[5]R. E. Watson and A. J. Freeman, Phys. Rev. 120, 1134 (1960).

[6]Note that the spin density of these "paired" electrons integrate to zero over all space, giving no contribution to the net spin.

[7]H. Alperin, Phys. Rev. Letters 6, 55 (1961).

[8]A similar negative spin density was observed in earlier calculations for the 4s electrons in the 3d transition elements (to be published) and in one instance for the 3d spin density as well (Freeman and Watson, reference 3).

[9]R. G. Shulman and V. Jaccarino, Phys. Rev. 103, 1126 (1956), and 108, 1219 (1957), and more recent work by these and other authors.

[10]M. Tinkham, Proc. Roy. Soc. (London) A236, 535 and 549 (1956).

[11]A. Mukherji and T. P. Das, Phys. Rev. 111, 1479 (1958); G. B. Benedek and T. Kushida, Phys. Rev. 118, 46 (1960).

[12]C. Sonnenschein (unpublished).

[13]A. Zalkin and D. H. Templeton, J. Am. Chem. Soc. 75, 2453 (1953).

[14]Although these overlaps are almost as large as those for the iron series fluorides, NMR studies of GdF_3 did not show any internal field at the F nucleus [V. Jaccarino (private communication)]. (The reason for this is not clear, but exchange polarization of the F^- wave functions by the Gd^{+3} ions is expected to be important.) R. G. Shulman and B. J. Wyluda, J. Chem. Phys. 30, 335 (1959), have, however, reported a negative NMR shift in the H_2O^{17} resonance in an aqueous solution of paramagnetic Gd ions, in keeping with the discussion in this paper.

[15]V. Jaccarino, B. J. Matthias, M. Peter, H. Suhl, and J. H. Wernick, Phys. Rev. Letters 5, 251 (1960), and V. Jaccarino (private communication).

[16]M. A. Ruderman and C. Kittel, Phys. Rev. 96, 99 (1954); T. Kasuya, Progr. Theoret. Phys. (Kyoto) 16, 45 (1956); K. Yosida, Phys. Rev. 106, 893 (1957).

[17]R. E. Watson and A. J. Freeman (to be published).

OPTICALLY DRIVEN SPIN PRECESSION

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The possibility of modulating a light beam at rf resonant frequencies by applying rf energy to an optically pumped spin system has been amply demonstrated theoretically[1,2] and experimentally.[3,4] We report here an interesting converse—that of modulating the light source at frequencies close to the Larmor frequency and observing a precessing spin polarization induced by the modulated light. The resulting resonance has quite different characteristics from the usual rf magnetic resonance; in particular, it does not show saturation effects although the linewidth does depend in part on the average intensity of the incident light. This is, to our knowledge, the first time that an rf resonance effect has been produced by means that do not involve variation of a field directly coupling the rf-separated energy states.

The effect may be observed in optically pumpable spin systems such as alkali metal vapors[1,3] or metastable helium[5] by applying circularly polarized resonance radiation at right angles to the magnetic field H_0 (Fig. 1). In an earlier paper[3] we developed a phenomenological treatment of optically pumped spin systems that included the effects of several light beams. If we adhere to the notation of reference 3, and specialize to a single light beam perpendicular to H_0, and no rf field, we obtain the following equations for the spin system:

$$dF/dt + i\gamma H_0 F + F/S_2 = P_x \mathfrak{M}',$$

$$dM_z/dt + M_z/S_1 = 0,$$

where $F = M_x + iM_y$, P_x is the pumping rate of the light, S_1 and S_2 are relaxation times including effects of the light, and $\mathfrak{M}'$ is the equilibrium polarization that would be produced by the light in the absence of a magnetic field and thermal

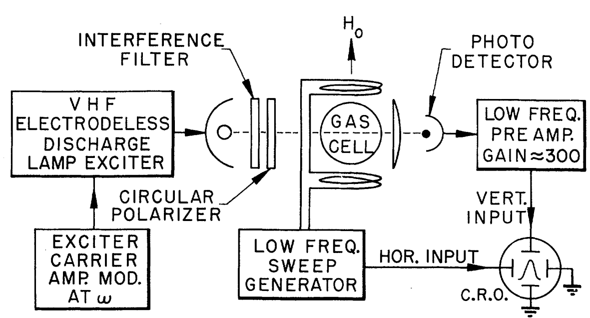

FIG. 1. Block diagram of apparatus. The interference filter is employed in alkali vapor to remove the $S_{1/2} \rightarrow P_{3/2}$ resonance radiation. In the metastable helium experiment no interference filter is used, and a high-frequency electrodeless discharge must be applied across the absorption cell to generate metastables.

