It is clear from Eq. (4) that a perturbation theory expansion of $\delta Q$ converges[9] with radius of convergence $\gamma=1$. It is also interesting to note that $\delta Q$ remains finite in the limit $\gamma\rightarrow 1$.

The corrections to the Uehling formula for $V(r)$ at small $r$ are very small, even for lead, so that its use for the $\mu$-meson work appears to be well justified.

Formulas like (4) can be obtained for all of the coefficients in the small-$p$ expansion of $Q(p)$, although the labor involved increases with the order of the coefficient. In view of the smallness of (4), however, it is unlikely that the terms beyond the cubic are ever important.

A fuller account of the work described above, together with some applications, will be subsequently submitted for publication.

* Work partially performed at Brookhaven National Laboratory, under the auspices of the U. S. Atomic Energy Commission.

[1] Koslow, Fitch, and Rainwater, Phys. Rev. **95**, 291 (1954).
[2] V. Fitch and J. Rainwater, Phys. Rev. **92**, 789 (1953).
[3] L. W. Cooper and E. M. Henley, Phys. Rev. **92**, 801 (1953).
[4] H. C. Corben, Phys. Rev. **94**, 787 (1954).
[5] D. L. Hill and K. W. Ford, Phys. Rev. **94**, 1617 (1954).
[6] E. A. Uehling, Phys. Rev. **48**, 55 (1935); R. Serber, Phys. Rev. **48**, 49 (1935).
[7] A. L. Schawlow and C. H. Townes, Science **115**, 284 (1952).
[8] W. Heisenberg and H. Euler, Z. Physik **98**, 714 (1936); H. Euler, Ann. Physik **26**, 398 (1936).
[9] One can also show that for a given value of $p$, $Q(p)$ is an analytic function of $\gamma$ within the circle $|\gamma|=1$.

## Polarization of Arsenic Nuclei in a Silicon Semiconductor*

A. Honig
*Department of Physics, University of California, Berkeley, California*
(Received August 12, 1954)

A NEW mechanism capable of producing nearly 100 percent polarization of nuclear spins under moderate conditions of field and temperature has been found in the course of electron spin resonance studies.

Electron spin resonances exhibiting resolved hyperfine structure have recently been observed by Fletcher *et al.*[1] on a number of impurity-doped silicon samples. This note is concerned with a similar sample of arsenic-doped silicon; it is reported to contain $1.3\times10^{17}$ As atoms per cm$^3$. The sample was generously provided by Dr. F. J. Morin of Bell Telephone Laboratories.

At a temperature of 4°K and at a frequency of about 9000 Mc/sec, the four resonances reported by Fletcher were observed. These lines correspond to each of the four possible orientations in the magnetic field of the $As^{75}$ nucleus, which has a spin of $\frac{3}{2}$. The lines were approximately 3 oersteds broad, were spaced about 73 oersteds apart, and exhibited inhomogeneous saturation behavior.[2]

On each one of the resonances, the following observations were made: If the magnetic field was swept twice through the same resonance with a time $t$ elapsing between the two traversals, the amplitude $A_2$ of the second traversal of the resonance line is decreased relative to the amplitude of the first traversal by approximately

$$A_2/A_1=1-e^{-t/T},$$

where $T$ is about 16 seconds. Also, by sweeping through two neighboring hyperfine components sufficiently rapidly, an *enhancement* of the second line relative to the first line was obtained, this enhancement being about a factor of two larger if the first line was one of the extrema of the hyperfine multiplet.

The proposed explanation of this effect utilizes the process whereby electron spin relaxation can effect a nuclear spin reorientation through the $\mathbf{I}\cdot\mathbf{S}$ magnetic hyperfine interaction. In sweeping through a resolved hyperfine resonance line using sufficient rf power, we suppose that virtually all of the relevant As nuclei undergo a $\Delta m_I$ of $\pm1$, thus depopulating the $m_I$ level associated with the particular line. Then, if the nuclear spin relaxation time is about 16 seconds, the observed effect results. However, in order for the net depopulation of the $m_I$ level to occur during the electronic resonance, it is necessary to have a mechanism whereby the number of nuclear spins flipped by electron spin relaxations is greatly enhanced when *on the electronic resonance.* A mechanism for this was suggested by J. I. Kaplan and is described in the following Letter. It consists essentially of a broadening of the power spectrum of the electron relaxation, centered at the electron spin Larmor frequency, due to the shortened lifetime of an electron spin state during resonance; this produces a larger Fourier amplitude at the nuclear Larmor frequency, thereby increasing the probability of a nuclear spin flip. In the present As-doped sample, it is estimated that, for an rf amplitude of $H_1=0.010$ oersted, the time for a nuclear spin flip would be of the order of $10^{-2}$ second due to this mechanism, as contrasted with 16 seconds under no rf.

Manifestations of this effect are also seen in sweeping through a single line. The shape of the line shows an asymmetry and large $g$ shift due to a progressive depopulation of the associated nuclear $m_I$ state. The *inhomogeneous* line width and spin diffusion time of the $Si^{29}$ nuclei enter into the quantitative analysis of this behavior.

In the present case, to polarize completely the As nuclei in a particular $m_I$ state, one has to sweep through the resonances corresponding to the other three $m_I$ states in a time small compared to the nuclear relaxation time. In the case of Si doped with an impurity having a spin of $\frac{1}{2}$, such as phosphorus, satisfying the resonance condition for one $m_I$ state would completely polarize the other state. The general requirement is that sufficient rf power be used so that the nuclear spin flip time in the presence of the rf will be short compared to the nuclear relaxation time in the absence of rf. It is to be

noted that saturation of the electronic resonance is not necessarily required.

