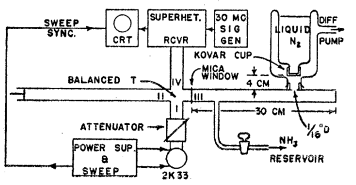

FIG. 1.

Kessler,[2] and Smith and Carter[3] working at approximately the same power levels, have failed to observe any such broadening, although the latter confirmed the saturation of the absorption. We have made an investigation of the 3,3 line at low pressures and powers of the order of 1 μw and find both effects are present.

The equipment is shown schematically in Fig. 1. The output of a frequency-modulated 2K33 reflex klystron is fed through attenuators into arm I of the balanced T. The construction of the T[4] is such that the r-f power divides equally between arms II and III, and none enters IV. Further, if II and III are electrically identical, their fields, after reflection from the ends, will cancel in IV. However, when the absorption in III is changed by introducing a gas, a signal proportional to the change in absorption enters IV and is detected by a superheterodyne receiver with a balanced mixer and band width of 8 Mc, giving an oscilloscope plot of frequency *vs.* absorption. Frequency differences on the oscilloscope are measured by introducing a signal of approximately the intermediate frequency (30 Mc) into the second detector. Each time the i-f sweeps across this signal it produces a video pip around the zero beat which can be positioned on the frequency axis by changing the frequency of the injected signal, allowing calibration of the trace. The ammonia is introduced into the wave guide at atmospheric pressure, then pumped out through a hole $\frac{1}{16}$ inch in diameter. The final pressure is determined by a deposit of solid ammonia at liquid nitrogen temperature on the Kovar cup. From the known variation of absorption with pressure we conclude that this pressure is not greater than 8×10^{-4} mm Hg and may be much less.

Our data on line width at half-intensity ($\Delta\nu$), and attenuation at the center of the line (α_0) as a function of incident power (P) are shown in Fig. 2. Absolute power measurements are accurate to within approximately a factor of 2; relative power measurements, 10 percent; line widths, 20 percent; attenuation, 30 percent.

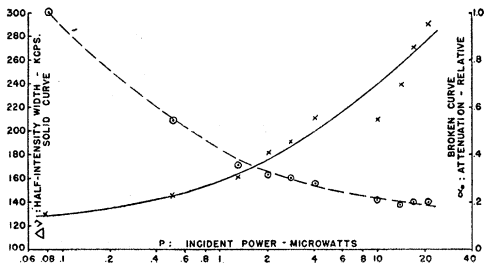

FIG. 2.

According to Townes,[1] saturation sets in when the rate of transition per molecule is approximately equal to the rate of collision. In view of his equation for this condition, which contains the assumption that the distribution of molecules is not affected by the incident power, saturation effects should be evident in our apparatus at powers less than about 100μ watt. Thus our data appear to be in agreement with Townes.

We wish to acknowledge the invaluable assistance of Professor R. H. Dicke in this work.

[1] C. H. Townes, Phys. Rev. **70**, 665 (1946).
[2] W. Gordy and M. Kessler, Phys. Rev. **71**, 640 (1947).
[3] W. V. Smith and R. L. Carter, Phys. Rev. **72**, 638 (1947).
[4] S. E. Miller, Proc. I.R.E. **35**, 345 (1947).

A Double Modulation Detection Method for Microwave Spectra*

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October 16, 1947

THE recent publication of a note on the above subject by Gordy and Kessler[1] has suggested to us the desirability of reporting some results of other experiments with a similar arrangement. The arrangement consists of applying a radiofrequency modulation voltage to the reflector of a Klystron in addition to the usual low frequency saw-tooth modulation voltage. The modulated microwave output power is allowed to pass through a wave guide section containing the absorbing gas and is then fed to a communications receiver tuned to the radiofrequency used for modulation. The receiver output is then displayed on an oscilloscope, the horizontal plates of which are synchronized with the low frequency saw-tooth voltage. This scheme has apparently occurred to numerous workers in different laboratories and was apparently first tested by Wilson and his colleagues,[2] who applied a 50-kc square wave to the reflector. They reported that the scheme reduced the crystal noise but did not show marked advantages over the usual low frequency system. The voltages used were apparently high enough to start and stop the Klystron at 50 kc per second. Hershberger[3] was the first to give a public report on this method of detection. In his first work Hershberger used a low voltage modulation frequency of 100 kc and has since worked at 50 kc with most satisfactory results.

In our own experiments we have, in general, used low modulating voltages and have used 20 kc and 600 kc for the modulation frequency. Although low modulating frequencies are to be desired from some points of view,** the results we obtained at 20 kc were disappointing. However, the lack of a good receiver for this extremely low frequency was a contributing factor to our lack of success. Our work at 600 kc has been more successful. In our experiments we found that the gains in signal-to-noise ratio over that obtainable by low frequency methods depend upon how much distortion of signal can be tolerated. Measurements made on one of the weaker ammonia lines indicate that a gain of 30 in signal-to-noise ratio could be

attained without introducing seriously objectionable distortion. Signals resulting from $N^{15}H_3$ lines can readily be observed without introducing serious distortion. If signal size for the 66 line of $N^{15}H_3$ was maximized, the signal-to-noise ratio could be made as large as sixty, but under these conditions the observed signal showed little resemblance to true line shape.

