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INVESTIGATION OF A FEW SIMPLE MOLECULAR GASES AS A POSSIBLE MOLECULAR LASER MATERIAL

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REPORT 1093-31

REPORT
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Grant Number	NsG-74-60
Investigation of	Receiver Techniques and Detectors for Use at Millimeter and Submillimeter Wavelengths
Subject of Report	Investigation of a Few Simple Molecular Gases as a Possible Molecular Laser Material
Submitted by	P. K-L Yin and S. H. Koozekanani Antenna Laboratory Department of Electrical Engineering
Date	1 November 1966

ABSTRACT

Energy levels of a few simple molecular gases which have a resonant energy level with the N_2 metastable level have been investigated for possible molecular laser material.

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INVESTIGATION OF A FEW SIMPLE MOLECULAR GASES AS A POSSIBLE MOLECULAR LASER MATERIAL

I. INTRODUCTION

Coherent sources lying in the infrared or the far-infrared region of the spectrum would be best and more efficiently produced with molecular gas lasers rather than atomic gas lasers. The reason lies simply in the fact that in atomic gases, disregarding the hyperfine or magnetic splitting, the electronic transitions necessary to reproduce an infrared photon would, in general, be between states having high quantum numbers n where the energy states lie close to each other. This fact reduces the efficiency greatly; moreover the upper states of atomic levels tend to have long life-times, which in turn can be shown to cause these states to be saturated at very low current discharges or low pressures. Hence atomic lasers at these wavelengths suffer both from low efficiency and low output power. However, the above problems are alleviated to a great extent when one considers molecular systems where one need not work between the electronically excited levels. The vibrational levels are rich in energy states and are low-lying in the energy scale. This feature could greatly enhance the efficiency. The following discussions will concern a few possible mechanisms of inversion and will review only a few of the many promising molecules suitable for laser action in the infrared region, so that investigators equipped to handle these gases may experiment with them.

II. MECHANISMS OF INVERSION

Among the few possible methods of population inversion of some of the energy levels of a certain gas with respect to its other levels, the method of resonant transfer has one of the highest efficiencies. In this method a gas molecule which has been excited to a metastable level, upon collision with another molecule, relinquishes its energy to the colliding particle and relaxes from its metastable level to the ground state. The excitation cross section for this process has its greatest value when the energy levels of the colliding particles are in resonance, or differ by less than kT.

Among the lasers which use this process for excitation are the He-Ne[1] laser in which the metastable levels of He are responsible for the inversion of the neon levels, and also the CO_2-N_2 [2] laser in which the vibrationally excited metastable level of N_2 excites the vibrational (001) level of CO_2. The energy levels in both the above processes are very close to each other. Yet another process which can aid greatly the inversion of some of the vibrational levels of the molecular gases is the addition of light gases in the discharge. When a particle collides with a vibrating molecule it can cause the vibrating level to relax to the ground state by transferring the vibrational energy to its kinetic energy.[3] Since the cross sections for this process for all of the vibrational levels are not equal, this can help to bring about a non-thermal distribution. An example of such a laser system is the He-CO_2 mixture.

III. REVIEW OF SOME SIMPLE MOLECULAR GASES

We shall now review some of the simple molecular gases which have energy levels close to the vibrationally excited metastable level ($v = 1$) of N_2. Most of these gases are extremely poisonous and a few may not be stable in a discharge; however, in the latter case, it is possible to excite the N_2 in another chamber and then mix it with the gas in question. The review is presented in a series of ten tables, which follow.

TABLE I

C_2H_2: Linear with center of symmetry ($D_{\infty}h$)

Energy level (cm^{-1})	Designation	Species
2215	00003^1	π_u
1973.8	01000	Σ_g^+
1956	$0002^\circ 1^1$	π_u
*1460	00002	Σ_g^+, Δ_g
1328.1	$0001^1 1^1$	Σ_u^+
*1224	00021	Σ_g^+, Δ_g
729.1	00001^1	π_u
611.8	$0001^1 0$	π_g

* Not observed Spectroscopically. Values are estimated without including the anharmonic correction.

Remark: $00003^1 - 0000^\circ 0^\circ$ is weak. Hence, it is not very favorable for laser action.

TABLE II

C_2D_2: Linear with center of symmetry ($D_{\infty}h$)

Energy level	Designation	Species
2311	01001	π_u
1762.4	01000	σ_g^+
1610	00003	π_u
1044	01001	Σ_u

Remark: 01001 —00000 is weak. Hence, it is not very favorable for laser action.

TABLE III

C_2N_2: Linear with center of symmetry ($D_{\infty h}$)

Energy level	Designation	Species
226	00001	π_u
506	00010	π_g
732	00011	Σ_u^+
848	01000	σ_g^+
1026	00002	Σ_g^+, Δ_g
2149	00100	σ_u^+
2322	10000	σ_g^+

Remark: 10000 level is very close to that of $N_2(v = 1)$. However, since transition to the ground state is forbidden, collision cross section is small.

TABLE IV

CS_2: Linear with center of symmetry (C_2v)

Energy level	Designation	Species
2329	$02^{0}1$	Σ_u^+
2183.9	$10^{0}1$	Σ_u^+
1523	$00^{0}1$	Σ_u^+
796	$02^{0}0$	Σ_g^+
656.5	$10^{0}0$	Σ_g^+
396.7	$01^{1}0$	π_u

TABLE V

SO_2: Asymmetric top nonlinear (C_2v)

Energy level	Designation	Species
2305	200	A_1
1871	011	B_1
1361	001	b_1
1151.2	100	a_1

TABLE VI

H_2O: Asymmetric top nonlinear (C_2v)

Energy level	Designation	Species
6874	021	B_1
5332	011	B_1
3755.8	001	B_1
3651.4	100	A_1
3151.4	020	A_1
1595	010	A_1

Remark: The lifetime of $N_2(v = 3)$ is short. Hence, a slim chance of laser action is expected with $N_2(v = 3)$.

