

The formula which has been obtained is in good agreement with all the experimental results; the effect of the term  $(\Delta + g_{\perp}\beta H \sin \alpha)^2 D^{-2}$  can be neglected for the experimental errors reported here. Hence we can only determine  $g_{\parallel}$  and  $A$  in the spin Hamiltonian:

$$g_{\parallel} = 1.92 \pm 0.01; \quad A = (1.93 \pm 0.02) \cdot 10^{-2} \text{ cm}^{-1}.$$

Measurement of the line intensities at various temperatures indicates that  $D > 0$  and is approximately  $10 \text{ cm}^{-1}$ .

The results which have been obtained are in agreement with the values  $g_{\parallel} = 1.98$ ,  $g_{\perp} = 1.82$  and  $D = 5.0 \text{ cm}^{-1}$ , obtained by van der Handel and Siegert<sup>4</sup> from measurements from the susceptibility of vanadium — ammonium alums.

The authors are indebted to S. V. Grum-Grzhimailo and A. A. Popov for preparation of the samples and to Professor A. I. Shal'nikov for participating in the low-temperature experiments.

<sup>1</sup>A. Siegert, *Physica* **4**, 138 (1937).

<sup>2</sup>J. H. van Vleck, *J. Chem. Phys.* **7**, 61 (1939).

<sup>3</sup>A. Abragam and M. H. L. Pryce, *Proc. Roy. Soc.* **205**, 135 (1951).

<sup>4</sup>van den Handel and A. Siegert, *Physica* **4**, 871 (1937).

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## DISPERSION OF SOUND IN METALS IN A MAGNETIC FIELD

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DISPERSION effects in the velocity of sound in solid metals, predicted by Alpher and Rubin,<sup>1</sup> have not been observed at the present time; this situation is probably a result of the fact that the effect is so small. In the present paper experiments in which this effect was observed are reported.

A special system was designed and built to investigate small changes in the velocity of acoustic vibrations; under favorable conditions this instru-

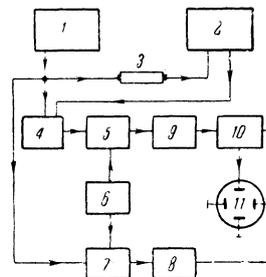


FIG. 1. Diagram of the measuring instrument. 1) 7 mc/sec crystal oscillator, 2) tuned amplifier, 3) sample, 4) electronic switch, 5) mixer, 6) quartz-crystal heterodyne unit, 7) mixer, 8) peaking amplifier, 9) frequency multiplier, 10) circular sweep generator, 11) cathode ray oscilloscope.

ment makes it possible to measure changes of approximately  $10^{-6}$  in the velocity of sound. The operation of the instrument is based on a comparison and measurement of the phase difference between vibrations which pass through the sample being investigated and those which are transmitted directly from an ultrasonic generator.

A block diagram of the measurement scheme is shown in Fig. 1. The high-frequency voltage from a quartz-crystal oscillator is applied to a quartz radiator which is fastened to one side of the cylindrical sample. A quartz detector is fastened to the second face of the sample; the voltage from the detector is then passed through a tuned amplifier to the phase meter.<sup>2</sup> A voltage obtained directly from the crystal radiator is also applied to the phase meter. Using a frequency multiplication factor of 18, phase differences of the order of 0.2 degrees can be measured.

X-cut quartz slabs 10 mm in diameter were used as ultrasonic radiators. The samples were cylindrical rods 20 cm long and 1.4 cm thick. Because of the high acoustic absorption in polycrystalline tin there was no need to take account of standing waves which could distort the results of the measurements; similarly there was no need to consider reflections from the side surfaces of the sample, produced by the cone-shaped radiation pattern of the quartz radiator. To avoid these effects in aluminum the surface was roughened by cutting to enhance scattering; the face at the receiving end was also cut at a small angle with respect to the axis.

