al foils irradiated with fission fragments.[8] For a current of 5 mA, half the critical current, the voltage change across a 10-ohm resistor in series with the superconductor should be at least 4 mV for the fission fragment and 1 mV for the alpha particle. The current may provide discriminator bias in virtue of its magnetic field which will control the ratio of superconducting to normal volume in the film.

The resistivity[9] ($\eta = 6.53 \times 10^3 \ln\Lambda / T_e^{3/2}$) of the initial microplasma due to an alpha particle is estimated to be about 10^{-7} ohm-cm, if $\ln\Lambda \sim 10$ and T_e is calculated from $T_e \sim (E_\alpha / JR_\alpha)/c_n \rho_n \pi r_d^2$ to be $\sim 10^8$ °K. Though η is large compared to that for the superconductor, it is smaller than the resistivity of the decaying thermal spike. The high resistivity, therefore, comes late in the evolution of the particle track. The rise time can be estimated to be $t_r \sim 10^{-11}$ second,[2] the time for the temperature to decay to the melting temperature where the resistivity becomes large. The resistive region will not grow due to Ohmic heating, because the rate of heat conduction across one-twelfth the correlation distance[10] for $T_n - T_0 = 0.75$°K is more than 10^4 times the rate of evolution of Joule heat. There will not be a "dead time," therefore. An order-of-magnitude estimate of the resistivity fall time is $t_f \sim r_\alpha / v_s$, where the speed of growth of a superconducting filament[11] piercing the disordered region is $v_s \sim 10$ cm/sec for tin. Thus, $t_f \sim 1$ microsecond.

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NUCLEAR POLARIZATION OF He^3 GAS BY METASTABILITY EXCHANGE WITH OPTICALLY PUMPED METASTABLE He^3 ATOMS

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(Received April 27, 1962)

We have found that exchange of metastability during collisions between ground-state and $^3S_1$ metastable He^3 atoms provides an extremely effective nuclear magnetic relaxation process for the ground-state He^3 atoms. We have exploited this mechanism in conjunction with optical pumping of $^3S_1$ atoms in weak magnetic fields to produce a high degree of nuclear polarization in He^3 gas at room temperature. We wish also to report the detection of magnetic resonances of both He^3 ground-state and $^3S_1$ atoms by conventional optical-pumping techniques.

The experimental arrangement employed is similar to that described by Colegrove and Franken for optical pumping of He^4 metastables.[1] Circularly polarized one-micron pumping light ($2\,^3P$-$2\,^3S$) from a helium lamp is passed through an absorption cell containing He^3 gas, a small fraction of which is maintained in the $^3S_1$ metastable state by an rf discharge. The pumping light tends to produce a polarization of the metastable He^3 atoms. However, as a consequence of metastability exchange collisions,[2]

$$He^3 + He^{3*} \rightarrow He^{3*} + He^3$$

(where the asterisk indicates an atom in the $^3S_1$ metastable state), the incident and emerging ground-state He^3 atoms may have magnetic quantum numbers differing by ± 1, while the corresponding metastables differ in their magnetic quantum numbers by ∓ 1. The net result of such exchange processes is to introduce mutual spin-flip operators connecting ground-state and metastable atoms. We find that the interaction involving these operators predominates in determining the ground-state He^3 nuclear magnetic relaxation rate; hence, neglecting the thermal equilibrium Boltzmann factors, the ground-state He^3 nuclei

are driven by the optical-pumping process to the same degree of polarization as that of the metastables.

To date, we have been able to induce a $(3.5 \pm 1)\%$ nuclear polarization in He^3 gas contained at a pressure of 1 mm Hg in a 40-cc Pyrex bulb. At 10-mm pressure in a similar Pyrex bulb, a polarization of about 0.8% has been obtained. In neither case were the bulb surfaces treated in any special way prior to admission of the He^3. D_0 resonance radiation (for inducing $2\,^3S_1$-$2\,^3P_0$ transitions of He^3)[3] was obtained from a 5-watt, 6-mm o.d., capillary He^4 lamp in conjunction with a rudimentary optical system employing a single $1\frac{1}{4}$-in. converging lens. Since the degree of polarization is limited in our experiments by the intensity of the pumping light, considerably higher polarizations should be realizable by use of more powerful lamps and a more favorable optical geometry. This technique should prove capable of providing polarized He^3 targets suitable for use in nuclear physics experiments.

