Nuclear Spins of I^{128} and I^{130}

J. E. SHERWOOD AND S. J. OVENSHINE
Oak Ridge National Laboratory, Oak Ridge, Tennessee
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The nuclear spins of I^{128} and I^{130} have been measured by means of an atomic beam magnetic resonance apparatus. A value of 1 was obtained for I^{128}, as predicted by Benczer *et al.* However, a value of 5 was obtained for I^{130}, in disagreement with the expectations of Caird and Mitchell. The nature of the discrepancy is indicated.

The apparatus and technique are described, with special attention to the source and detector arrangements.

INTRODUCTION

At present, the atomic beam magnetic resonance technique appears to be the most fruitful method of measuring nuclear moments. The experimental approach is very nearly the same as that introduced by Rabi and his collaborators in the thirties, the principal difference being that radioactive detection has made possible the study of many materials which were previously inaccessible. This technique is being used for determining the moments of radioactive nuclei in at least five laboratories in this country and several abroad.

We have chosen the neutron-excess isotopes of iodine for our initial studies, largely because of favorable physical and chemical properties as described below. Several isotopes of iodine have been reported on by the Berkeley atomic beam group.[1] Neutron-excess isotopes may readily be prepared with the existing facilities at Oak Ridge National Laboratory.

EXPERIMENTAL METHOD

Nuclear spins are customarily determined from observations of the weak-field Zeeman spectra of the atom. The energy levels are given, at low magnetic field, by

$$W_{f,m}=W_0(f)+mg_f\mu_0H.$$

Here f is the total angular momentum quantum number, $f=i+j,\ i+j-1,\ \ldots\ |i-j|$, where i and j are the nuclear and electronic angular momentum quantum numbers; $m=f, f-1, \ldots -f$;

$$g_f=g_J\frac{f(f+1)+j(j+1)-i(i+1)}{2f(f+1)}+g_i\frac{f(f+1)-j(j+1)+i(i+1)}{2f(f+1)};$$

$W_0(f)$ is the internal energy of the atom due to coupling of the nuclear and electronic angular momenta, and μ_0 is the Bohr magneton. For the transitions considered, $\Delta m=\pm1$, $\Delta f=0$, and $W_0(f)$ is constant. The frequency of the (single-quantum) transitions is then simply

$$\nu_f=g_f(\mu_0/h)H.$$

Thus each i gives a g_f and therefore a frequency for a given f.

It is worth noting that the term in g_i is very small and may be neglected; thus the line frequency is not affected by the magnitude of the nuclear magnetic moment. In this respect the atomic beam technique is superior to conventional spectroscopic methods.

To be observable, a transition must be such as to cause a large change in the *strong*-field magnetic moment of the atom. In the present work, the deflecting magnets are so arranged that only transitions which reverse the sign of the strong-field atomic magnetic moment cause refocussing; this is the "flop-in" method of Zacharias.[2] Figure 1 shows the atomic energy levels for $i=1$, $j=\frac{3}{2}$,

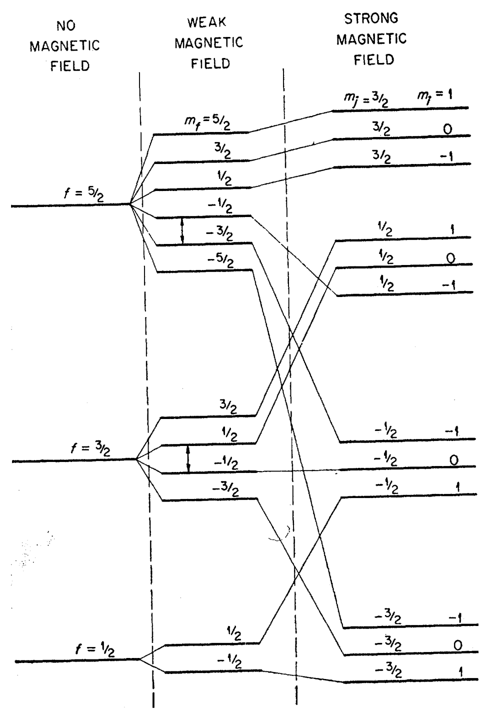

FIG. 1. Atomic energy levels *vs* magnetic field for $j=\frac{3}{2}$, $i=1$, $\mu_i>0$.

[1] Garwin, Green, and Lipworth, Phys. Rev. 111, 534 (1958), Bull. Am. Phys. Soc. Ser. II, 3, 370 (1958), Phys. Rev. Letters 1, 292 (1958).

[2] J. R. Zacharias, Phys. Rev. 61, 270 (1942).