TABLE VII

H_2S: Asymmetric top nonlinear (C_2v)

Energy level	Designation	Species
2422	020	A_1
1290	010	a_1

Remark: It may not be very favorable for laser action because 020 level of H_2S lies above that of N_2 ($v = 1$).

TABLE VIII

N_2O: Asymmetric top nonlinear (C_2v)

Energy level	Designation	Species
2220	011	B_1
1621	001	b_1
1320	100	a_1
1373	020	—
648	010	a_1

TABLE IX

A_3H_3: Symmetric top (C_{3v})

Energy level	Designation	Species
2162	ν_3	E
2115.2	ν_1	A_1
1812	$2\nu_2$	A_1
999.4	ν_4	E
906	ν_2	A_1

TABLE X

C_3O_2: Linear with center of symmetry ($D_{\infty}h$)

Energy level	Designation	Species
2290	ν_3	σ_u^+
2200	ν_1	σ_g^+
2190	—	π_u
1980	—	π_u
1850	—	π_u
1760	—	π_u
1670	—	π_u
1570	ν_4	σ_u^+
1470	—	π_u or σ_u^+
1387	—	π_u
1225	—	Σ_u^+
1226	—	Σ_u^+ or π_u
1114	—	Σ_g^+
1024	—	π_u
909	—	π_u
1176	—	Σ_g^+
843	—	σ_g^+
586	ν_5	π_g
557	ν_7	π_u

Remark: ν_3 is very strong. But when warm it decomposes.

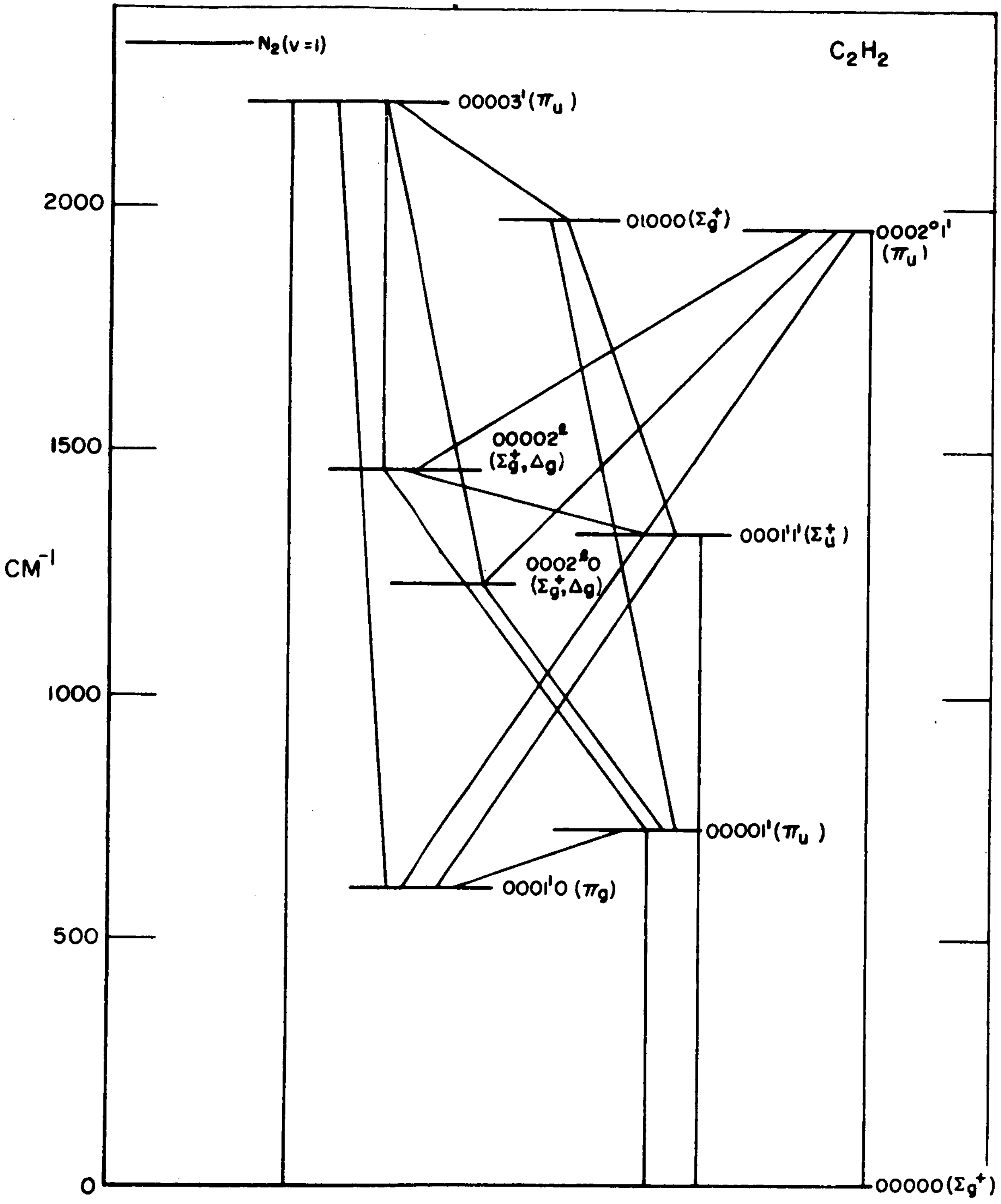

Fig. 1. Vibrational energy level diagram of C_2H_2.

