Introduction

This appendix contains information of general interest to help explain some of the details of discussions where the terms used to explain nuclear events may not be too well known. It also lists the definitions of the coded items that are used in various experiments in this manual.

Linear and Logic Signal Standards in EG&G ORTEC NIM Instruments

Introduction to NIM

EG&G ORTEC has established itself as the leading manufacturer of NIM modules and related products since the introduction of the Standardized Nuclear Instrument Module (NIM). We offer the largest selection of NIM electronics available anywhere, and all modules conform to the standards outlined in AEC (adopted by DOE) Report TID-20893 (Rev) which ensures compatibility between instruments provided by various manufacturers. Specifications and testing of EG&G ORTEC NIM modules are made in accordance with "IEEE Standard Test Procedures for Amplifiers and Preamplifiers for Semiconductor Radiation Detectors for Ionizing Radiation" where applicable.

LINEAR AND LOGIC STANDARDS AND CONNECTIONS Since many EG&G ORTEC instruments utilize both linear and logic signals it is always important to distinguish between linear and logic connections when setting up NIM equipment. The amplitude of a linear signal contains information about the energy of a detected event. Therefore, linear signals vary over a range of amplitudes, and the analysis of linear signal amplitudes from an instrument reveals the energy spectrum of the photon source. By contrast, logic signals have a fixed amplitude and shape. They are used to provide timing information and to control the function of subsequent instruments in a system. Both linear and logic signal connections are made by coaxial cables and standard BNC connectors.

LINEAR SIGNALS Linear signals from EG&G ORTEC NIM modules conform to the NIM-standard preferred practices for 0 to 10 V spans.

Standard polarity and span do not apply to the linear signal between the preamplifier and the amplifier. This signal must be variable in span and polarity to accommodate particular applications. However, all EG&G ORTEC preamplifiers are standardized with respect to the output pulse shape and typically furnish a 50 μs or greater time-constant tail pulse to the main amplifier. The main amplifier accommodates this standardized input pulse with a compatible pole-zero-cancellation facility. In addition, EG&G ORTEC main amplifiers accommodate either input polarity.

Linear Signal Interconnections EG&G ORTEC instruments always provide linear output signals through a very low source impedance, typically $<1\ \Omega$. Some instruments also provide the output signals through a second circuit with 93-Ω source impedance.

The low impedance ($<1\ \Omega$) allows connection of almost any load without loss of signal span due to internal loss in the source impedance itself. For instance, a 100-Ω load may be driven to the full 10 V span. If a 93-Ω source must drive a 93-Ω or 100-Ω load, half of the span will be lost. For these reasons, the low-impedance outputs are simpler to use. They also permit paralleled multiple loads without loss of span. A potential problem with the low-impedance output is oscillation due to reflections from unterminated cables more than 5 ft long. For this reason cables should be terminated at the receiving end or connected to the 93-Ω output if it is available. The 93-Ω outputs may be used for full-span signal transfer only if the receiving end of the output cable is essentially an open circuit, meaning 1000 Ω or more in practice. If a lower impedance is encountered, the span will be reduced. The chief virtue of the 93-Ω output is absolute stability for variable cable conditions, obtained at the expense of variable span dependent on load impedance.

LOGIC SIGNALS All EG&G ORTEC instruments use standardized (positive and fast negative) logic signals to provide full interunit compatibility.

Positive Logic Signals The standard positive logic signal is used for slow- to medium-speed logic signals with repetition rates from dc to 20 MHz. The NIM-standard Preferred Practice provisions define this signal by the following amplitude limits:

	Output (must deliver)	**Input (must respond to)**
Logic 1	+4 to +12 V	+3 to +12 V
Logic 0	+1 to −2 V	+1.5 to −2 V

In addition, EG&G ORTEC imposes further standards on the positive logic signal:

Pulse width: 0.5 μs nominally.
Source impedance: 10 Ω or less nominally.
Input impedance: 1000 Ω or more nominally.

Connection of the positive logic sources and loads should be made with 93-Ω coaxial cables. RG-62A/U cables with UG-260/U (BNC) connectors are recommended.

For cable lengths under 5 ft, impedance-matching cable termination is not usually required since reflections are not a problem. In longer cable lengths, proper termination with a 100-Ω terminator is advisable to prevent cable reflections.

Fast Negative Logic Signals The standard fast negative logic signal is used when rise time or repetition rate requirements exceed the capability of the standard positive logic pulses. The NIM Preferred Practice provisions define this signal as one that is furnished into a 50-Ω impedance with the following characteristics:

	Output (must deliver)	Input (must respond to)
Logic 1	−14 to −18 mA	−12 to −36 mA
Logic 0	−1 to +1 mA	−4 to +20 mA

Because of the fast rise time, the fast negative logic signal must be used with properly terminated cables to prevent reflections. Therefore 50-Ω cables and terminations such as RG-58C/U cables with UG-88/U connectors are recommended.

The rise time of the fast negative logic pulse is not specified in the NIM Preferred Practice provisions. In EG&G ORTEC instruments the rise time is typically 2 ns. The leading edge is normally used for all triggering, and width is unimportant except for repetition and rate considerations.

Equipment and Supplies Identified by Code

Source Kits

SK-1G Sealed Solid Disk Gamma-Ray Sources ~1 μCi, ^{137}Cs, ^{60}Co, ^{22}Na, ^{65}Zn, ^{54}Mn.

SK-1X Sealed X-Ray Sources (Disk Type) 1–5 μCi, ^{57}Co, ^{55}Fe, ^{65}Zn.

SK-1A Unsealed Alpha Sources (Disk Type) 0.01–0.1 μCi, ^{241}Am, ^{210}Po, ^{244}Cm.

SK-1B Sealed Beta and Conversion Electron Sources (Disk Type) 1–5 μCi, ^{204}Tl, ^{207}Bi, ^{137}Cs, ^{113}Sn.

OT8 RaD and E Split Check Source Set; ^{210}Pb and ^{210}Bi, ~1 μCi, includes blank-half to retain geometry when using either half alone.

Detector Stands and Housings

M-NaI-3 Stand for 2- x 2-in. NaI Tube; 6 counting levels.

MPM-9 Stand for 2- x 2-in. Phototube; supports the Phototube above the 305 Vacuum Chamber.

MGM-5 Stand for GM Counter; contains GM Tube and stand with 6 counting levels.