The degree of nuclear polarization was determined by measuring the intensity of the ground-state He^3 nuclear magnetic resonance signal in a field of 310 gauss provided by a Varian 12-in. magnet with a $5\frac{1}{4}$-in. gap. The signal was observed under slow passage conditions[4] with a twin-T bridge and National HRO-60 communications receiver, the resonance being excited at 1 Mc/sec by a Hewlett-Packard 606A signal generator. The spectrometer was calibrated by observing the proton resonance in benzene under identical experimental conditions, except that the field for proton resonance at 1 Mc/sec was 235 oersteds. A correction was made for the slight difference (~30%) in proton and He^3 resonance linewidths. Linewidths of about 0.15 gauss and 0.20 gauss for the proton and He^3 resonances, respectively, were determined by magnetic field inhomogeneities.

Polarizations have also been determined independently by measurements of the intensity of the He^4 pumping light transmitted through the He^3 absorption cell. The polarization of the metastables, which is the same as that of the ground state, is $P = \Delta I/I$, where I is the total D_0 light absorbed by the metastables, and ΔI is the change in light absorbed when the metastables are depolarized by a strong rf field. This equation holds only when a small fraction of the pumping light is absorbed. Such measurements, made in the earth's magnetic field (~0.4 gauss), yield He^3 polarizations at 1-mm pressure and 10-mm pressure of 4% and 0.8%, respectively, in agreement with the values determined at 310 gauss by nuclear magnetic resonance.

It is interesting to compare the He^3 polarizations achieved in these experiments with that obtained by Bouchiat, Carver, and Varnum in a somewhat similar experiment.[5] They utilized, as the He^3 polarization mechanism, the relatively weak dipolar interaction between He^3 buffer gas at 2.8 atmospheres pressure and optically pumped rubidium vapor at 10^{-3}-mm pressure. However, competing He^3 relaxation processes not involving interaction with rubidium atoms predominated and limited the He^3 polarization to 0.01%, in contrast to the approximately 10% polarization of the Rb atoms. It is the much more effective spin coupling of the optically pumped species to the ground state, afforded by the metastability exchange process, which allows us to achieve higher He^3 polarizations than Bouchiat et al.

The details of the optical-pumping and polarization processes will be considered now with reference to Fig. 1. The concentrations of He^3 ground-state atoms and He^3 metastables will be denoted by N and n, respectively. T_r represents the ground-state nuclear magnetic relaxation time which would result from processes not involving

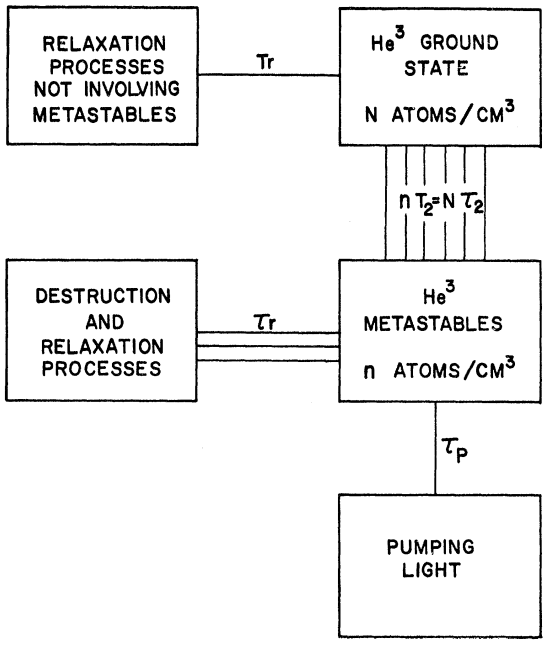

FIG. 1. Schematic diagram indicating the interactions determining the equilibrium polarizations of metastable and ground-state systems. Symbols are defined in the text.

metastables. We define the pumping time τ_p as the reciprocal of the rate at which photons are absorbed from the pumping light by metastable atoms. τ_γ is the spin-lattice relaxation time of the metastables in the absence of pumping, determined primarily by decay to the ground state as a result of collision with walls and with electrons and ions present in the discharge. τ_2 is the average time of existence of a metastable before undergoing an exchange process with a ground-state atom.

