Title

NUCLEAR ALIGNMENT OF THE ^ GROUND STATE OF 131Xe BY ""ELECTRON PUMPING AND METASTABILITY-EXCHANGE COLLISIONS

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Berkeley, California

UCRL-17579

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

July 13, 1967

ERRATUM

TO: All recipients of UCRL-17579

FROM: Technical Information Division

Subject: UCRL-17579, "Nuclear Alignment of the $^1S_0$ Ground State of ^{131}Xe by 'Electron Pumping' and Metastability-Exchange Collisions," Tetsuo Hadeishi and Chung-Heng Liu, May 24, 1967

Please replace page 3 of the subject report with the attached corrected page.

orientation so generated in the first system is communicated to the second system by collisions. The magnetic resonance of the second system is monitored by change in the transparency of the first system to resonance radiation.

In our experiment, instead of one of the systems being oriented by resonance radiation, the system is aligned by "electron pumping" from the ground state to the metastable state (first system). The alignment of the metastable state is communicated to the ground state of ^{131}Xe (second system) through metastability exchange collisions.[3]

A "strong" collision, in which one atom is in the ground state and the other in the metastable state, results in an exchange of electron angular momentum and excitation energy, so that a nucleus which enters the collision in a ground state may leave it in a metastable state.[3,4] It is assumed that angular momentum is conserved in the collisions.

Our paramagnetic resonance experiments on Xe metastable-state atoms, Xe($^3P_2$), formed and aligned by electron impact,[1] showed that the magnetic sublevels with $M_J = 0$ and ± 1 are more selectively excited than those states with $M_J = \pm 2$, as one would expect from the theory of inelastic collisions for low-energy electronic impact.

Since the nuclear spin of ^{131}Xe is 3/2, it is evident that, because of conservation of angular momentum in collisions, the $M_I = 1/2$ and $-1/2$ in the $^1S_0$ ground state are more populated in equilibrium,[5] considering the hyperfine structure of ^{131}Xe. The magnetic resonance of the ground state can be monitored by the change in the transparency of the system of metastable-state atoms to resonance radiation.[5]

Figure 1 shows the experimental results. The magnetic field was calibrated by noting the paramagnetic resonance of even isotopes of the metastable state of Xe($^3P_2$).[1] Full magnetic resonance bandwidth was 15 Hz. We believe that this surprisingly wide bandwidth is due to the inhomogeneous magnetic field due to the indirectly heated cathode heater wire. The observed nuclear magnetic moment is $\mu = 0.6874 \pm 0.0023$ nuclear magneton. It is in agreement with published values found by means of conventional NMR methods.[6] Since the purpose of this experiment was not to measure the magnetic moment but instead to study the phenomena, no attempts were made to improve the accuracy. However, it is evident, even with $\Delta\nu = 15$ Hz, that at higher value of magnetic field, extremely precise nuclear magnetic moment determination is possible.

Figure 2 shows the experimental arrangement. It is identical to that used in our previous experiment,[1] except that it has no resonance lamp for observing the resonance absorption. Although it may seem surprising, we found that it is possible to use the resonance radiation emitted from the plasma as a light source to monitor the change in the resonance absorption by the metastable state. The electron tube was operated under the space-charge neutralization condition, with a gas pressure of about 0.55×10^{-3} torr and an electron current density of 70 mA/cm^2, at slightly above the ionization potential energy.

We believe that our observation of the NMR signal of the $^1S_0$ ground state with I = 3/2 demonstrated the transfer of alignment of the Xe($^3P_2$) metastable state to the nucleus in the $^1S_0$ ground state through collisions. We believe that our NMR observation of the nucleus gives a strong support for our observation of exchange collisions between the

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An alignment of a nucleus in the $^1S_0$ ground state of ^{131}Xe was achieved through exchange collisions with the metastable state formed and aligned by electron impact. The nuclear alignment in the ground state was observed by monitoring the change of linearly polarized resonance absorption by the Xe($^3P_2$) metastable state as we caused a nuclear magnetic resonance.

In this letter, we report on a new method of nuclear alignment in the $^1S_0$ ground state of a noble gas atom. The nucleus was aligned by means of a transfer of alignment due to "strong" collisions between (a) the initially randomly oriented nucleus of ^{131}Xe with nuclear spin $I = 3/2$ in the $^1S_0$ ground state, and (b) $^3P_2$ metastable-state atoms aligned by "electron pumping" by electron impact; the collisions result in nuclear alignment of ^{131}Xe in the ground state. There are two major processes of metastable-state alignment by electron impact; (a) by direct electron-impact excitation from the ground state to the metastable state, resulting in the alignment, and (b) electron-impact excitation and alignment of those energy levels lying higher than the metastable state, which then cascade to the metastable state, resulting in transfer of alignments to the metastable state. Although the second process (cascading) corresponds to "electron pumping," similar to optical pumping, we shall for simplicity refer to processes (a) and (b) together as electron pumping.