MT-624 Three Stands for the Gamma Time-of-Flight Experiment. One stand is used for positioning the ^{22}Na source; the other two are for mounting the phototubes on axis with the source coincident gamma rays.

Absorber Kits and Target Kits

PbAl-23 Contains 10 lead absorbers from 800 to 8000 mg/cm^2 and 20 aluminum absorbers from 0 to 3000 mg/cm^2.

3-Z2 Contains 3 foils each of the following: Al, Fe, Cu, Mo, Sn, Ta, and Pb. Thicknesses range from 400 mg/cm^2 to 1500 mg/cm^2.

MCU-5 10 copper asorbers in the range from 1.25 mg/cm^2 to 7.05 mg/cm^2.

MNI-5 10 nickel absorbers in the range from 1.5 mg/cm^2 to 8.25 mg/cm^2.

M-12 Sample set for x-ray fluorescence includes: Fe, Ni, Cu, Zn, Mo, Cd, Ag, Ge, and Zr plus 3 composite samples.

M-15 Rutherford Scattering Target Kit; contains thin foils of Cu, Al, Au, and Ag.

313 Neutron Activation Sample Set; contains 3-gm sample of high-purity metal: V, Al, Ge, Mn, and Cu.

317 Neutron Activation Sample Set; contains; Ag, Ti, W, Na, and Co.

V-17 Contains 10 each vanadium samples used for Experiment 17.4.

RE-17 Contains elements with high activation cross section samples of In, La, Br, and I.

Cd-17 Six (6) each cadmium shields for Experiment 17.6.

318 Contains 6 samples with high cross sections for fast neutrons: Mg, Na, Si, V, Fe, and Cr.

MC252 Six (6) each Ag foils for fission fragment time-of-flight energy loss.

MAL-25 Six (6) each Ag foils for alpha particle energy loss by time-of-flight.

301 Air Pollution Filter Standards; to be used with either Model 311 or 312 Chambers for standardization; contains: Si, Ca, Fe, Cu, and Ag.

Individual Absorbers and Shields

AlFl-1 Aluminum Foil, 2 x 2 in. x 2 mg/cm^2
AlFl-2 Aluminum Foil, 2 x 2 in. x 5 mg/cm^2
AlFl-3 Aluminum Foil, 2 x 2 in. x 10 mg/cm^2
AlFl-4 Aluminum Foil, 2 x 2 in. x 20 mg/cm^2
AlFl-5 Aluminum Foil, 2 x 2 in. x 50 mg/cm^2

AlPl-1 Aluminum Plate, 4 x 4 x 1/8 in.
AlRd-1 Aluminum Rod, 0.5 in. diam x 4 in. long
AlRd-2 Aluminum Rod, 2 cm diam x 1 cm long (~10 g)
AlRd-3 Aluminum Rod, 6 cm diam x 7 cm long
AuFl-1 Gold Foil, 200 $\mu g/cm^2$
AuFl-x Gold Foil, 1.31 to 27.1 mg/cm^2
CdPl-1 Cadmium Plate, 4 x 4 x 1/16 in.
CuRd-1 Copper Rod, 6 cm diam x 7 cm long
NiFl-1 Nickel Foil, 2 x 2 in. x 5 mg/cm^2
NiFl-x Nickel Foil. 0.74 to 13.46 mg/cm^2
PbPl-1 Lead Plate, 3 x 3 x 1/16 in.
PbPl-2 Lead Plate, 4 x 4 x 1/16 in.
PbPl-3 Lead Plate, 4 x 4 x 1 in.
PbRd-1 Lead Rod, 6 cm diam x 7 cm long
PnPl-1 Paraffin Plate, 4 x 4 x 1/2 in.
PnPl-2 Paraffin Plate, 4 x 4 x 1 in.
FeRd-1 Iron Rod, 6 cm diam x 7 cm long
PnRd-1 Paraffin Shadow Bar Rod, 6 cm diam x 7 cm long
SlPl-1 Steel Plate, 4 x 4 x 1/8 in.

Chambers, Howitzers, Angular Correlation Tables, Filter Sample Collectors

302 Portable, High-Velocity Filter Collector for collecting air pollution samples. Air flow rates up to 70 cubic feet per minute.

305 Vacuum Can with Thin Plastic Window, 4 in. diam x 6 in. high. Most α and β experiments can be done in this chamber and also α,γ or β,γ coincidence experiments.

306 Angular Correlation Table, 46 in. x 46 in. x 30 in. high. Contains lead shields for fixed and movable 2 x 2 in. NaI detectors. The angular settings are accurate to ±0.1°.

307 Rutherford Scattering Chamber, 11-3/4-in. diam x 5-1/4-in. high; polished aluminum. The detector can be moved under vacuum with an accuracy of ±0.25°

308 Neutron Howitzer, 3 ft x 3 ft x 3 ft; contains four each 1-in. activation ports for neutron sources up to 10 Ci. The source can be locked in the chamber for safety while the students are doing the experiment.

309 Compton Scattering Apparatus, 36 in. x 46 in. x 30-in. high. Rotating shield for 2 x 2 in. NaI detector. Angular accuracy ±0.10°. The lead shield for the ^{137}Cs source can be locked for student safety.

310 Proportional Counter Chamber; vacuum chamber 8-in. diam x 3-in. deep. Four sample positions which can be indexed under vacuum. Primarily designed for x-ray attenuation measurements.

311 Chamber for X-Ray Fluorescence Measurements with a Si(Li) Detector; 8-in. diam x 3-in. deep. Designed to fit onto an upright Si(Li) detector. Four each selectable sample positions under vacuum.

312 Chamber for X-Ray Fluorescence with a Proportional Counter. Same as Model 311 except it is designed to be used with a high-resolution proportional counter.

M367 Alpha Particle Time-of-Flight Chamber; 11-3/4 in. diam x 5-1/4-in. high. Provisions for movable source and detectors. Flight paths up to 22.5 cm are possible. High vacuum tested to 1 x 10^{-6} mm of Hg.

3C52 Fission Fragment Studies Chamber; 8-in. diam x 3-in. deep. Four sample positions which can be indexed under vacuum. The fission source and solid-state detector are precisely aligned on axis with the absorber foils.

