Measurement of the L/K-Capture Ratio in Fe^{55} Decay*

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The L and K x-radiations of manganese resulting from orbital-electron capture in a gaseous source of Fe^{55} have been studied in a multiwire proportional counter. The L/K-capture ratio was found to be 0.108 $\pm$0.006, in good agreement with the theoretical value.

INTRODUCTION

ACCURATE measurements of the L/K-capture ratio for simple allowed transitions have been carried out for only two nuclei, A^{37} and Ge^{71}. In the former case[1] good agreement was obtained with the theoretical results of Brysk and Rose[2] after taking account of the electron correlation correction factor of Odiot and Daudel.[3] However, for Ge^{71} the experimental L/K ratio[4] is 20% larger than the theoretical value,[2] and it seemed desirable to carry out measurements on another nucleus to see whether this discrepancy could be confirmed.

Fe^{55} decay was chosen for two reasons: (1) it is a simple allowed electron capture transition with a half-life of 2.60 years; and (2) a volatile iron compound (ferrocene) is fairly easily prepared. The internal bremsstrahlung spectrum has been measured by several groups[5–8] and the transition energy of 223$\pm$7 kev thus obtained is in good agreement with the value obtained from nuclear reaction studies.[9,10] No previous measurement of the L/K ratio had been made for this nucleus.

Measurements of the L/K ratio for nuclei with $Z<35$ generally have been made by introducing the radioactive material to a proportional counter as part of the gas filling and observing the resulting L and K peaks in the counter pulse distribution. Unfortunately, this straightforward method has the disadvantage, which becomes increasingly important as the energy of the x-radiation increases, that because of the finite dimensions of the counter some of the K x-rays escape detection in the counter gas. This is particularly undesirable in measurements of L/K ratios because the escape of $K\alpha$ x-rays (approx. 85% of the total K x-rays) not only diminishes the observed K x-radiation intensity, but also leads to an increase in the observed L x-radiation intensity due to the detection of the L x-radiation emitted along with the K_α x-ray. The observed L/K ratio can be corrected to take this effect into account but only an approximate value can be obtained for this correction, and this is in any case strongly dependent on the value assumed for the K-fluorescence yield, which is a quantity on which experimental limits are still quite high.

For nuclei heavier than A^{37} the escape correction becomes prohibitively large if counters of normal size and pressure are used, and, to circumvent the difficulties associated with the construction and operation of large, high-pressure counters, Drever, Moljk, and Curran[4,11] developed an anticoincidence system for their measurements on Ge^{71}. In this instrument the central counter is surrounded by a second proportional counter system in anticoincidence, all the counters being enclosed in one metal case. The counting volume of the central counter is defined by a ring of wires joined to the case, and further wires divide the layer of gas surrounding the central counter into several separate proportional counters. K x-rays escaping from the central counter are detected in the anticoincidence ring counters, which are arranged to have a diameter, at a workable gas pressure, equal to several half-distances. The pulses from the ring counters are used to gate the pulses from the central counter. With conventional counter dimensions and gas pressure the escape correction in such a system can be reduced to a few percent for a case such as Fe^{55}.

The iron compound used as the gaseous source was ferrocene (bicyclopentadienyl iron), which has a vapor pressure of about 0.2 mm at room temperature and is chemically very stable.

APPARATUS

The total diameter of the counter is 6 inches and the sensitive length of the central counter is 32 inches. The cathode of the central counter consists of 12 stainless steel wires of 0.010-inch diameter arranged in a circle of 2-in diameter, and connected electrically to the case. The volume between this circle of wires and the case is divided into six separate proportional counters by another 6 wires, which, together with the inner circle of wires, form the cathodes of the anticoincidence counters; the anodes of these counters, as well as of the

