TABLE I. Summary of grain-counting data.

Energy interval, Mev	Average E/μ	Total number of grains	Total length of track (microns)	Grains per 100μ
2–5	7	1613	4778	33.8±0.6
5–10	15	5777	16445	35.1±0.4
10–15	25	7818	22149	35.4±0.3
15–20	35	7933	21997	36.0±0.3
20–25	45	6333	17541	36.1±0.3
25–30	55	4947	13834	35.8±0.4
30–35	65	5764	15732	36.6±0.4
35–45	80	5092	13890	36.6±0.4

in the ionization. The gains have been counted in an effort to detect a corresponding increase in grain density.

It has been found that an experienced observer can count grains consistently, and that the deviations from the mean of the number of grains in intervals as small as 180μ, for all tracks of the same energy and in the same plate, are roughly gaussian.

The grain-counting data for all tracks in the same 5-Mev energy interval have been grouped together and the results are shown in Table I. There is an observable increase in grain density of about 7 percent in the region $E/\mu=7$ to 40 or 60 after which the density is constant. This is roughly in agreement with the measurements on cosmic-ray particles of Pickup and Voyvodic[7] who report an increase of 10 percent from a minimum at $E/\mu=3$ to a constant value at $E/\mu=20$. Our results, like theirs, seem to favor the ionization theory of Wick.[8]

I wish to thank Dr. J. A. Gray for his continued interest and help during the course of this work and the National Research Council of Canada for the award of a bursary.

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Energy Response of NaI (Tl) Crystals to Alpha-Particles of Less than 10 Mev*

RALPH H. LOVBERG†
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
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RECENT investigation[1] of the response of NaI crystals as scintillation counters of charged particles has shown that, although the light output is essentially linear with energy of incident electrons, protons, and deuterons, there is nonlinearity in the response to alpha-particles of less than 10 Mev. The investigation described here was undertaken to determine in detail the shape of this nonlinearity.

In this experiment, energy control was accomplished by air attenuation and the particles were allowed to strike a freshly cleaved crystal face. To avoid the usual rapid moisture contamination of the crystal surface in the open atmosphere, the entire operation was performed in a dry-box, with signal and high voltage cables brought into the 5819 photomultiplier by means of airtight feed-through connectors. P_2O_5 was used as a drying agent, and no detectable deterioration of crystals cleaved in the box took place in a three-week period.

Two sources of alpha-particles were used, both thin to their own radiations. The first was a "thorium active" deposit yielding alpha-groups at 8.78 Mev and 6.04 Mev from ThC′ and ThC disintegrations, respectively. The second was Pu^{239}, giving 5.16-Mev alphas. Both sources were deposited on the ends of probe rods which passed through a light-tight, sliding seal in the end of the phototube housing. The 1×1×0.1-cm crystal was held to the tube face by a wire clip, with a drop of mineral oil providing additional optical coupling.

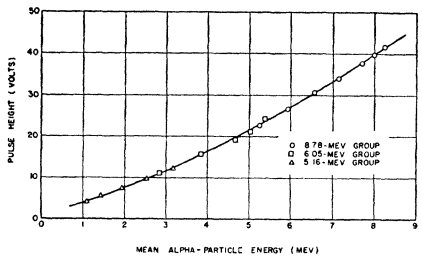

FIG. 1. Mean output pulse height as a function of computed mean energy.

The thorium probe was used in seven positions from 1.00 to 6.00 cm from the crystal, and the Pu source in five positions from 2.00 to 3.62 cm, the near position in each case being the limit at which the source backing reflected a significant amount of light back into the photocathode, producing spurious heightening of output pulses.

Appropriate range corrections for the local atmospheric pressure of 60.2 cm Hg were made, and the mean particle energies were computed from Bethe's range-energy curves.[2]

Output of the 5819 was fed into a low gain preamplifier for polarity inversion, through a Los Alamos model 503 pulse amplifier, and into a continuously variable single-channel pulse-height discriminator. Linearity of the electronic system was checked by applying standard pulses to the phototube anode resistor and observing the corresponding discriminator dial readings. No corrections were found necessary.