MAX 21 Chamber for Innershell Ionization Studies. The chamber is coupled to a Si(Li) x-ray detector with high vacuum techniques. The source, foils, and center line of the detector are all precisely aligned for geometrical purposes. The system can be evacuated to 1 x 10^{-6} mm of Hg.

HTS-1 High Transmission Stand Set for the Total Neutron Cross Section Experiment. The stands are Webb designed for minimum neutron scattering.

Glossary

Absorption Coefficient: Fractional decrease in the intensity of a beam of x- or gamma-radiation per unit thickness (linear absorption coefficient), per unit mass (mass absorption coefficient), or per atom (atomic absorption coefficient) of absorber, due to deposition of energy in the absorber. The total absorption coefficient is based on the sum of individual energy absorption processes (Compton effect, photoelectric effect, and pair production).

Absorption Coefficient, Atomic: The linear absorption coefficient of a nuclide divided by the number of atoms per unit volume of the nuclide. It is equivalent to the nuclide's total cross section for the given radiation.

Absorption Coefficient, Compton: That fractional decrease in the energy of a beam of x- or gamma-radiation due to the deposition of the energy to electrons produced by Compton effect in an absorber. (See also Scattering, Compton.)

Absorption Coefficient, Linear: A factor expressing the fraction of a beam of x- or gamma-radiation absorbed in unit thickness of material. In the expression $I = I_0e^{-\mu x}$, I_0 is the initial intensity, I is the intensity of the beam after passage through a thickness, x, of the material, and μ is the linear absorption coefficient.

Absorption Coefficient, Mass: The linear absorption coefficient per cm divided by the density of the absorber in grams per cm^3. It is frequently expressed as μ/ρ, where μ is the linear absorption coefficient and ρ the absorber density.

Alpha Particle: A helium nucleus, consisting of two protons and two neutrons, with a double positive charge.

Analysis, Activation: A method of chemical analysis, especially for small traces of material, based on the detection of characteristic radionuclides following a nuclear bombardment.

Analysis, Feather: A technique for the determination of the range in aluminum of the beta particles of a radio-element by comparison of the absorption curve with the absorption curve of a reference series, usually ^{210}Bi (range 501 mg/cm^2).

Angstrom Unit (Å): One angstrom unit equals 10^{-8} cm.

Atomic Number: The number of orbital electrons surrounding the nucleus of a neutral atom and according to present theory the number of protons in the nucleus (Symbol: Z).

Attenuation: The process by which a beam of radiation is reduced in intensity when passing through some material. It is the combination of absorption and scattering processes and leads to a decrease in flux density of the beam when projected through matter.

Attenuation Coefficient, Compton: The fractional number of photons removed from a beam of radiation per unit thickness of a material through which it is passing as a result of Compton effect interactions.

Attenuation Factor: A measure of the opacity of a layer of material for radiation traversing it; the ratio of the incident intensity to the transmitted intensity. It is equal to I_0/I, where I_0 and I are the intensities of the incident and emergent radiation, respectively. In the usual sense of exponential absorption ($I = I_0e^{-\mu x}$) the attenuation factor is $e^{-\mu x}$, where x is the thickness of the material, and μ is the absorption coefficient.

Auger Effect: The emission of an electron from the extranuclear portion of an excited atom when the atom undergoes a transition to a less excited state.

Average Life (Mean Life): The average of the individual lives of all the atoms of a particular radioactive substance. It is 1.443 times the radioactive half-life.

Avogadro's Number (6.025 x 10^{23} physical scale): Number of atoms in a gram atomic weight of any element; also the number of molecules in the gram molecular weight of any substance.

Backscattering: The deflection of radiation by scattering processes through angles >90° with respect to the original direction of motion.

Barn: Unit expressing the probability of a specific nuclear reaction taking place in terms of cross-sectional area. Numerically it is 10^{-24} cm^2.

Beta Particle: Charged particle emitted from the nucleus of an atom and having a mass and charge equal in magnitude to those of the electron.

Branching: The occurrence of two or more modes by which a radionuclide can undergo radioactive decay. For example, RaC can undergo α and β^- decay, ^{64}Cu can undergo β^-, β^+, and electron capture decay. An individual atom of a nuclide exhibiting branching disintegrates by one mode only. The fraction disintegrating by a particular mode is the branching fraction for that mode. The branching ratio is the ratio of two specified branching fractions (synonym: multiple disintegration).

Bremsstrahlung: Secondary photon radiation produced by deceleration of charged particles passing through matter.

Capture, Electron: A mode of radioactive decay involving the capture of an orbital electron by its nucleus. Capture from a particular electron shell is designated as K-electron capture, L-electron capture, etc.

Capture, K-Electron: Electron capture from the K shell by the nucleus of the atom. Also loosely used to designate any orbital electron-capture process.

Capture, Radiative: The process by which a nucleus captures an incident particle and loses its excitation energy immediately by the emission of gamma radiation.

Compton Effect: An attenuation process observed for x- or gamma-radiation in which an incident photon interacts with an orbital electron of an atom to produce a recoil electron and a scattered photon of energy less than the incident photon.

Conversion, Internal: A mode of radioactive decay in which the gamma rays from excited nuclei cause the ejection of orbital electrons from the atom. The ratio of the number of internal conversion electrons to the number of gamma quanta emitted in the de-excitation of the nucleus is called the "conversion ratio."

Cosmic Rays: High energy particulate and electromagnetic radiations which originate outside of the earth's atmosphere.

Coulomb: Unit of electrical charge in the practical system of units. A quantity of electricity equal to 3 x 10^9 electrostatic units of charge.

Cross Section, Nuclear: The probability that a certain reaction between a nucleus and an incident particle or photon will occur. It is expressed as the effective "area" that the nucleus presents for the reaction. (See Barn.) Macroscopic cross section refers to the cross section per unit volume (preferably) or per unit mass. Microscopic cross section is the cross section of one atom or molecule.

Decay, Radioactive: Disintegration of the nucleus of an unstable nuclide by the spontaneous emission of charged particles and/or photons.

Delta Ray: Any secondary ionizing particle ejected by recoil when a primary ionizing particle passes through matter.

Deuterium: A heavy isotope of hydrogen having one proton and one neutron in the nucleus (Symbol: D or ^2_1H).

Disintegration, Constant: The fraction of the number of atoms of a radioactive nuclide which decay in unit time; λ in the equation $N = N_0e^{-\lambda t}$, where N_0 is the initial number of atoms present and N is the number of atoms present after some time, t.