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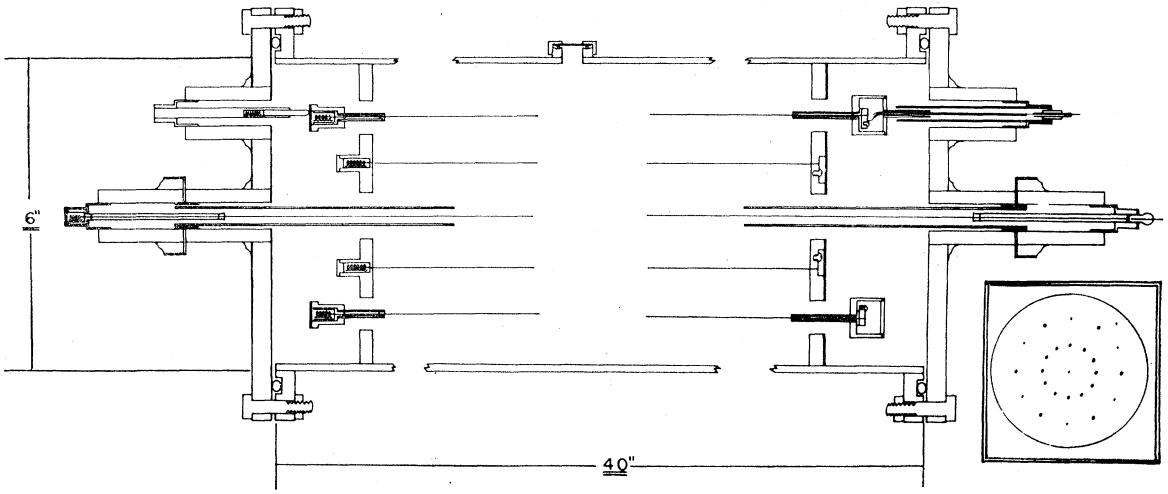

FIG. 1. General construction view of the multiwire counter with inset showing arrangement of the wires.

central counter, being stainless steel wires of 0.003-inch diameter.

The wires are kept taut by individual springs and, with the exception of the anode of the central counter, are mounted between two brass rings, which are held apart by three brass rods. The whole ring system can thus be removed entirely from the counter, facilitating cleaning or insertion of new wires if necessary. All counting wires are shielded from insulation breakdown by a guard tube system maintained at the same potential as the wires. The six wires forming the anodes of the ring counters are connected together inside the guard system and an electrical connection taken out through a guard tube and a high-voltage ceramic-metal vacuum seal to a preamplifier. The central counter is provided with field-correcting tubes as well as guard tubes, and electrical connections to these and to the central anode are brought out through similar seals. In order to enable the gains of the central and ring counters to be adjusted independently, a separate high-voltage power supply is connected to the anodes of the ring counters. A diagram of the counter is given in Fig. 1.

Pulses from the central counter are fed through a preamplifier, a nonoverloading linear amplifier with 3.6-μsec double delay-line clipping and a 10-μsec delay-line, to a linear anticoincidence gate. Pulses from the ring counters are amplified in a similar system and used to control the gate, the length of which was 60 μsec during the experiment. Those pulses which pass through the gate are fed to an oscilloscope and single-channel analyzer. The analyzer channel-width was calibrated between runs using a precision pulse generator. A block diagram of the electronics is given in Fig 2.

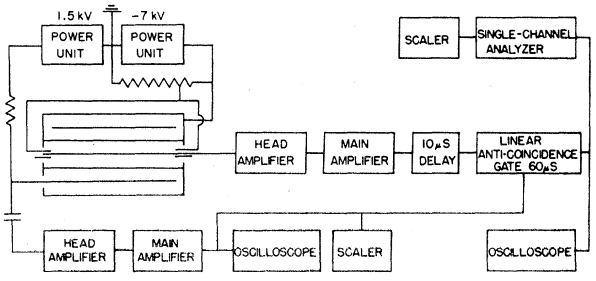

FIG. 2. Block diagram of the electronics.

The operation of the counter was first tested by observing the K and L peaks of A^{37}, a trace of which was introduced to the counter. In spite of the unusual construction, the energy resolution in both the central and ring counters is as good as would be obtained with a conventional counter. Figure 3 shows the 6.5 kev K-peak given by the ring counters with an Fe^{55} gaseous source, and the small amplitude of the low-energy tail indicates that very few K x-rays stopped in the ring counters would give pulses too small to trigger the gate, which was biased at 3.5 kev throughout the experiment. The tail is mainly due to natural background, which is shown as a dotted line in the figure but has not been subtracted.

EXPERIMENTAL PROCEDURE

Fe^{55} was obtained from Oak Ridge National Laboratory in the form of ferric chloride in hydrochloric acid solution. Ferrocene was prepared by the reaction between ferrous chloride and sodium cyclopentadiene in tetrahydrofuran as solvent. The solvent was evaporated at reduced pressure and the ferrocene collected and purified by sublimation.

Four separate samples of ferrocene were introduced into the counter, ranging in weight from a few mg to about 20 mg. It was found that the presence of the ferrocene at a partial pressure of about 0.1 mm had no effect on the operation of the counter, and background measurements made after pumping out the counter indicated that none of the source remained on the counter walls permanently.

