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NUCLEAR PUMPING OF A NEUTRAL CARBON LASER*

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SUMMARY

Nuclear pumped lasing on the neutral carbon line at 1.45μ has been achieved in mixtures of He-CO, He-N_2-CO, He-CO_2, and Ne-CO and Ne-CO_2. A minimum thermal neutron flux of $2 \times 10^{14} n/cm^2$-sec was sufficient for oscillation in the helium mixtures. The peak of the laser output was delayed up to 5.5 ms relative to the neutron pulse in He-CO_2, He-N_2-CO, Ne-CO and Ne-CO_2 mixtures while no delay was observed in He-CO mixtures. Lasing was obtained with helium pressures from 20 to 800 T, Ne pressures from 100 to 200 T, CO from 0.25 to 20 mT, N_2 from 0.5 to 5 mT, and CO_2 from 0.1 to 25 mT in the respective mixtures.

INTRODUCTION

Nuclear pumped lasing on the neutral carbon transition, $C(3p\,^1P_1)$ - $C(3s\,^1P_1^o)$, at 1.45μ has been observed in mixtures of He-CO, He-N_2-CO, He-CO_2, Ne-CO and Ne-CO_2. (ref. 1,2) Lasing on this transition was first reported by Patel (ref. 3) in an electric discharge. However, the present work represents the first time it has been achieved by nuclear pumping and places this mixture among less than a dozen in this category. This laser is especially interesting for possible space applications due to the relatively low neutron flux ($2 \times 10^{14} n/cm^2$-sec) required and the apparent presence of internal energy storage as signified by millisecond time delays between the neutron input and laser output.

EXPERIMENTAL ARRANGEMENT

The laser cavity consisted of an 86-cm long pyrex tube with ends cut at Brewster's angle, and enclosing a 68-cm long by 2.5-cm-i.d. aluminum cylinder coated on the inner surface with boron-10. MeV alpha-particles released from this coating via neutron-induced reactions in the boron provided the pump energy. Ultimately, however, a bulk of the excitation produced arises from secondary collisional processes rather than direct alpha-gas atom collisions. Two dielectric mirrors having 99.9% reflectivity at 1.45μ and a 3-m radius of curvature were separated by 117 cm to form the optical cavity. The laser cell was placed in the thruport of the University of Illinois TRIGA reactor. Being approximately tangent to the core, this beam port allows high fluxes (up to 10^{15}n/cm^2-sec) over a 1-meter long region. A small chopping fan powered with an electric motor was mounted so as to provide alternate blocking and unblocking of the back mirror. In this way the cavity could be spoiled several times during a reactor pulse to provide a test of lasing. A vacuum line attached to the laser cell and an ion gauge mounted at the vacuum — gas filling station provided a means to control gas concentrations and monitor background pressures (typically < 10^{-6} Torr).

The arrangement of the reactor experiment is illustrated in Fig. 1. Two PbS infrared detectors and a monochromator (with a 295-groove/mm grating blazed at 2.1μ) served as detection and filtering devices for the 1.45μ line.

RESULTS

In Fig. 2, a typical output signal is shown where chopping of the cavity is used to verify oscillation. This particular system used He-CO gas mixtures with CO as an impurity (~.25 mT) in 50 T He. Note that the neutron pulse is coincident with the laser signal.

Figure 3 demonstrates a drastically different situation where the laser signal is delayed by 3.5 ms. This delay was observed in He-N_2-CO, He-CO_2, Ne-CO, and Ne-CO_2 gas mixtures; but not He-CO. This particular figure is taken from He-CO_2 data. The delay is caused by a long lived intermediate state within a multiple collisional process. (ref. 2) As indicated by Fig. 4, this level is thought to be an excited vibrational-rotational state in CO which must decay into a ground level before subsequent collisions can excite it into the upper laser level. However, no direct experimental data are available to support this hypothesis.

The delay phenomena observed in He-N_2-CO, He-CO_2, Ne-CO and Ne-CO_2 is highly pressure dependent, and Fig. 5 maps this for He-CO_2. At the lower total pressures the delay occurs at small partial pressures of CO_2. Figures 6 and 7 show the partial pressure dependence of CO and CO_2 respectively with 150 T Ne.