Disintegration, Nuclear: A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus. When numbers of nuclei are involved, the process is characterized by a definite half-life.

Electron: Negatively charged particle which is a constituent of every neutral atom. Unit of negative electricity equal to 4.8 x 10^{-10} electrostatic units or 1.6 x 10^{-19} coulomb. Its mass is 0.000549 atomic mass units.

Electron Volt (eV): A unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Larger multiple units of the electron volt are frequently used, viz: keV for thousand or kilo electron volts, MeV for million electron volts, and BeV for billion electron volts; 1 eV = 1.6 x 10^{-12} erg.

Element: Pure substance consisting of atoms of the same atomic number which cannot be decomposed by ordinary chemical means.

Emulsion, Nuclear: A photographic emulsion specially designed to permit observation of the individual tracks of ionizing particles.

Energy: Capacity for doing work. Potential energy is the energy inherent in a mass because of its position with reference to other masses. Kinetic energy is the energy possessed by a mass because of its motion; cgs units: g-cm^2/s^2 or ergs.

Energy, Binding: The energy represented by the difference in mass between the sum of the component parts and the actual mass of the nucleus.

Energy, Excitation: The energy required to change a system from its ground state to an excited state. With each different excited state there is associated a different excitation energy.

Energy, Ionizing: The average energy lost by ionizing radiation in producing an ion pair in a gas. For air it is about 33 eV.

Energy, Radiant: The energy of electromagnetic waves, such as radio waves, visible light, x rays and gamma rays.

Energy, Reaction (Nuclear): In the disintegration of a nuclear reaction, it is equal to the sum of the kinetic or radiant energies of the reactants minus the sum of the kinetic or radiant energies of the products. (If any product of a specified reaction is in an excited nuclear state, the energy of subsequently emitted gamma radiation is not included in the sum.) The ground-state nuclear reaction energy is the reaction energy when all reactant and product nuclei are in their ground states (Symbol: Q_0).

Excitation: The addition of energy to a system, thereby transferring it from its ground state to an excited state. Excitation of a nucleus, an atom, or a molecule can result from absorption of photons or from inelastic collisions with other particles.

Fluorescence: The emission of radiation of particular wavelengths by a substance as a result of absorption of radiation of shorter wavelength. This emission occurs essentially only during the irradiation.

Flux: For electromagnetic radiation, the quantity of radiant energy flowing per unit time. For particles and photons, the number of particles or photons flowing per unit time.

Gamma Ray: Short wavelength electromagnetic radiation of nuclear origin with a range of wavelengths from about 10^{-8} to 10^{-11} cm, emitted from the nucleus.

Geiger Region: In an ionization radiation detector, the operating voltage interval in which the charge collected per ionizing event is essentially independent of the number of primary ions produced in the initial ionizing event.

Geiger Threshold: The lowest voltage applied to a counter tube for which all pulses produced in the counter tube are of substantially the same size, regardless of the size of the primary ionizing event.

Geometry, Good: In nuclear physics measurements, an arrangement of source and detecting equipment so that the use of finite source size and finite detector aperture introduces little error.

Gram Atomic Weight: A mass in grams numerically equal to the atomic weight of an element.

Half-Life, Radioactive: Time required for a radioactive substance to lose 50% of its activity by decay. Each radionulcide has a unique half-life.

Half Value Layer (Half Thickness): The thickness of any particular material necessary to reduce the intensity of an x-ray or gamma-ray beam to one-half its original value.

Ionization: The process or the result of any process by which a neutral atom or molecule acquires either a positive or a negative charge.

Ionization, Total: The total electric charge of one sign on the ions produced by radiation in the process of losing all of its kinetic energy. For a given gas, the total ionization is closely proportional to the initial ionization and is nearly independent of the nature of the ionizing radiation. It is frequently used as a measure of radiation energy.

Ion Pair: Two particles of opposite charge, usually referring to the electron and positive atomic or molecular residue resulting after the interaction of ionizing radiation with the orbital electrons of atoms.

Isobar: One of two or more different nuclides having the same mass number but differing in atomic number. Originally called isobares but the name "isobars" is now generally employed.

Isomer: One of several nuclides having the same number of neutrons and protons but capable of existing, for a measurable time, in different quantum states with different energies and radioactive properties. Commonly, the isomer of higher energy decays to one with lower energy by the process of isomeric transition.

Isotope: One of several nuclides having the same number of protons in their nuclei, and hence having the same atomic number, but differing in the number of neutrons, and therefore in the mass number. Almost identical chemical properties exist between isotopes of a particular element. The use of this term as a synonym for nuclide is to be discouraged.

Isotope, Stable: A nonradioactive isotope of an element.

keV: The symbol for 1000 electron volts, or 10^3 eV.

Mass Number: The number of nucleons (protons and neutrons) in the nucleus of an atom.

MeV: The symbol for 1 million electron volts, or 10^6 eV.

Micron: Unit of length equal to 10^{-6} meter. Preferred usage is "micrometer." Use of "micron" is discouraged by IUPAP.

Mil: Linear measurement unit equal to one-thousandth of an inch.

Neutrino: A neutral particle of very small rest mass postulated to account for the continuous distribution of energy among the particles in the beta-decay process and to allow for conservation of momentum in beta decay.

Neutron: Elementary nuclear particle with a mass approximately the same as that of a hydrogen atom and electrically neutral; its mass is 1.008982 mass units. Neutrons are commonly divided into sub-classifications according to their energies as follows: thermal, around 0.025 eV; epithermal, 0.1 eV to 100 eV; slow, $<$100 eV; intermediate, 10^2 to 10^5 eV; fast, $>$0.1 MeV.

Nucleon: Common name for a constituent particle of the nucleus; applied to protons and neutrons, but will include any other particle found to exist in the nucleus.

Nucleus (Nuclear): That part of an atom in which the total positive electric charge and most of the mass are concentrated.

Nuclide: A species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons, Z, number of neutrons, N, and energy content; or, alternatively, by the atomic number Z, mass number $A = (N + Z)$, and atomic mass. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable time; thus nuclear isomers are separate nuclides, whereas promptly decaying excited nuclear states and unstable intermediates in nuclear reactions are not so considered.