From optical-pumping measurements on He^4, performed under experimental conditions nearly identical to those employed here, we estimate $1/\tau_\gamma + 1/\tau_p \simeq 10^4$ sec^{-1} for a 1-mm pressure of He^4. τ_2 can be obtained from the relation $1/\tau_2 = \sigma v N$, where $\sigma = 10^{-15}$ cm^2 is the known metastability exchange cross section[1] and v is the mean velocity of atoms in the gas. Using $v \simeq 10^5$ cm/sec and $N = 3.5 \times 10^{16}$ atoms/cc (corresponding to a 1-mm pressure of He^3 at room temperature), we find $\tau_2 \simeq 3 \times 10^{-7}$ sec.

Using the τ_2 value obtained above, it is easy to demonstrate the effectiveness of the metastability exchange process in mixing the He^3 nuclear spin states. The ground-state atom emerging from a collision in which metastability has been exchanged will have no memory of its spin orientation prior to having become a metastable if $\Delta\omega\tau_2 \gg 1$, where $\Delta\omega \simeq 4 \times 10^{10}$/sec is the hyperfine splitting of the $^3S_1$ state.[6] Since this condition is obviously satisfied in the experiments reported here, it is apparent that a He^3 ground-state atom resulting from a metastability exchange collision will have a high probability of occurring in a spin state different from that of the incident ground-state atom. The sole factor determining the allowed spin states of the emerging atoms is that the total angular momentum of the colliding particles, and its projection along the applied magnetic field, be conserved during the collision.

Since τ_2 is much smaller than τ_γ and τ_p, it follows that polarizations of the metastable and ground-state atoms are essentially "locked" together. Hence, in the conventional optical-pumping experiment, one would expect to be able to detect with equal sensitivity the ground-state He^3 nuclear resonance at 3.2 kc/sec G and the metastable resonance at 1.9 Mc/sec G; i.e., saturation of either ground-state or metastable transitions will result in depolarization of both systems. We have observed strong optical-pumping signals in the earth's field at both frequencies, using a PbS detector to monitor the pumping light transmitted by the absorption cell.

Let us now consider the time T_p which characterizes the approach to equilibrium polarization of the metastable and ground-state systems from an initially depolarized state. If T_2 is defined as the average time between successive exchange collisions of a given ground-state atom with a metastable, then $T_2 = \tau_2 N/n$, since each metastable must "process" N/n ground-state atoms. T_2 is, in fact, equal to the transverse relaxation time of the ground-state He^3 atoms, since every metastable ground-state exchange collision mixes the He^3 spin states. However, only a fraction τ_2/τ of these collisions, where $1/\tau = 1/\tau_\gamma + 1/\tau_p$, is effective in polarizing the ground-state system, since the total angular momentum in the coupled systems can change only when a metastable undergoes a τ_γ or a τ_p process. Thus, neglecting T_γ processes, the time required to pump the coupled metastable and ground-state systems to their equilibrium polarizations will be $T_p = \tau N/n$. The effect of T_γ will be to reduce the pumping time to a value given by $1/T_p' = 1/T_p + 1/T_\gamma$. Figure 2 is a photograph of the optical-pumping signal observed, for a He^3 absorption cell at 1 mm Hg pressure, as the polarization is allowed to build up from an intiallly depolarized state, which can be obtained by saturation of either the metastable or ground-state magnetic transitions. The experimentally obtained pumping time is typically about 8 seconds for a 1-mm cell, but depends strongly on the density of metastable atoms in the absorption cell, hence on the discharge intensity.

We estimate that T_γ is of the order of or greater than T_p, since the optical-pumping signal observed is comparable in intensity to that obtained from a He^4 absorption cell under the same experimental conditions. If T_γ were much smaller than T_p, its effect would be to reduce substantially the He^3

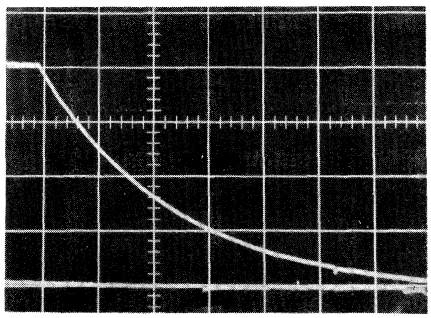

FIG. 2. Photograph of polarization buildup as displayed on oscilloscope. Time base is 4 sec/cm.

metastable polarization attainable, hence the optical-pumping signal in He^3 relative to that in He^4.

