free to move in the x-, y-, and z-directions respectively. Starting with cubic $BaTiO_3$ above 120°C, and cooling the crystal, the effect of the mismatch in ionic size as the lattice contracts is first to squeeze one of the oxygens, say O_z, out of its plane of Ba ions. This results in a spontaneous polarization and a deformation of the crystal, the symmetry becoming tetragonal. Contraction in the directions at right angles to the polarization occurs, since the Ba ions, which were pressing against the O_z ion, can now come together by a small amount proportional to the square of the O_z displacement z. A simple geometrical argument based on hard spheres in contact gives for the transverse contraction $-\Delta a/a = (z/a)^2$, where "a" is the lattice constant. The polarization P_{0z} due to displacement of O_z is $2eza^{-3}$, so that the transverse contraction becomes

$$-\Delta a/a = (a^4/4e^2)P_{0z}^2 = 3.8\times 10^{-12}P_{0z}^2.$$

Experimentally,[8] $-\Delta a/a$ is found to be accurately proportional to the square of the total polarization, with a coefficient of 1.2×10^{-12}. Thus, if P_{0z} represents 56 percent of the total polarization, the transverse electrostriction is given correctly.

The displacement of O_z relieves the instability of the lattice to a certain extent; as we further cool the crystal, a second group of oxygens, say the O_y, get squeezed out of their symmetrical positions, and the polarization now has equal components in the z and y directions, the crystal distorting to orthorhombic symmetry. On further cooling, the O_x ions are squeezed out of place, resulting in a net polarization directed toward the diagonal of the original cube, and the symmetry becomes rhombohedral. All of these changes of phase and polarization direction are observed experimentally.[8]

Certain obvious refinements of this model would change the above numerical estimates, but it is clear that we get a qualitative understanding of two of the most puzzling features of $BaTiO_3$, namely the existence of three phase transitions with shifts of the direction of spontaneous polarization, and the very large electromechanical coupling.

I am indebted to Professor E. P. Wigner and Dr. B. T. Matthias for helpful discussions.

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On the Hyperfine Structure of Hydrogen and Deuterium*

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A NEW determination of the hyperfine structure separation of both hydrogen and deuterium in the $^2S_{\frac{1}{2}}$ state has been made by the atomic beam method. The new values are, for several reasons, of considerably greater precision than those previously reported.[1] The r-f circuit which produced the oscillating magnetic field was arranged so that no Doppler effect[2] could occur to shift or broaden the lines. The deflecting fields, which were set up by current carrying conductors, were sufficiently remote from the transition region to have a negligible effect on the field in that region. The transition field itself was extremely stable since the transitions were observed in the permanent residual laboratory field of about 0.3 gauss. The Pirani gauge detector, of a design proposed by Zacharias,[3] was extremely fast so that no very great demands were put on the stability of the frequency source, and it was possible to accumulate a large body of significant data.

In the case of hydrogen, the σ-line $(1, 0)\leftrightarrow(0, 0)$ and the two π-lines $(1, 1)\leftrightarrow(0, 0)$ and $(1, 0)\leftrightarrow(1, -1)$ were observed. The σ-line gives the hyperfine structure separation, ν_H, directly after the application of a small quadratic correction of about 0.3 kc in these measurements. The difference in the frequencies of the two π-lines is identically equal to ν_H. All frequency measurements were made in terms of the 5 Mc signal from WWV. For several runs, each of which consisted of many measurements of the line centers, the following results were obtained:

Run	Method	$\nu_H\times 10^{-6}$ sec.$^{-1}$
1	σ-line	1420.4056±0.0010
2	σ-line	1420.4053±0.0005
2	π-lines	1420.4051±0.0016
3	σ-line	1420.4048±0.0005
	Weighted Mean	1420.4051±0.0003

The stated uncertainty is about twice the usual probable error.