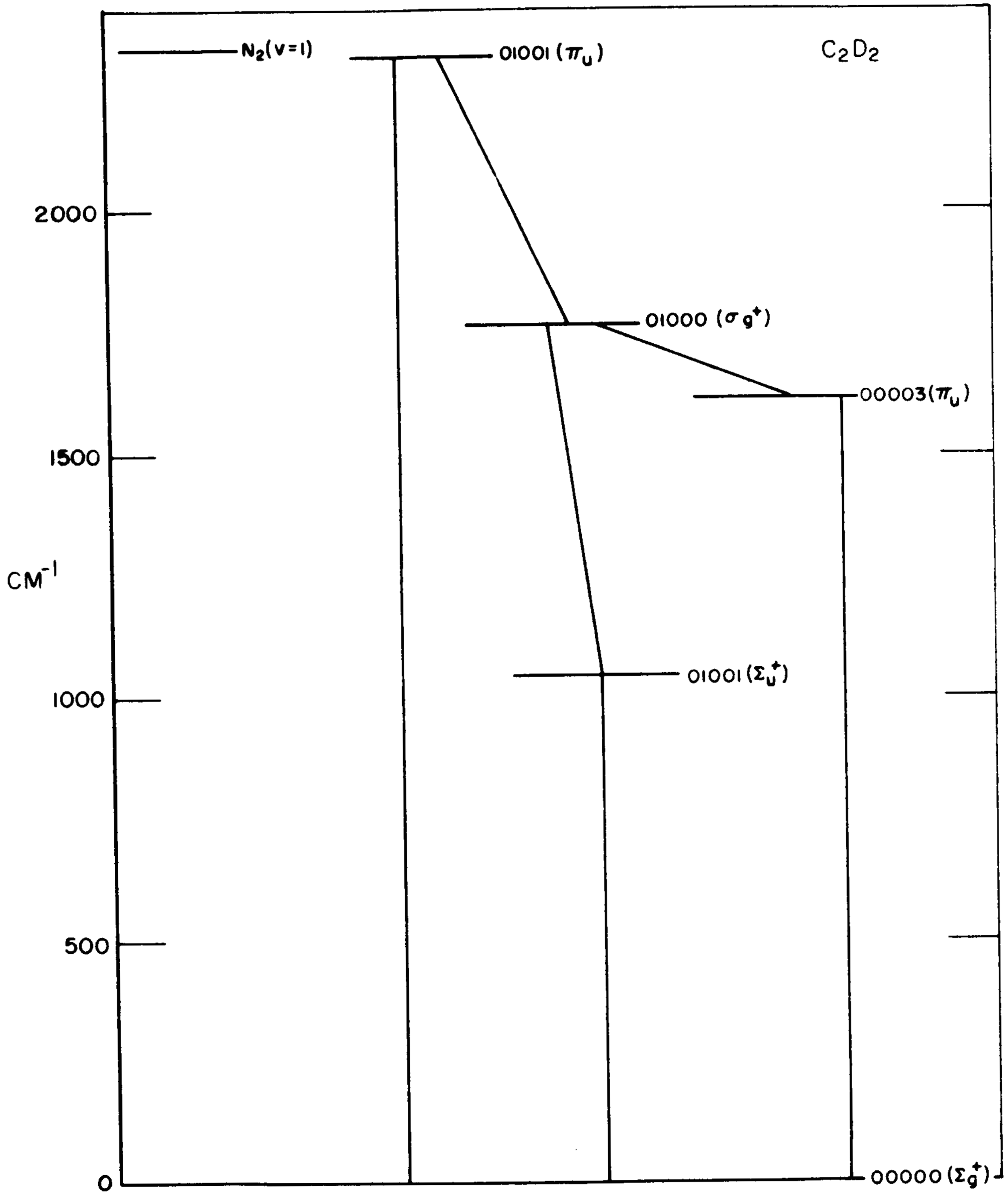

Fig. 2. Vibrational energy level diagram of C_2D_2.