Lasing was observed over a wide range of total pressures in He (20 to 800 T) and partial pressures of CO and CO_2 (~2 to 25 mT). In the Ne buffered system lasing was observed for total pressures from 100 to 200 T and at partial pressures of CO and CO_2 from 5 to 15 mT. Figure 8 shows that peak power output in the He-CO system occurred at 600 T He and 2 mT CO while in He-CO_2 (see Fig. 9) the maximum power output occurred at 600 T He and 4 mT CO_2. The Ne-CO and Ne-CO_2 systems, as shown in Figures 10 and 11, demonstrate markedly different characteristics. The peak power ouput occurred at carbon doner partial pressures of about 6 mT and Ne pressures of 150 T. This behavior is thought to be due to the massiveness of Ne as compared to He. The lowest thermal neutron flux in which a Ne- carbon impurity laser was observed is 4.9×10^{14}n/cm^2-sec.

CONCLUSION

In summary, the neutral carbon laser at 1.45μ has been pumped via nuclear excitation in five separate gas mixtures: He-CO, He-N_2-CO, He-CO_2, Ne-CO and Ne-CO_2. Four of these mixtures have demonstrated delays on the order of milliseconds which appear to be associated with multiple collision processes. All of the systems oscillated over a wide range of pressures.

The presence of the delay, which implies the existence of an energy storage mechanism, is thought to be important for various potential applications requiring Q switching. An example is the use of nuclear pumped lasers for neutron-coupled feedback-type operation of a laser fusion reactor. (ref. 4). Space applications requiring high-energy pulsed lasers present another possibility.

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3. C. K. N. Patel, *Lasers*, Vol. 2, edited by A. K. Levine (Marcel Dekker, New York, N. Y., 1968), pp. 57-62.

4. G. H. Miley, "Direct Nuclear Pumped Lasers," in *Laser Interactions and Related Plasma Phenomena*, Vol. 4, Schwarz and Hora, eds. (Plenum Press, New York, N. Y., 1977), pp. 181-228.

REACTOR EXPERIMENTAL SETUP

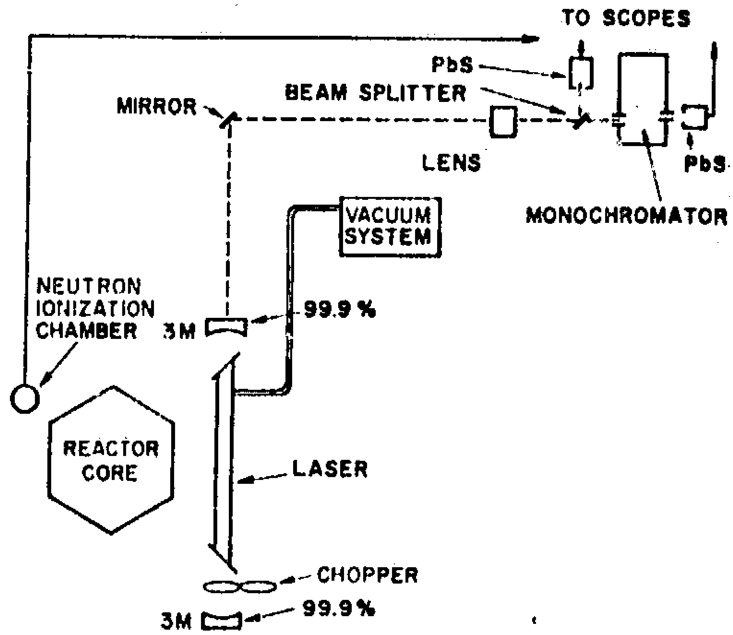

Figure 1. Experimental arrangement. The laser (not-to-scale) was separated from the detector by ~7 meters of radiation shielding.