Deuterium has two nearly field independent, unresolved π-lines at weak fields, $(\frac{3}{2}, \frac{1}{2})\leftrightarrow(\frac{1}{2}, -\frac{1}{2})$ and $(\frac{3}{2}, -\frac{1}{2})\leftrightarrow(\frac{1}{2}, \frac{1}{2})$. The frequency separation of these lines is $2g_I\mu_0H/h$ which in our case is about 0.4 kc. Since the probability of each of these transitions is the same, and since atoms in the states $(\frac{3}{2}, \frac{1}{2})$ and $(\frac{3}{2}, -\frac{1}{2})$ have substantially identical trajectories in the apparatus as have also atoms in the states $(\frac{1}{2}, \frac{1}{2})$ and $(\frac{1}{2}, -\frac{1}{2})$, the center of gravity of the observed line, of about 22 kc half width, can be used to fix ν_D without ambiguity. From numerous measurements on these lines and from less precise measurements on other π-lines to determine the quadratic correction, we find:

$$\nu_D = (327.38424\pm 0.00014)\times 10^{-6} \text{ sec.}^{-1}.$$

From these results, the experimental value of the ratio of ν_H ν_D is:

$$(\nu_H/\nu_D)_{\text{exp}} = 4.3386484\pm 0.0000020.$$

This value may be compared to the theoretical value of the ratio which is given by the expression:

$$(\nu_H/\nu_D)_{\text{theor}} = 4/3(m_H/m_D)^3(\mu_H/\mu_D)$$

where m_H and m_D are the reduced masses of an electron in hydrogen and deuterium respectively. Using the value of μ_H/μ_D determined by Smaller, Yasaitas, and Anderson,[4] and $m_H/m_e = 1835.979\pm 0.056$:[5]

$$(\nu_H/\nu_D)_{\text{theor}} = 4.3393876\pm 0.0000008.$$

The discrepancy between the experimental and theoretical ratio may be written as:

$$(\nu_H/\nu_D)_{\text{exp}} = (\nu_H/\nu_D)_{\text{theor}}[1-(1.703\pm 0.007)\times 10^{-4}].$$

This result agrees with the less accurate result of Nafe and Nelson.[1]

From theoretical considerations of the effects of internal nuclear motion on the hyperfine structure of deuterium, Low[6] obtains:

$$(\nu_H/\nu_D) = (\nu_H/\nu_D)_{\text{theor}}[1-(1.83\pm 0.22)\times 10^{-4}].$$

In view of the large uncertainty in the theoretical calculation, it is not possible to draw a significant conclusion from the disagreement between the observed and calculated values. However, the accurately known discrepancy between the deserved and calculated values of the ratio of the ν's makes possible a careful investigation of the structure of the deuteron.

The fine structure constant, α, may be found[7] from the known value of ν_H and from the known value of μ_H/μ_0. The new value of ν_H does not significantly alter the previously stated value of α. However, the present precision in ν_H is greater than that of any other quantity in the theoretical relationship. It is of interest to note that a very much improved precision in the value[8] of μ_H/μ_0, new calculations for the diamagnetic fields at a nucleus in a molecule,[9] a new [10] fourth-order correction of the spin magnetic moment of the electron, and a very much improved value of the velocity of light[11] now suggest the possibility of obtaining α to a

very high degree of precision, limited by the theoretical approximations in the relationship between ν_H and μ_H.

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The Nuclear Magnetic Moment of Scandium[45]

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IN a recent letter with the above title in this journal, Sheriff and Williams[1] present a value of 4.7617 ± 0.0010 nuclear magnetons for the magnetic moment of Sc^{45} after having made a diamagnetic correction of 0.260 percent in accordance with Lamb's[2] formula.

It is the purpose of this note to point out that the diamagnetic correction according to Lamb's formula is 0.151 instead of 0.260 percent. When Sheriff and Williams' experimental results are recalculated with this value of the Lamb correction they give for the magnetic moment of Sc^{45}

$$\mu(Sc^{45})=4.7564\pm0.0010 \text{ nuclear magnetons.}$$

Although the result of Sheriff and Williams originally disagreed with the recent results of Proctor and Yu[3] and Hunten,[4] the above correction brings it into agreement within the experimental limit of error.

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Gamma-Rays of Ag^{105} and Ag^{106}

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THE gamma-rays of Ag^{106} (8.2*d*) and Ag^{105} (45*d*) have been measured by Enns[1] and Deutsch *et al.*[2] The results are shown in Table I.

Since the measurements were made a number of years ago when techniques had not been developed to their present state, it was decided to repeat these measurements. In addition it was hoped that the energy levels of Pd^{106} determined from K-capture in Ag^{106} could be checked against those determined from the disintegration of Rh^{106}.