Pair Production: An absorption process for x- and gamma-radiation in which the incident photon is annihilated in the vicinity of the nucleus of the absorbing atom with subsequent production of an electron and positron pair. This reaction only occurs for incident photon energies exceeding 1.02 MeV.

Photoelectric Effect: A process by which a photon ejects an electron from an atom. All the energy of the photon is absorbed in ejecting the electron and in imparting kinetic energy to it.

Photon: A quantity of electromagnetic energy whose value in ergs is the product of its frequency in cycles/s and Planck's constant. The equation is: $E = h\nu$.

Planck's Constant: A natural constant of proportionality, (h), relating the frequency of a quantum of energy to the total energy of the quantum:

$$h = \frac{E}{\nu} = 6.624 \times 10^{-27} \text{ erg-s.}$$

Positron: Particle equal in mass to the electron and having an equal but opposite charge.

Power, Stopping: A measure of the effect of a substance upon the kinetic energy of a charged particle passing through it.

Rare Earth: Any of the series of very similar metals ranging in atomic number from 57 through 71.

Reaction (Nuclear): An induced nuclear disintegration, that is, a process occurring when a nucleus comes into contact with a photon, an elementary particle, or another nucleus. In many cases the reaction can be represented by the symbolic equation: $X + a \rightarrow Y + b$ or, in abbreviated form, X(a,b)Y, in which X is the target nucleus, a is the incident particle or photon, b is an emitted particle or photon, and Y is the product nucleus.

Roentgen: An exposure dose of x- or gamma-radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign (abbreviated R).

Scattering: Change of direction of subatomic particle or photon as a result of a collision or interaction.

Scattering, Compton: The inelastic scattering of a photon through interaction with atomic electrons, accompanied by ejection of a recoil electron from the atom with which the interaction occurred. Compton-scattered photons carry away a fraction of the incident photon energy, ranging from an average of about 85% of the initial energy for a 0.1-MeV photon to an average of about 30% for a 10-MeV photon. Sometimes referred to as incoherent scattering.

Scattering, Elastic: Scattering effected through the agency of elastic collisions and therefore with conservation of kinetic energy of the system. Rayleigh scattering is a form of elastic scattering.

Scattering, Inelastic: The type of scattering which results in the nucleus being left in an excited state and the total kinetic energy being decreased.

Time Units: Standardized abbreviations for time units are:

1 y = 1 year
1 d = 1 day
1 h = 1 hour
1 min = 1 minute
1 s = 1 second
1 ms = 1 millisecond = 10^{-3} s
1 μs = 1 microsecond = 10^{-6} s
1 ns = 1 nanosecond = 10^{-9} s
1 ps = 1 picosecond = 10^{-12} s

Tritium: (^3_1H or T) The hydrogen isotope having one proton and two neutrons in the nucleus.

X-Rays: Penetrating electromagnetic radiations having wavelengths shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions it is customary to refer to photons originating in the nucleus as gamma rays and those originating in the extranuclear part of the atom as x rays. These rays are sometimes called roentgens, after their discoverer, W. C. Roentgen.

Relative Sensitivities of Elements to Thermal Neutron Activation

The following table of neutron activation analysis sensitivities, taken from ORAU Report 102, Isotopic Neutron Source Experiments, by G. I. Gleason, should be quite useful to schools that have either an isotopic neutron source such as Am-Be or a small ^{252}Cf neutron source. The numbers in the table are equally valid for thermalized accelerator neutron sources. Information can be extracted from this table in regard to unknowns that are used in the activation analysis experiments in this manual.

Experimentally determined sensitivities are relative and are based on the sensitivity of aluminum. If the irradiation and counting system is capable of measuring the results from 1 milligram of aluminum, then it is capable of measuring the listed quantity of each element in milligrams. In each case, the reaction product and gamma energy have been selected to give the best interference-free sensitivity.

Irradiation to saturation is assumed for nuclides having half-lives in seconds or minutes. An overnight, (16-h), irradiation is assumed for longer-lived nuclides.

Measurements of the activities were made with NaI(Tl) scintillation detectors. Sensitivity was assigned on the basis of the amount of the element required to produce a discharge count rate of 100 net counts per minute in the photopeak for the product nuclide. The listed relative sensitivities would be approximately the same for measurement with a Ge(Li) detector. With Ge(Li), longer counting periods are necessary because of their lower efficiencies; hence, very short half-life activities can be expected to show a decreased sensitivity. The higher resolution of the Ge(Li) detector, however, is an advantage when interferences are present.