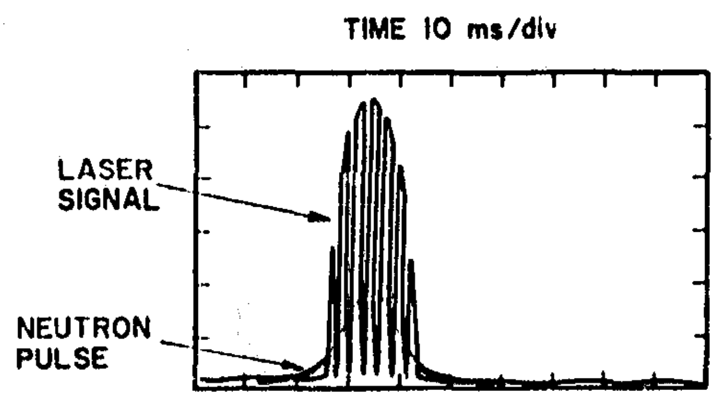

Figure 2. Typical data from the He-CO system. Note that the neutron pulse and laser signal are coincident.

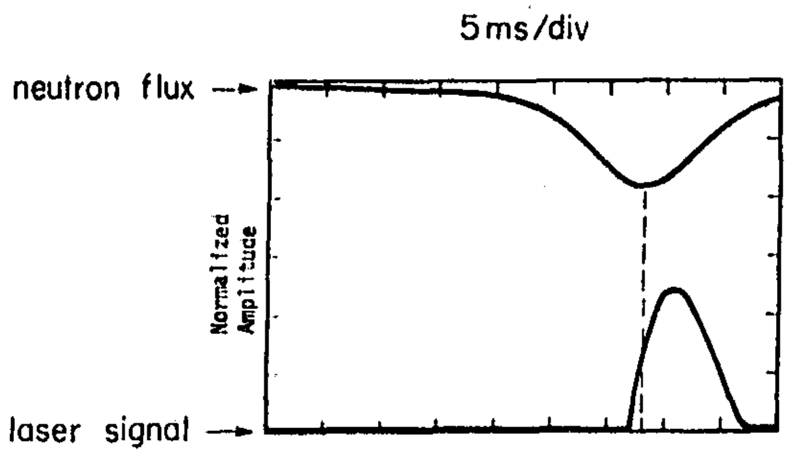

Figure 3. Laser output demonstrating a delay at ~0.25-mT CO_2 and 50-T He. (The neutron flux is inverted on this reproduction of an actual oscilloscope trace)