In the present experiments Ag^{106} and Ag^{105} were produced by bombarding Pd with deuterons or Rh with alpha-particles in the Indiana University cyclotron. The first reaction also gave some Ag^{111} in addition to Ag^{105} and Ag^{106}. In no case were Ag^{106} and Ag^{105} produced separately since in the bombardment with alpha-particles both $Rh(\alpha, n)$ and $Rh(\alpha, 2n)$ reactions took place. Chemical separations to isolate silver were made. The assignment of the lines to the several isotopes was made by watching the decay of the source.

The lines having an 8-day period, and hence attributed to Ag^{106}, have energies of 0.515, 0.722, 1.04 and 1.54 Mev. In comparing these results with those of Peacock[3] on Rh^{106} it is to be noted that he finds lines at 0.51, 0.75 and 1.25 Mev but none at 1.04 and 1.54 Mev, while the line at 1.26 Mev is not seen in Ag^{106}.

The gamma-rays associated with the 45-day period, Ag^{105}, have energies of 0.064, 0.278, 0.340 Mev with two weak lines at 0.220 and 0.437 Mev. From energy considerations it would appear that the line at 0.340 Mev is probably in parallel with the lines at 0.278 and 0.064 Mev which are in cascade. The lines 0.220 and 0.437 Mev are probably in another branch of the K-capture process.

TABLE I. Early measurements on gamma-rays of Ag^{106}, Ag^{105}.

	Ag^{105} (Energy in Mev)	Ag^{106} (Energy in Mev)
Enns	0.29, 0.42, 0.51, 0.62	0.69, 1.06
Deutsch, Roberts, Elliott	0.282, 0.345, 0.430, 0.650	0.505, 1.06, 1.63, 0.72(?)

The source produced from the $Pd(dn)$ reaction contained Ag^{111} (7.5 days). The beta-ray spectrum was measured and a Fermi plot made of the data. The beta-ray spectrum of Ag^{111} appears to be simple with an end point at 1.06 Mev, in agreement with the work of Helmholtz, *et al.*[4] In addition, internal conversion lines for gamma-rays at 0.515 (Ag^{106}), 0.338, 0.278 and 0.064 (Ag^{106}) were obtained. An Auger line at 19 kev was observed which corresponds to the $K-L-M$ energy difference in Pd.

We are indebted to Dr. M. B. Sampson and the cyclotron crew for making the bombardments.

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Detection of Scintillations from Crystals with a Photo-Sensitive Geiger-Müller Counter*

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PHOTO-SENSITIVE Geiger-Müller counters have been the subject of long study at this laboratory. Very high quantum efficiencies, as indicated by his often-mentioned starlight experiments, were achieved by Locher[1,2] who employed a multitude of photo-cathode surfaces in making his photon counters at Bartol. Locher's account[1] of his work in photo-sensitive surfaces at the Rice Institute remains even today one of the very best available discussions of photon counting.

Glasser and Beaseley[3,4] describe interesting measurements in which long-period *phosphorescence* from gamma-rays on NaCl was observed with the use of a photo-sensitive G-M counter. This type of emission is to be differentiated from instantaneous fluorescence employed in the detection of nuclear particles by photo-multipliers.

Interest in photon counting was revived at Bartol when Scherb[5] discovered a discharge technique at liquid air temperatures which increased considerably the photo-sensitivity of the thus treated counter. The use of scintillating phosphors in conjunction with photo-multipliers again focused attention at this laboratory on the possibility of detecting fluorescent scintillations with G-M counters, and the feasibility of photon counters for scintillation detection was speculated upon in discussions at Oak Ridge.[6]

In the past several months, the writers have devoted considerable effort to reproducing many of Locher's early photon counters in an effort to attain sufficient quantum efficiency to detect scintillations from currently used crystals such as NaI. However, difficulties were encountered in matching the wave-lengths of the scintillations from the crystals with the peak of the spectral response of the cathode surfaces of the various counters. The alkali metals were usually employed, but it was found that appreciable response at wave-lengths greater than 3600A was difficult to obtain. Moreover, counters of the alkali metals seemed to have a high background arising, perhaps, from thermionic effects.

Finally it was decided to abandon the attempt to find cathode surfaces suitable for use with currently available crystals and to concentrate upon development of crystals which might fluoresce