Neutron Activation Sensitivities

Atomic Number	Element	Product Nuclide	Half-Life	Measured E_γ (keV)	Relative Sensitivity*	Atomic Number	Element	Product Nuclide	Half-Life	Measured E_γ (keV)	Relative Sensitivity*
9	Fluorine	^{20}F	11.6 s	1634	60.	49	Indium	^{116m}In	53.7 m	1293	0.006
11	Sodium	^{24}Na	15.0 h	2754	1.5	50	Tin	^{125m}Sn	9.5 m	331	15.
12	Magnesium	^{27}Mg	9.46 m	844	35.	51	Antimony	^{122}Sb	64.3 h	564	0.7
13	Aluminum	^{28}Al	2.32 m	1779	1.0	52	Tellurium	^{131}Te	24.8 m	150	5.7
17	Chlorine	^{38}Cl	37.3 m	2168	8.	53	Iodine	^{128}I	25.0 m	443	0.3
19	Potassium	^{42}K	12.4 h	1525	28.	55	Cesium	^{134m}Cs	2.9 h	127	0.4
20	Calcium	^{49}Ca	8.8 m	3084	260.	56	Barium	^{139}Ba	83.0 m	166	3.2
21	Scandium	^{46m}Sc	18.7 s	143	0.03	57	Lanthanum	^{140}La	40.2 h	1597	0.8
22	Titanium	^{51}Ti	5.79 m	320	18.	58	Cerium	^{143}Ce	33.7 h	293	14.
23	Vanadium	^{52}V	3.75 m	1434	0.07	59	Praseodymium	^{142}Pr	19.2 h	1576	5.
24	Chromium	^{51}Cr	27.8 d	320	85.	60	Neodymium	^{149}Nd	104.0 m	211	5.
25	Manganese	^{56}Mn	2.58 h	847	0.015	62	Samarium	^{153}Sm	46.8 h	103	0.07
27	Cobalt	^{60m}Co	10.5 m	59	0.23	63	Europium	^{152m}Eu	9.3 h	963	0.008
28	Nickel	^{65}Ni	2.53 h	1482	130.	64	Gadolinium	^{161}Gd	3.6 m	360	–
29	Copper	^{66}Cu	5.10 m	1039	6.	65	Terbium	^{160}Tb	72.0 d	299	4.
30	Zinc	^{69m}Zn	14.1 h	439	23.	66	Dysprosium	^{165}Dy	2.32 h	95	0.01
31	Gallium	^{72}Ga	14.1 h	834	0.32	67	Holmium	^{166}Ho	26.8 h	81	0.2
32	Germanium	^{75m}Ge	48.0 s	140	5.2	68	Erbium	^{171}Er	7.52 h	308	0.36
33	Arsenic	^{76}As	26.4 h	559	0.32	69	Thulium	^{170}Tm	129.0 d	84	90.
34	Selenium	^{77m}Se	17.4 s	162	0.27	70	Ytterbium	^{175}Yb	101.0 h	396	1.5
35	Bromine	^{80}Br	16.8 m	616	0.8	71	Lutetium	^{176m}Lu	3.7 h	88	0.2
37	Rubidium	^{86m}Rb	1.02 m	556	5.	72	Hafnium	^{179m}Hf	18.6 s	214	0.05
38	Strontium	^{87m}Sr	2.83 h	389	3.	73	Tantalum	^{182}Ta	115.0 d	1121	35.
39	Yttrium	^{89m}Y	16.1 s	909	23.	74	Tungsten	^{187}W	24.0 h	686	0.4
42	Molybdenum	^{101}Tc	14.2 m	307	8.	75	Rhenium	^{188}Re	16.7 h	155	0.07
44	Ruthenium	^{105}Ru	4.4 h	724	12.	76	Osmium	^{193}Os	31.5 h	139	35.
45	Rhodium	^{104m}Rh	4.3 m	51	0.03	77	Iridium	^{192}Ir	74.2 d	317	0.3
46	Palladium	^{109m}Pd	4.7 m	189	5.5	78	Platinum	^{199}Pt	31.0 m	543	25.
47	Silver	^{110m}Ag	24.0 s	658	0.35	79	Gold	^{198}Au	64.7 h	412	0.027
48	Cadmium	^{111m}Cd	49.0 m	245	18.	80	Mercury	^{197}Hg	65.0 h	78	1.2

*The numbers in this column indicate the number of units (weight) of an element that provide a count rate equal to the count rate furnished from irradiation of one unit weight of aluminum.

X-Ray Critical-Absorption and Emission Energies in keV

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Increased use of energy-proportional detectors for x rays has created a need for a table of energy values of K and L absorption and emission series.

The table presented here includes all elements. Most values were obtained by a conversion to keV of tabulated experimental wavelength values (1–3); some are from previous energy-value compilations (4,5). Where a choice existed, the value chosen was the one derived from later work. Certain values were determined by interpolation, using Moseley's law. (All this is annotated in footnotes.)

The conversion equations relating energy and wavelength used are (6)

$$E(\text{keV}) = (12.39644 \pm 0.00017)/\lambda(\text{Å})$$
$$= 12.39644/1.002020\ \lambda(\text{kX unit})$$

In computing values the number of places retained sufficed to maintain the uncertainty in the original source value. The values in the table have been listed uniformly to 1 eV. However, chemical form may shift absorption edges as much as 10–20 eV (4,5).

To discover computational errors a fit was made to Moseley's law. In general the values were consistent, however there were a few irregularities due to the deviation of some input values (1). These were retained in the body of the table but a set of values calculated to fit better are footnoted.

* * *

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X-Ray Critical-Absorption and Emission Energies in kev

Atomic Number	Element	K series					L series							
		K_{ab}	$K\beta_2$	$K\beta_1$	$K\alpha_1$	$K\alpha_2$	L_{Iab}	L_{IIab}	L_{IIIab}	$L\gamma_1$	$L\beta_2$	$L\beta_1$	$L\alpha_1$	$L\alpha_2$
1	Hydrogen	0.0136‡												
2	Helium	0.0246‡												
3	Lithium	0.055			0.052									
4	Beryllium	0.116§			0.110									
5	Boron	0.192†			0.185									
6	Carbon	0.283			0.282									
7	Nitrogen	0.399			0.392									
8	Oxygen	0.531			0.523									
9	Fluorine	0.687†			0.677									
10	Neon	0.874*			0.851§		0.048†	0.022†	0.022†					
11	Sodium	1.08*		1.067	1.041		0.055§	0.034§	0.034§					
12	Magnesium	1.303		1.297	1.254		0.063	0.050	0.049					
13	Aluminum	1.559		1.553	1.487	1.486	0.087	0.073**	0.072**					
14	Silicon	1.838		1.832	1.740	1.739	0.118*	0.099**	0.098**					
15	Phosphorus	2.142		2.136	2.015§	2.014§	0.153*	0.129§	0.128§					
16	Sulphur	2.470		2.464	2.308	2.306	0.193*	0.164**	0.163**					
17	Chlorine	2.819¶		2.815	2.622	2.621	0.238*	0.203§	0.202§					
18	Argon	3.203		3.192§	2.957	2.955	0.287*	0.247**	0.245**					
19	Potassium	3.607		3.589	3.313	3.310	0.341*	0.297**	0.294**					
20	Calcium	4.038		4.012	3.691	3.688	0.399*	0.352	0.349			0.344	0.341	
21	Scandium	4.496		4.460	4.090	4.085	0.402*	0.411**	0.406**			0.399	0.395	
22	Titanium	4.964		−4.931	4.510	4.504	0.530*	0.460**	0.454**			0.458	0.452	
23	Vanadium	5.463		−5.427	4.952	4.944	0.604*	0.519**	0.512**			0.519	0.510	
24	Chromium	5.988		−5.946	5.414	5.405	0.679*	0.583**	0.574**			0.581	0.571	
25	Manganese	6.537		6.490	5.898	5.887	0.762*	0.650**	0.639**			0.647	0.636	
26	Iron	7.111		7.057	6.403	6.390	0.849*	0.721**	0.708**			0.717	0.704	
27	Cobalt	7.709		7.649	6.930	6.915	0.929*	0.794**	0.779**			0.790	0.775	
28	Nickel	8.331	8.328	8.264	7.477	7.460	1.015*	0.871**	0.853**			0.866	0.849	
29	Copper	8.980	8.976	8.904	8.047	8.027	1.100*	0.953	0.933			0.948	0.928	
30	Zinc	9.660	9.657	9.571	8.638	8.615	1.200*	1.045	1.022			1.032	1.009	
31	Gallium	10.368	10.365	10.263	9.251	9.234	1.30*	1.134**	1.117**			1.122	1.096	
32	Germanium	11.103	11.100	10.981	9.885	9.854	1.42*	1.248**	1.217**			1.216	1.186	
33	Arsenic	11.863	11.863	11.725	10.543	10.507	1.529	1.359	1.323			1.317	1.282	
34	Selenium	12.652	12.651	12.495	11.221	11.181	1.652	1.473	1.434			1.419	1.379	
35	Bromine	13.475	13.465	13.290	11.923	11.877	1.794§	1.599**	1.552**			1.526	1.480	
36	Krypton	14.323	14.313	14.112	12.648	12.597	1.931§	1.727**	1.675**			1.638§	1.587**	
37	Rubidium	15.201	15.184	14.960	13.394	13.335	2.067	1.866	1.806			1.752	1.694	1.692
38	Strontium	16.106	16.083	15.834	14.164	14.097	2.221	2.008	1.941			1.872	1.806	1.805
39	Yttrium	17.037	17.011	16.736	14.957	14.882	2.369	2.154	2.079			1.996	1.922	1.920
40	Zirconium	17.998	17.969	17.666	15.774	15.690	2.547	2.305	2.220	2.302	2.219	2.124	2.042	2.040

