GAMMA RAY SPECTROSCOPY OF TIN - 113 AND OF ISOTOPES PRODUCED BY CYCLOTRON IRRADIATION OF COPPER

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A lithium drifted germanium detector and a NaI(Tl) sum coincidence spectrometer have been used in the study of the decay schemes of Sn^{113}, Zn^{62}, Cu^{62}, and Cu^{61}. A method is described for reducing the amount of positron annihilation radiation in the spectrum of a positron emitter. An ion exchange column was used for separating zinc and copper.

An upper limit of 0.04% has been set on the 648 keV cross over transition in In^{113}. The end-point energy of the inner bremsstrahlung radiation following the decay of Sn^{113} to the 393 keV level in In^{113} is found to be 680 $\pm$ 10 keV, giving a decay energy of 1.10 MeV.

The half-life of Zn^{62} has been found to be 9.3 $\pm$ 0.2 hours. Four new transitions in the decay have

been found at 303, 345, 549, and 640 keV. The energies and intensities of the others have been accurately established using the germanium detector.

The 1170 and 880 keV transitions in the decay of Cu^{62} have been confirmed.

The gamma rays in the decay of Cu^{61} have been studied and their energies and intensities measured.

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Abstract

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Chapter 1

INTRODUCTION

The atomic nucleus is a complex structure, and the theory describing it is in a rather incomplete state. Because any present theory that would describe all aspects of the nucleus would have too many parameters to be easily visualized by the human mind, various models have been proposed to describe different sets of properties of the nucleus. These are the optical model for scattering theory, and the shell model and the collective model for description of energy levels, to mention a few.

The shell model, or single particle model in particular, is applied to decay schemes. In this model the spin and parity of a nuclear state are given by a single nucleon, the rest of the nucleus being thought of as a closed system. Since a gamma ray represents an electromagnetic transition between two energy levels in a nucleus can then be determined from a knowledge of the gamma spectrum emitted. It is hoped that when enough knowledge about the nucleus has been gathered it will be possible to set up a comprehensive theory describing it.

In the study of decay schemes an important experimental result is the decay energy, from ground state to ground state. For electron capture decays, this energy can sometimes be measured through the inner bremsstrahlung spectrum, and this was the prime purpose of the study of Sn^{113} .

THEORY ON INNER BREMSSTRAHLUNG

There exists a probability that a nucleus X^{A}_{Z} having another nucleus Y^{A}_{Z-1} with lower total energy as its neighbor, will decay to this state. If the total decay energy available is greater than 1.022 MeV, then both positron emission and electron capture transitions are possible modes of decay. This decay will occur with a characteristic half-life which is given by the sum of the individual decay probabilities of positron emission and electron capture. In the latter, an orbital electron is captured by the nucleus which then emits a neutrino. The probability of this capture is roughly proportional to the amount of overlap of the wave functions of the electron and the nucleus. For this reason K-electron capture predominates over L-capture transitions whenever this is energetically possible. Since positron emission involves the creation of a positron emission involves the creation of a positron, it is possible that electron capture will be energetically possible even though positron emission is not. The ratio of the probability of positron emission to the probability of electron capture for a nucleus of given atomic number is given by Bouchez and Depommier (Bouchez and Depommier, 1960).

Accompanying K capture there is a weak

continuum of high energy gamma radiation called "Inner bremsstrahlung". Theoretical calculations have been done on this (Morrison and Schiff, 1940) using second order perturbation theory, assuming either Fermi or Gamow - Teller couplings for the weak interaction causing the decay of the nucleus. Their result for the distribution of intensity with energy of this inner bremsstrahlung is of the form

$$(N(k)/k)^{1/2} = \text{const}(w-k)$$

where k is the energy and N(k) is the number of photons at this energy, and w is the energy endpoint of the inner bremsstrahlung. Then if we assume that this endpoint corresponds to a decay to the ground state of the resultant nucleus, the total decay energy will be given by the energy endpoint of the inner bremsstrahlung plus the binding energy of the K electron. The total number of bremsstrahlung photons emitted per disintegration is given by