We wish to thank Professor P. A. Franken, Dr. Alan Reinberg, and Dr. Michiel de Wit for valuable discussions related to this work. We gratefully acknowledge the technical contributions of F. D. Sinclair and J. L. Center.

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EXCITED ISOBARIC STATES IN MEDIUM-A NUCLEI*

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(Received April 2, 1962)

The importance of isotopic spin considerations ($\Delta T = 0$) in "mirror-nuclei" (p,n) reactions has been pointed out by Bloom et al.[1] For nonmirror nuclei we have previously demonstrated the existence of isobaric states[2,3] using the (p,n) reaction. The (p,n) reaction was assumed to go as follows[4]: The incoming proton reacts with an "excess neutron" (a neutron corresponding to an unfilled proton state), exchanges its charge, and is emitted as a neutron. Although previously published V^{51}-Cr^{51} spectra[2,3] showed no evidence for excited isobaric states, Rost[5] suggested that the excitation of excited isobaric states was more probable in even-even nuclei than in odd-even nuclei. Herein we present experimental evidence for the existence of excited isobaric states from the (p,n) reaction on medium-A nonmirror even-even nuclei and show that these states correspond to the excited states of the target nucleus.

The Livermore Variable-Energy Cyclotron and time-of-flight techniques[6] have been used to study (p,n) spectra from selected target nuclei. We have previously reported[3] measurements up to a proton bombarding energy of 14.8 MeV where all spectra show one strong neutron group at an energy corresponding in excitation in the final nucleus to the isobaric counterpart (analog state) of the target ground state, i.e., the Q value is the usual Coulomb energy displacement. The modification of the rf cavity of the cyclotron enabled us to obtain protons with energies in excess of 18 MeV. This higher proton energy permits us to look at higher excitations in the residual nucleus in the region of the isobaric ground state (analog state) with considerable reduction in background, since the principal background obscuring neutrons from the isobaric state is composed of neutrons from compound nucleus decay.

The time-of-flight spectra resulting from 17-MeV proton bombardment of even-even target nuclei Fe and Ni are shown in Fig. 1. The analog state neutron group is clearly seen, as in a first excited isobaric state. Excited isobaric states are also seen for Ar, Ti, Zn, and Se. The Q values for the excited isobars are listed in Table I along with the first excited states of the target nuclei. It seems clear then that excited isobaric states exist corresponding to the excited

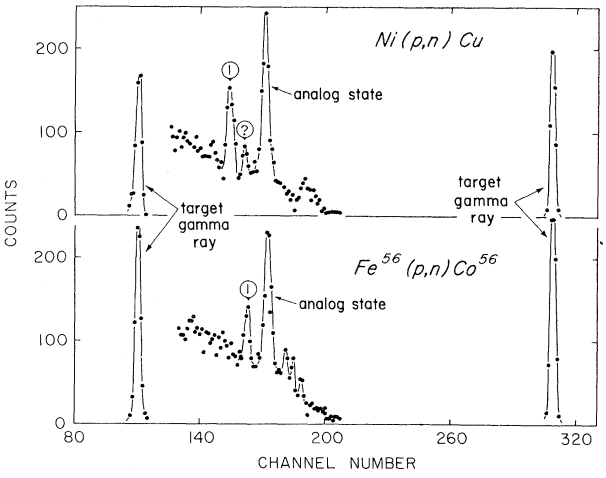

FIG. 1. Time-of-flight spectra from 17-MeV proton bombardment of Fe and Ni. Time calibration of the system is 1.9 nsec/channel and increasing time of flight is toward the left. The flight path was 11.4 meters.

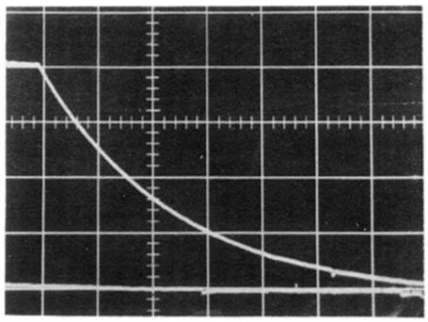

FIG. 2. Photograph of polarization buildup as displayed on oscilloscope. Time base is 4 sec/cm.