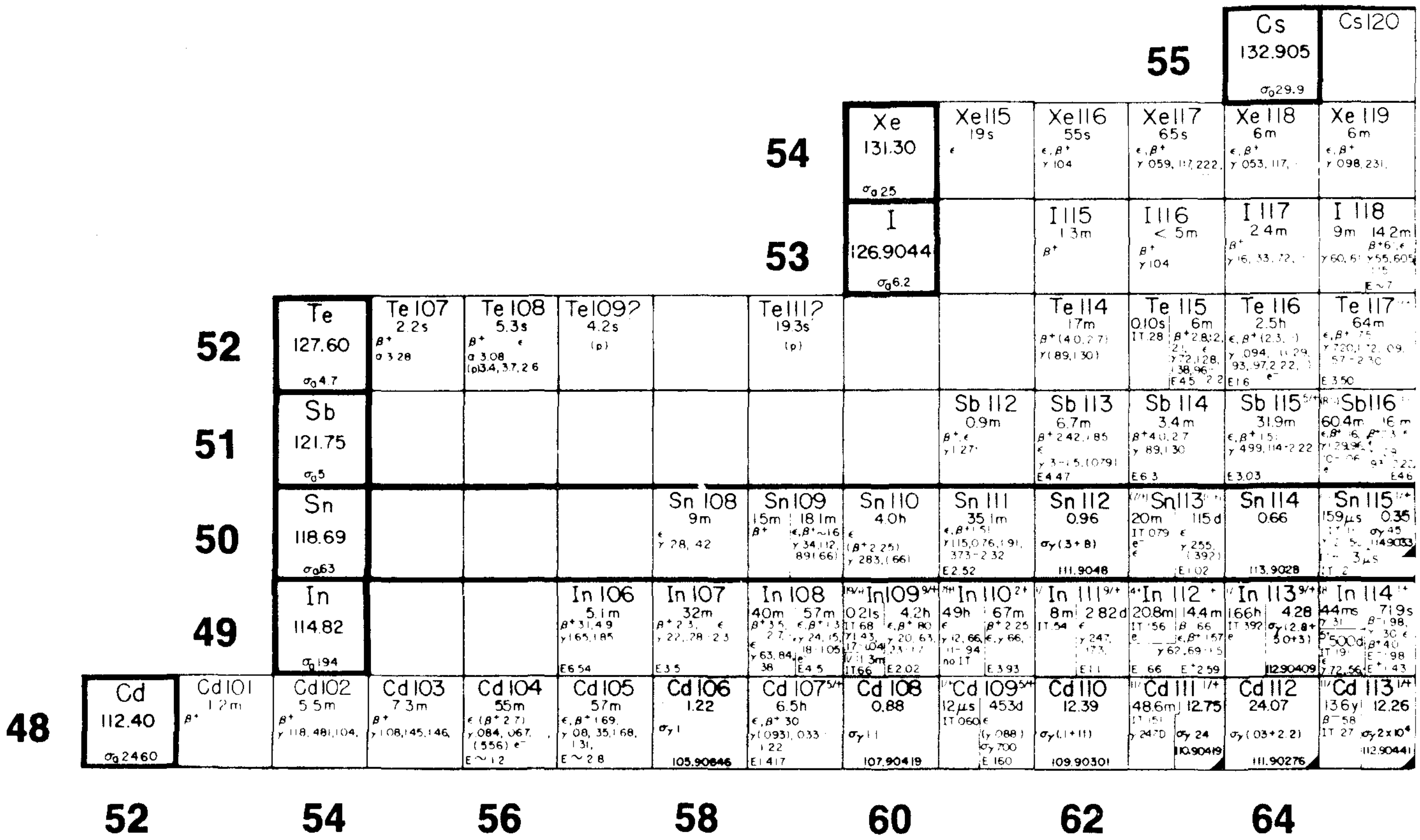
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Cs
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Xe117
Xe118
Xe119
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I
126.9044
I115
I116
I117
I118
52
Te
127.60
Te107
Te108
Te109?
Te111?
Te114
Te115
Te116
Te117
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Sb
121.75
Sb112
Sb113
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Sb115
Sb116
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Sn
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Sn108
Sn109
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Sn111
Sn112
Sn113
Sn114
Sn115
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In
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In106
In107
In108
In109
In110
In111
In112
In113
In114
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Cd
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Cd102
Cd103
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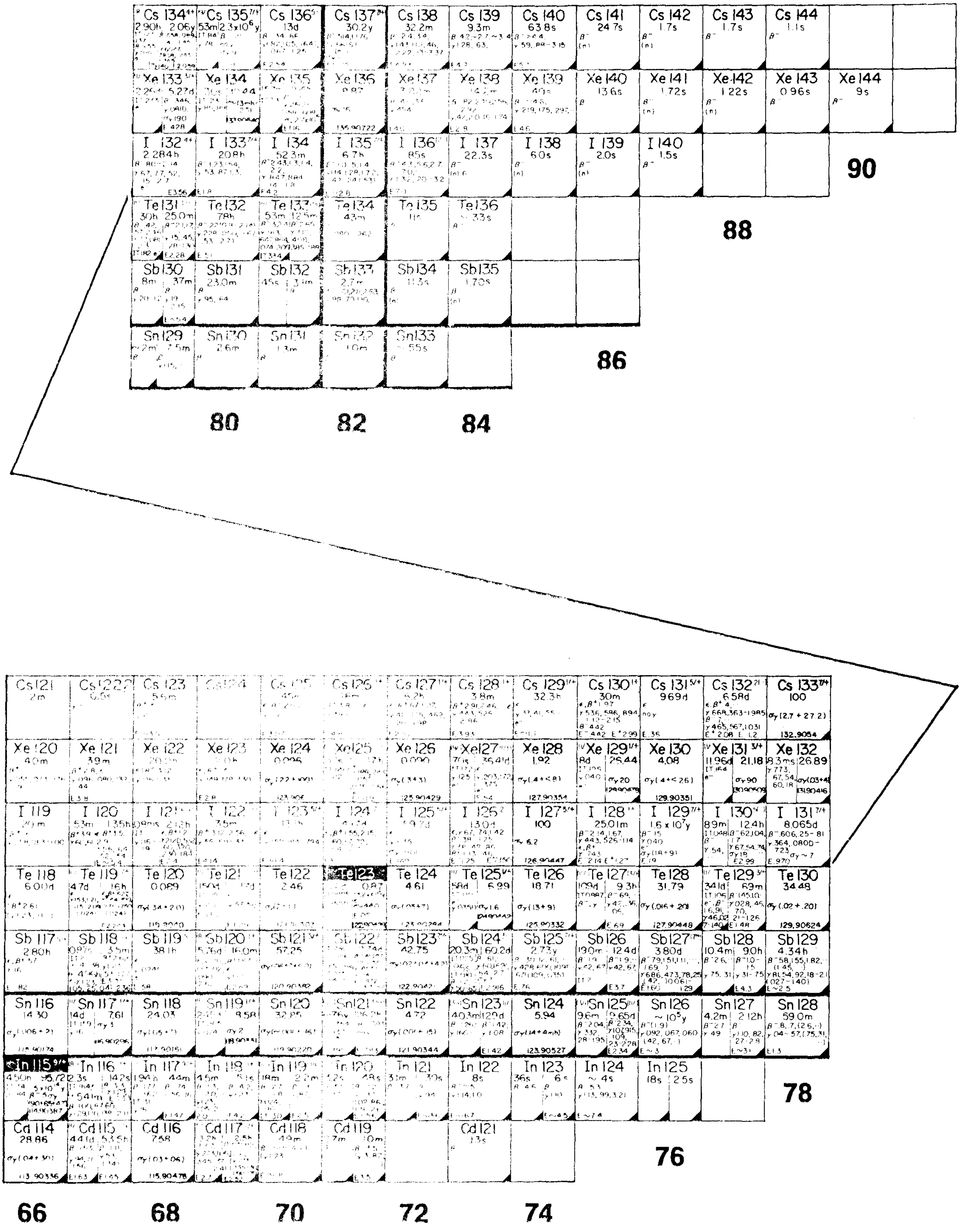