It should be possible to apply this effect toward obtaining polarized samples for the study of nuclear level decay schemes. Another consequence is that it is possible to measure nuclear relaxation times in systems where the nuclear resonance cannot be observed because of the strong and fluctuating local magnetic field at the nucleus due to the electrons.

It is a pleasure to thank the members of the solid state group at the University of California for many stimulating discussions.

* This work has been assisted in part by the U. S. Office of Naval Research and the U. S. Signal Corps.

[1] Fletcher, Yager, Pearson, Holden, Read, and Merritt, Phys. Rev. **94**, 1392 (1954).
[2] A. M. Portis, Phys. Rev. **91**, 1071 (1953).

## Nuclear Electric Quadrupole Moment of $Na^{23}$

S. SENGUPTA
*Government College, Darjeeling, West Bengal, India*
(Received August 2, 1954)

IT has recently been reported by Sagalyn[1] that the nuclear electric quadrupole moment of $Na^{23}$ is $+0.1\times10^{-24}$ cm². On Mayer's single-particle level scheme, there are three possible configurations for the ground state of $Na^{23}$. They are $[(d_{5/2})^3]_{3/2}$, $[(d_{5/2})^2 s_{1/2}]_{3/2}$, $[(d_{3/2})^3]_{3/2}$. The actual level order here, as given by Mayer,[2] is $d_{5/2}$, $s_{1/2}$, $d_{3/2}$. The last assignment, though giving a positive $Q$, is extremely improbable, because of the large departure of the observed magnetic moment from the Schmidt limit. Mayer herself preferred the first assignment, especially because a calculation of $\mu$ with $jj$ coupling gives for this configuration a value of 2.87 nm, in fairly good agreement with the experimental value of 2.22 nm. However, as has been shown by Sagalyn,[1] the quadrupole moment in this configuration with $jj$ coupling comes out to be zero. Hence the $(d_{5/2})^3$ configuration also cannot be accepted. We are thus left with the second alternative. Calculations for both magnetic and quadrupole moments have been carried out for this configuration with $jj$ coupling. The wave functions for the $(d_{5/2})^2$ configuration are calculated by the method of Gray and Wills[3] and the total wave function for $(d_{5/2})^2 s_{1/2}$ is then antisymmetrized by the method given in Condon and Shortley.[4] The $(d_{5/2})^2$ state is coupled with the $s_{1/2}$ state to give the observed spin of 3/2. The result gives

$$\mu = 1.78 \text{ nm},$$

$$Q = +(8/35)\langle r^2\rangle_{\text{Av}} = +0.041\times10^{-24} \text{ cm}^2,$$

where $\langle r^2\rangle_{\text{Av}}$ is calculated from the formula $r=1.5A^{\frac{1}{3}}\times10^{-13}$ cm. Thus the observed magnetic dipole and electric quadrupole moments of $Na^{23}$ are found to support the assignment $[(d_{5/2})^2 s_{1/2}]_{3/2}$ for its ground state.

[1] P. L. Sagalyn, Phys. Rev. **94**, 885 (1954).
[2] M. G. Mayer, Phys. Rev. **78**, 16 (1950).
[3] N. M. Gray and L. A. Wills, Phys. Rev. **38**, 248 (1931).
[4] E. U. Condon and G. H. Shortley, *Theory of Atomic Spectra* (Cambridge University Press, London, 1953), p. 213.

## *K* Mesons and a Charged Hyperon Produced by 3-Bev Protons in Emulsions*

W. F. FRY AND M. S. SWAMI
*Department of Physics, University of Wisconsin, Madison, Wisconsin*
(Received August 4, 1954)

A GROUP of glass backed plates and pellicles were exposed inside the Cosmotron to 3-Bev protons. The proton flux was greatly reduced from the normal operating intensity, and the plates were exposed to about 5 pulses from the Cosmotron. The proton track density in the plates is about $5\times10^5$ tracks/cm².

The emulsions were area scanned with an over-all magnification of about 100×, looking for slow heavy mesons, hyperons, and bound $\Lambda^0$ particles. In this note we describe three events which are interpreted as two $K$ mesons and a hyperon. These three events were found in 4.5 cc of emulsion. A detailed description of bound $\Lambda^0$ particles will be given elsewhere.

The essential characteristics of the three events are given in Table I.

A photograph of the production and decay of particle $K_1$ is shown in Fig. 1. The track of the $K$ meson is 7000 microns long and stops in the same plate, giving rise to a secondary track which is nearly in the plane of the emulsion and is 24 000 microns long in the same plate. The ionization along the secondary track was measured by blob counting and was compared with 3-Bev proton tracks at the same depth in the emulsion. The ionization of the secondary particle was found to be $1.08\pm0.06$ times that of the 3-Bev protons. The scattering parameter, $p\beta$, of the secondary particle was found to be $180\pm13$ Mev/$c$ by using cells of 200 microns. The kinetic energy of the secondary particle is $121\pm9$ Mev, $109\pm8$ Mev, or $180\pm13$ Mev if we assume it to be a $\mu$ meson, a $\pi$ meson, or an electron respectively. The expected relative ionization,[1] compared with 3-Bev protons, is $1.1\pm0.02$ for a $\mu$ meson and $1.2\pm0.02$ for a $\pi$ meson. The measured ionization and multiple scattering strongly indicate that the secondary particle is a $\mu$ meson or an electron. If the secondary particle is assumed to be a $\pi$ meson, the expected ionization differs from the measured value by about two standard deviations. The mass of the $K_1$ particle was found to be $850\pm150 m_e$ by using the constant sagitta method.[2,3] The event is consistent with the decay of a meson of