Atomic Number	Element	K series K_{ab}	$K\beta_2$	$K\beta_1$	$K\alpha_1$	$K\alpha_2$	L series $L_{I ab}$	$L_{II ab}$	$L_{III ab}$	$L\gamma_1$	$L\beta_2$	$L\beta_1$	$L\alpha_1$	$L\alpha_2$
41	Niobium	18.987	18.951	18.621	16.614	16.520	2.706	2.467**	2.374	2.462	2.367	2.257	2.166	2.163
42	Molybdenum	20.002	19.964	19.607	17.478	17.373	2.884	2.627	2.523	2.623	2.518	2.395	2.293	2.290
43	Technetium	21.054§	21.012§	−20.585¶	18.410¶	18.328¶	3.054§	2.795§	2.677§	2.792§	2.674§	2.538§	2.424§	2.420§
44	Ruthenium	22.118	22.072	21.655	19.278	19.149	3.236§	2.966	2.837	2.964	2.836	2.683	2.558	2.554
45	Rhodium	23.224	23.169	22.721	20.214	20.072	3.419	3.145	3.002	3.144	3.001	2.834	2.696	2.692
46	Palladium	24.347	24.297	23.816	21.175	21.018	3.617	3.329	3.172	3.328	3.172	2.990	2.838	2.833
47	Silver	25.517	25.454	24.942	22.162	21.988	3.810	3.528	3.352	3.519	3.348	3.151	2.984	2.978
48	Cadmium	26.712	26.641	26.093	23.172	22.982	4.019	3.727	3.538	3.716	3.528	3.316	3.133	3.127
49	Indium	27.928	27.859	27.274	24.207	24.000	4.237	3.939	3.729	3.920	3.713	3.487	3.287	3.279
50	Tin	29.190	29.106	28.483	25.270	25.042	4.464	4.157	3.928	4.131	3.904	3.662	3.444	3.435
51	Antimony	30.486	30.387	29.723	26.357	26.109	4.697	4.381	4.132	4.347	4.100	3.843	3.605	3.595
52	Tellurium	31.809	31.698	30.993	27.471	27.200	4.938	4.613	4.341	4.570	4.301	4.029	3.769	3.758
53	Iodine	33.164	33.016	32.292	28.610	28.315	5.190	4.856	4.559	4.800	4.507	4.220	3.937	3.926
54	Xenon	34.579	34.446¶	33.644	29.802¶	29.485¶	5.452	5.104	4.782	5.036§	4.720§	4.422§	4.111§	4.098§
55	Cesium	35.959	35.819	34.984	30.970	30.623	5.720	5.358	5.011	5.280	4.936	4.620	4.286	4.272
56	Barium	37.410	37.255	36.376	32.191	31.815	5.995	5.623	5.247	5.531	5.156	4.828	4.467	4.451
57	Lanthanum	38.931	38.728	37.799	33.440	33.033	6.283	5.894	5.489	5.789	5.384	5.043	4.651	4.635
58	Cerium	40.449	40.231	39.255	34.717	34.276	6.561	6.165†	5.729	6.052	5.613	5.262	4.840	4.823
59	Praseodymium	41.998	41.772	40.746	36.023	35.548	6.846	6.443	5.968	6.322	5.850	5.489	5.034	5.014
60	Neodymium	43.571	43.298¶	42.269	37.359	36.845	7.144	6.727	6.215	6.602	6.090	5.722	5.230	5.208
61	Promethium	45.207§	44.955§	−43.945¶	38.649¶	38.160¶	7.448§	7.018§	6.466§	6.891§	6.336§	5.956	5.431	5.408§
62	Samarium	46.846	46.553¶	45.400	40.124	39.523	7.754	7.281¶	6.721	7.180	6.587	6.206	5.636	5.609
63	Europium	48.515	48.241	47.027	41.529	40.877	8.069	7.624	6.983	7.478	6.842	6.456	5.846	5.816
64	Gadolinium	50.229	49.961	48.718	42.983	42.280	8.393	7.940	7.252	7.788	7.102	6.714	6.059	6.027
65	Terbium	51.998	51.737	50.391	44.470	43.737	8.724	8.258	7.519	8.104	7.368	6.979	6.275	6.241
66	Dysprosium	53.789	53.491	52.178	45.985	45.193	9.083	8.621¶	7.850¶	8.418	7.638	7.249	6.495	6.457
67	Holmium	55.615	55.292**	53.934§	47.528	46.686	9.411	8.920	8.074	8.748	7.912	7.528	6.720	6.680
68	Erbium	57.483	57.088	55.690	49.099	48.205	9.776	9.263	8.364	9.089	8.188	7.810	6.948	6.904
69	Thulium	59.335¶	58.969**	57.576¶	50.730	49.762	10.144	9.628	8.652	9.424	8.472	8.103	7.181	7.135
70	Ytterbium	61.303	60.959	59.352	52.360	51.326	10.486	9.977	8.943	9.779	8.758	8.401	7.414	7.367
71	Lutecium	63.304	62.946	61.282	54.063	52.959	10.867	10.345	9.241	10.142	9.048	8.708	7.654	7.604
72	Hafnium	65.313	64.936	63.209	55.757	54.579	11.264	10.734	9.556	10.514	9.346	9.021	7.898	7.843
73	Tantalum	67.400	66.999	65.210	57.524	56.270	11.676	11.130	9.876	10.892	9.649	9.341	8.145	8.087
74	Tungsten	69.508	69.090	67.233	59.310	57.973	12.090	11.535	10.198	11.283	9.959	9.670	8.396	8.333
75	Rhenium	71.662	71.220	69.298	61.131	59.707	12.522	11.955	10.531	11.684	10.273	10.008	8.651	8.584
76	Osmium	73.860	73.393	71.404	62.991	61.477	12.965	12.383	10.869	12.094	10.596	10.354	8.910	8.840
77	Iridium	76.097	75.605	73.549	64.886	63.278	13.413	12.819	11.211	12.509	10.918	10.706	9.173	9.098
78	Platinum	78.379	77.866	75.736	66.820	65.111	13.873	13.268	11.559	12.939	11.249	11.069	9.441	9.360
79	Gold	80.713	80.165	77.968	68.794	66.980	14.353	13.733	11.919	13.379	11.582	11.439	9.711	9.625
80	Mercury	83.106	82.526	80.258	70.821	68.894	14.841	14.212	12.285	13.828	11.923	11.823	9.987	9.896
81	Thallium	85.517	84.904	82.558	72.860	70.820	15.346	14.697	12.657	14.288	12.268	12.210	10.266	10.170
82	Lead	88.001	87.343	84.922	74.957	72.794	15.870	15.207	13.044	14.762	12.620	12.611	10.549	10.448
83	Bismuth	90.521	89.833	87.335	77.097	74.805	16.393	15.716	13.424	15.244	12.977	13.021	10.836	10.729
84	Polonium	93.112	92.386	89.809	79.296	76.868	16.935	16.244	13.817	15.740	13.338	13.441	11.128	11.014
85	Astatine	95.740	94.976	92.319	81.525	78.956	17.490	16.784	14.215	16.248	13.705	13.873	11.424	11.304
86	Radon	98.418	97.616	94.877	83.800	81.080	18.058	17.337	14.618	16.768	14.077	14.316	11.724	11.597
87	Francium	101.147	100.305	97.483	86.119	83.243	18.638	17.904	15.028	17.301	14.459	14.770	12.029	11.894
88	Radium	103.927	103.048	100.136	88.485	85.446	19.233	18.481	15.442	17.845	14.839	15.233	12.338	12.194
89	Actinium	106.759	105.838	102.846	90.894	87.681	19.842	19.078	15.865	18.405	15.227	15.712	12.650	12.499
90	Thorium	109.630	108.671	105.592	93.334	89.942	20.460	19.688	16.296	18.977	15.620	16.200	12.966	12.808
91	Protactinium	112.581	111.575	108.408	95.851	92.271	21.102	20.311	16.731	19.559	16.022	16.700	13.291	13.120
92	Uranium	115.591	114.549	111.289	98.428	94.648	21.753	20.943	17.163	20.163	16.425	17.218	13.613	13.438
93	Neptunium	118.619	117.533	114.181	101.005	97.023	22.417	21.596	17.614	20.774	16.837	17.740	13.945	13.758
94	Plutonium	121.720	120.592	117.146	103.653	99.457	23.097	22.262	18.066	21.401	17.254	18.278	14.279	14.082
95	Americium	124.876	123.706	120.163	106.351	101.932	23.793	22.944	18.525	22.042	17.677	18.829	14.618	14.411
96	Curium	128.088	126.875	123.235	109.098	104.448	24.503	23.640	18.990	22.699	18.106	19.393	14.961	14.743
97	Berkelium	131.357	130.101	126.362	111.896	107.023	25.230	24.352	19.461	23.370	18.540	19.971	15.309	15.079
98	Californium	134.683	133.383	129.544	114.745	109.603	25.971	25.080	19.938	24.056	18.980	20.562	15.661	15.420
99		138.067	136.724	132.781	117.646	112.244	26.729	25.824	20.422	24.758	19.426	21.166	16.018	15.764
100		141.510	140.122	136.075	120.598	114.926	27.503	26.584	20.912	25.475	19.879	21.785	16.379	16.113