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Cs 137
Cs 138
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Cs 140
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Cs 143
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Xe 137
Xe 138
Xe 139
Xe 140
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Xe 142
Xe 143
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I 139
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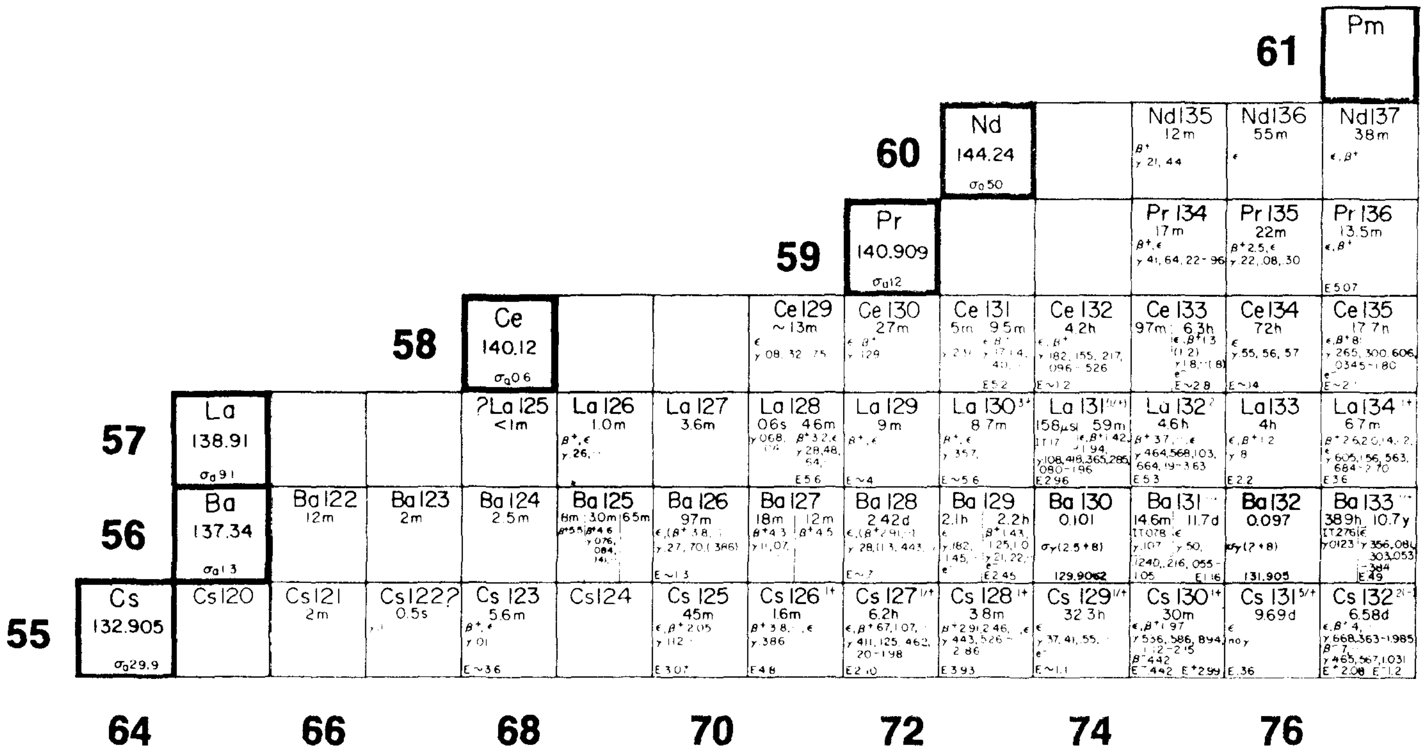

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Pm
60
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Nd137
38m
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Pr
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Pr 134
17m
Pr 135
22m
Pr 136
13.5m
58
Ce
140.12
Ce 129
~13m
Ce 130
27m
Ce 131
Ce 132
4.2h
Ce 133
Ce 134
72h
Ce 135
57
La
138.91
?La 125
<1m
La 126
1.0m
La 127
3.6m
La 128
La 129
9m
La 130
8.7m
La 131
La 132
4.6h
La 133
4h
La 134
6.7m
56
Ba
137.34
Ba 122
12m
Ba 123
2m
Ba 124
2.5m
Ba 125
Ba 126
97m
Ba 127
Ba 128
2.42d
Ba 129
Ba 130
0.101
Ba 131
11.7d
Ba 132
0.097
Ba 133
10.7y
55
Cs
132.905
Cs 120
Cs 121
2m
Cs 122?
0.5s
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5.6m
Cs 124
Cs 125
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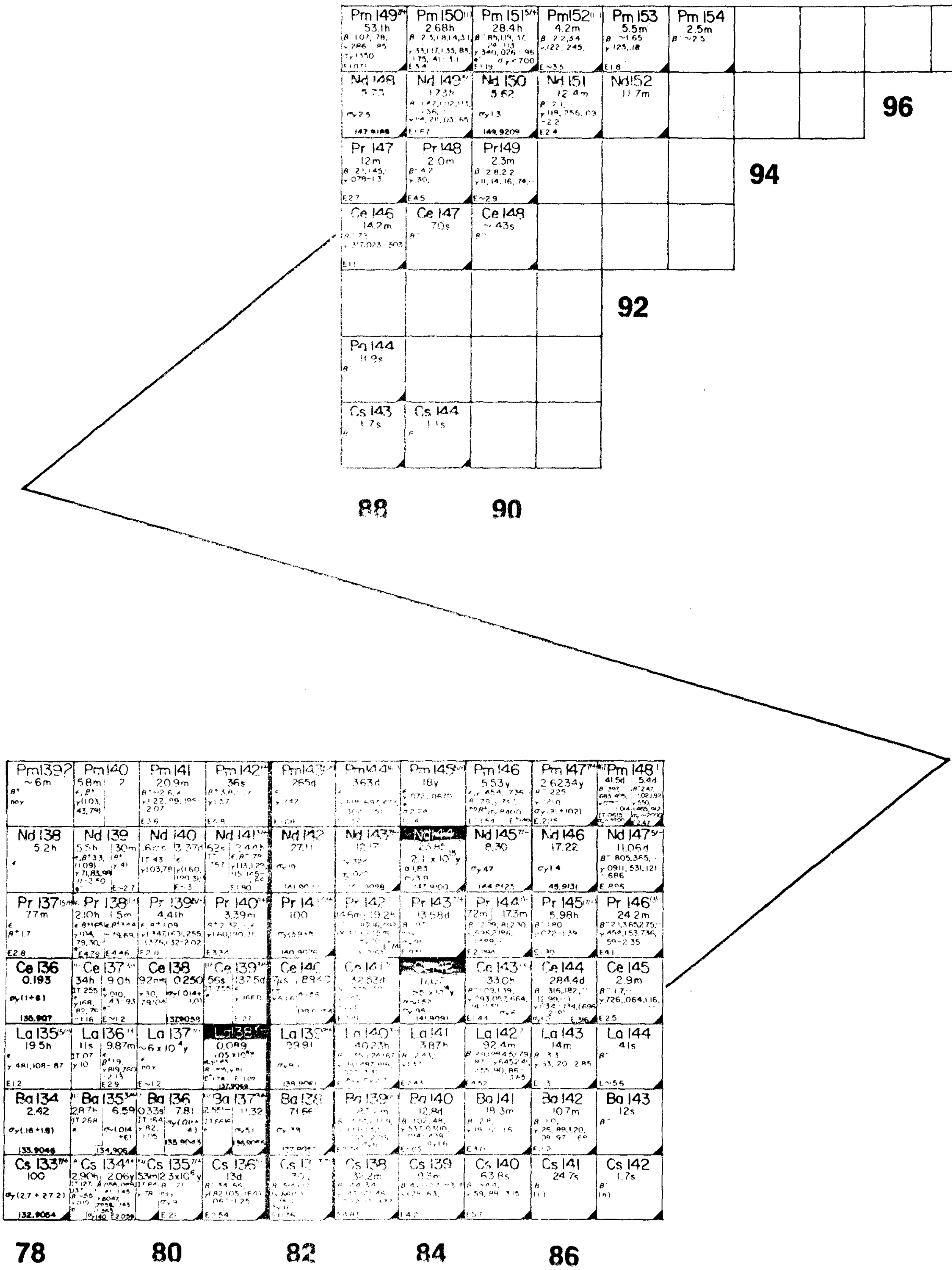