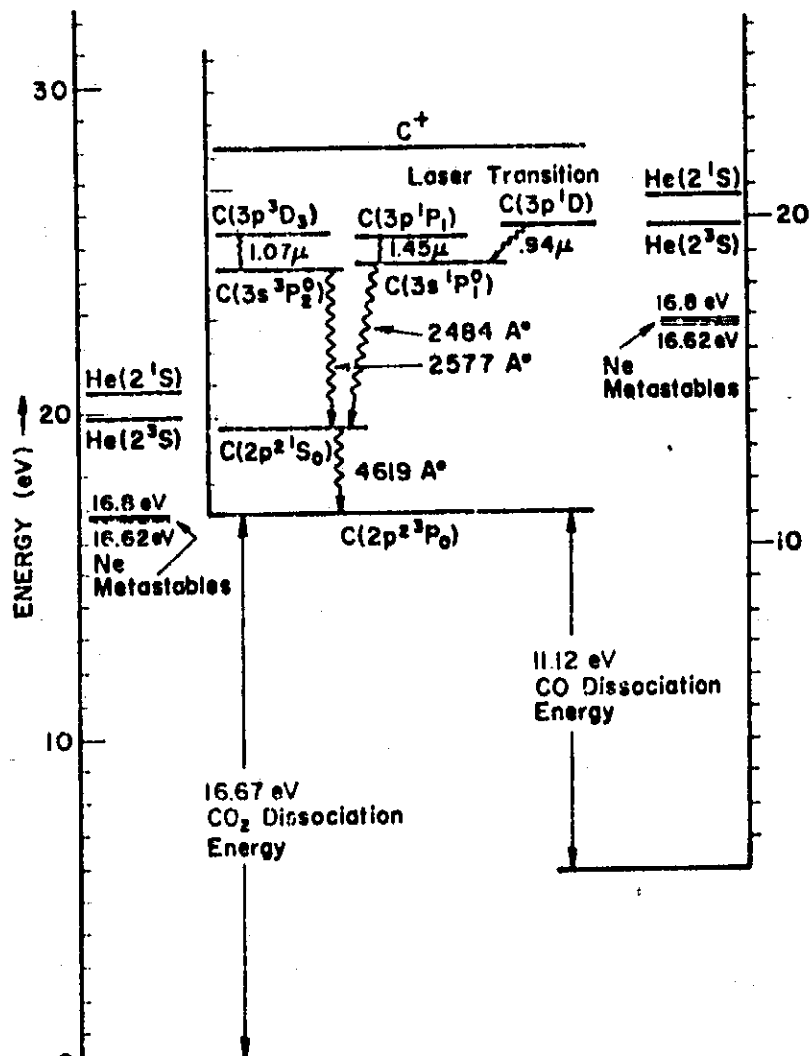

Figure 4. Energy level diagram of the 1.45μ carbon laser indicating possible excitation pathways.

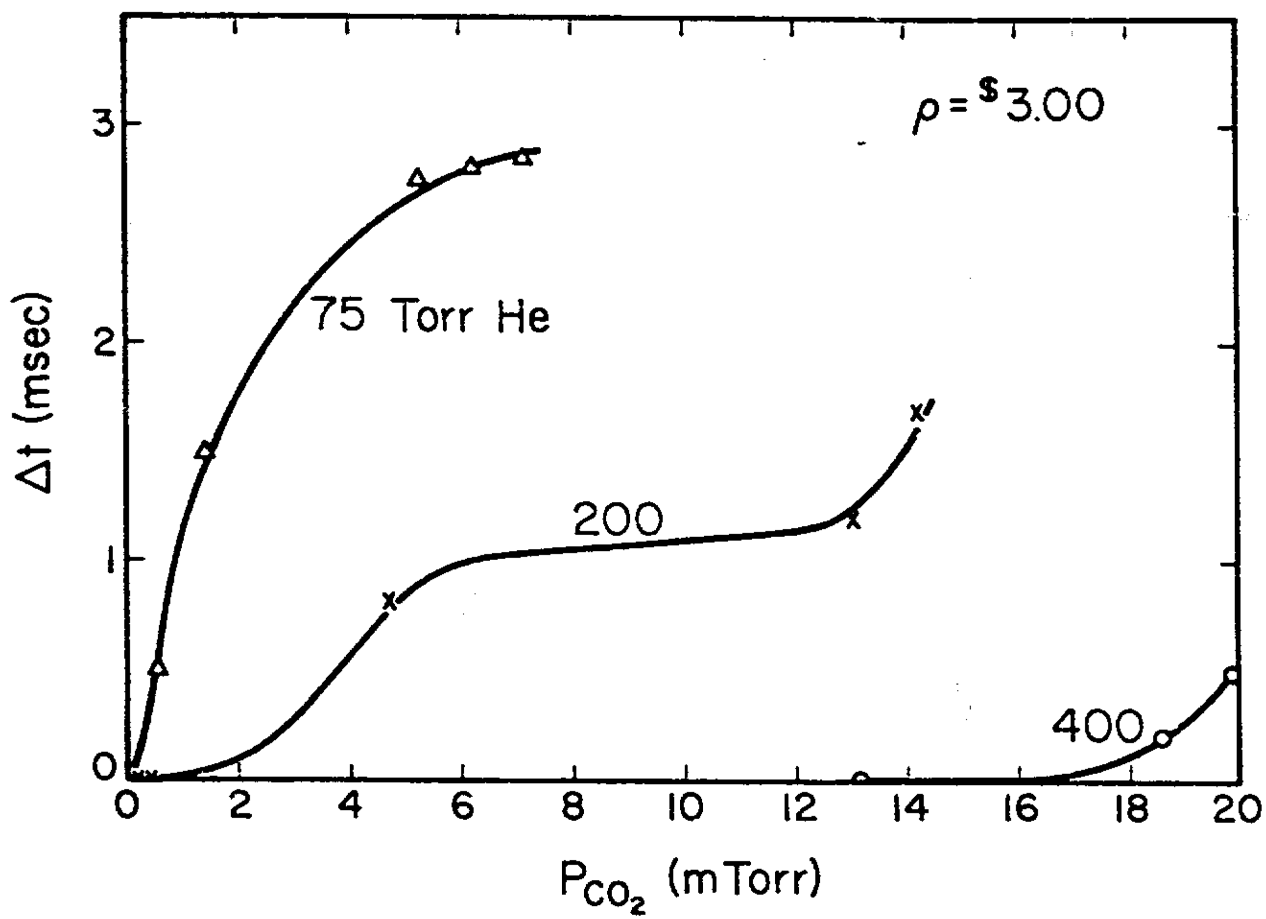

Figure 5. Dependence of time delay CO_2 partial pressures at He pressures of 75, 200 and 400 T.

