method should provide a means of measuring the nuclear spin. The present results are in agreement with the well-established spin of $\frac{3}{2}$ for Na^{23}. It is planned to extend the method to nuclei of spins other than $\frac{3}{2}$ using the molecular beam technique. This method of measuring spins and quadrupole interactions may also be applicable to the resonance absorption[6,7] and nuclear induction[8] methods.

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Plastic Flow of Metals

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ONE of the most important problems connected with the plastic flow of metals is the one of determining the combined effects of strain, strain rate, and temperature on the stress required for plastic flow. In general, these relations should apply to plastic flow in situations when the stress distribution is complex; as well as for the case of deformation under the action of simple tensile stress. However, this note will describe only the relations between the variables for the case of simple tension.

It has been found[1] that at a constant strain rate and temperature, the stress (σ) and strain (ϵ) are related by the following equation:

$$\sigma = K(\epsilon)^m, \tag{1}$$

where K and m are constants that may depend upon the strain rate and temperature. Further, an empirical relation[2] between stress and strain rate (α) has also been developed:

$$\sigma = K_1(\alpha)^n, \tag{2}$$

where K_1 and n may depend upon the strain and temperature. In addition to these relations, another has been found giving all combinations of temperature and strain rate that correspond to a given stress at a fixed strain.[3-5] The relation can be written in the following forms:

$$l = \alpha/\alpha_1 e^{Q/RT}, \tag{3}$$

or

$$Q/R = -T \ln \alpha/\alpha_1, \tag{3a}$$

where α_1 may be a function of the strain, Q a function of stress and strain, and R is the gas constant.

From these three equations, a general relation connecting all four variables has been derived:

$$\sigma = C(\alpha/\alpha_0)^{DT}\epsilon^{(E-FT \ln \alpha/\alpha_0)} \tag{4}$$

where α_0, C, D, E, and F are constants of the material.

Two important consequences of this equation can be described briefly. The equation can be rewritten in logarithmic form:

$$\frac{\ln \sigma - \ln C - E \ln \epsilon}{F \ln \epsilon - D} = -T \ln \alpha/\alpha_0. \tag{4a}$$

Upon comparison with Eq. (3a) it is found that Q should vary linearly with the logarithm of the stress. This relation is in disagreement with the ideas of Becker,[6] Kauzmann,[7] and Dushman *et al.*[8] However, upon replotting the recalculated[3] values of Q, obtained from Dushman's data against the logarithm of the stress, straight lines are obtained.

Furthermore, it is seen from (4a) that the logarithm of the stress should vary directly with the temperature, the slope being a linear function of the logarithm of the strain rate. By replotting data obtained by Nadai and Manjoine,[9] these relations have been confirmed.

The problem of determining the entire plastic behavior of a metal in the range of temperature, strain rate, and strain in which it undergoes no phase changes becomes only a question of evaluating the five constants of Eq. (4). There are many conclusions that may be drawn from it. It has important applications to the problem of creep and to the theory of plastic flow. These relations will be discussed further in papers now in preparation.

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The Inversion Spectrum of Ammonia

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WHILE our detailed analysis of this spectrum awaits publication in the *Proceedings of the Royal Society*, the paper of the above title by W. E. Good[1] calls for the following comments.

1. The splitting of the inversion spectrum of ammonia, according to the theory of Sheng, Barker, and Dennison,[2] should be represented by a formula of the type

$$\bar{\nu} = \bar{\nu}_0 - A(J^2+J) + BK^2, \tag{1}$$

where the terms involving the rotational quantum numbers J, K correspond to the first term in the expansion of an exponential function. In our letter[3] of February 12, 1946, to *Nature*, we suggested a formula which, after correcting the $\bar{\nu}_0$ term for an error in the sign of the reduction of the wave numbers to a vacuum, becomes

$$\bar{\nu} = 0.7935 - 0.0050_5(J^2+J) + 0.0070_4K^2 + 0.63\{-0.0050(J^2+J) + 0.0070K^2\}^2 \text{ cm}^{-1} \text{ (vacuum)}, \tag{2}$$

exponential expansion. The extra term involves no further empirical coefficients, since the 0.63 is merely (1/2)/0.7935.

In his letter[4] the 20th of April, 1946, to *The Physical Review*, written before the author had seen our publication, Good suggested the formula

$$\tilde{\nu}=0.7932-0.0048(J^2+J-K^2)+0.0020K^2.$$

The expression now obtained by Good[1] is

$$\tilde{\nu}=0.79347-0.005048(J^2+J)+0.007040K^2+0.00001546(J^2+J)^2-0.00004260(J^2+J)K^2+0.00002920K^4, \quad (3)$$

where all the coefficients are empirical. On multiplying out, (2) becomes

$$\tilde{\nu}=0.7935-0.0050_5(J^2+J)+0.0070_4K^2+0.000016_1(J^2+J)^2-0.000044_9(J^2+J)K^2+0.000031_2K^4. \quad (2a)$$

It is surprising that Good made no comment on the close agreement between the two expressions. It should be noted that the accuracy of the measurement of frequency is the same in the two experiments, since the ±5. Mc/sec. claimed by Good corresponds to our ±0.02 percent. We did not feel justified, however, in evaluating the coefficients to greater accuracy, since even third-order terms would be appreciable for some lines.