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Ce 147
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Ba 144
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96
94
92
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Pm 141
Pm 146
Pm 148
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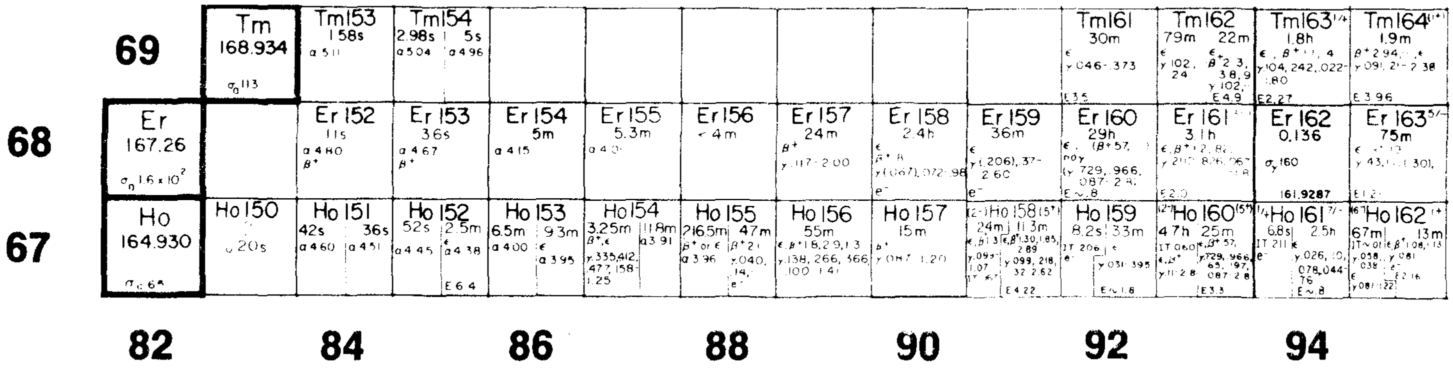
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Ho
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Er 152
Er 153
Er 154
Er 155
Er 156
Er 157
Er 158
Er 159
Er 160
Er 161
Er 162
Er 163
Ho 150
Ho 151
Ho 152
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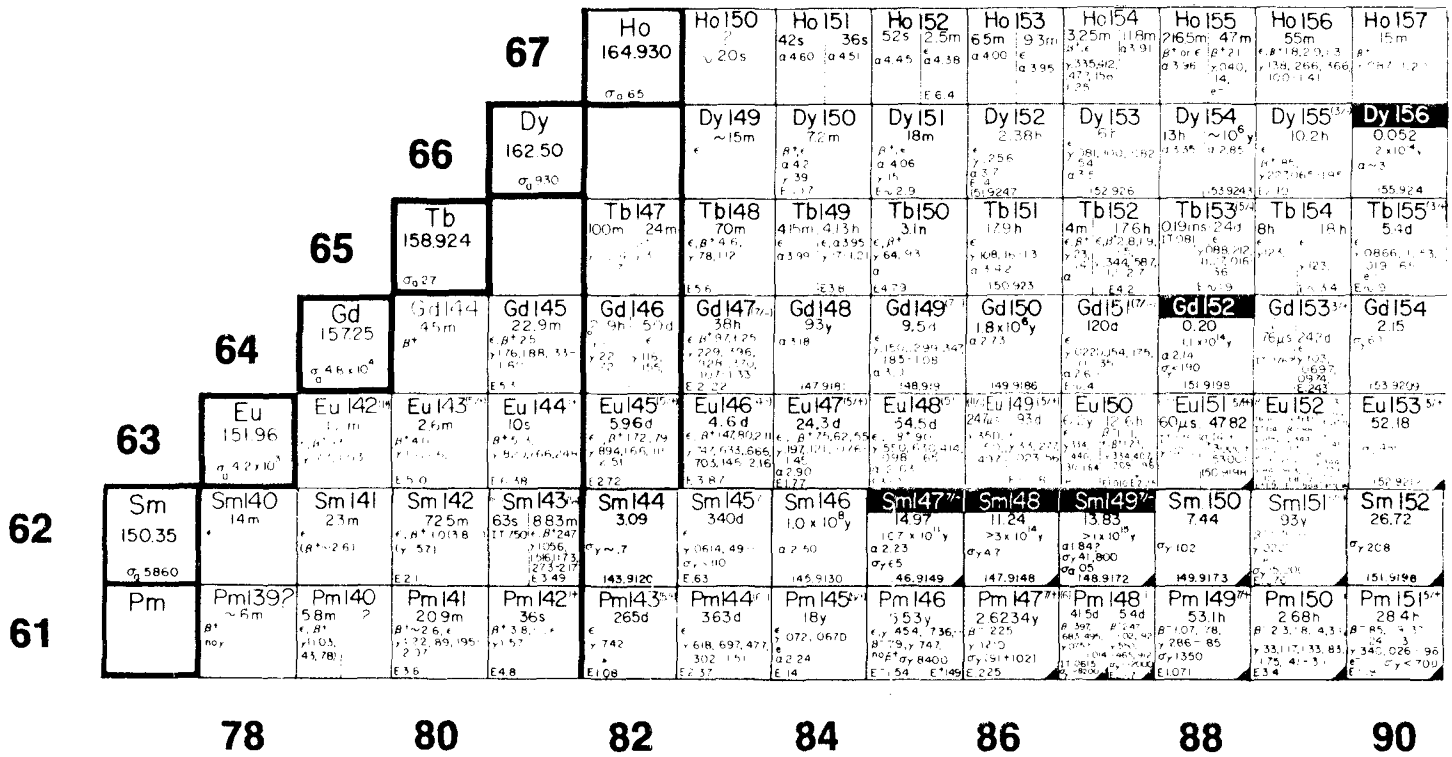
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Ho
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Dy