A method of alignment of the metastable-state atoms of Xe was described in our previous letter,[1] dealing with exchange collisions between the $Xe^+(^2P_{3/2})$ ionic ground state and the $Xe(^3P_2)$ metastable state. The mechanism of nuclear alignment we used is very similar to the exchange collisions between the ionic ground state and metastable state of Xe.[1]

The main purposes of this experiment were: (a) to give additional experimental evidence to support the processes involved in our observation of exchange collisions between the ionic ground state $Xe^+(^2P_{3/2})$ and the metastable state $Xe(^3P_2)$, both aligned by electron impact, since considerable controversy has arisen in regard to the processes involved; (b) to offer a new method that may work with short-lived radioactive gases that it is not possible to observe by conventional NMR technique; and (c) to investigate an "electron pumping" cycle.

Definite advantages of our method over the conventional NMR and optical pumping method are (a) a much smaller sample required for this experiment than for the conventional NMR method, and (b) faster alignment of the metastable state by "electron pumping" than by optical pumping, thus extending the nuclear magnetic resonance investigation to a great variety of atoms.

The method of detection is based on the spin-exchange experiment first performed in the brilliant work by Dehmelt,[2] using an optical pumping method. In the Dehmelt experiment, a mixture of vapor is illuminated by circularly polarized resonance radiation of one of two species of atoms, thus orienting the system of atoms in the ground state. The orientation so generated in the first system is communicated to the second system by collisions. The magnetic resonance of the second system is monitored by change in the transparency of the first system to resonance radiation.

In our experiment, instead of one of the systems being oriented by resonance radiation, the system is aligned by "electron pumping" from the ground state to the metastable state (first system). The alignment of the metastable state is communicated to the ground state of ^{131}Xe (second system) through metastability exchange collisions.[3]

A "strong" collision, in which one atom is in the ground state and the other in the metastable state, results in an exchange of electron angular momentum and excitation energy, so that a nucleus which enters the collision in a ground state may leave it in a metastable state.[3,4] It is assumed that angular momentum is conserved in the collisions.

Our paramagnetic resonance experiments on Xe metastable-state atoms, Xe($^3P_2$), formed and aligned by electron impact,[1] showed that the magnetic sublevels with $M_J = 0$ and ± 1 are more selectively excited than those states with $M_J = \pm 2$, as one would expect from the theory of inelastic collisions for low-energy electronic impact.

Since the nuclear spin of ^{131}Xe is 3/2, it is evident that, because of conservation of angular momentum in collisions, the $M_I = 1/2$ and $-1/2$ in the $^1S_0$ ground state are more populated in equilibrium.[5] (The hyperfine interaction in the metastable state for odd isotopes of xenon is neglected in the above discussion, for simplicity.) The magnetic resonance of the ground state can be monitored by the change in the transparency of the system of metastable-state atoms to resonance radiation.[5]

Figure 1 shows the experimental results. The magnetic field was calibrated by noting the paramagnetic resonance of even isotopes of the metastable state of Xe($^3P_2$).[1] Full magnetic resonance bandwidth was 15 Hz. We believe that this surprisingly wide bandwidth is due to the inhomogeneous magnetic field due to the indirectly heated cathode heater wire. The observed nuclear magnetic moment is $\mu = 0.6874 \pm 0.0023$ nuclear magneton. It is in agreement with published values found by means of conventional NMR methods.[6] Since the purpose of this experiment was not to measure the magnetic moment but instead to study the phenomena, no attempts were made to improve the accuracy. However, it is evident, even with $\Delta\nu = 15$ Hz, that at higher value of magnetic field, extremely precise nuclear magnetic moment determination is possible.

Figure 2 shows the experimental arrangement. It is identical to that used in our previous experiment,[1] except that it has no resonance lamp for observing the resonance absorption. Although it may seem surprising, we found that it is possible to use the resonance radiation emitted from the plasma as a light source to monitor the change in the resonance absorption by the metastable state. The electron tube was operated under the space-charge neutralization condition, with a gas pressure of about 0.55×10^{-3} torr and an electron current density of 70 mA/cm^2, at slightly above the ionization potential energy.