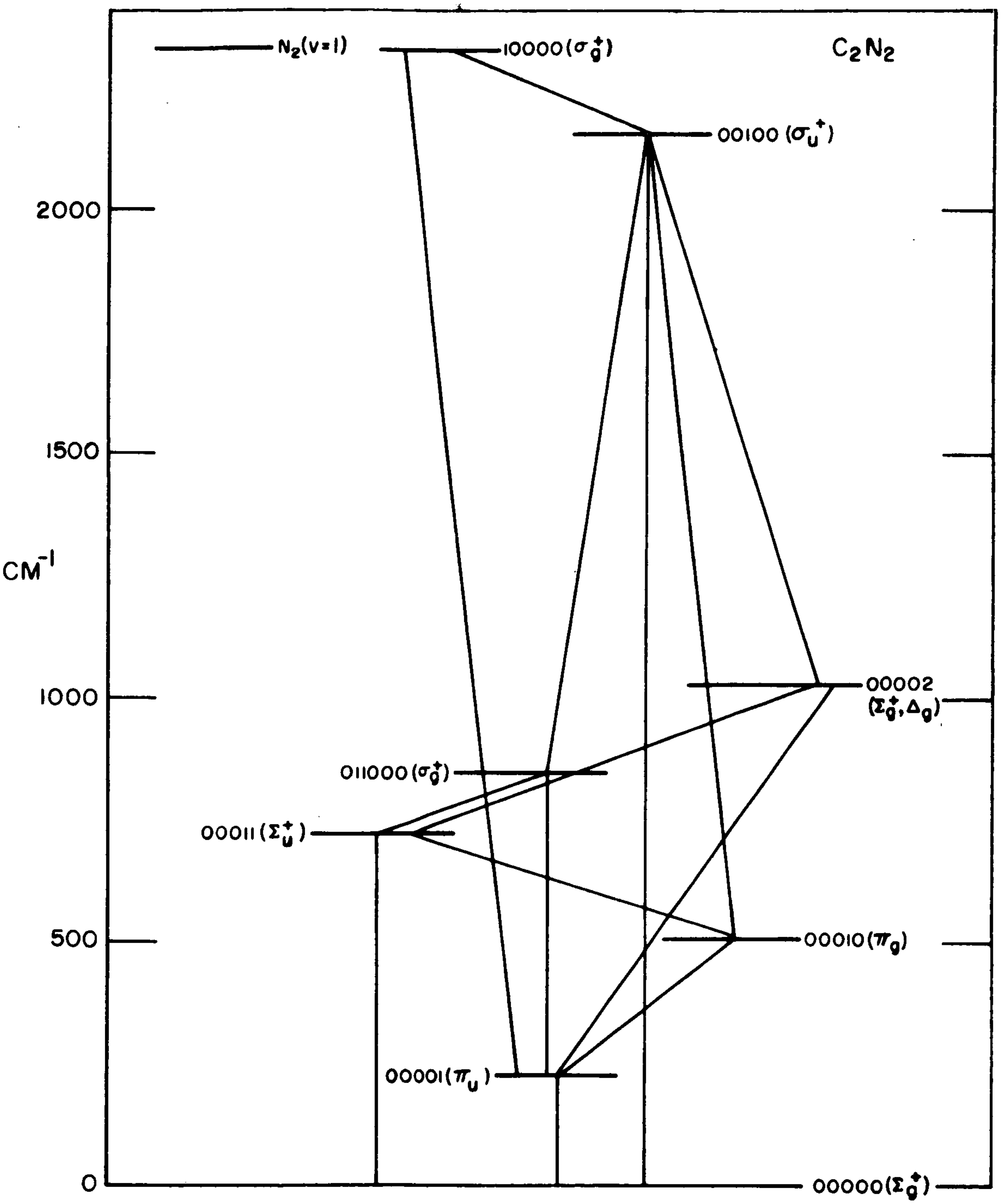

Fig. 3. Vibrational energy level diagram of C_2N_2.

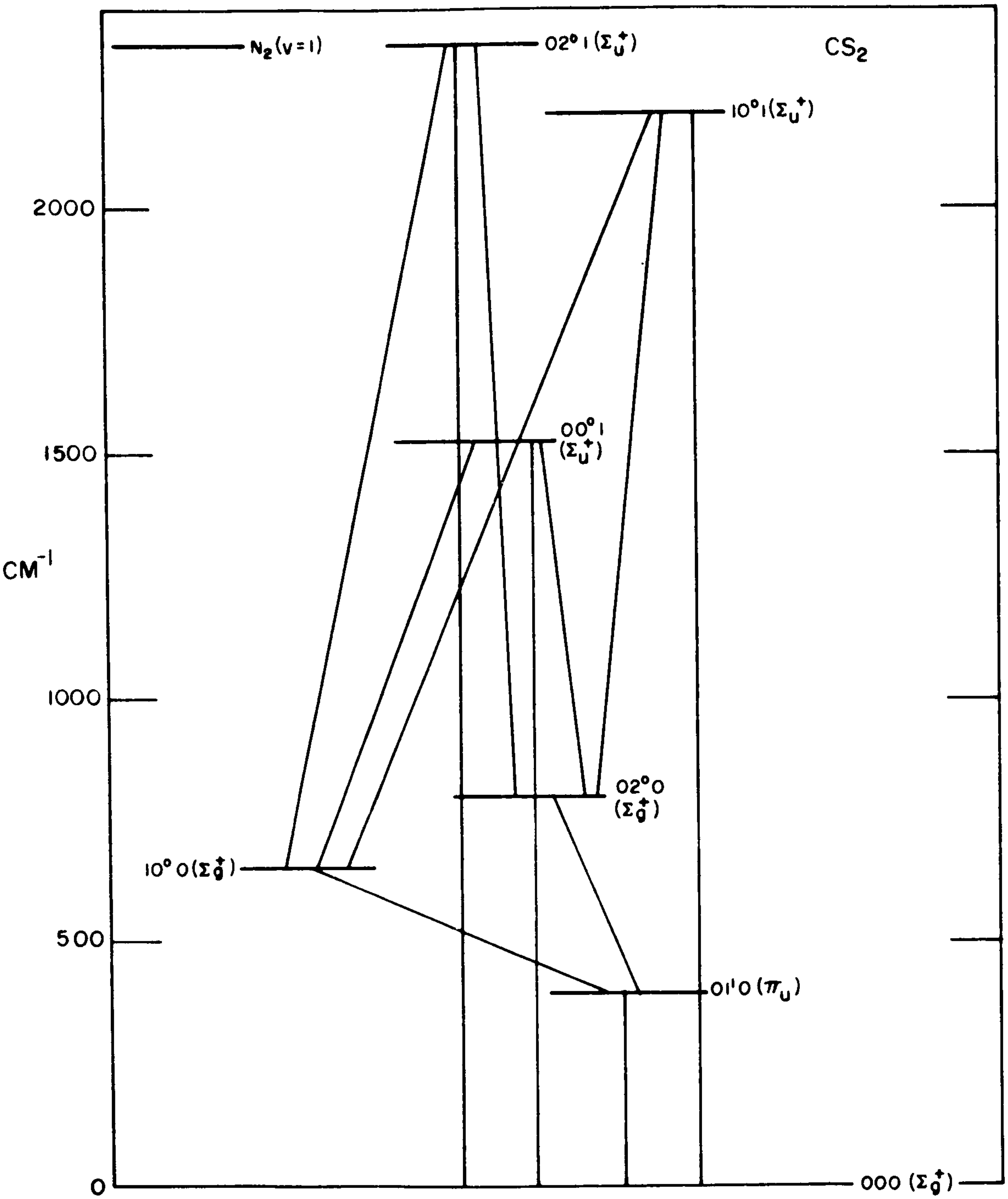

Fig. 4. Vibrational energy level diagram of CS_2.