2. The comparison of the relative intensities of the lines made by Good assumes that the widths of the different lines are all the same. The widths of 17 lines measured by us vary as $3[K^2/(J^2+J)]^{\frac{1}{2}}$, and from these widths the absolute intensities can be calculated. Our measured intensities agree with the calculated values within ±5 percent, while the intensities shown in Good's Fig. 5 are considerably smaller. For instance we find 0.044 db/meter for the line (6, 3), whereas Good's value appears to be less than 0.01 db/meter. The calculated value is 0.042 db/meter.

3. The following factors affect the change of intensity with temperature, in addition to those enumerated by Good.

(a) The change in the relative populations of the two levels of the inversion doublet causes the intensity to vary as $1/T$, corresponding to the fact that the cancellation of the absorption by induced emission is less at low temperature.

(b) At a given pressure the lines become broader, not sharper, as stated by Good, as the temperature is lowered, because the number of molecules per cc varies as $1/T$, while the molecular velocity varies only as $\sqrt{T}$.

4. Good suggests that the fall in intensity at low pressures shown in his Fig. 4 is owing to the interruption of the absorption by collision with the walls of the wave guide, which would ultimately cause the collision frequency to become independent of the pressure. At room temperature in a wave guide with the usual narrow dimension of 4.5 mm, however, an ammonia molecule would collide with the walls about $13\cdot10^4$ times per second giving a line-breadth constant ($\Delta\nu$) of $13\cdot10^4/2\pi\cdot10^6=0.02$ Mc/sec. The value of $\Delta\nu$ for the line (3, 3), estimated from Good's Fig. 4a, is, however, 0.4 Mc/sec. which must therefore be attributed to collisions between molecules. This indicates that the collision cross section for this absorption is considerably greater than the kinetic theory value; our measurements of the width of this line show that the ratio of the two cross sections is actually 14.

5. We suggest that the diminution in the intensity as the pressure is reduced may be owing to disturbance of thermal equilibrium, as the absorption of energy tends to equalize the populations of the upper and lower levels. We have observed this effect by determining the absorption coefficient at various energy densities in a resonant cavity, and find that the reduction in the intensity is in close agreement with that calculated from the measured energy density. In a wave guide of cross-sectional area A through which a power W is flowing, the attenuation γ should be less than that (γ_0), which would be observed if thermal equilibrium were preserved, by a factor

$$\gamma/\gamma_0=\frac{2}{a}\left(1-\frac{1}{(1+a)^{\frac{1}{2}}}\right),$$

where

$$a=\frac{16\pi(\mu mn)^2}{3(hc)^2(\Delta\tilde{\nu})^2}\cdot\left(\frac{\lambda g}{\lambda}\right)\cdot\frac{W}{Ac}.$$

Inserting our measured value for the line breadth constant ($\Delta\tilde{\nu}$) we find that a power of one milliwatt would be sufficient to reduce the intensity of the line (3, 3) by a factor of 3 at a pressure of $1.5\cdot10^{-2}$ mm Hg. The usual types of oscillator give 20–30 mw; allowing 10 db of attenuation and 3 db for the division of power between the two guides, it would seem quite possible that a milliwatt of power was flowing through the ammonia. Thus the disturbance of thermal equilibrium appears a likely explanation for the drop in the intensity at low pressure and may also explain the abnormally low intensities shown in Fig. 5 of Good's paper.

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Additional Cosmic-Ray Measurements with the V-2 Rocket

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ANOTHER cosmic-ray experiment has been done in a V-2 rocket, fired on October 10 at White Sands, New Mexico (Geom. $\lambda=41°$N). Measurements were made with the counter arrangement shown in Fig. 1, of the ratio of total intensity as measured in the threefold telescope 1, 2, 3, to the intensity below 15.2 cm of lead as measured by the fourfold coincidences 1, 2, 3, (6+7+8). The quantities included in the parentheses were electronically paralleled for this measurement. Because of space limitations, it was not possible to make the solid angle of the fourfold set completely include that of the threefold. The ratio of these solid angles was determined to be 0.37 by a ground calibration. A third channel measured sixfold coincidences 1, 2, 3, 6, 7, 8. Each of these three channels was protected against the shower rays found in a previous experiment[1]