In Fig. 1, mean output pulse height for each probe position is plotted against computed mean energy. In every position, the peak of the pulse-height distribution could be determined to within one volt.

I wish to thank Mr. Hugh Stoddart of the Los Alamos cyclotron group for preparation of the sources used in this experiment.

* Work done under the auspices of the AEC.
† Now at the Department of Physics, University of Minnesota, Minneapolis 14, Minnesota.
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The Hyperfine Structure of $^2P_{\frac{1}{2}}$ State of the Stable Chlorine Isotopes*

JOHN GORDON KING AND VINCENT JACCARINO
Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received September 27, 1951)

FROM observations of the hyperfine structure (hfs) interaction in an external magnetic field, the nuclear magnetic dipole coupling constants ($a_{1/2}$) for the $^2P_{1/2}$ metastable state of the stable chlorine isotopes have been obtained. As will be shown, the results of these measurements are in excellent agreement with recent work on the ratio of the nuclear magnetic moments of the two isotopes. Use has been made here of the atomic beam magnetic resonance method, as in previous work in the hfs of the $^2P_{3/2}$ state of chlorine.[1,2]

In Fig. 1 the interaction energy of an atom with $I=\frac{3}{2}$ and $J=\frac{1}{2}$ in an external magnetic field is displayed. An estimate of the hfs separation, ΔW, can be had from consideration of the form of the interaction[1,3]

$$\Delta W=h\Delta\nu=2ha=-\mu_0^2 g_1 \mathfrak{F}\frac{4L(L+1)}{J(J+1)}\langle r^{-3}\rangle_{\mathrm{Av}},$$

where $\mathfrak{F}$ is a relativistic correction factor of order 1.0 for both the $P_{1/2}$ and $P_{3/2}$ states of chlorine, and the other symbols have their usual meaning. Since the hfs of the $P_{3/2}$ state is known quite accurately, and one may assume $(\langle r^{-3}\rangle_{\mathrm{Av}})_{3/2}$ is equal to $(\langle r^{-3}\rangle_{\mathrm{Av}})_{1/2}$ to

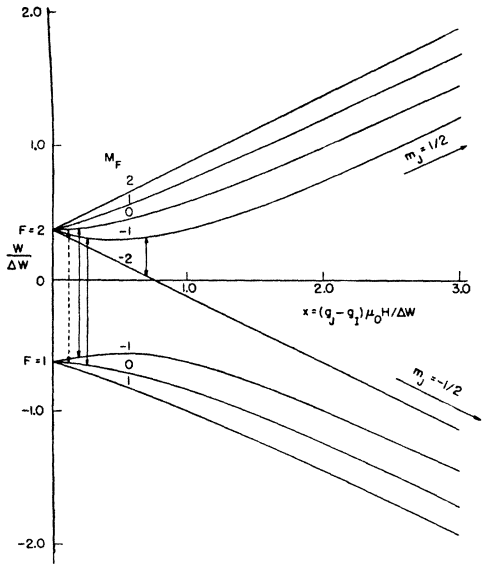

FIG. 1. The energy levels of an atom in an external magnetic field, with electronic angular momentum $J=1/2$ and nuclear angular momentum $I=3/2$.

within a few percent, an approximate value of $\Delta\nu_{1/2}{}^{35}$ and $\Delta\nu_{1/2}{}^{37}$ may be estimated. Unfortunately both of these values lie in a region of the radiofrequency spectrum (1700 Mc/sec—2100 Mc/sec) that renders a gross search for the zero field $\Delta F=\pm 1$ transitions most impracticable.

As a consequence, successively more accurate values for $\Delta\nu$ for each isotope had to be obtained from observations of the transition $(F=2, m_F=-1\leftrightarrow F=2, m_F=-2)$ (see Fig. 1) in successively larger magnetic fields[4] since

$$\nu(2,-1\leftrightarrow 2,-2)=g_I(\mu_0 H/h)+(\Delta\nu/2)(1-x+x^2)^{\frac{1}{2}}.$$

The transitions $(F=3, m_F=-1\leftrightarrow F=3, m_F=-2)_{3/2}{}^{35}$ and $(F=4, m_F=-3\leftrightarrow F=4, m_F=-4)_{1/2}{}^{133}$ of Cl^{35} and Cs^{133}, respectively, were used to calibrate the magnetic field.