We believe that our observation of the NMR signal of the $^1S_0$ ground state with $I = 3/2$ demonstrated the transfer of alignment of the Xe($^3P_2$) metastable state to the nucleus in the $^1S_0$ ground state through collisions. We believe that our NMR observation of the nucleus gives a strong support for our observation of exchange collisions between the

$Xe^+(^2P_{3/2})$ and $Xe(^3P_2)$ states in the case of alignment (not orientation), since the only difference in this experiment is that the angular momentum involved in the $^1S_0$ ground state is the nuclear angular momentum with $I = 3/2$, while in our previous experiment the angular momentum involved is the electronic angular momentum with $J = 3/2$. The theory describing how the alignment of the metastable state is expected to be changed as one resonates the aligned ground state is to be published elsewhere. This experiment may perhaps be thought of as an "electron pumping" experiment, similar to an optical pumping of ground-state atoms first demonstrated by Kastler and Brossel, although the processes involved in this experiment are much more complex. Also, "electron pumping" phenomena of the $Xe(^3P_2)$ metastable state due to cascading transitions from the higher states, resulting in the alignment of the metastable state, in addition to the alignment of the metastable state by direct electron impact, was experimentally observed. This phenomenon will be reported elsewhere.

Another interesting feature of this experiment may perhaps be that, by means of an extremely simple device (just a simple diode!), it was possible to observe NMR of ^{131}Xe quite readily. It is somewhat obvious that by use of this technique, radioactive samples such as ^{133}Xe, ^{135}Xe, and many other noble gas atoms having $I > 1/2$ should readily be observed.

It is our great pleasure to express our appreciation to Dr. G. W. Series of The Clarendon Laboratory for stimulating conversation and private communication. The first author also appreciates the interesting and stimulating comments of Professor H. G. Dehmelt of the University of Washington during his visit to our Laboratory.

Footnote and References

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FIGURE CAPTIONS

Fig. 1. The first trace (a) shows the paramagnetic resonance of Xe($^3P_2$) even isotopes. The second trace (b) shows the nuclear magnetic resonance of ^{131}Xe in the $^1S_0$ ground state with a linearly oscillating magnetic field at ν = 2.5680 Hz. The third trace (c) shows a typical NMR signal by a digitalized signal-averaging system for four sweeps over the resonance at different H_0 and ν values from those of trace (a).

Fig. 2. Block diagram of experimental setup. Electronic equipment used throughout the experiment was all commercially available except for a homemade electron tube.