For $Z \leq 69$, values without symbols are derived from (1). Values prefixed with a − sign are $K\beta_{1+3}$.

For $Z \geq 70$, absorption-edge values are from (4) in the case of Z = 70–83, 88, 90, and 92; remaining absorption edges to Z = 100 are obtained from these by least-squares quadratic fitting. All emission values for $Z \geq 70$ are derived from the preceding absorption edges, and others based on (4), using the transition relations $K\alpha_1 = K_{ab} - L_{III}$, $K\alpha_2 = K_{ab} - L_{II}$, $K\beta_1 = K_{ab} - M_{III}$, etc.

* Obtained from R. D. Hill, E. L. Church, J. W. Mihelich (5). † Derived from Compton and Allison (2). ‡ Derived from C. E. Moore (3).

¶ Values derived from Cauchois and Hulubei (1) which deviate from the Moseley law. Better-fitting values are: Z = 17, K_{ab} = 2.826; Z = 43, $K\alpha_1$ = 18.370, $K\alpha_2$ = 18.250, $K\beta_1$ = 20.612; Z = 54, $K\alpha_1$ = 29.779, $K\alpha_2$ = 29.463, $K\beta_2$ = 34.398; Z = 60, $K\beta_2$ = 43.349; Z = 61, $K\alpha_1$ = 38.726, $K\alpha_2$ = 38.180, $K\beta_1$ = 43.811; Z = 62, $K\beta_2$ = 46.581, L_{II} = 7.312; Z = 66, L_{II} = 8.591, L_{III} = 7.790; Z = 69, K_{ab} = 59.382, $K\beta_1$ = 57.487.

§ Calculated by method of least squares. ** Calculated by transition relations.