$\mu_i > 0$; the observable (single-quantum) transitions are indicated by double arrows. Quadrupole effects have been neglected.

APPARATUS

General

The apparatus (Fig. 2) is built around a steel table, 3′×3′×3′, the top of which has been machined flat. Brass cylinders 8 in. long and 12 in. in diameter serve as oven chamber and detector chamber. These are attached to vertical bulkheads on two opposite sides of the table, and are joined by a 4-in. brass "beam tube" made in three sections. The deflecting magnets slide on the table top; their pole tips pass through the walls of the first and third sections of the beam tube and are sealed by means of greased O-rings. The center section of the beam tube carries the collimator and exciter coil and may be moved relative to the magnet sections with which it communicates by means of bellows. Thus magnets and collimator may be aligned while the beam is on. Two 4-in. mercury diffusion pumps evacuate the beam tube and detector chamber to 2 or 3×10^{-7} mm of Hg.

The oven chamber vacuum system includes a 4-in.oil diffusion pump, valve, trap, and cooled shielded flange which closes the oven chamber. All are mounted on a rolling framework. This arrangement permits easy access to the oven chamber. A valve separates the oven chamber from the beam tube so that the vacuums are maintained independently.

Because of the high activities involved, considerable lead shielding has been provided, mainly around the oven chamber. Cooled baffles at the oven chamber exit and detector chamber entrance, as well as strategically placed lead bricks, enable the counting to be carried out inside the vacuum system as described below.

Source

Since elemental iodine is quite volatile at room temperatures, it is convenient to maintain the iodine source at ice temperature outside the vacuum system and pass the vapor in through a tube. The vapor is largely diatomic but our measurements indicate that substantially 100% dissociation is obtained by heating the vapor to 650°C. In practice, we maintain the oven head at 750°C–800°C. Few materials can withstand the corrosive effects of iodine at these temperatures. However, after a number of trials, we have adopted solid gold components with complete success.

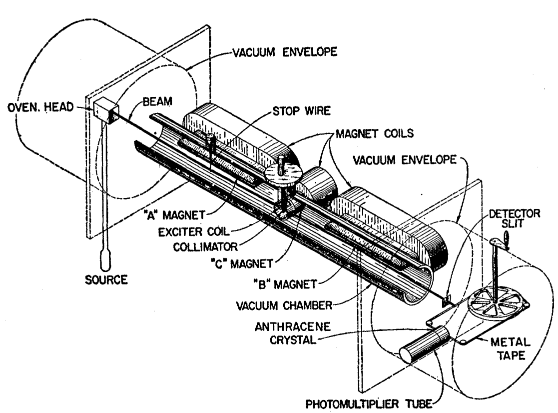

FIG. 2. Schematic diagram of atomic beam apparatus.

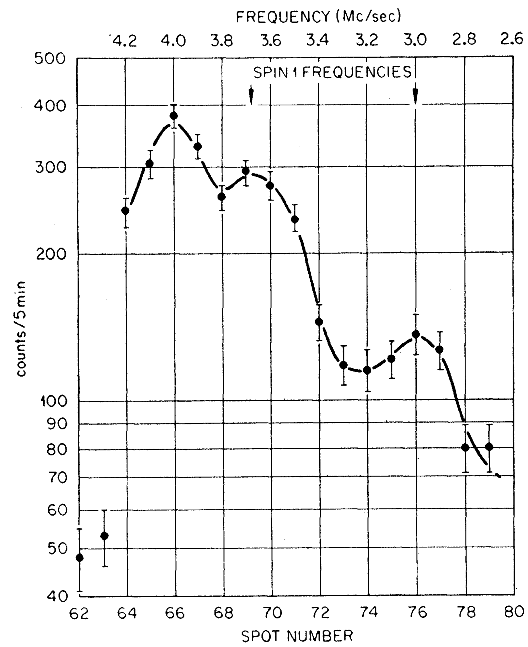

FIG. 3. Frequency sweep for I^{128}. $H=2.63$ oersteds.

Magnets

The gaps of the deflecting magnets are 3 in. long and are contoured to correspond to the equipotentials of a two-wire field, similar to the design given by Davis.[3] The magnet windings are outside the vacuum system and are powered by general purpose regulated power supplies. A current of 200 ma gives an average field of about 10 000 oersteds.

The *C*-field, in which the transitions take place, is obtained from the stray fields of the deflecting magnets by suitably placed magnetic shields. The resultant field, about $2\frac{1}{2}$ oersteds, is of a convenient magnitude for spin searching.[4] Auxiliary coils were provided, however, for raising the field to about 10 oersteds.