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Gd
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Sm
150.35
Pm
Ho 150
Ho 151
Ho 152
Ho 153
Ho 154
Ho 155
Ho 156
Ho 157
Dy 149
Dy 150
Dy 151
Dy 152
Dy 153
Dy 154
Dy 155
Dy 156
Tb 147
Tb 148
Tb 149
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Sm 142
Sm 143
Sm 144
Sm 145
Sm 146
Sm 147
Sm 148
Sm 149
Sm 150
Sm 151
Sm 152
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Pm 140
Pm 141
Pm 142
Pm 143
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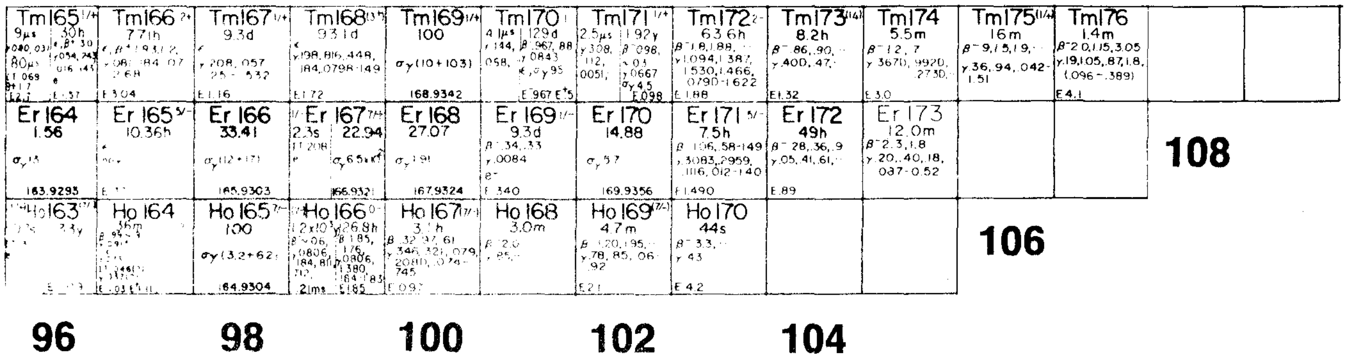
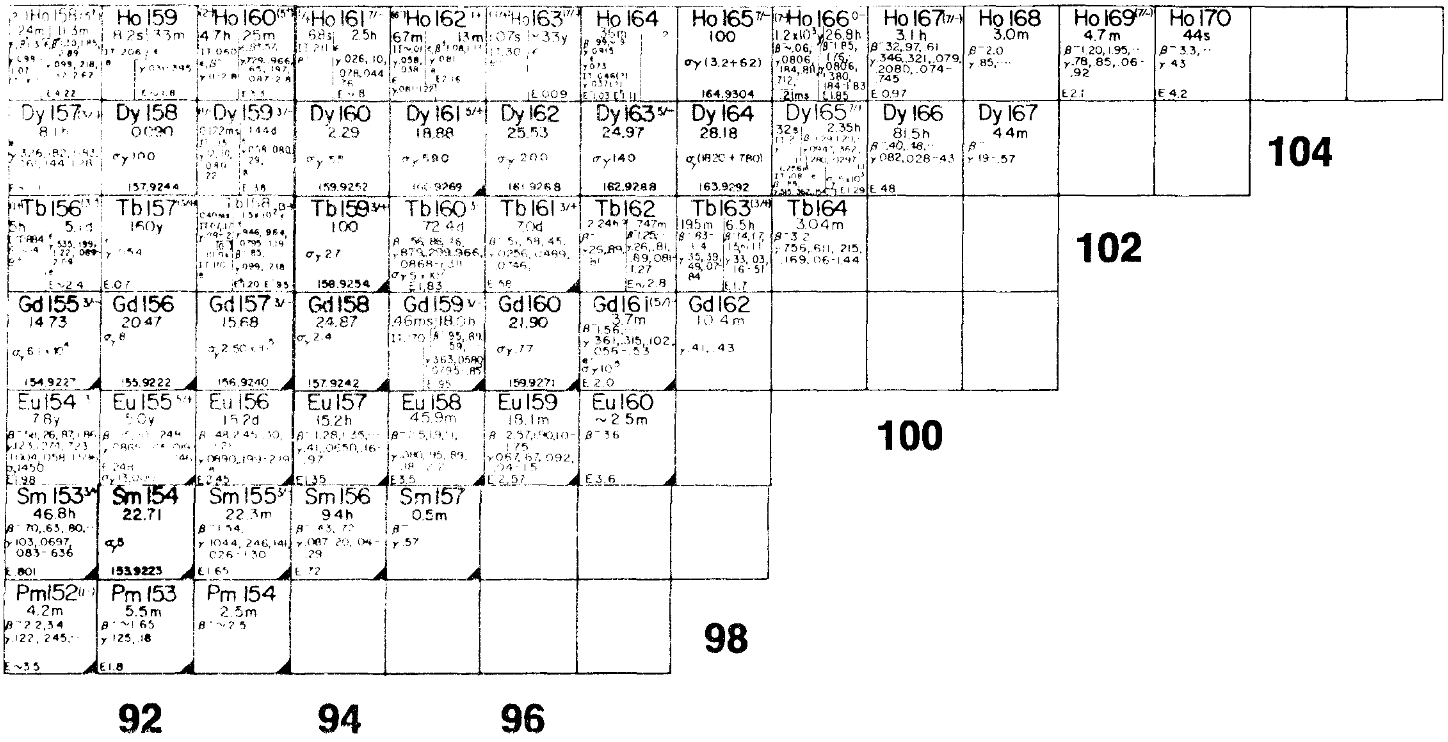
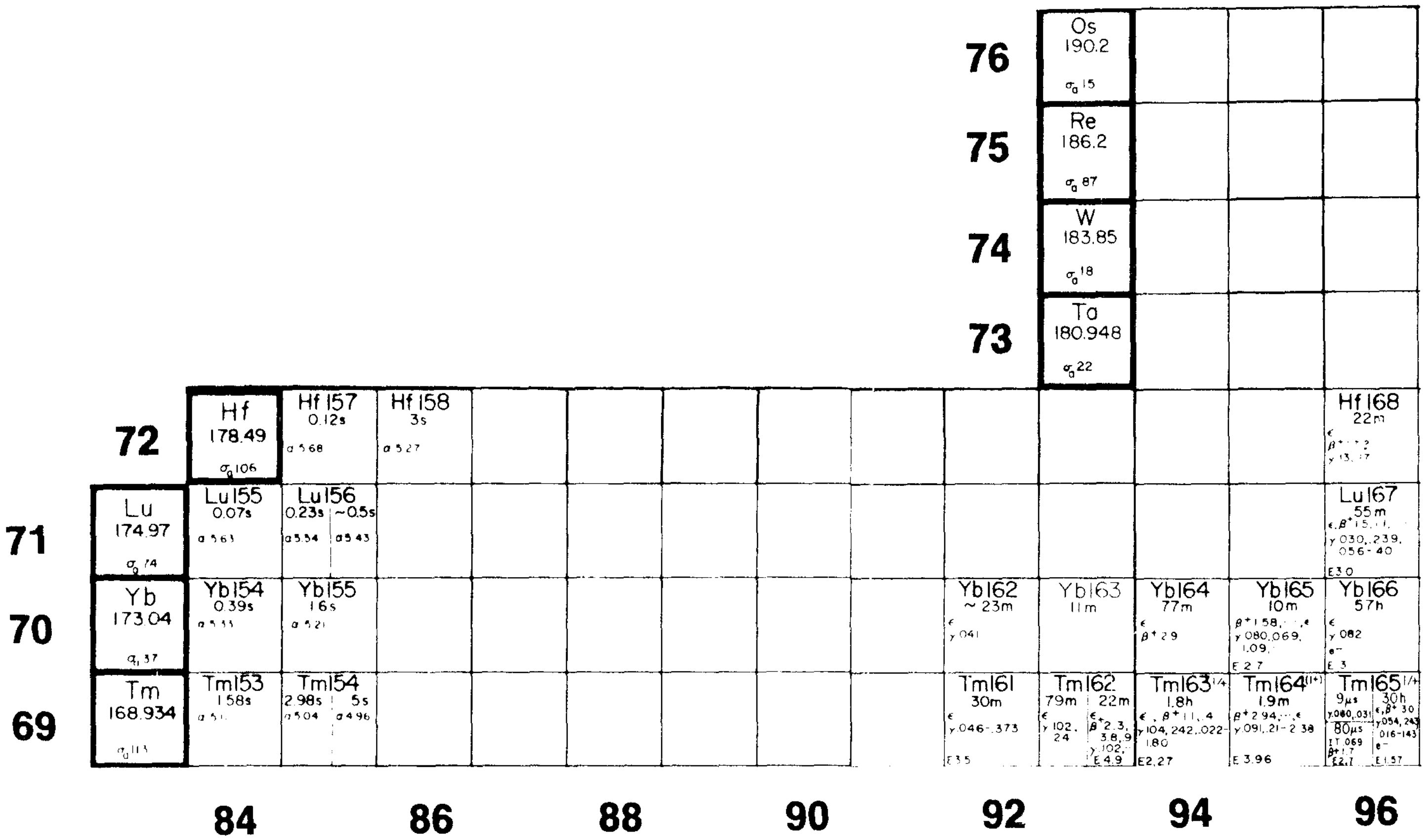
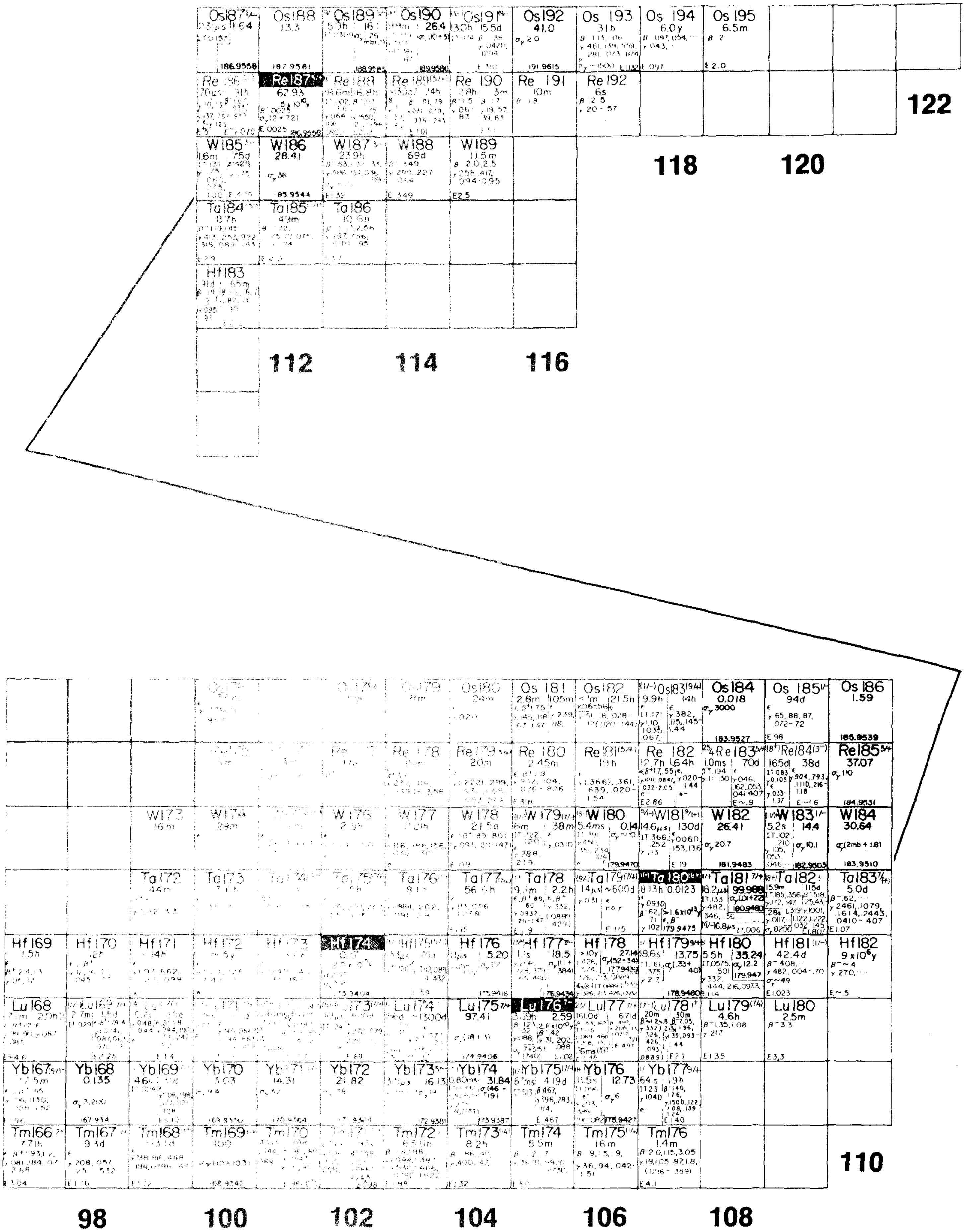
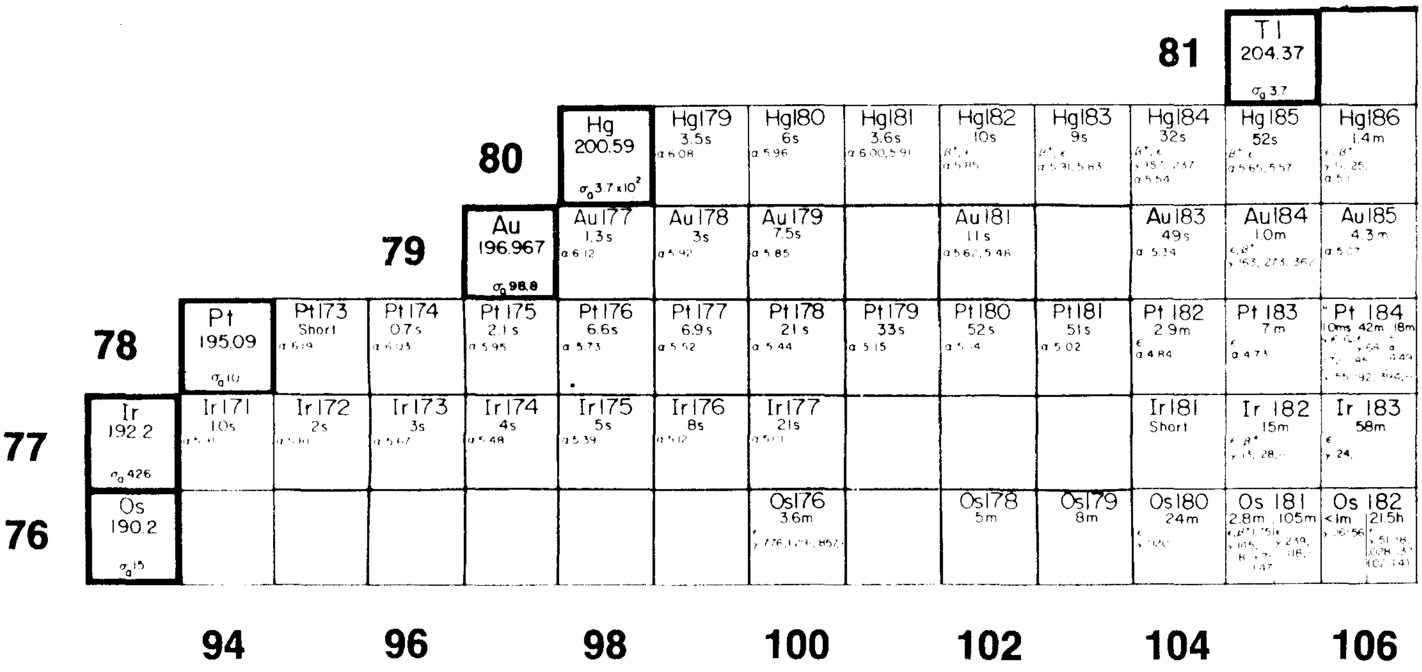