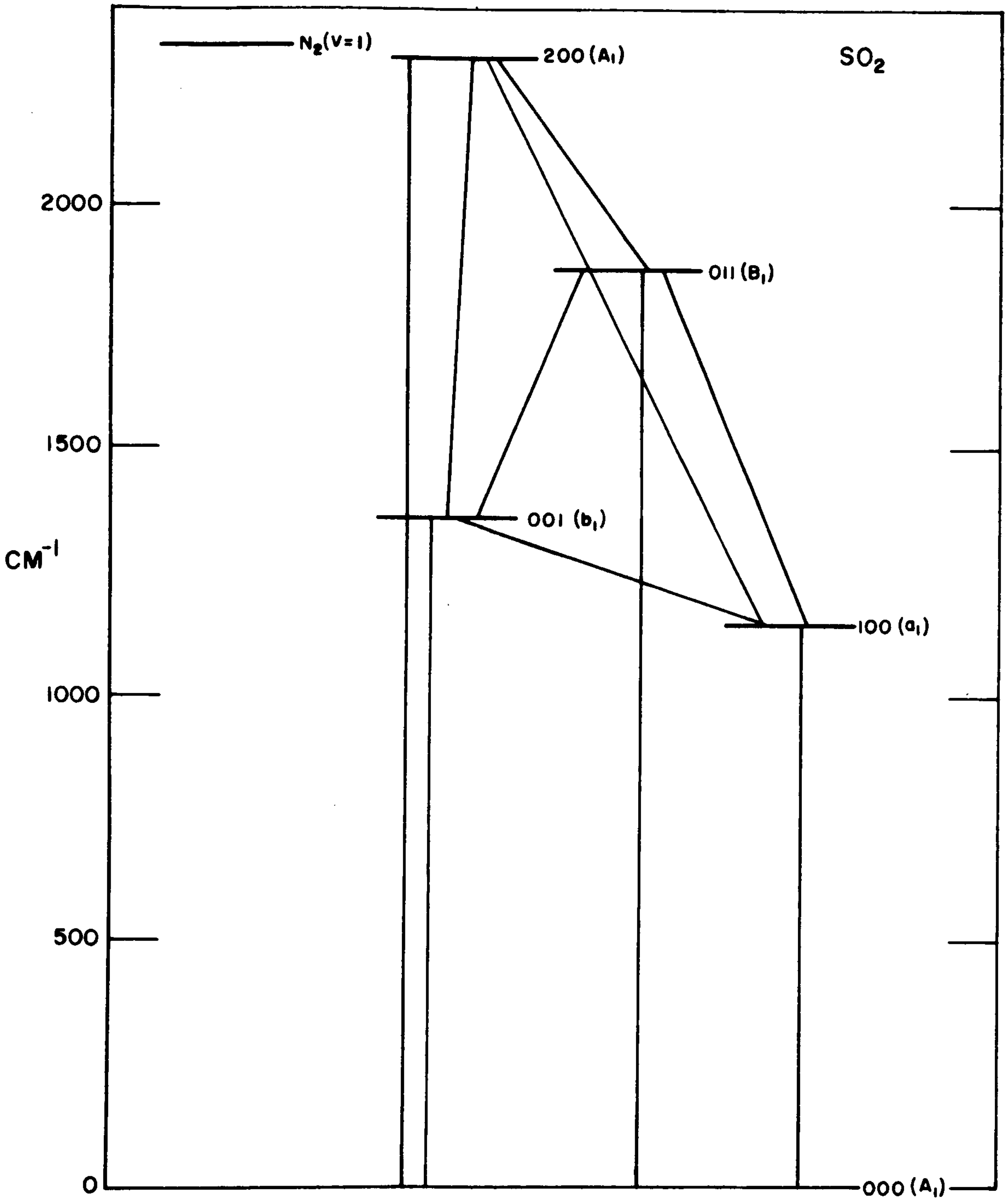

Fig. 5. Vibrational energy level diagram of SO_2.

