Although a calculation of the wave functions in the operating region would be quite involved, it is likely that mixing of the states has greatly reduced the transition probability between levels 2 and 3. Relatively weak paramagnetic absorption observed in the absence of saturating power confirms this, and better maser performance should be obtainable by operating at lower magnetic fields (200–300 gauss) where stronger absorption is observed. This would require a somewhat lower pumping frequency than 9 kMc/sec.

About 28 milliwatts of saturating power is required, which is considerably greater than that reported by McWhorter and Meyer.[2] A reduction should be obtained by using a cavity mode at the saturating frequency which has no magnetic field nodes within the crystal.

A new design for a tunable maser which incorporates these improvements is being constructed and may be useful in radio astronomy for observing Doppler-shifted hydrogen radiation.

* The research reported in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

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‡ Visiting staff.

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Two-Level Solid-State Maser*

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MICROWAVE amplification and oscillation have been observed at 4.2°K using two-level electron spin systems.[1] The materials used were single crystals of quartz and of magnesium oxide, each containing paramagnetic defects introduced by neutron irradiation.[2,3]

Samples were mounted in a reflection cavity resonant at 9 kMc/sec and having a loaded Q of ~6000. Inversion of the electron populations was brought about by adiabatic rapid passage,[4] in which the magnetic field was swept through resonance. The field sweep also prevents excessive radiation damping[5] immediately after inversion by taking the Larmor frequency off cavity resonance.[6] Microwave power for the inversion was supplied in pulses of 50 to 100 μsec duration and about one-half watt amplitude at a repetition rate of 10 cps. For convenience, inversion and amplification were observed as the magnetic field was swept back through resonance at a controlled delay after the inverting sweep. Under these conditions the duration of the amplifying period was controlled by the rate of the return field sweep. The power reflected from the cavity was monitored with a frequency-stabilized cw klystron and a superheterodyne detector.

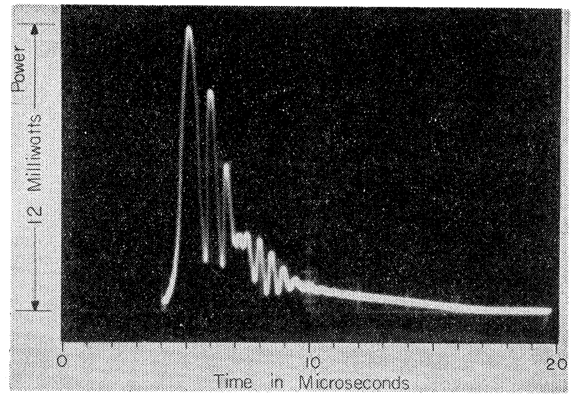

Fig. 1. Power emitted from cavity under oscillation conditions as the magnetic field is swept through resonance after inversion.

With a quartz sample containing $\sim 10^{18}$ spins, the inverted state persisted for 2 milliseconds at 4.2°K; and regenerative amplification occurred for times up to 1.2 milliseconds after inversion, the gain decreasing with time. A value of $\sim 5\times 10^6$ sec^{-1} was obtained for the product (gain)$^{\frac{1}{2}}\times$band width, for gains between 8 and 21 db. With sufficient inverting power and with or without monitoring power, oscillation was observed on the return through resonance. The peak power emitted during oscillation was 12 milliwatts in a pulse of about 10 microseconds duration. Figure 1 shows a typical oscillation pulse. The structure of the pulse may be associated with field inhomogeneities known to be present. Similar structure has been reported for spontaneous emission in doped silicon by Feher *et al.*[7] After an oscillation pulse, amplification was still observed when subsequent field sweeps were applied. Figure 2 shows the result of repeated field sweeps at 130-microsecond intervals. The wide signal on the left is caused by the inverting pulse. The signal occurring on the second sweep is oscillation. The next eight signals represent amplification each time the field passes through resonance, the gain falling from 16 db on the third sweep to 6 db on the seventh and to less than 0 db on the eleventh.

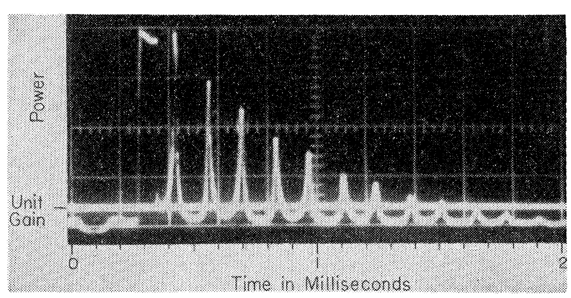

Fig. 2. Power reflected from cavity as a function of time after inversion as magnetic field is swept repeatedly through resonance. Horizontal trace represents unity power reflection. The inverting pulse and the oscillation peak both saturate the detector. Monitoring power: 4×10^{-8} watt.

With an MgO sample containing $\sim 10^{17}$ spins, the inverted state persisted for about 2.5 milliseconds at 4.2°K. Amplification was observed with a gain of 20 db at 125 microseconds after inversion, falling to 3 db at 720 microseconds.