Tm165
Tm166
Tm167
Tm168
Tm169
Tm170
Tm171
Tm172
Tm173
Tm174
Tm175
Tm176
Er 164
Er 165
Er 166
Er 167
Er 168
Er 169
Er 170
Er 171
Er 172
Er 173
Ho 163
Ho 164
Ho 165
Ho 166
Ho 167
Ho 168
Ho 169
Ho 170
108
106
96
98
100
102
104

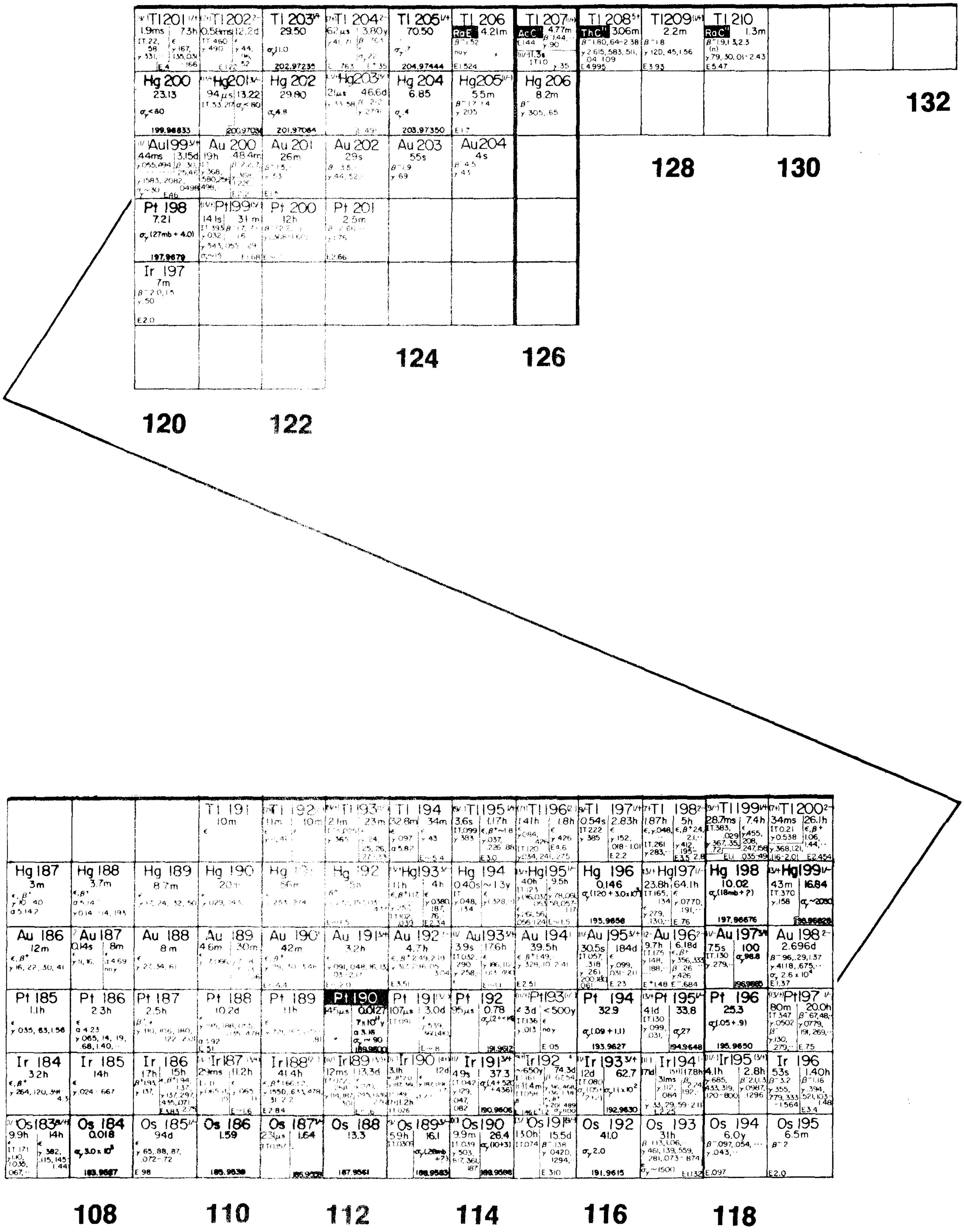

Ho 158
Ho 159
Ho 160
Ho 161
Ho 162
Ho 163
Ho 164
Ho 165
Ho 166
Ho 167
Ho 168
Ho 169
Ho 170
Dy 157
Dy 158
Dy 159
Dy 160
Dy 161
Dy 162
Dy 163
Dy 164
Dy 165
Dy 166
Dy 167
104
Tb 156
Tb 157
Tb 158
Tb 159
Tb 160
Tb 161
Tb 162
Tb 163
Tb 164
102
Gd 155
Gd 156
Gd 157
Gd 158
Gd 159
Gd 160
Gd 161
Gd 162
Eu 154
Eu 155
Eu 156
Eu 157
Eu 158
Eu 159
Eu 160
100
Sm 153
Sm 154
Sm 155
Sm 156
Sm 157
Pm 152
Pm 153
Pm 154
98
92
94
96

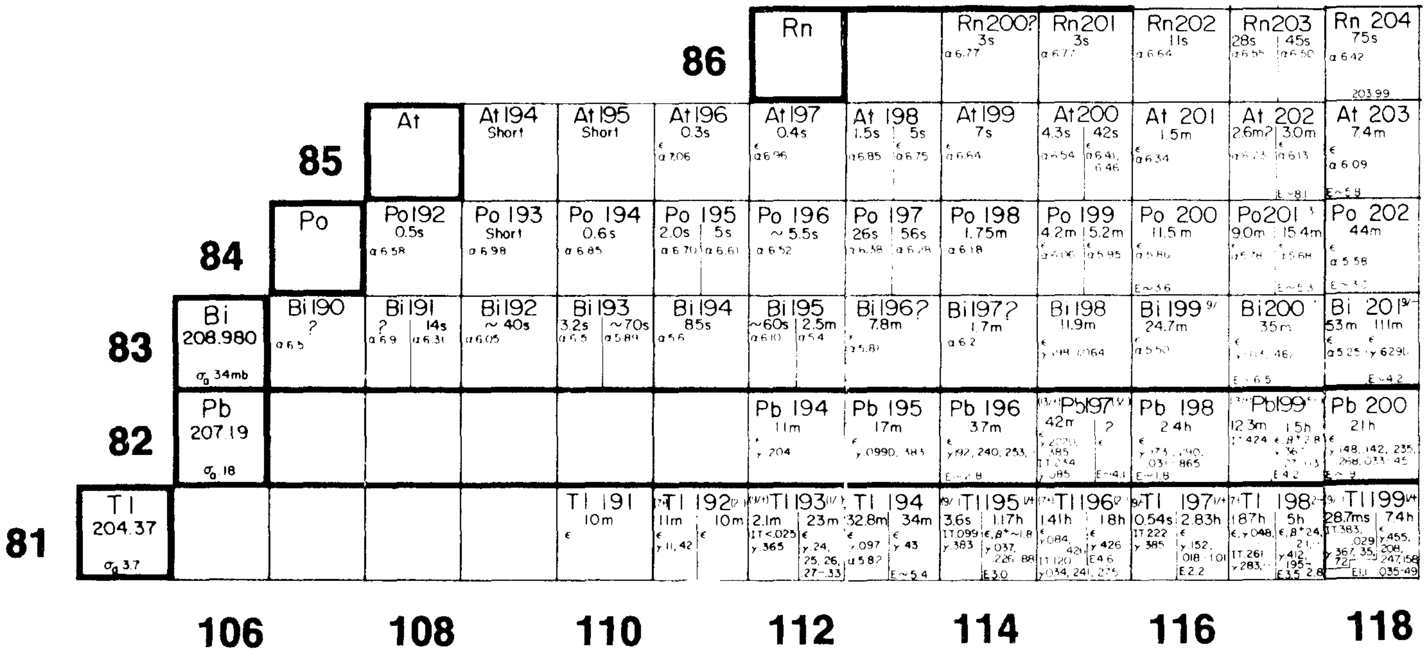

76
Os
190.2
75
Re
186.2
74
W
183.85
73
Ta
180.948
72
Hf
178.49
Hf 157
0.12s
Hf 158
3s
Hf 168
22m
71
Lu
174.97
Lu155
0.07s
Lu156
0.23s
~0.5s
Lu167
55m
70
Yb
173.04
Yb154
0.39s
Yb155
1.6s
Yb162
~23m
Yb163
11m
Yb164
77m
Yb165
10m
Yb166
57h
69
Tm
168.934
Tm153
1.58s
Tm154
2.98s
5s
Tm161
30m
Tm162
79m
22m
Tm163
1.8h
Tm164
1.9m
Tm165
30h
84
86
88
90
92
94
96