relaxation effects. Normally (with no modulation) the steady-state solution is very small ($M_Z = 0$, $F \propto 1/\gamma H_0$). However, let the light be modulated so that

$$P_x = a + b \cos\omega t,$$

$$1/S_2 = R + b \cos\omega t,$$

then a large steady-state solution exists of the form

$$F = \frac{\frac{1}{2} b \mathfrak{M}'}{R + i\Delta\omega} e^{-i\omega t},$$

where $\Delta\omega = \gamma H_0 - \omega$.

The effect can be observed most easily as a change in average intensity of the transmitted light. The absorption of light by the cell is proportional to $P_x(1 - M_x)$, and the resulting signal in the photocell is then proportional to

$$-\frac{\frac{1}{4} R b^2 \mathfrak{M}'}{R^2 + \Delta\omega^2} + (\text{terms at } \omega \text{ and } 2\omega),$$

which represents a secular increase in the transmitted light at resonance.

One can picture the effect as follows. If one takes a "snapshot" of the system at $t = 0$ in a time short compared with a Larmor cycle, the effect of H_0 is a negligible perturbation and the light "pumps" a small amount of polarization in the x direction. This polarization immediately starts to precess in the xy plane at the Larmor frequency and is added vectorially to the polarization produced at all other instants of time. For unmodulated light this vector sum is clearly very small or zero. If the light is modulated at the Larmor frequency, however, then the polarization produced at $t = 0$ is not exactly cancelled by that produced at $t = \pi/\omega$ and is reinforced by the polarization produced at $t = 2\pi/\omega$, $4\pi/\omega$, etc. An equivalent point of view is to consider the system in a coordinate system rotating at ω; since the "rotating" lamp is turned on only when it is pointing in a certain preferred direction, it is effectively stationary in a frame of reference for which the effective magnetic field is very weak. Optical pumping then takes place as if the effective field were parallel to the light beam.

We have observed the effect in Cs and Rb vapor at Larmor frequencies between 175 and 350 kc/sec, and in He at 1.4 Mc/sec. Helium provides the best demonstration of the effect because a greater index of modulation can apparently be achieved than with alkali vapor lamps, and the signal is proportional to the square of the modulation index. In He with 60-cycle sweep and about 60% modulation of the lamp exciter carrier, the signal is comparable in amplitude to the standard magnetic resonance signal.

We are investigating the possibility of extending this technique to higher resonant frequencies.

[1]H. G. Dehmelt, Phys. Rev. 105, 1924 (1957).

[2]N. Bloembergen, P. Pershan, and L. Wilcox, Phys. Rev. 120, 2014 (1960).

[3]W. E. Bell and A. L. Bloom, Phys. Rev. 107, 1559 (1957).

[4]J. Dodd, W. Fox, G. W. Series, and M. Taylor, Proc. Phys. Soc. (London) 74, 789 (1959).

[5]F. D. Colegrove and P. A. Franken, Phys. Rev. 119, 680 (1960).

LEPTONIC DECAY OF A Σ^- HYPERON*

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The search for the leptonic decay modes of the Σ hyperons has not been entirely successful until now. The only previous positive evidence[1] is the decay in flight of a Σ particle of unknown charge. If the decay particle is taken as a pion, the Q value would be too high by two and one-half times the quoted error. Recent systematic search for the leptonic decay in the bubble chamber among a much larger sample of decays has yielded no further confirmation of these decays.[2]

We report here a clear example of the decay $\Sigma^- \rightarrow e^- + \nu + n$. It was obtained in an exposure of the Columbia-Brookhaven 30-in. propane chamber to a 2-Bev π^- beam at the Brookhaven Cosmotron. The event is reproduced in Fig. 1. The incident pion produces one long positive prong, a V^0, and a prong which breaks sharply after 7 mm. Measurements on these tracks are given in Table I. There is no question that the track which is emitted almost straight back from the