A search was then conducted for the $\Delta F=\pm 1, \Delta m_F=\pm 1$ transitions, and the Zeeman effect of the following lines was observed in the neighborhood of 2075 Mc/sec for Cl^{35}, and of 1726 Mc/sec for Cl^{37}

(a) $(2, 2\leftrightarrow 1, 1)$

(b) $(2, 1\leftrightarrow 1, 0)$, $(2, 0\leftrightarrow 1, 1)$ } not resolved at small fields;

(c) $(2, -1\leftrightarrow 1, 0)$, $(2, 0\leftrightarrow 1, -1)$ } not resolved at small fields.

The correct dependence on magnetic field was found in all cases, and at a field corresponding to $x^{35}=0.27$ the transitions (c) are easily resolved and are approximately field independent. (These are indicated in Fig. 1.) From this observation a value of $\mu^{35}=0.82\pm 0.08$ nuclear magnetons was obtained.

A precision measurement of $\Delta\nu_{1/2}{}^{35}$ and $\Delta\nu_{1/2}{}^{37}$ was made, using a radiofrequency field of special design having components parallel to the external field. For this, the following $\Delta F=\pm 1, \Delta m_F=0$ transitions were observed: $(2, 1\leftrightarrow 1, 1)$ field dependent to first order in x; $(2, 0\leftrightarrow 1, 0)$ field independent to first order in x; $(2, -1\leftrightarrow 1, -1)$ field dependent to first order in x. Although the field was kept at a value such that these lines were clearly resolved, the second-order magnetic correction to the transition $(2,0\leftrightarrow 1, 0)$ was less than 0.0005 Mc/sec. In Fig. 2 a resonance curve is shown from which the value of $\Delta\nu_{1/2}{}^{35}$ was obtained.

Frequencies in the neighborhood of 2075 Mc/sec were obtained from a c.w. Raytheon QK-174A magnetron[5] operated from highly

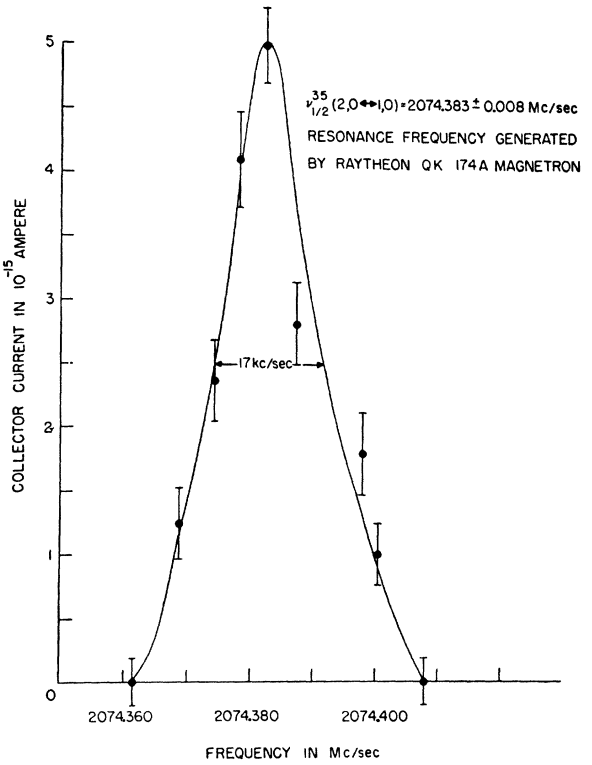

FIG. 2. The transition indicated by the dotted line in Fig. 1, induced by an rf field parallel to the external magnetic field.

filtered power supplies. A suitable modified F-4800 jamming transmitter using a 2C39 lighthouse tube was found to be satisfactory for frequencies in the vicinity of 1726 Mc/sec. Using harmonics from a 5-Mc/sec, crystal-controlled oscillator kept at zero beat with WWV's signal, and a G.R. 620A frequency meter for interpolation purposes, the error in frequency measurement was kept to less than one part in 10^6.