One serious objection to the use of the present double modulation method is that all irregularities in power received by the crystal are amplified in the same manner as the spectral lines. Hence, the beginning and end of the "mode" will always give large signals. Any sharp reflection peaks existing in the transmission line will also give rise to unwanted signals. For short wave guides the reflections are usually much broader than spectral lines observed at low pressure, and hence may be distinguished from lines visually or by means of low frequency rejection filters.[4] However, as the absorption sections are made longer the observed reflection peaks become sharper and hence more difficult to distinguish from spectral lines. Hence, there are definite limitations in the length of "absorption cell" which can be used in this method of detection; these limitations are the same as those for any method involving "sharpness" as a criterion of the recognizability of absorption lines.

We wish to thank Professor E. B. Wilson and Dr. C. H. Townes for helpful discussions last spring during the early stages of our experiments, to thank Professor Walter Gordy for telling us of his work prior to publication of his recent note, and to express our appreciation to Dr. W. D. Hershberger for sending us information concerning his more recent work on the subject.

* This work was done in connection with Contract No. W28-099ac-179 between Watson Laboratories of the Air Materiel Command, Red Bank, New Jersey, and the Ohio State University Research Foundation.

[1] W. Gordy and M. Kessler, Phys. Rev. **72**, 644 (1947).

[2] E. B. Wilson, unpublished report: Progress Report 3, N5ori-76 Harvard.

[3] W. D. Hershberger, paper before Symposium on Molecular Spectra and Molecular Structure, Ohio State University, June 1947.

** Note: For low modulation frequencies, the modulation products are proportional to the "sharpness" of the absorption lines.

[4] The use of low frequency rejection filters obviously introduces distortion of line shapes, since the rejected frequencies make a definite contribution to true line shapes. However, it is possible that properly designed filters can be used without introducing *objectionable* distortion. Gordy and Kessler report that the use of filters can actually result in an apparent gain in resolution. (Phys. Rev. **71**, 640 (1947).) Hershberger, who has used filters in his work for some time, reports definite distortion of line shape but has used filters quite successfully.

On the Pressure-Volume and Pressure-Compressibility Relation of Metals

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October 1, 1947

IT has been shown in a previous work[1] of the author that, by further development of the statistical theory of the atom, it is possible to develop a statistical metal theory[2] which enables us to give a full account of the metallic bond of the alkali and alkaline earth metals and, further, to compute the constants of these metals as well as several relations between them without the help of empiric or semi-empiric parameters. The lattice energy U per metal atom—from which all further conclusions can be derived in a simple way—can be expressed as follows:

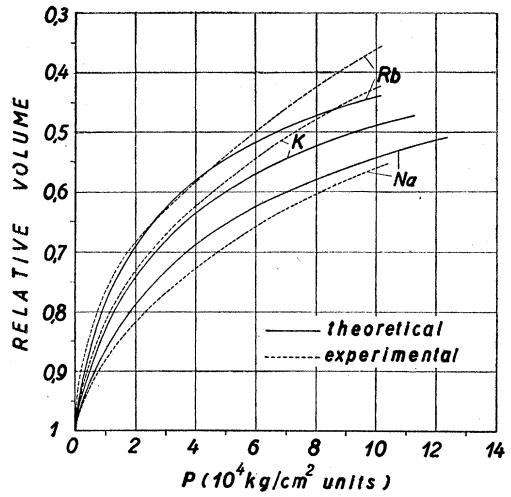

FIG. 1. Comparisons of theoretical and experimental values of pressure-volume relations.

$$U=A_0+\frac{A_1}{R}+\frac{A_2}{R^2}+\frac{A_3}{R^3}+\frac{A_4}{R^4}, \tag{1}$$

where R denotes the radius of the elementary sphere containing one metal atom and the coefficients A_i are constants, their value being determined only by the distribution of the electrons and the potential within the ions, and the number of the metal electrons per atom. The constants A_i can be easily calculated.

With the help of (1) the pressure P at the absolute zero point of temperature can be expressed as follows:

$$P=-\frac{dU}{d\Omega}=-\frac{1}{4\pi R^2}\frac{dU}{dR}=\frac{1}{4\pi R^7}\times(A_1R^3+2A_2R^2+3A_3R+4A_4), \tag{2}$$

where $\Omega=4\gamma R^3/3$ denotes the volume of the elementary sphere. Substituting the expression $(3\Omega/4\pi)^{\frac{1}{3}}$ for R, the equation yields the pressure-volume relation of the metal.

In the above mentioned work I calculated this relation for the metals Na, K, Rb, and Cs up to pressures of about 4.10^4 kg/cm², and I compared the results with those of Bridgman corrected for the absolute zero point of temperature. Recently, the measurements of Bridgman were extended[3] to the alkali metals Na, K, Rb, and to several other elements up to pressures of 10^5 kg/cm² at the temperature $T=296°$K and this induced me to extend theoretical investigations to high pressures of the same order and compare my results with those of Bridgman.

It appears—supposing a constant density distribution of the metal electrons throughout—that the theory is applicable even to these high pressures without change. As long as we apply to the metal ions the statistical model corrected by the electron exchange, the so-called Thomas-Fermi-Dirac model, even at these high pressures there is no overlapping of the electron clouds of neighboring ions. And even calculating the electron distribution of the metal