$$\frac{N(\text{photon})}{N(\text{capture})} = \int_0^w \frac{N(k)dk}{N(\text{capture})} = \frac{a}{12\pi}(w/mc^2)^2$$

where a is the fine structure constant and mc^2 is the energy of an electron at rest. Then by a suitable normalization, we can say that the bremsstrahlung spectral shape is of the form $x(1-x)^2$, where x is a quantity proportional to k. If a portion of the bremsstrahlung spectrum is found experimentally, then the total number of bremsstrahlung photons per disintegration can be found using this theory. For example, suppose the total number of counts under the curve is known from x equals 1 to x equals 0.65. We see that

$$\frac{\int_0^1 x(1-x)^2 \, dx}{\int_{.65}^1 x(1-x)^2 \, dx}$$ can be evaluated

to yield 7.9. Then, by multiplying by this factor the total number of bremsstrahlung photons per disintegration is obtained. Various corrections can be made to this simple theory (Martin and Glauber, 1956); however, it is reasonable to assume that the simple theoretical results should be of the correct order of magnitude.

Chapter 2

APPARATUS

Sum Coincidence Spectrometer

For coincidence work a set of NaI(Tl) spectrometers was used. Most of this equipment has been described previously by Brown (Brown, 1964) and Ungrin (Ungrin, 1965) and this will not be repeated. Detectors used were Harshaw (NaI(Tl)) integral line detectors. One detector consists of a 1 3/4" by 2" crystal optically coupled to a 2 inch R.C.A. photomultiplier tube type 8053. The other has a 3" by 3" crystal directly coupled to a 3" photomultiplier tube type 8054. This use of different sized crystals is convenient in sum coincidence spectrometry (Brown and Roulston, 1965). The apparatus includes twin double - delay line amplifiers after a design by Chase and Svelto (Chase and Svelto, 1961). A cross - over pick - off coincidence system (ORTEC model 205) was used for the fast coincidence channel. The resolving time varied with window width of the single channel analysers from a low of about 20 nanoseconds for narrow windows to about 150 nanoseconds for both windows wide open. One of the problems encountered with this system was that careful setting of the cross - over pick - offs was required. Even so, due to a slight mismatching of the delay lines in the amplifiers, there was a " walk " with pulse height variation of about 15 nanoseconds over the range of one amplifier, with the other amplifier held fixed. This was found using both an oscilloscope and a time-to-amplitude converter (NE 9110). A resolving time much longer than this was used so as to avoid trouble from the " walk ". This method had the advantage over a trigger circuit firing on all pulses in that energy discrimination was built into the fast timing circuit. With this circuit we were able to go to lower energies, the previous trigger circuit used by Brown and Ungrin not operating below 50 keV.

The sum coincidence experiments were performed using a two parameter Nuclear Data 4096 channel analyser (see fig. 1 a for block diagram). Our system is basically the same as that of Hoogenboom (Hoogenboom, 1959), with the exception that a fast timing circuit has been added. Instead of a single channel analyser determining the sum energy of the coincident gamma rays, a range of sums is displayed on the y-axis of the two parameter analyser. This is an important advantage in dealing with short lived sources.