Since the frequencies involved in this work were only a few megacyles/sec, the oscillating magnetic field

[3] L. Davis, Massachusetts Institute of Technology, Research Laboratory of Electronics, Technical Report No. 88, 1948 (unpublished).

[4] At lower fields, considerable difficulty was encountered due to "Majorana flop." This phenomenon consists of unwanted transitions brought on by the vagaries of weak magnetic fields and their gradients.

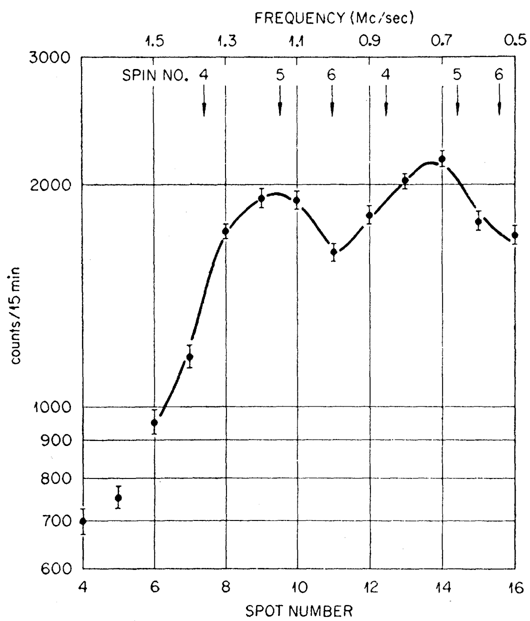

FIG. 4. Frequency sweep for I^{130}. $H=2.63$ oersteds.

could be obtained from a simple coil of 5 or 6 turns, so oriented as to favor $|\Delta m|=1$ transitions. The rf current was monitored.

Detector

Beam intensity is measured by allowing the beam to deposit on a metal tape (iodized copper in the present case) which is cooled near the point of deposit by the proximity of a liquid nitrogen trap. Upon turning a handle external to the vacuum system, the active spot on the tape is transferred into a shielded region where the activity of the spot is measured by means of an anthracene scintillation counter. Our tapes normally have provision for 100 spots so that it is only necessary to break the vacuum for tape rewind after 3 or 4 runs.

I^{128}: PREPARATION AND RESULTS

I^{128} was prepared by irradiating 100-mg samples of elemental iodine (I^{127}) in the Low Intensity Test Reactor. Since the element cannot readily be transferred by pouring, it was necessary to irradiate the iodine in the same container used in the source. Thus the capsule must not become highly radioactive and must withstand the corrosive action of iodine as well as the intense neutron and γ-flux of the reactor for some hours. It was found that "Natural Ultra-ethylux" (a plastic similar to polyethylene and manufactured by Westlake Plastics Company) met the above requirements. This material is similar to polyethylene but is more machineable.

The short half-life of I^{128} (24.5 min) necessitated great haste in the initial steps of the experiment. Thus the first deposition was ordinarily begun 9 minutes after the sample left the reactor, half a mile away. The procedure was to deposit for 5 minutes while irradiating the beam with rf power of one frequency and counting a previously deposited spot. At the end of 5 minutes, the tape was turned, the frequency changed, and the counter reading recorded and reset. These adjustments occupied a 30-second interval, after which the cycle was repeated. Thus the frequency was varied linearly with time and the data show the build-up and decay of the stray beam activity as well as any observable transitions.

Figure 3 shows the result of a frequency sweep in the neighborhood of the frequencies corresponding to spin 1. (The frequencies corresponding to spin 2, for example, were 2.136 Mc/sec and 1.855 Mc/sec and were not covered in this run.) In this figure, spots 62 and 63 at the beginning of the run represent machine background counting rates since no beam was deposited at the corresponding points of the tape. The stray beam (unflopped) first appears at spot 64 while the machine background continues to rise. The 25-minute decay eventually predominates, however, and in the absence of flop the curve would show a smooth decay after spot 66. However, two well-defined peaks appear superimposed on this curve at frequencies corresponding to spin 1.