The novel use of a magnetron for atomic beam measurements suggests the feasibility of observing the direct $\Delta F=\pm 1$ transitions for precision measurements of the $\Delta\nu$ of various alkalies as well as of gallium and indium, using existing magnetrons and klystrons.

The following results for the hfs interaction in the $^2P_{1/2}$ state of chlorine 35 and 37 have been established:

$$\Delta\nu_{1/2}{}^{35}=2074.383\pm 0.008 \text{ Mc/sec};$$
$$\Delta\nu_{1/2}{}^{37}=1726.700\pm 0.015 \text{ Mc/sec}.$$

In Table I we have listed recent measurements on the ratio of the nuclear magnetic dipole interaction of the two isotopes. It is interesting to consider why one would expect such close agreement between the various ratios. For two isotopes with the same value of I and with similar magnetic moments, combined with the small electron wave function density at the nucleus, both for the $P_{1/2}$ and $P_{3/2}$ configurations for $Z=17$, one would expect any hfs

TABLE I. Data on the nuclear magnetic constants of Cl^{35} and Cl^{37}.

Method	Ratio of magnetic constants
Nuclear induction[a] using HCl	$g_I{}^{35}/g_I{}^{37}=1.2014\pm 0.0001$
Nuclear induction[b] using LiCl	$g_I{}^{35}/g_I{}^{37}=1.2013\pm 0.0001$
Atomic beam[c] magnetic resonance—$^2P_{3/2}$	$a_{3/2}{}^{35}/a_{3/2}{}^{37}=1.20136\pm 0.00005$
Atomic beam magnetic resonance—$^2P_{1/2}$ (this paper)	$a_{1/2}{}^{35}/a_{1/2}{}^{37}=1.201357\pm 0.000013$

[a] W. G. Proctor and F. C. Yu, Phys. Rev. **81**, 20 (1951).
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[c] See reference 2.

anomaly resulting from the distributed nuclear magnetic moment over the finite nuclear volume to be quite small.[6] Another electron-nuclear interaction which would affect the magnetic-dipole coupling constants is the perturbation of levels with the same value of F in the $P_{3/2}-P_{1/2}$ fine structure doublet, in this case the $F=2$ and $F=1$ levels. An estimate of the order of magnitude of this interaction reveals that both hfs ratios would be changed by less than one part in 100,000.

We wish to thank Professors B. T. Feld and J. R. Zacharias for their counsel.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and the ONR.

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Phase Transitions in Solid Solutions Containing $PbZrO_3$

GEN SHIRANE
Tokyo Institute of Technology, Oh-okayama, Tokyo, Japan
(Received September 25, 1951)

RECENT investigations on the dielectric[1,2] and structural[3] properties of lead zirconate have shown that this crystal is not a ferroelectric but an antiferroelectric. At the same time, the study[4] of solid solutions of $PbZrO_3$ and $PbTiO_3$ has revealed that when some of the Zr ions in $PbZrO_3$ are replaced by Ti ions, a ferroelectric intermediate phase can be observed between the paraelectric and antiferroelectric phases. The $(Pb-Ba)ZrO_3$[5] and $(Pb-Sr)ZrO_3$ systems have now been investigated to determine whether such an intermediate phase can be observed also in these systems.

Specimens were made from PbO, $BaCO_3$, $SrCO_3$, and high purity ZrO_2 which are the same chemicals as used for the previous study.[2] These ingredients were mixed in the desired compositions and then sintered at temperatures between 1200° and 1300°C after preliminary calcination.