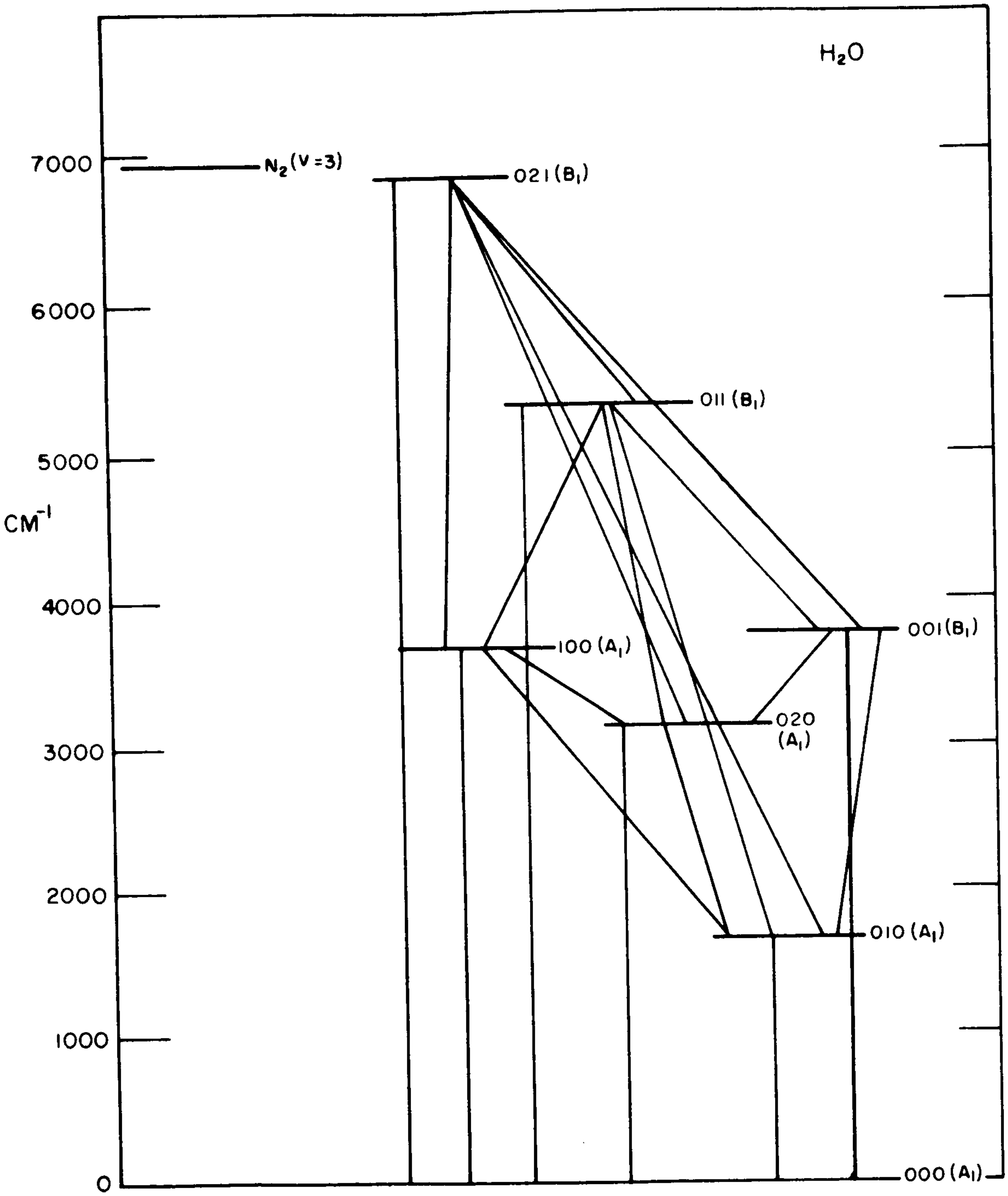

Fig. 6. Vibrational energy level diagram of H_2O.

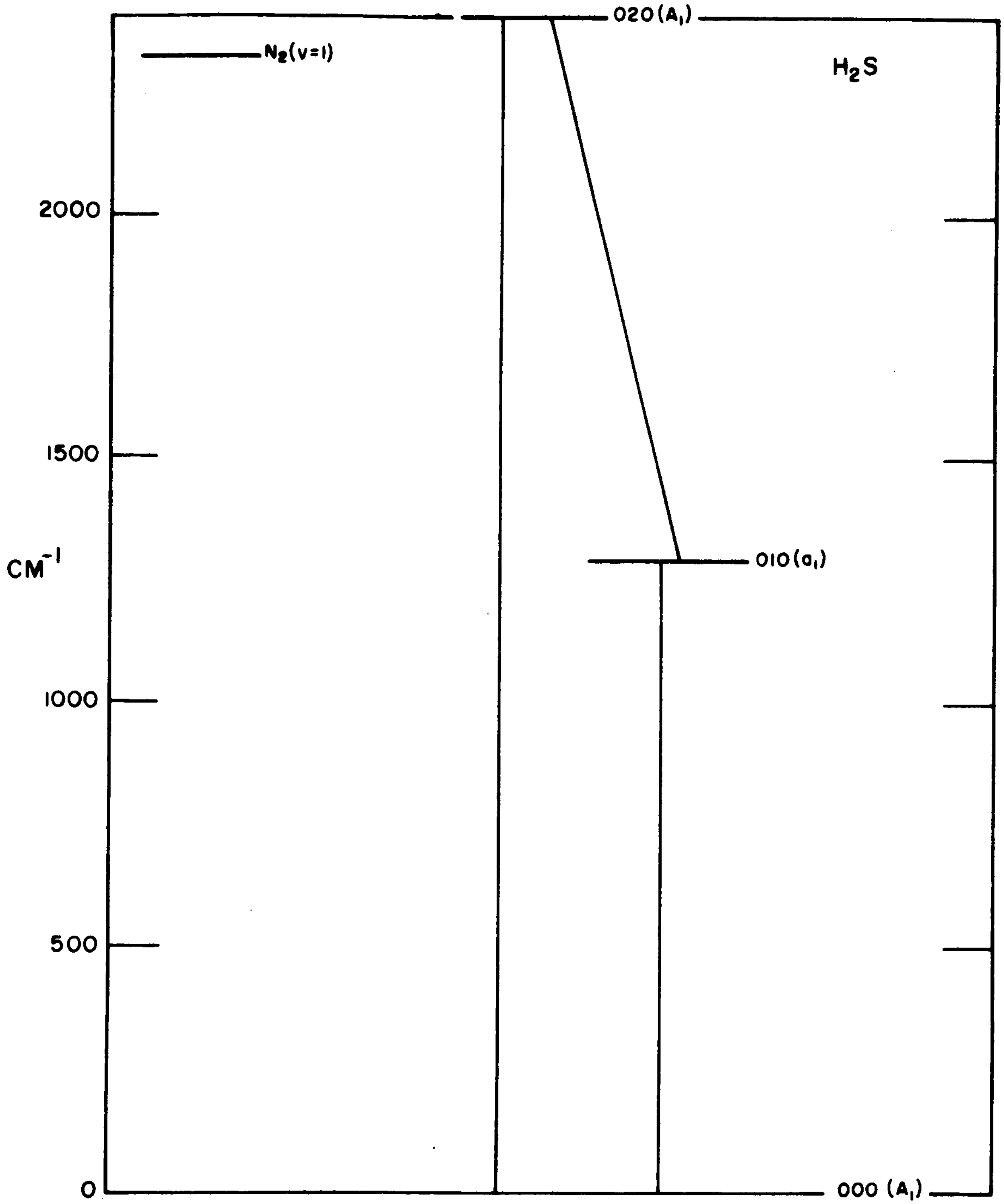

Fig. 7. Vibrational energy level diagram of H_2S.