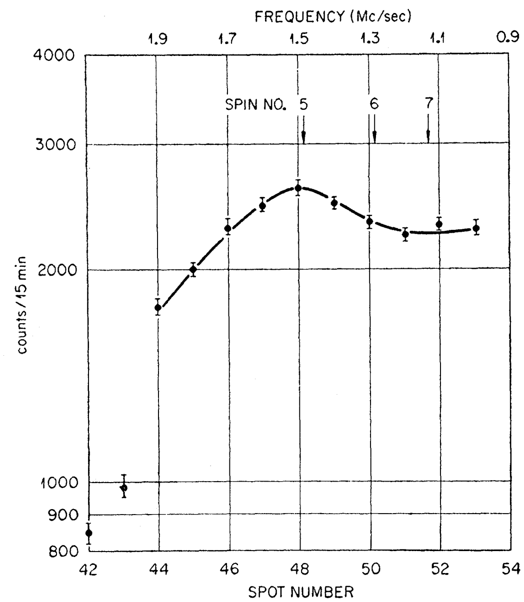

FIG. 5. Frequency sweep for I^{130}. $H=3.55$ oersteds.

Similar results have been obtained repeatedly, at two values of the C field. These results show, unambiguously, that the spin of I^{128} is 1. This is in agreement with the decay studies of Benczer *et al.*[5]

I^{130}: PREPARATION AND RESULTS

I^{129} can be obtained in relatively large quantities as a fission product. Thus the Oak Ridge National Laboratory Radioisotopes Department was able to prepare a

[5] Benczer, Farrelly, Koerts, and Wu, Phys. Rev. **101**, 1027.

half-and-half mixture of elemental I^{127} and I^{129} in 75-mg quantities. This mixture was irradiated in the reactor for 6 hours. The I^{128} activity was allowed to decay and the sample was then run through the machine in exactly the same way as with I^{128}, but with 15-minute counting and deposition times.

Figure 4 shows the result of a frequency sweep. There is good agreement between the observed line frequencies and those calculated for spin 5, while there is no indication for spin 6, the expected value. Further confirmation was made by raising the *C*-field and repeating the experiment, after calibrating with I^{128}. As shown in Fig. 5, verification of spin 5 was obtained, whereas no indications appeared at frequencies corresponding to spin 6 or 7.

The decay of this isotope has been studied by Roberts, Elliot, Downing, Peacock and Deutsch[6] and by Caird and Mitchell[7]; the latter group suggested spin 6 for the ground state of I^{130}.

Recently, Smith, Stelson, and McGowan[8] re-examined this isotope. The decay scheme shown in Fig. 6 is consistent with their results and with those of Caird and Mitchell. Smith *et al.* also carried out gamma-gamma angular correlation measurements and found that the 1.19-0.528-0 Mev level decay can be represented only by $4(Q)2(Q)0$ by $2(96\%\ D+4\%\ Q)2(Q)0$ transitions. In the first case, the 1.19-Mev level would be 4+ and the I^{130} ground state should undergo β decay to this level. Smith *et al.* searched for such a β-group but were unable to find it. They were able to set a lower limit of 9.8 for the corresponding log *ft* value, which is anomalously high. The second case gives rise to an anomaly also, inasmuch as such 2+ to 2+ transitions are known to proceed mainly via *E*2. No full explanation seems available at this time although the 4+ assignment seems more plausible.

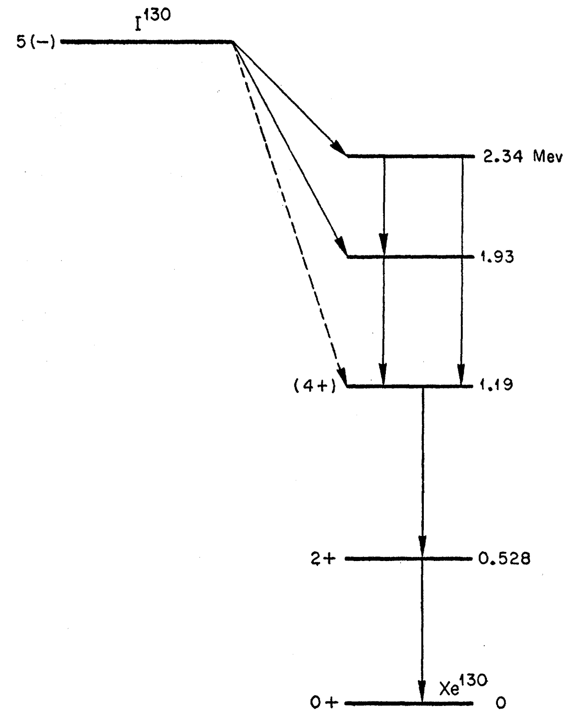

FIG. 6. Decay of I^{130}.

ACKNOWLEDGMENTS

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[6] Roberts, Elliott, Downing, Peacock, and Deutsch, Phys. Rev. **64**, 268 (1943).
[7] R. S. Caird and A. C. G. Mitchell, Phys. Rev. **94**, 412 (1954).
[8] Smith, Stelson, and McGowan (private communication) and to be published.