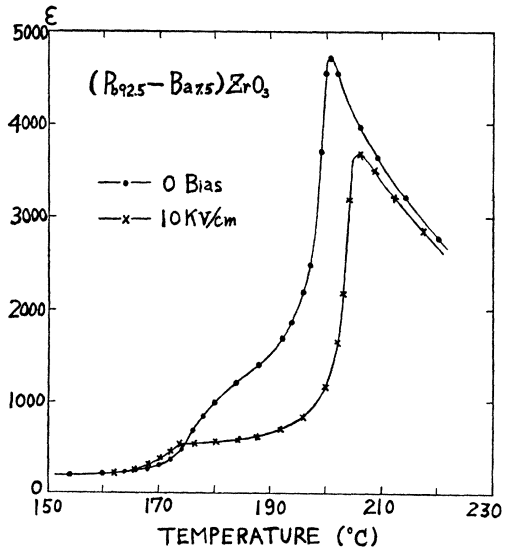

FIG. 1. Effect of a dc biasing field of 10 kv/cm on the permittivity of $(Pb92.5-Ba7.5)ZrO_3$ at 1 Mc/sec.

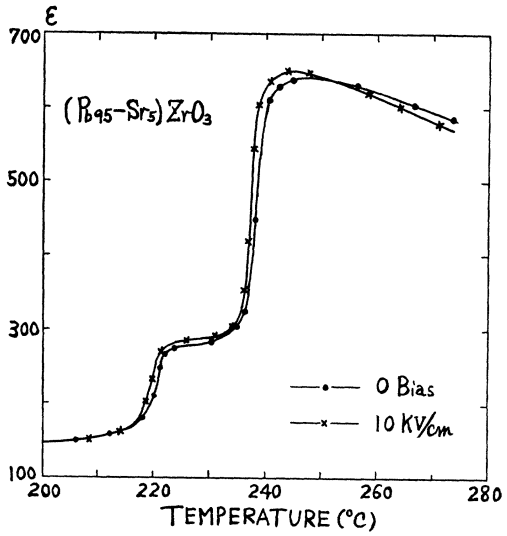

FIG. 2. Effect of a dc biasing field of 10 kv/cm on the permittivity of $(Pb95-Sr5)ZrO_3$ at 1 Mc/sec.

Curves of permittivity *vs* rising temperature for $(Pb92.5-Ba7.5)-ZrO_3$ and $(Pb95-Sr5)ZrO_3$ are shown in Figs. 1 and 2. Besides the remarkable maximum at the ordinary Curie point, another small anomaly can be perceived in these two curves.[6] It is to be noticed here that the anomaly at the lower transition in $(Pb95-Sr5)ZrO_3$ is more pronounced than that of $(Pb92.5-Ba7.5)ZrO_3$, whereas the peak value at the Curie point of the former is smaller than that of the latter.

To confirm whether the properties of these intermediate phases are both ferroelectric, as in the case of $Pb(Zr-Ti)O_3$, we have carried out the study of the $D-E$ characteristics of the present solid solutions under an ac field of 20 kv/cm. The curve for $(Pb92.5-Ba7.5)ZrO_3$ shows typical hysteresis loops in the intermediate phase between 175° and 200°C, insuring the ferroelectricity of this phase. On the other hand, the curve for $(Pb95-Sr5)ZrO_3$ shows no hysteresis loops and is almost linear, not only in the lowest phase but also in the intermediate phase, except at temperatures just below the upper transition point in which a slight upward curvature was observed. This result seems to suggest that the intermediate phase in this specimen is not ferro-

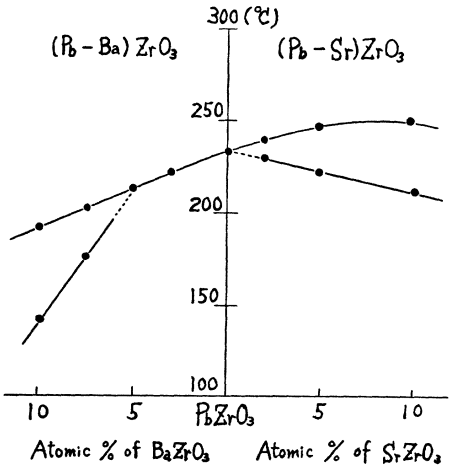

FIG. 3. Phase diagram of the $(Pb-Ba)ZrO_3$ and $(Pb-Sr)ZrO_3$ systems.