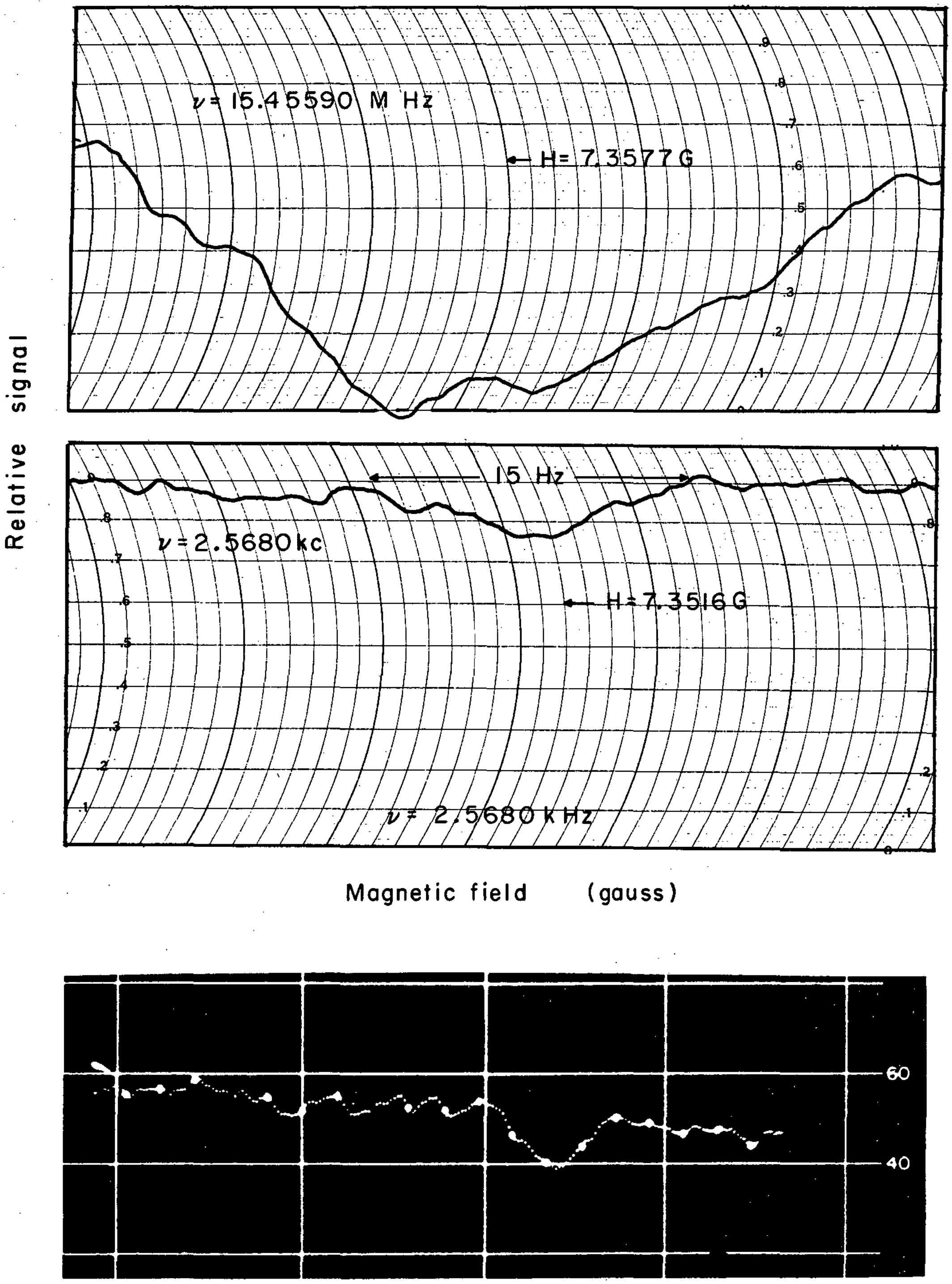

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Fig. 1

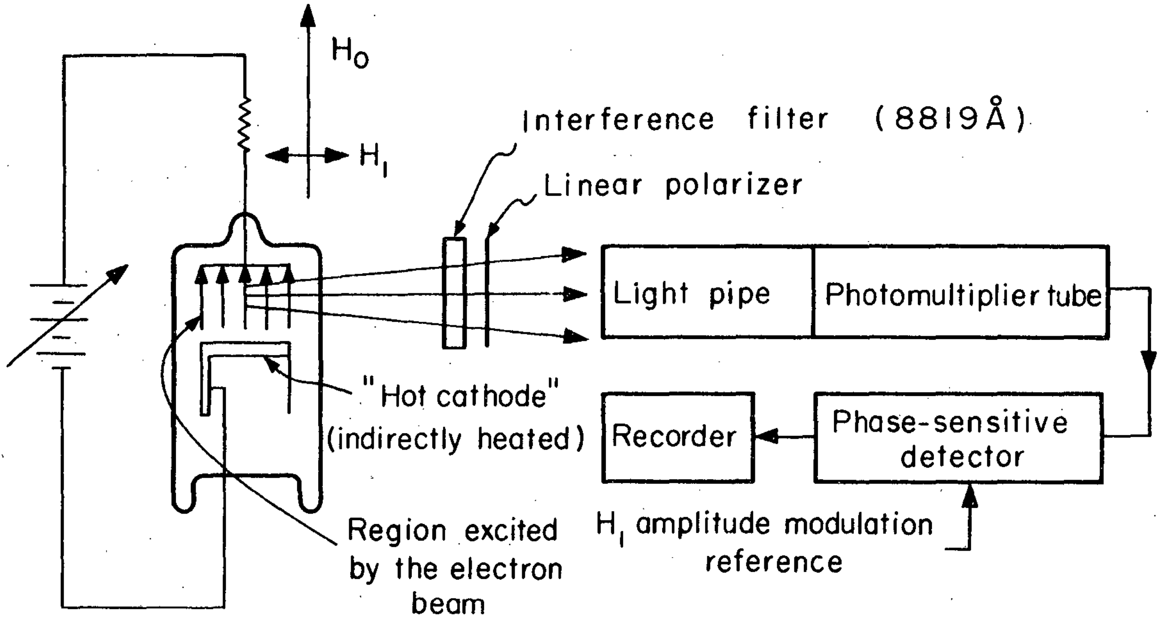

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Fig. 2