Figure 1

Apparatus

a) Block Diagram of Sum Coincidence

Spectrometer

TWO PARAMETER SUM COINCIDENCE

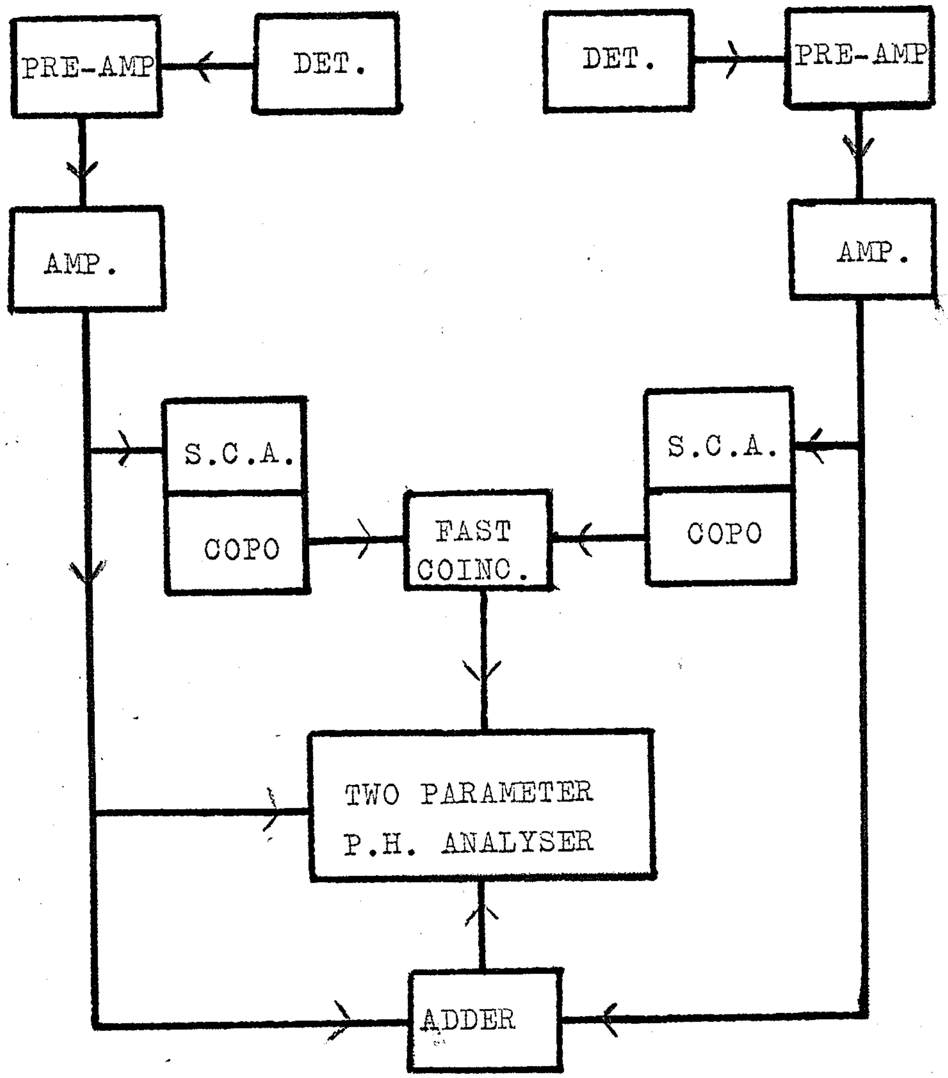
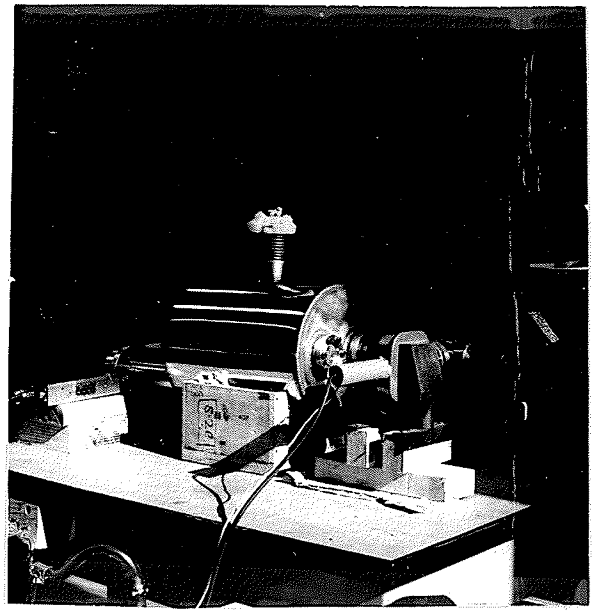