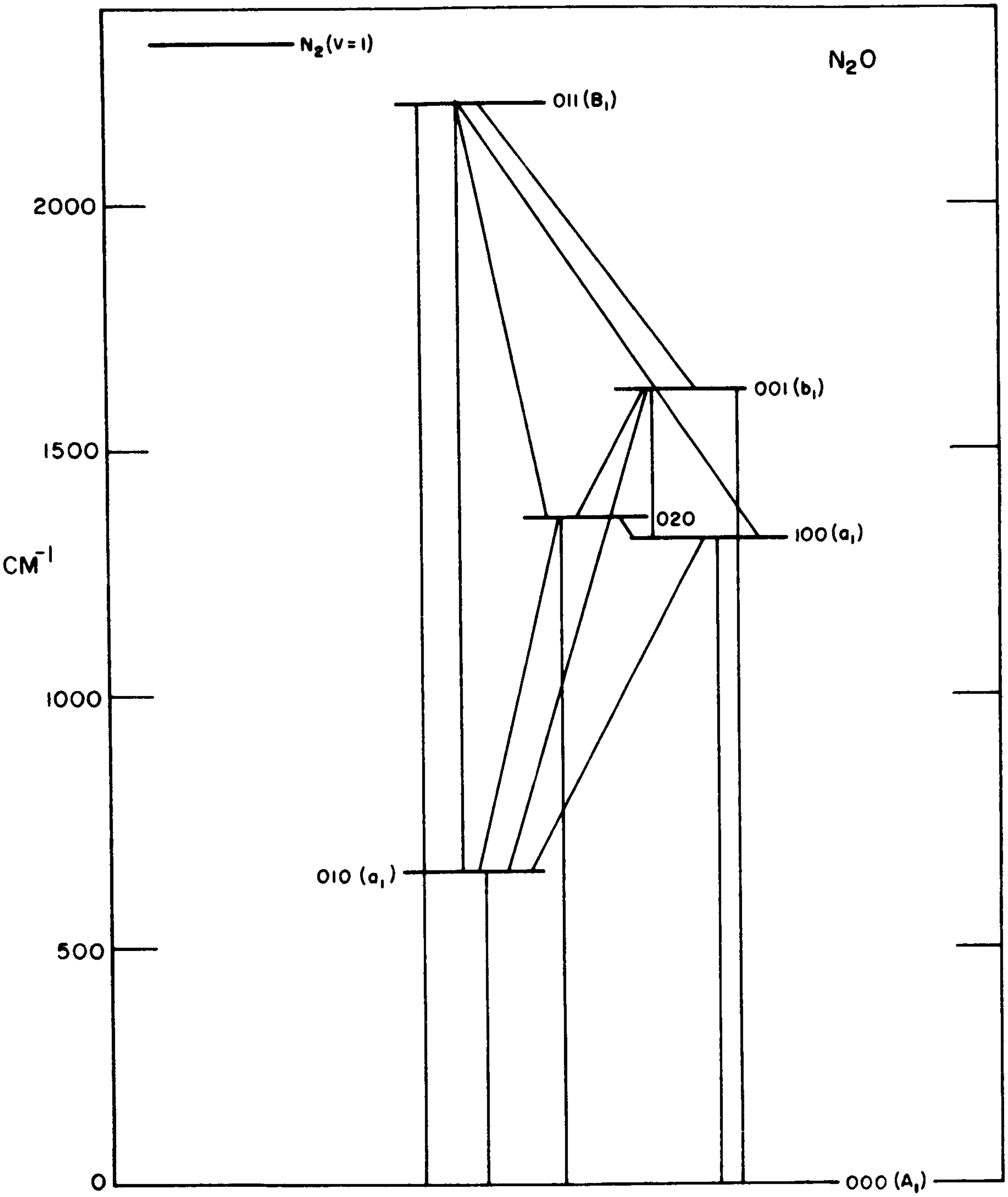

Fig. 8. Vibrational energy level diagram of N_2O.