Measurements were made at argon pressures of $\frac{1}{2}$, 1, and 2 atmos, with methane being added to a pressure of 10 cm as a quenching gas. At each pressure the K and L intensities were measured both by plotting differential pulse-height spectra and by integral-bias counting.

Some of the measurements at 2 atoms. pressure were performed with the counter heated to various temperatures up to about 70°C. No change was observed from the results obtained at room temperature, and, since the vapor pressure of ferrocene increases very rapidly with the temperature, this was an indication that none of the source had been condensed on the counter walls.

Pulse-height spectra in the regions of the 6.5-kev K-peak and the 0.76-kev L-peak are shown in Figs. 4 and 5. These are typical of about ten such spectra analyzed at 2 atmos pressure. The small peak at about 11 volts in Fig. 4 is an argon escape peak. In these diagrams the background is shown as a dashed line but has not been subtracted.

RESULTS

The ratio of counts in the L-peak to counts in the K-peak at $\frac{1}{2}$, 1, and 2 atmos pressure was found to be 0.124, 0.112, and 0.111, respectively. At $\frac{1}{2}$ atmos an appreciable fraction of K x-rays escape from the central counter and through the ring counters, giving rise to an apparent increase in the L/K ratio. At 1 atmos escape through the ring becomes very small and there is little variation in the observed L/K ratio with increase in pressure above the value. However, even at 2 atmos several small corrections have to be made to take account of K x-ray escape.

At 2 atmos the thickness of the ring counters is equivalent to about seven half-distances for the K x-rays and approximate calculations[12] show that the fraction which escape through the ends of the counter is 6×10^{-3}, and the fraction which hit the wires defining the sensitive volume of the central counter and are not detected is 4×10^{-3}. Corrections for dead-time in the electronics are negligible.

The true L/K-capture ratio R is then obtained from the observed value R' by substitution in the formula

$$R=R'(1-P\omega_K)-P\omega_K k,$$

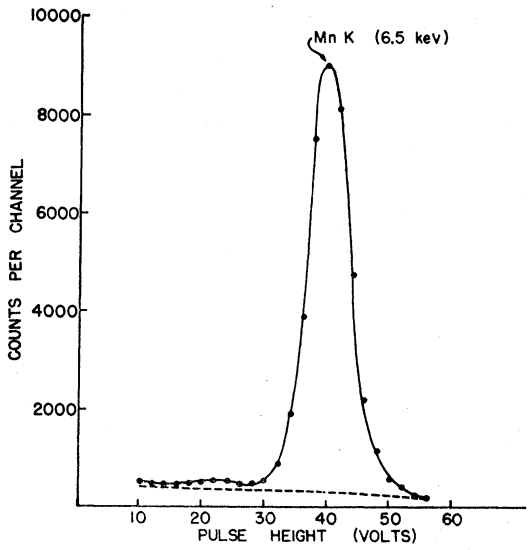

FIG. 3. Fe^{55} K-peak from the ring counters. The natural background is shown by the dashed line but has not been subtracted.

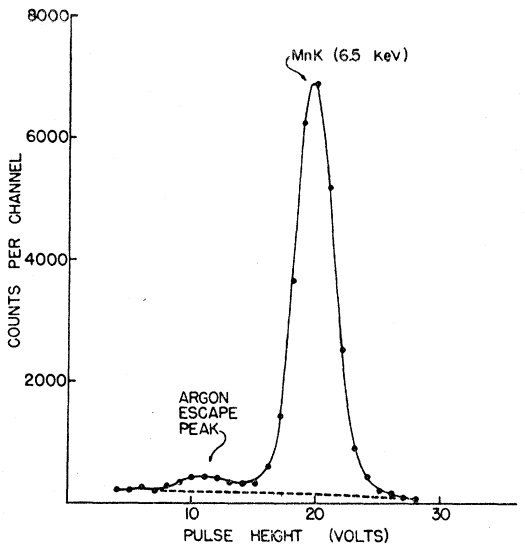

FIG. 4. Fe^{55} K-peak from the central counter in anticoincidence with the ring counters. The natural background is shown by the dashed line but has not been subtracted.