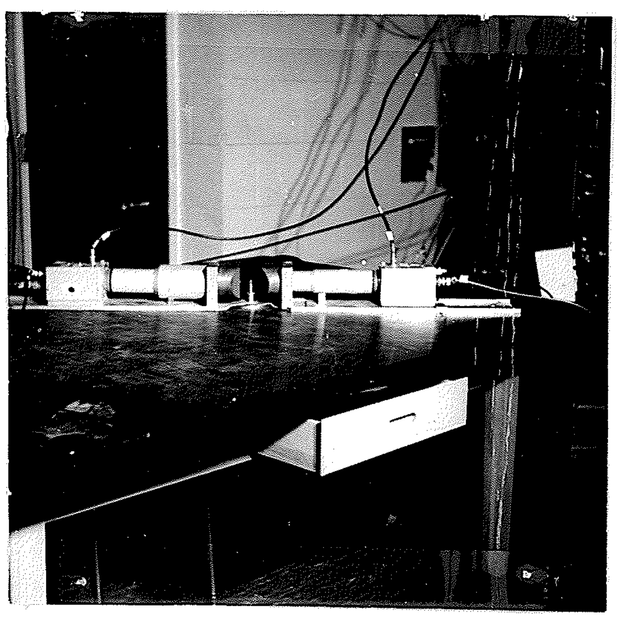
Figure 1

Apparatus

b) Cryostat and Detectors



Cryostat



NaI(Tl) Detectors

Lithium Drifted Germanium Detector

The normal resolution of a NaI(Tl) detector is 8%, although resolutions of 6% on the 661 keV Cs^{137} peak have been reported under good conditions. The principal limitation on the resolution attainable by scintillation detectors is the statistical variation in the number of photoelectrons emitted at the photocathode of the photomultiplier. This is due to the fact that it takes about 30 eV to produce an ion pair in NaI, in addition to the relatively low efficiency for conversion of light to electrons at the photocathode of the phototube.

One of the Chief advantages of using a solid state diode is that it requires only about 3 eV per ion pair in semiconductors such as germanium or silicon. This causes them to possess an inherently better resolution. The problem in the past has been the manufacture of diodes with sufficiently large depletion depths. The technique of making lithium drifted silicon diodes of sufficient depletion depth was mastered first. These were quite useful for stopping particles such as electrons, alphas, and protons. Because silicon has a low atomic number, these diodes were not very good for gamma ray spectroscopy, as the large Compton distribution obscured the small photopeaks.

Recently, the process of drifting lithium into germanium to form diodes has been mastered. Due to the higher atomic number of germanium, the cross section for the photoelectric effect is much higher. This enables them to be used at energies above 100 keV, which is the practical limit for photopeak production in silicon.

Because of the higher mobility of lithium in germanium as compared to silicon, it is necessary to operate these detectors below $-40\,^{\circ}$C. in order to keep the lithium from drifting out of the depletion region. For convenience, the usual practice is to operate them at liquid nitrogen temperature.

The detector used had an area of 2.8 cm^2 and a depletion depth of 2 mm. (R. C. A. type SJGG-2). It was kept in a cryostat containing liquid nitrogen. The cryostat used was kept evacuated using a model 921-0011 Varion " Vac-ion " pump which kept the pressure below 10^{-8} mm. of mercury. This prevented the detector leads from frosting up and slowed heat loss from the liquid nitrogen container. The preamplifier used was type NE 5231, and had a noise level of 2.1 keV at zero input capacitance and a noise slope of 0.04 keV/pF..

The spectrum was fed into a Nuclear Data 4096 channel analyser. The best resolution (full width of peak at half maximum height) obtained on the 122 keV peak of Co^{57} was 3.9 keV. After several months the detector inadvertently warmed up, due to vacuum failure. After it was repaired, it was found that the resolution had deteriorated to 4.3 keV on the 122 keV peak of Co^{57}. The leakage current of this detector was of the order of 10^{-9} amperes.

The efficiency of detection of gamma rays in the energy range below 1 MeV was quite low (of the order of 0.1 to 1%). The relative efficiency calibration of this detector was obtained using peaks of known intensity of La^{140}. A typical efficiency curve for one of the geometries used is included. As can be noted, the efficiency curve rises very sharply in the energy region below 200 keV, making efficiency calibration difficult in this region. It should be mentioned that the efficiency calibration was found to be dependent on the geometry used, particularly in the low energy region.

Figure 2

Ge(Li) Detector Efficiency Calibration