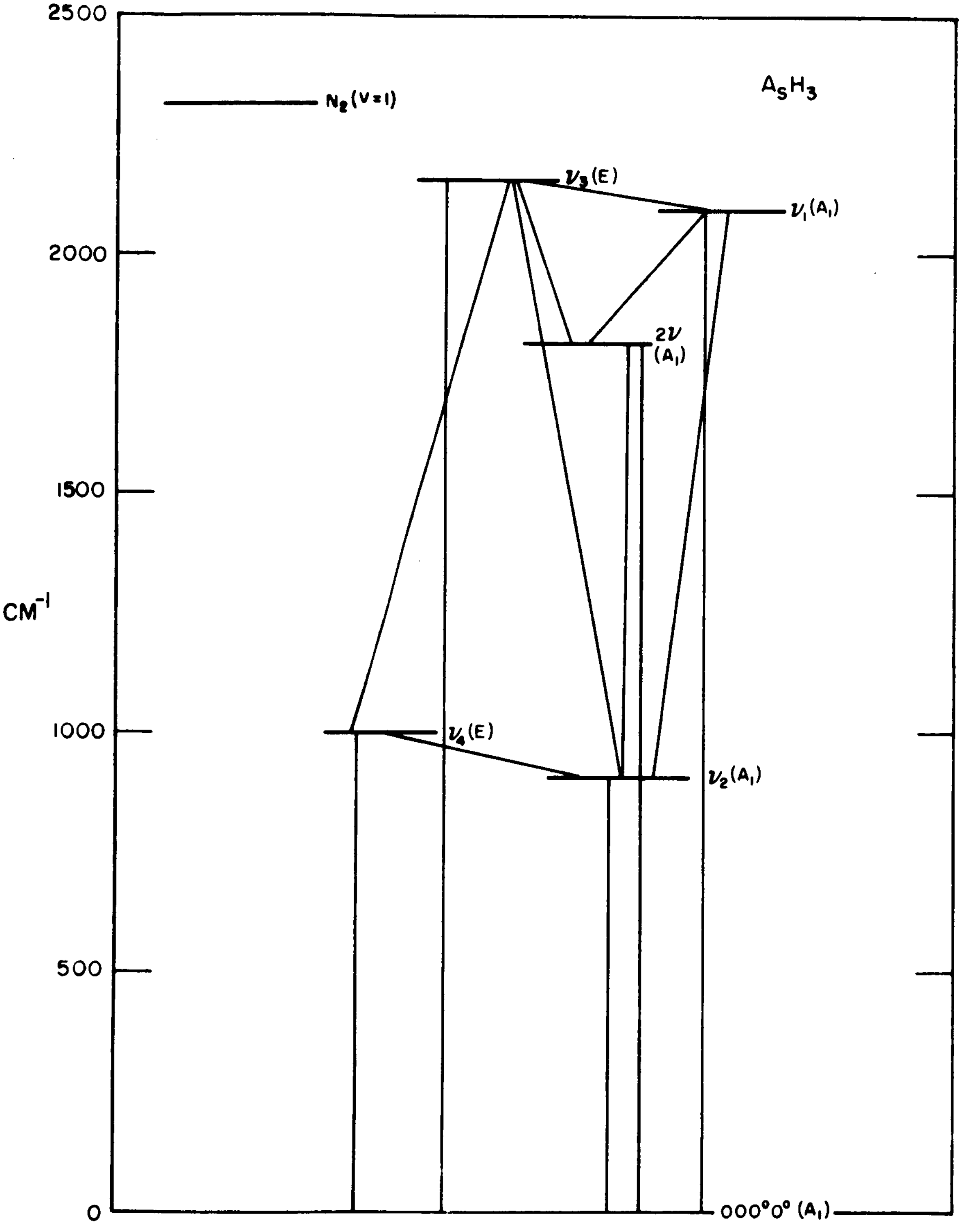

Fig. 9. Vibrational energy level diagram of A_sH_3.

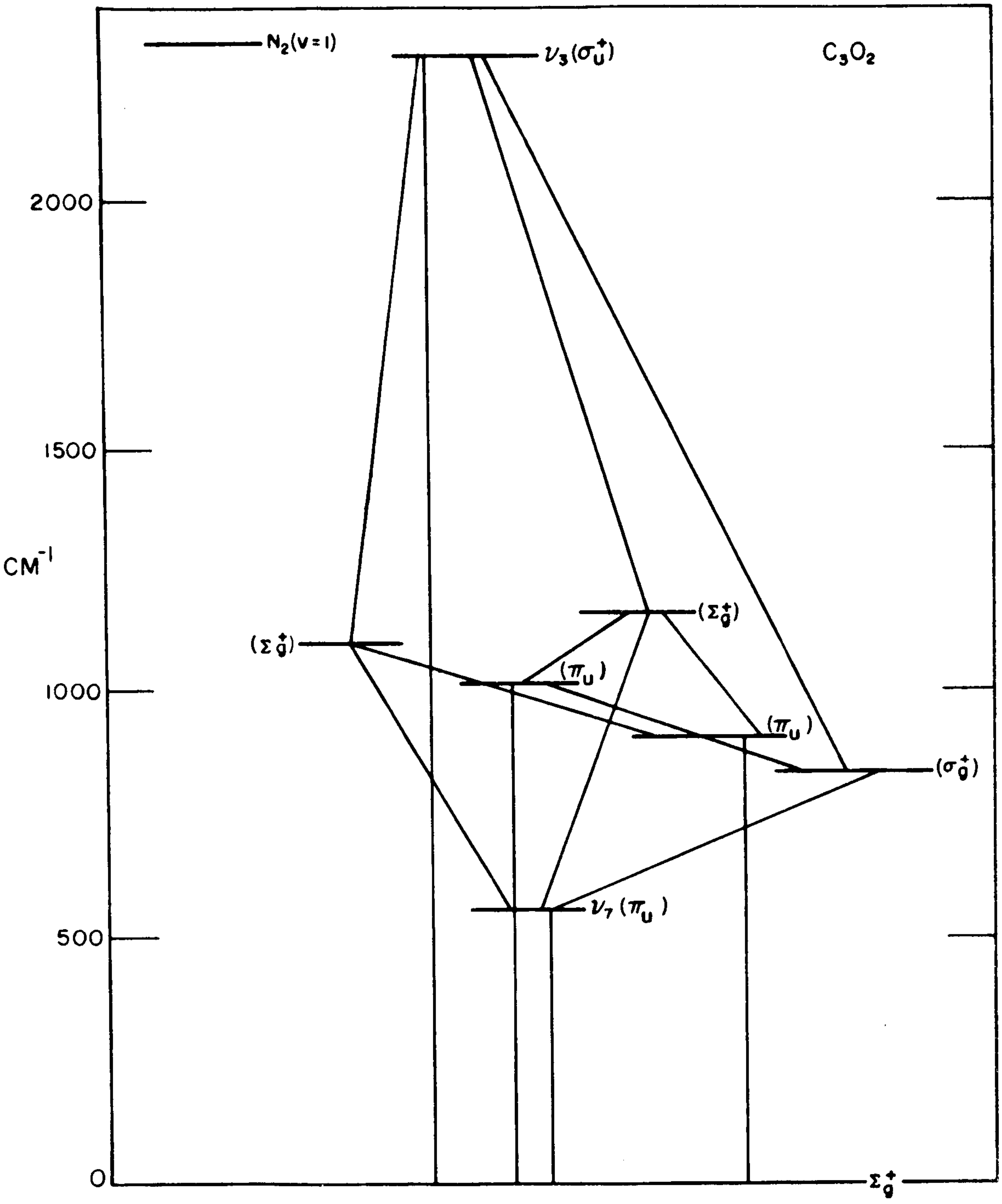

Fig. 10. Vibrational energy level diagram of C_3O_2.

IV. SUMMARY

A few of the simple gases having resonant energy level with the v = 1 vibrational level of N_2 have been investigated. The vibrational level of N_2(v = 1) is about 2330 cm^{-1} above the ground level and is a metastable state. Because of its long lifetime it is a suitable gas for transferring its energy to other gases being in resonance with it.