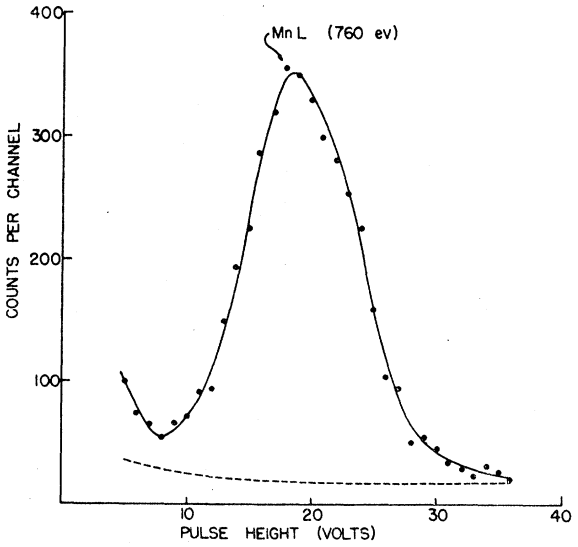

FIG. 5. Fe^{55} L-peak from the central counter in anticoincidence with the ring counters. The natural background is shown by the dashed line but has not been subtracted.

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where P is the probability of a K x-ray escaping from the counter, ω_K is the K-fluorescence yield of manganese, and k is the fraction of K_α x-rays in the manganese K series. The values of ω_K and k used in this work were 0.308[13] and 0.87,[14] respectively, but due to the very small value of P the final result is very insensitive to variations in the values of these quantities.

Using the mean value 0.111 obtained from several separate measurements of R', the L/K-capture ratio of Fe^{55} is obtained as

$$R=0.108\pm0.006.$$

Most of the uncertainty in the measurement arises in the determination of the number of counts in the L-peak. The statistical error is less than 1%.

From the curves of Brysk and Rose[2] the theoretical value of the L/K ratio for Fe^{55} is 0.097, which is slightly lower than the experimental value. Recently, however, Odiot and Daudel[3] have shown that in the theoretical calculations it is necessary to take into account the correlations between the positions of the atomic electrons, and this results in higher values of the theoretical L/K ratio. At present, correction factors have been calculated only for helium, beryllium, and argon, but the magnitude of the correction falls off rapidly with increasing atomic number and for Fe^{55} is of the order of 5–10%. Hence, with this correction, there is excellent agreement between the theoretical and experimental values of the L/K ratio.

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Collective Enhancement of $E2$ Matrix Elements in Light Nuclei*

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Several electric quadrupole transitions in nuclei in the neighborhood of O^{16} are discussed. The well-known strong enhancement of the single-nucleon matrix elements is interpreted as resulting from the virtual excitation of a collective 2+ state in the O^{16} core. It is found that an energy of 18 Mev for this state gives a satisfactory account of all of the experimental data. The enhanced matrix elements are expressed in terms of an effective charge, which is calculated in detail within the framework of the nuclear shell model. The value of the effective charge depends on the particular independent-nucleon states involved in the transition and is found to be approximately 0.5, 0.7, and 0.9 for $2s-1d$, $1d-1d$, and $1p-1p$ matrix elements, respectively. Of special interest is the result that the N^{14} quadrupole moment should possess the relatively large value of 3×10^{-26} cm^2, or about three times the simple shell-model value. This prediction has recently been confirmed by high-energy electron scattering measurements. The relation of the present work to previous theoretical treatments of enhancement by the methods of the hydrodynamic model and of configuration mixing is discussed. The Appendix on center-of-mass effects contains an explicit demonstration of the cancelling of the classical recoil quadrupole moment of O^{17} by a quantum mechanical exchange term.

I. INTRODUCTION

THE deformation of the nuclear core due to interaction with a few independent particles (or holes) outside a closed shell can be studied in analogy with the well-known process of the polarization of the vacuum in quantum electrodynamics. In analogy to the role played by the electron-positron pairs in the latter theory, the contribution of the core polarization to quadrupole moments and transition probabilities represents the result of virtual creation and annihilation of nucleon-hole pairs in the nucleus. The detailed consideration of the contributing virtual pair states corresponds to the description of the enhanced electromagnetic moments in terms of configuration mixing.[1–3] These straightforward treatments of configuration mixing by means of perturbation theory with a not unreasonably small energy denominator encounter difficulty in supplying an enhancement sufficiently large to agree with the experimental $E2$ moments and transition rates. This difficulty, which is discussed in detail below, originates in the inherently collective nature of the core deformation, which is not adequately taken into account by the perturbation approach.

Explicitly collective treatments of the nuclear polarization in terms of deformation of the surface of the core have been given by various authors.[4–6] It is the purpose of the present work[7] to give a treatment of

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