The velocity of sound in a magnetic field is given by the expression:\*

$$c_l = c_{l0} \left( 1 + \frac{s^2}{2c_{l0}^2} \sin^2 \vartheta \right), \quad c_t = c_{t0} \left( 1 + \frac{s^2}{2c_{t0}^2} \cos^2 \vartheta \right).$$

Here  $c_l$  is the velocity of longitudinal wave while  $c_t$  is the velocity of the transverse wave,  $s^2 = \mu H^2 / 4\pi \rho$ ,  $\rho$  is the density,  $\vartheta$  is the angle between

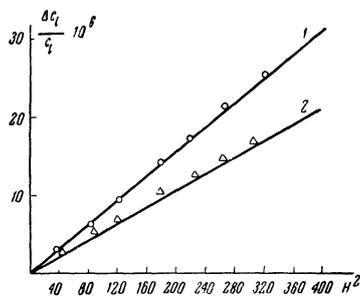


FIG. 2. The velocity of sound as a function of magnetic field.

the wave vector and the magnetic field,  $H$  is the magnetic field and  $\mu$  is the magnetic permeability. These formulas apply when  $\sigma \gg c^2\omega/4\pi\mu c_l^2$ , where  $\sigma$  is the conductivity,  $\omega$  is the vibration frequency and  $c$  is the velocity of light.

In Fig. 2 are shown the results of experiments carried out at room temperature in a magnetic field perpendicular to the axis of the sample ( $\sin \varphi = 1$ ). The relative change in velocity  $c_l$  is plotted along the ordinate axis while the square of the magnetic field is plotted along the abscissa axis. The solid lines are obtained by calculation: (1) for tin ( $c_{l_0} = 2630$  meters/sec), (2) for aluminum ( $c_{l_0} = 6,000$  meters/sec). The absolute values of the velocity were measured by a pulse

method. As is apparent from the curves, the experimental points are in good agreement with the theoretical values.

Thus it has been established that the acoustic velocity is proportional to  $H^2$  in a magnetic field and the magnitude of the effect is that predicted by the theory.

It is interesting to note that in bismuth, in which the condition  $\sigma \gg c^2\omega/4\pi\mu c_l^2$  is not satisfied, no dispersion in the acoustic velocity at room temperature was found.

In conclusion we wish to express our gratitude to Prof. A. I. Akhiezer and S. V. Peletminskii for calling our attention to this effect.

\*These expressions were obtained independently from Alpher and Rubin by A. I. Akhiezer and S. V. Peletminskii.

<sup>1</sup>R. A. Alpher and R. I. Rubin, *J. Acoust. Soc. Am.* **26**, 452 (1954).

<sup>2</sup>Samoilo, et al., *Trudy Moscow Engineering Institute* **21**, 89 (1956).

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## THE NEGATIVE ION $H_2^-$

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ACCORDING to theoretical calculations,<sup>1,2</sup> the molecule  $H_2$  in the lowest electronic state has no affinity for electrons. Nevertheless, the possibility of a stable negative ion  $H_2^-$  is not excluded. This unusual situation is due to the fact that, although the fundamental vibrational level of the system  $H, H^-$  (which is the  $H_2^-$  ion) is higher than the fundamental vibrational level of the  $H_2$  molecule, it has a much larger internuclear separation. The removal of an electron from the  $H_2^-$  ion corresponds to an electron transition at an internuclear separation of the order of 3 Å, where the potential curve for the  $H_2$  molecule rises higher than the curve for the  $H_2^-$  ion. According to Dalgarno and McDowell<sup>2</sup> the "vertical energy of electron removal" from the  $H_2^-$  ion is 0.9 eV.

As far as we are aware, the  $H_2^-$  ion has never

been observed. We have attempted to obtain some evidence for this ion, using the "recharging" method<sup>3</sup> to produce it. Water vapor and antimony vapor were introduced simultaneously into an ion source and bombarded by a beam of electrons (0.3 ma; 80 eV). The resulting negative ions were analyzed in a mass spectrometer connected to an electron multiplier.<sup>4</sup>

When water vapor alone was present in the ion source, the ions  $H^-$ ,  $O^-$  and  $OH^-$  were formed. When antimony vapor was subsequently introduced into the source, the additional ions  $Sb^-$ ,  $Sb_2^-$ , and  $Sb_3^-$  appeared, together with a negative ion of mass 2. There were also maxima corresponding to mass values of 0.5,  $\approx 3$ , and  $\approx 6$ . These maxima must be assigned to fragmentary ions, arising from the dissociation of primary ions. To suppress the ion fragments, a retarding potential of 1500 volts was applied to the first diode of the multiplier, while maintaining the primary ion energy at 800 eV. When this was done, the peaks corresponding to the masses 0.5, 3, and 6 completely disappeared; the amplitudes of the peaks at mass 1 ( $H^-$ ) and mass 2 were practically unchanged. This shows that both these maxima were due to primary ions formed in the source. The height of the peak at mass 2 depended on the vapor pressure of the antimony; even under the most favor-