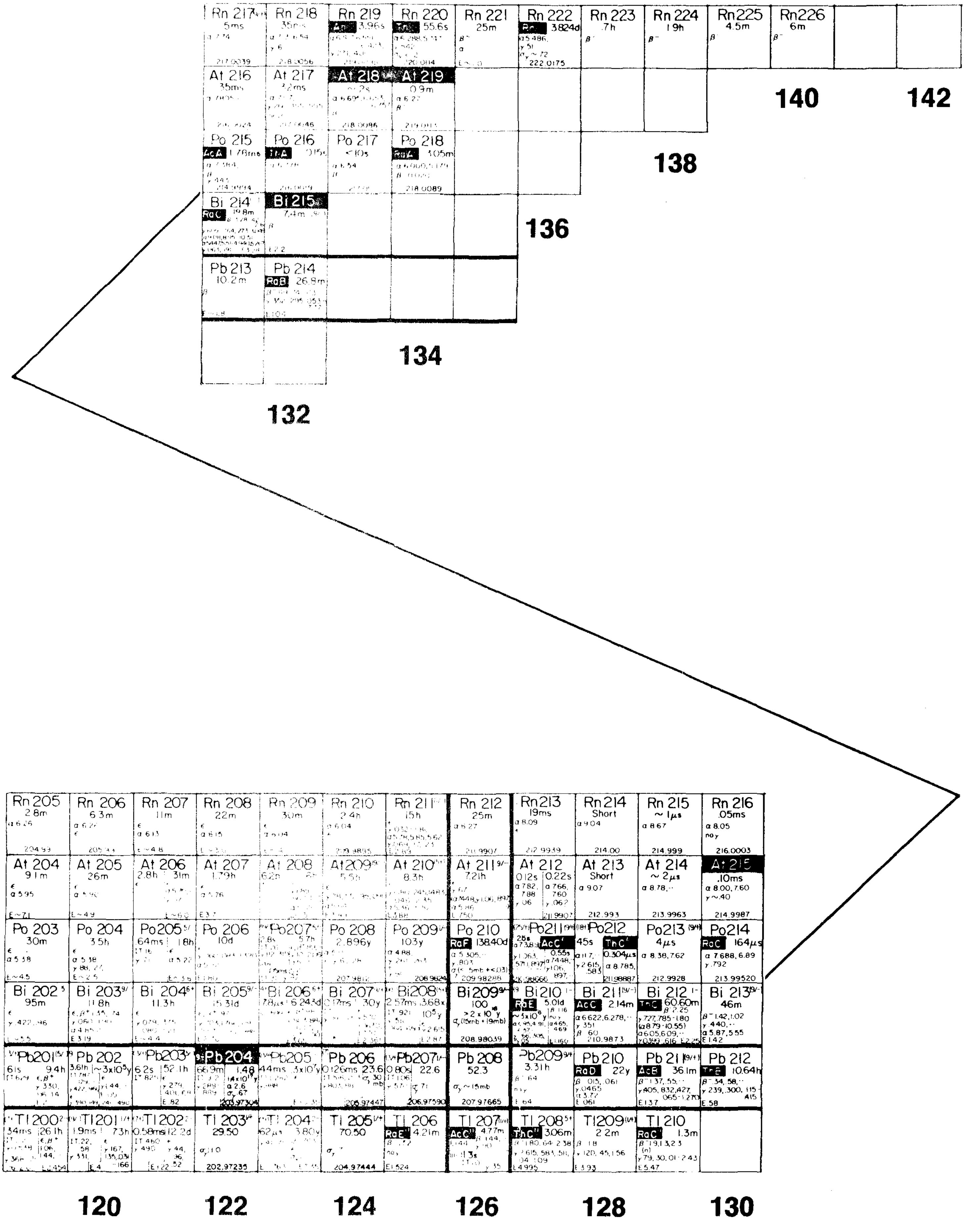


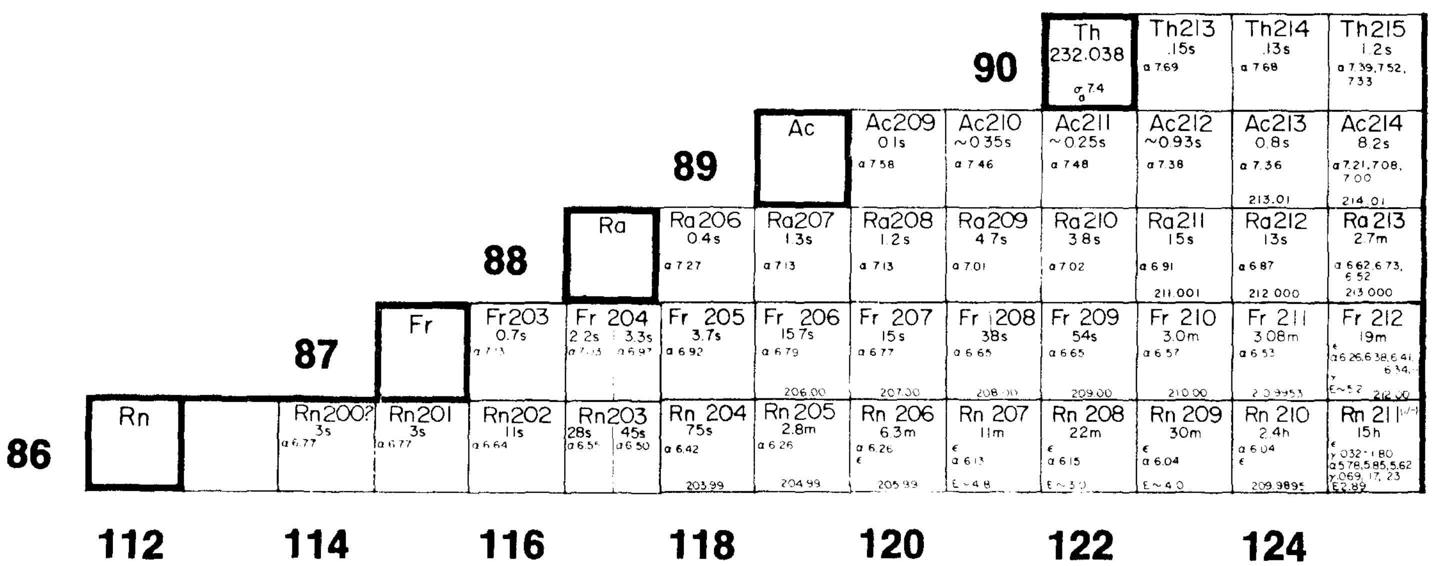
Os187 Os188 Os189 Os190 Os191 Os192 Os 193 Os 194 Os 195
Re186 Re187 Re188 Re189 Re 190 Re 191 Re192
W185 W186 W187 W188 W189
Ta184 Ta185 Ta186
Hf183
122
118
120
112
114
116
Os181 Os182 Os183 Os184 Os 185 Os 186
Re 178 Re179 Re 180 Re181 Re 182 Re183 Re184 Re185
W173 W174 W176 W177 W178 W179 W180 W181 W182 W183 W184
Ta172 Ta173 Ta176 Ta177 Ta178 Ta179 Ta180 Ta181 Ta182 Ta183
Hf169 Hf170 Hf171 Hf172 Hf173 Hf174 Hf175 Hf176 Hf177 Hf178 Hf179 Hf180 Hf181 Hf182
Lu168 Lu169 Lu173 Lu174 Lu175 Lu176 Lu177 Lu178 Lu179 Lu180
Yb167 Yb168 Yb169 Yb170 Yb171 Yb172 Yb173 Yb174 Yb175 Yb176 Yb177
Tm166 Tm167 Tm168 Tm169 Tm170 Tm172 Tm173 Tm174 Tm175 Tm176
110
98
100
102
104
106
108

