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ATOMIC HYDROGEN MASER*

H. M. Goldenberg,† D. Kleppner, and N. F. Ramsey
Harvard University, Cambridge, Massachusetts

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Up to the present it has not been possible to produce maser oscillations with gaseous atoms due to the weakness of the magnetic dipole radiation matrix elements. However, with sufficiently long interaction times with the radiation field, oscillation can be achieved. Such increased interaction time and correspondingly narrowed resonance widths have been obtained in the present experiment by retaining the atoms in a storage box[1,2] with suitable walls. In this fashion self-sustained emission at the atomic hydrogen hyperfine transition frequency has been observed in an atomic beam maser. Mean interaction times up to 0.3 sec have so far been measured.

A diagram of the apparatus is given in Fig. 1. Atomic hydrogen from a Wood's discharge source passes through a six-pole state selecting magnet which focuses atoms in the $F=1$, $m=0$ and $F=1$, $m=1$ states onto an aperture in a paraffin-coated quartz bulb. The bulb is located in the center of a cylindrical rf cavity, operating in the TE_{011} mode, which is tuned to the ($F=1$, $m=0 \rightarrow F=0$, $m=0$) hyperfine transition frequency, approximately 1420.405 Mc/sec. The conditions are such that the atoms spontaneously radiate to the lower hyperfine level while in the bulb. The atoms make random collisions with the paraffin-covered bulb wall and eventually leave the bulb through the entrance aperture. Due to the small interaction with the paraffin surface they are not seriously perturbed for at least 10^4 collisions.

The criterion for self-sustained oscillation is that the power delivered to the cavity by the atomic beam must equal that lost by the cavity. In our case, with an average interaction time of 0.3 sec and a loaded cavity $Q=60\,000$, the minimum beam flux needed for oscillation is 4×10^{12} particles per second. The maximum power delivered to the cavity by this beam is approximately 10^{-12} watt. However, in the present case the detecting probe is weakly coupled to the cavity so that the detected power is considerably less. The width of the resonance $\Delta\nu_\gamma$ without maser operation is about 1 cps as compared to several kc/sec in a conventional ammonia maser. The bulb used is approximately 15 cm in diameter, and has an entrance aperture of 1-mm radius. It is loaded with paraffin[3] in air, and is then baked while under vacuum.

The signal is detected by mixing it with a 1450-

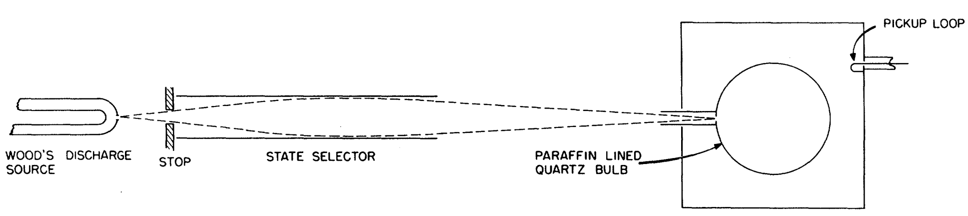

FIG. 1. Schematic diagram of atomic hydrogen maser.

Mc/sec signal obtained from the 5-Mc/sec output from an Atomichron by multiplication in a Gertsch FM4A frequency multiplier. The 29.595-Mc/sec i.f. signal is amplified and mixed in a phase discriminator with a similar signal from a Gertsch AM-1 stabilized oscillator. The resultant low-frequency signal passes through an *RC* filter, which limits the detector's over-all bandwidth, and is displayed on an oscilloscope.

In addition to oscillation, stimulated emission has also been observed. In this case oscillation is completely suppressed by shortening the mean time in the bulb (by means of a larger entrance aperture) or by loading the cavity. A pulse of rf at the transition frequency is fed into the cavity by a second coupling loop (not shown in Fig. 1). If this pulse is of the correct intensity the electron spin of the atom is precessed 90°, and the atom will continue to radiate after the rf has been turned off. A picture of the oscilloscope trace of this radiation is shown in Fig. 2. The amplifier is gated off during the stimulating pulse at the beginning of the sweep. The signal envelope decays with a time constant equal to the mean time in the bulb. The oscillating component of the signal is due to a slight offset in the local oscillator which is introduced for purposes of display. An interesting feature of this method of inducing emission is that those atoms which happen to be in the cavity for greater than the mean time are subject to more than one rf pulse. The mean interaction time of these atoms is then

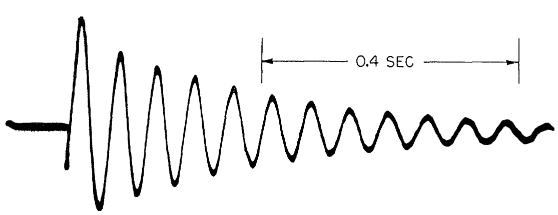

FIG. 2. Pulsed stimulated emission.

longer than the mean time in the cavity, and is characterized by the total time between the pulses they experience. If the pulse intensity is reduced so that it takes two pulses to put an atom in a state of maximum radiation, then the resonance line has a width characteristic of the pulse repetition frequency, which can be made several times smaller than the natural linewidth in the bulb.

The magnetic-field-independent hyperfine transition has been used to observe the field-dependent Zeeman transitions, $F=1,\ m=0 \rightarrow F=1,\ m=1)$ and $(F=1,\ m=0,\ \rightarrow F=1,\ m=-1)$ by means of a double resonance method. A signal at the Zeeman frequency was coupled into the cavity at the same time that the hyperfine transition was occurring. The intensity of the hyperfine signal then decreased because the mean lifetime of atoms in the $F=1$, $m=0$ state was reduce due to their making transitions to the other $F=1$ states. This technique offers a method of measuring the static magnetic field to high accuracy.

This experiment represents the first successful use of the storage box principle. We believe that the atomic hydrogen maser will allow determination of the hyperfine splitting of the hydrogen isotopes to considerably higher precision than is now known. In addition, as a time standard, the maser may have a stability greatly exceeding that of any other standard yet proposed.

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†National Science Foundation Predoctoral Fellow.

[1]N. F. Ramsey, Rev. Sci. Instr. 28, 58 (1956).

[2]D. Kleppner, N. F. Ramsey, and P. Fjelstad, Phys. Rev. Letters 1, 232 (1958).

[3]The paraffin used is a high melting point variety supplied under the trade name "Paraflint" by Moore and Munger, New York, New York.