We are indebted to Dr. R. A. Weeks of the Oak Ridge National Laboratory for irradiating the materials and to Mr. B. R. McAvoy for his assistance.

* Supported in part by Wright Air Development Command, U. S. Air Force.

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Energy Levels of an Asymmetric Rotor

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MICROWAVE spectroscopy is at present seriously handicapped by the lack of sufficiently extensive tables of the rotational energy of a rigid rotor. This is commonly described either by the E_τ, κ rotation of King, Hainer, and Cross[1] or by a series expansion[2] of a quantity w in powers of the Wang asymmetry parameter, b. The available tables[2] give E_τ at 0.01 intervals of κ up to $J=12$. More recent compilations[3,4] give the coefficients in the series expansion up to $J=40$, but this converges prohibitively slowly when $|\kappa|<0.9$ and the K value is small.

Work in progress here on bent triatomic molecules requires accurate energies for $J>12$ and large asymmetries. A satisfactory technique has been developed by use of the method of Golden.[5] This originally required an exceptionally good tabulation of characteristic values $M(s)$ of the Mathieu equation of parameter s. The new method instead uses the energy tables[2] for low J to obtain the energy levels of higher J by a "stepup" process, to be described.

Golden gives the result:

$$w=M(4\theta)-2\theta+\alpha\theta'+\beta\theta'^2+\cdots,$$

where

$$\theta=\tfrac{1}{2}|b|\left[J(J+1)-1-\frac{1}{2J(J+1)}\right],$$

$$\theta'=\tfrac{1}{2}|b|\left[1+\frac{1}{2J(J+1)}\right],$$

the terms in α and β being small corrections.

The stepup process consists of increasing J while simultaneously decreasing the asymmetry, b, so that θ remains constant. The quantity w then also remains constant, apart from small variations in θ'. The appropriate value of w for the lower J and larger asymmetry is found from the tables,[2] and corrected for higher J by using the values of α and β listed by Golden.[5] In practice it was necessary to develop more complicated relations in the E_τ, κ rotation, but this does not affect the rapidity and convenience of the process.

Table I compares tabulated values of E_τ for the level $12_{12,0}$ with values calculated by the above method and by the series expansion up to b^6.

There is good agreement for asymmetries so large that the series oscillates violently, though agreement becomes less good as the asymmetry increases, making the method valueless for $|\kappa|<0.5$. It is also inaccurate when K is comparable with J, but the series expansion is then satisfactory. The value of the technique is that it gives satisfactory energies where other methods fail, and could yield even better results by use of these as starting points for an iteration solution of the secular determinant. Much tedious computation can also be saved by the recently suggested use of energy moments.[6]

Table I. Comparison of values of E_τ for the level $12_{12,0}$.

	$\kappa=0.90$	$\kappa=0.80$
Tabulated value	151.111552	148.695733
Stepup from $11_{11,0}$	151.111558	148.695724
Stepup from 6_{60}	151.111397	148.694102
Stepup from 3_{30}	151.109561	148.572802
Stepup from 2_{20}	151.068250	
Series expansion	151.923200	230.240702

I am grateful to the Department of Scientific and Industrial Research for a Studentship supporting this work and to Dr. T. M. Sugden for helpful discussions.

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Specific Heat of He^3 below 1°K

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THE first measurements of the specific heat of liquid He^3 under its saturated pressure by deVries and Daunt[1] covered the temperature range 0.5°K to 2.3°K. Subsequent measurements by Roberts and

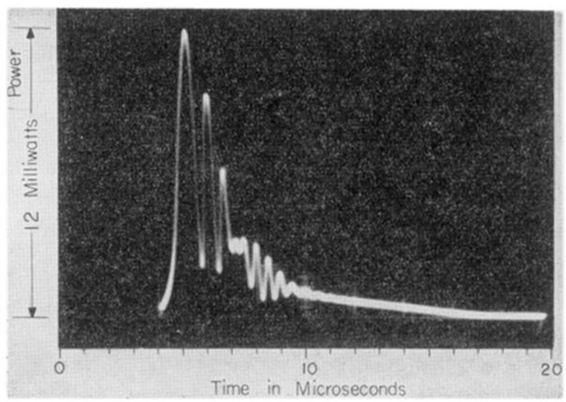

FIG. 1. Power emitted from cavity under oscillation conditions as the magnetic field is swept through resonance after inversion.

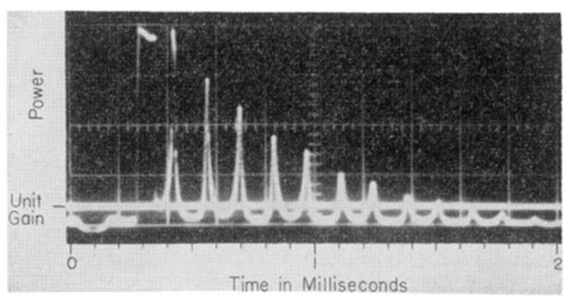

FIG. 2. Power reflected from cavity as a function of time after inversion as magnetic field is swept repeatedly through resonance. Horizontal trace represents unity power reflection. The inverting pulse and the oscillation peak both saturate the detector. Monitoring power: 4×10^{-8} watt.