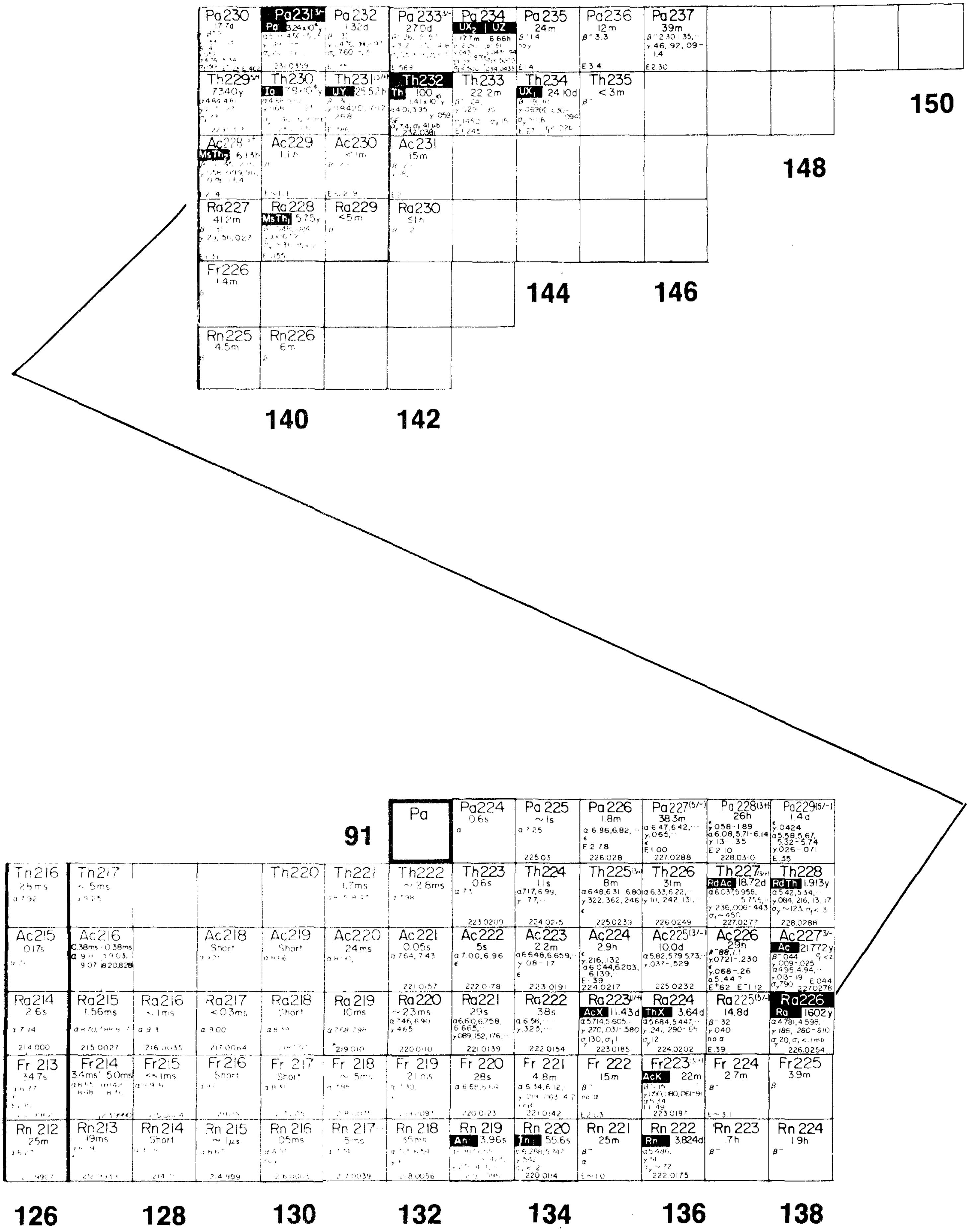

81
Tl
204.37
80
Hg
200.59
Hg179
3.5s
Hg180
6s
Hg181
3.6s
Hg182
10s
Hg183
9s
Hg184
32s
Hg185
52s
Hg186
1.4m
79
Au
196.967
Au177
1.3s
Au178
3s
Au179
7.5s
Au181
11s
Au183
49s
Au184
1.0m
Au185
4.3m
78
Pt
195.09
Pt173
Short
Pt174
0.7s
Pt175
2.1s
Pt176
6.6s
Pt177
6.9s
Pt178
21s
Pt179
33s
Pt180
52s
Pt181
51s
Pt182
2.9m
Pt183
7m
Pt184
77
Ir
192.2
Ir171
1.0s
Ir172
2s
Ir173
3s
Ir174
4s
Ir175
5s
Ir176
8s
Ir177
21s
Ir181
Short
Ir182
15m
Ir183
58m
76
Os
190.2
Os176
3.6m
Os178
5m
Os179
8m
Os180
24m
Os181
2.8m
105m
Os182
21.5h
94
96
98
100
102
104
106


Tl 201
Tl 202
Tl 203
Tl 204
Tl 205
Tl 206
Tl 207
Tl 208
Tl 209
Tl 210
Hg 200
Hg 201
Hg 202
Hg 203
Hg 204
Hg 205
Hg 206
Au 199
Au 200
Au 201
Au 202
Au 203
Au 204
Pt 198
Pt 199
Pt 200
Pt 201
Ir 197
132
128
130
124
126
120
122
Tl 191
Tl 192
Tl 193
Tl 194
Tl 195
Tl 196
Tl 197
Tl 198
Tl 199
Tl 200
Hg 187
Hg 188
Hg 189
Hg 190
Hg 191
Hg 192
Hg 193
Hg 194
Hg 195
Hg 196
Hg 197
Hg 198
Hg 199
Au 186
Au 187
Au 188
Au 189
Au 190
Au 191
Au 192
Au 193
Au 194
Au 195
Au 196
Au 197
Au 198
Pt 185
Pt 186
Pt 187
Pt 188
Pt 189
Pt 190
Pt 191
Pt 192
Pt 193
Pt 194
Pt 195
Pt 196
Pt 197
Ir 184
Ir 185
Ir 186
Ir 187
Ir 188
Ir 189
Ir 190
Ir 191
Ir 192
Ir 193
Ir 194
Ir 195
Ir 196
Os 183
Os 184
Os 185
Os 186
Os 187
Os 188
Os 189
Os 190
Os 191
Os 192
Os 193
Os 194
Os 195
108
110
112
114
116
118


86
85
84
83
82
81
Rn
Rn200?
Rn201
Rn202
Rn203
Rn 204
At
At194
At195
At196
At197
At 198
At199
At200
At 201
At 202
At 203
Po
Po192
Po 193
Po 194
Po 195
Po 196
Po 197
Po 198
Po 199
Po 200
Po201
Po 202
Bi
208.980
Bi190
Bi191
Bi192
Bi193
Bi194
Bi195
Bi196?
Bi197?
Bi198
Bi 199
Bi200
Bi 201
Pb
207.19
Pb 194
Pb 195
Pb 196
Pb197
Pb 198
Pb199
Pb 200
Tl
204.37
Tl 191
Tl 192
Tl193
Tl 194
Tl195
Tl196
Tl 197
Tl 198
Tl199
106
108
110
112
114
116
118


Rn 217
Rn 218
Rn 219
Rn 220
Rn 221
Rn 222
Rn 223
Rn 224
Rn225
Rn226
At 216
At 217
At 218
At 219
Po 215
Po 216
Po 217
Po 218
Bi 214
Bi 215
Pb 213
Pb 214
132
134
136
138
140
142
Rn 205
Rn 206
Rn 207
Rn 208
Rn 209
Rn 210
Rn 211
Rn 212
Rn213
Rn214
Rn 215
Rn 216
At 204
At 205
At 206
At 207
At 208
At209
At 210
At 211
At 212
At 213
At 214
At 215
Po 203
Po 204
Po205
Po 206
Po207
Po 208
Po 209
Po 210
Po211
Po212
Po213
Po214
Bi 202
Bi 203
Bi 204
Bi 205
Bi 206
Bi 207
Bi208
Bi209
Bi210
Bi 211
Bi 212
Bi 213
Pb201
Pb 202
Pb203
Pb 204
Pb205
Pb 206
Pb207
Pb 208
Pb209
Pb210
Pb 211
Pb 212
Tl 200
Tl 201
Tl 202
Tl 203
Tl 204
Tl 205
Tl 206
Tl 207
Tl 208
Tl209
Tl 210
120
122
124
126
128
130


90
Th
232.038
Th213
Th214
Th215
89
Ac
Ac209
Ac210
Ac211
Ac212
Ac213
Ac214
88
Ra
Ra206
Ra207
Ra208
Ra209
Ra210
Ra211
Ra212
Ra213
87
Fr
Fr203
Fr 204
Fr 205
Fr 206
Fr 207
Fr 208
Fr 209
Fr 210
Fr 211
Fr 212
86
Rn
Rn200?
Rn201
Rn202
Rn203
Rn 204
Rn 205
Rn 206
Rn 207
Rn 208
Rn 209
Rn 210
Rn 211
112
114
116
118
120
122
124


Pa230
Pa231
Pa232
Pa233
Pa234
Pa235
Pa236
Pa237
Th229
Th230
Th231
Th232
Th233
Th234
Th235
Ac228
Ac229
Ac230
Ac231
Ra227
Ra228
Ra229
Ra230
Fr226
Rn225
Rn226
150
148
144
146
140
142
91
Pa
Pa224
Pa225
Pa226
Pa227
Pa228
Pa229
Th216
Th217
Th220
Th221
Th222
Th223
Th224
Th225
Th226
Th227
Th228
Ac215
Ac216
Ac218
Ac219
Ac220
Ac221
Ac222
Ac223
Ac224
Ac225
Ac226
Ac227
Ra214
Ra215
Ra216
Ra217
Ra218
Ra219
Ra220
Ra221
Ra222
Ra223
Ra224
Ra225
Ra226
Fr213
Fr214
Fr215
Fr216
Fr217
Fr218
Fr219
Fr220
Fr221
Fr222
Fr223
Fr224
Fr225
Rn212
Rn213
Rn214
Rn215
Rn216
Rn217
Rn218
Rn219
Rn220
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Rn222
Rn223
Rn224
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128
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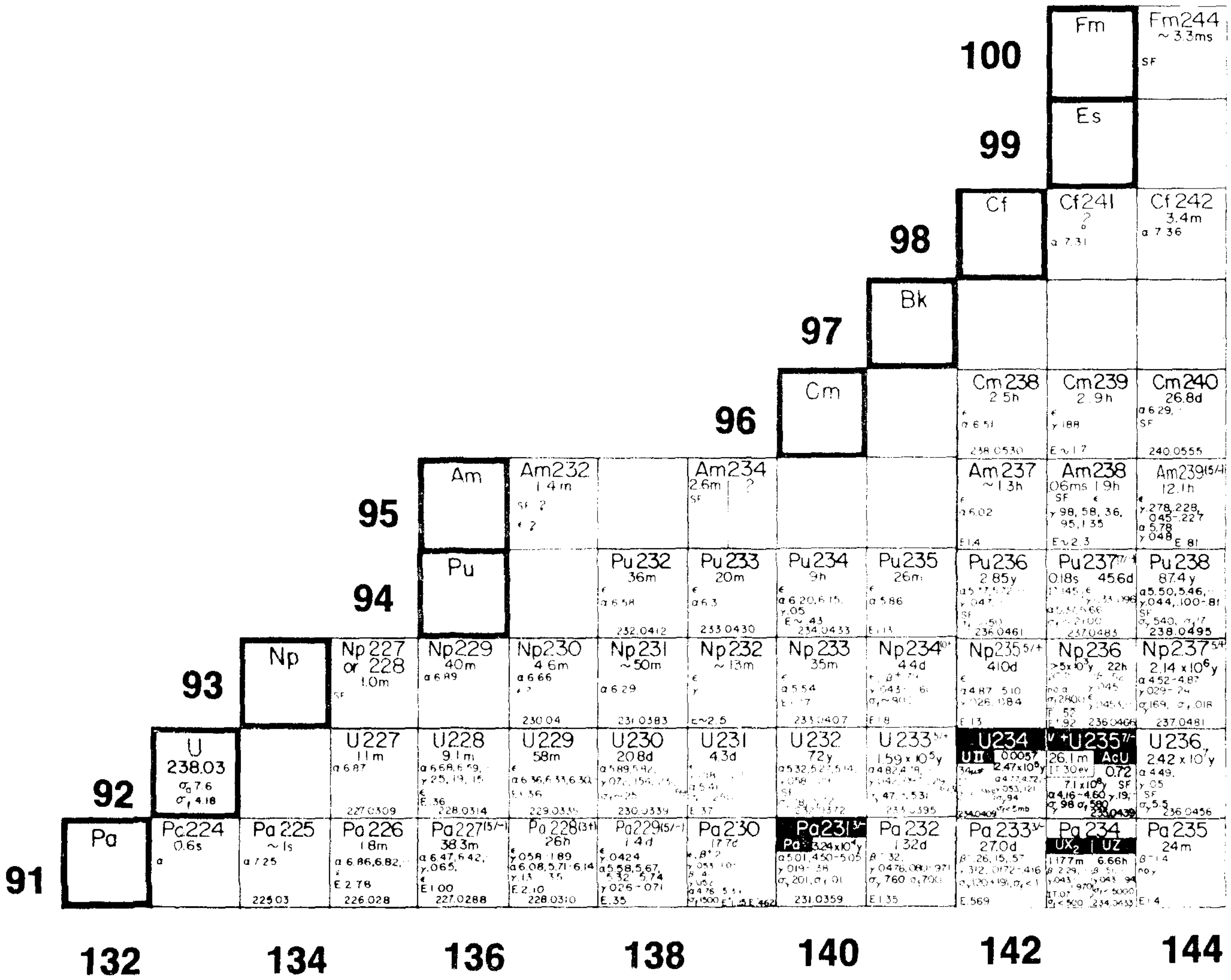
136
138



100
99
98
97
96
95
94
93
92
91
Fm
Fm244
Es
Cf
Cf241
Cf242
Bk
Cm
Cm238
Cm239
Cm240
Am
Am232
Am234
Am237
Am238
Pu
Pu232
Pu233
Pu234
Pu235
Pu236
Pu237
Pu238
Np
Np227 or 228
Np229
Np230
Np231
Np232
Np233
Np234
Np235
Np236
Np237
U
238.03
U227
U228
U229
U230
U231
U232
U233
U234
U235
U236
Pa
Pa224
Pa225
Pa226
Pa227
Pa228
Pa229
Pa230
Pa231
Pa232
Pa233
Pa234
Pa235
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134
136
138
140
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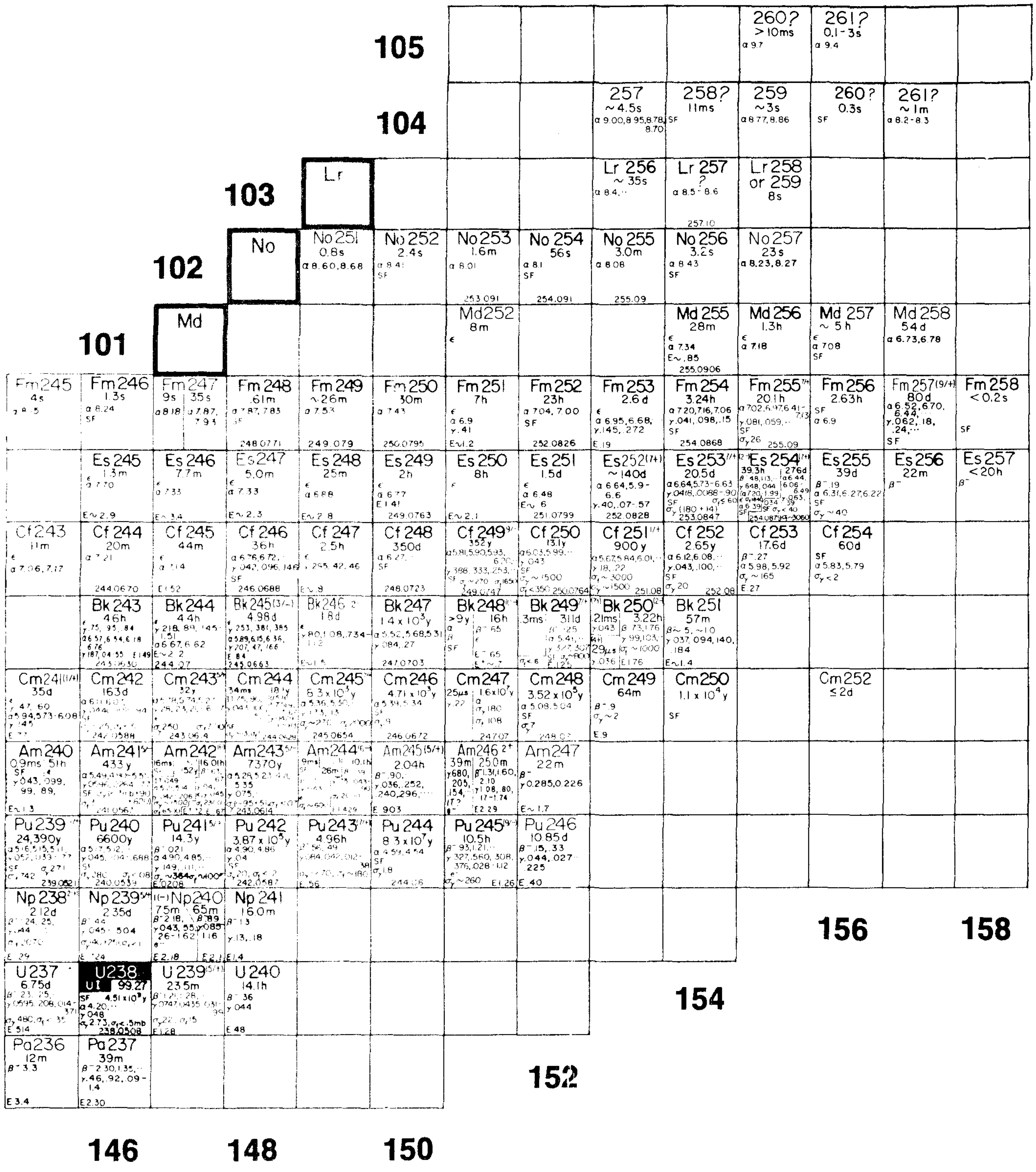
105
104
103
102
101
260? >10ms
261? 0.1-3s
257 ~4.5s
258? 11ms
259 ~3s
260? 0.3s
261? ~1m
Lr
Lr 256 ~35s
Lr 257 ?
Lr 258 or 259 8s
No
No 251 0.8s
No 252 2.4s
No 253 1.6m
No 254 56s
No 255 3.0m
No 256 3.2s
No 257 23s
Md
Md 252 8m
Md 255 28m
Md 256 1.3h
Md 257 ~5h
Md 258 54d
Fm 245 4s
Fm 246 1.3s
Fm 247 9s 35s
Fm 248 .61m
Fm 249 ~2.6m
Fm 250 30m
Fm 251 7h
Fm 252 23h
Fm 253 2.6d
Fm 254 3.24h
Fm 255 20.1h
Fm 256 2.63h
Fm 257 80d
Fm 258 <0.2s
Es 245 1.3m
Es 246 7.7m
Es 247 5.0m
Es 248 25m
Es 249 2h
Es 250 8h
Es 251 1.5d
Es 252 ~140d
Es 253 20.5d
Es 254
Es 255 39d
Es 256 22m
Es 257 <20h
Cf 243 11m
Cf 244 20m
Cf 245 44m
Cf 246 36h
Cf 247 2.5h
Cf 248 350d
Cf 249 352y
Cf 250 13.1y
Cf 251 900y
Cf 252 2.65y
Cf 253 17.6d
Cf 254 60d
Bk 243 4.6h
Bk 244 4.4h
Bk 245 4.98d
Bk 246 1.8d
Bk 247
Bk 248 16h
Bk 249 311d
Bk 250 3.22h
Bk 251 57m
Cm 241 35d
Cm 242 163d
Cm 243 32y
Cm 244 18.1y
Cm 245
Cm 246
Cm 247
Cm 248
Cm 249 64m
Cm 250
Cm 252 ≤2d
Am 240 51h
Am 241 433y
Am 242
Am 243 7370y
Am 244
Am 245 2.04h
Am 246
Am 247 22m
Pu 239 24,390y
Pu 240 6600y
Pu 241 14.3y
Pu 242
Pu 243 4.96h
Pu 244
Pu 245 10.5h
Pu 246 10.85d
Np 238 2.12d
Np 239 2.35d
Np 240 7.5m 65m
Np 241 16.0m
U 237 6.75d
U 238 99.27
U 239 23.5m
U 240 14.1h
Pa 236 12m
Pa 237 39m
146
148
150
152
154
156
158

LIST OF ATOMIC ELEMENTS

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