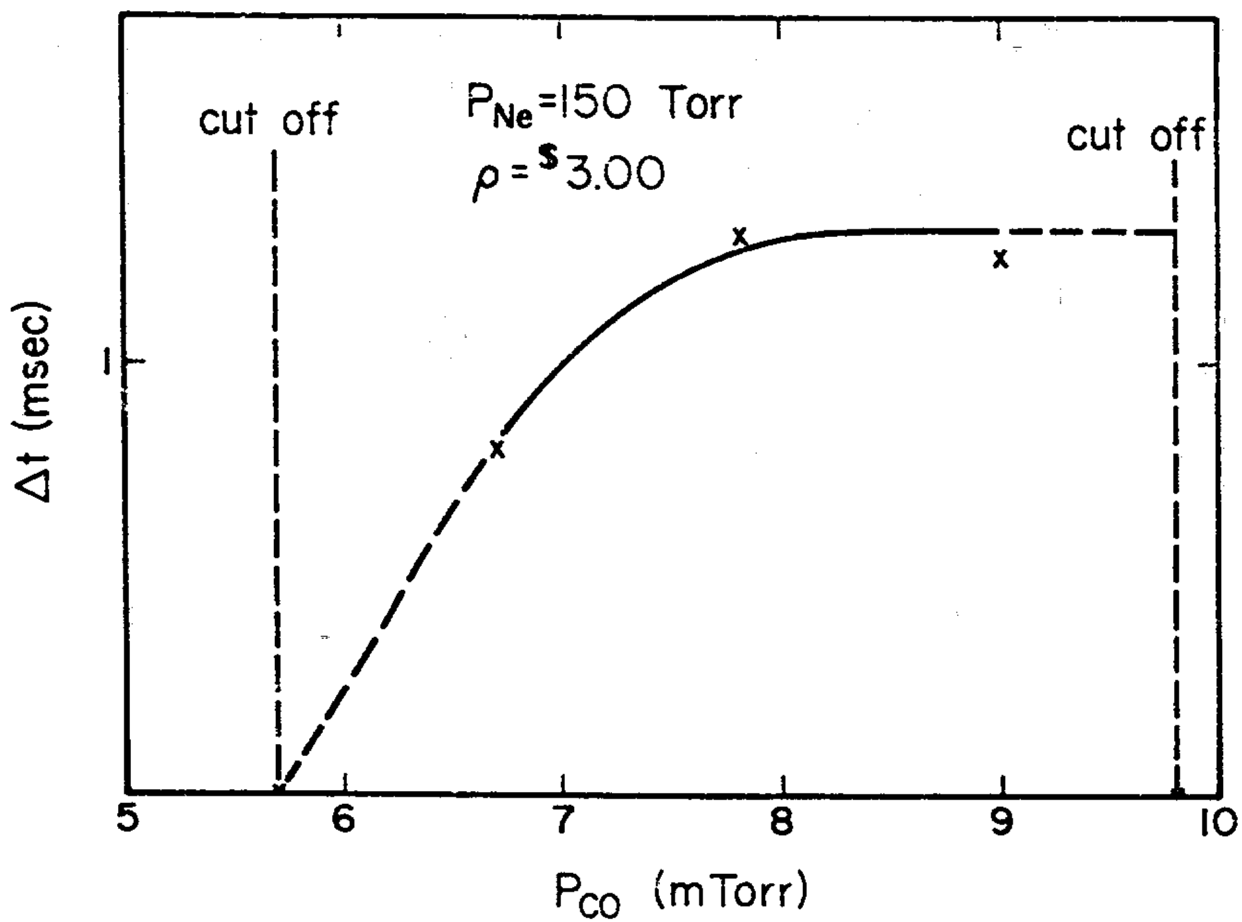

Figure 6. Time delay vs. partial pressure of CO in 150-T N_e.

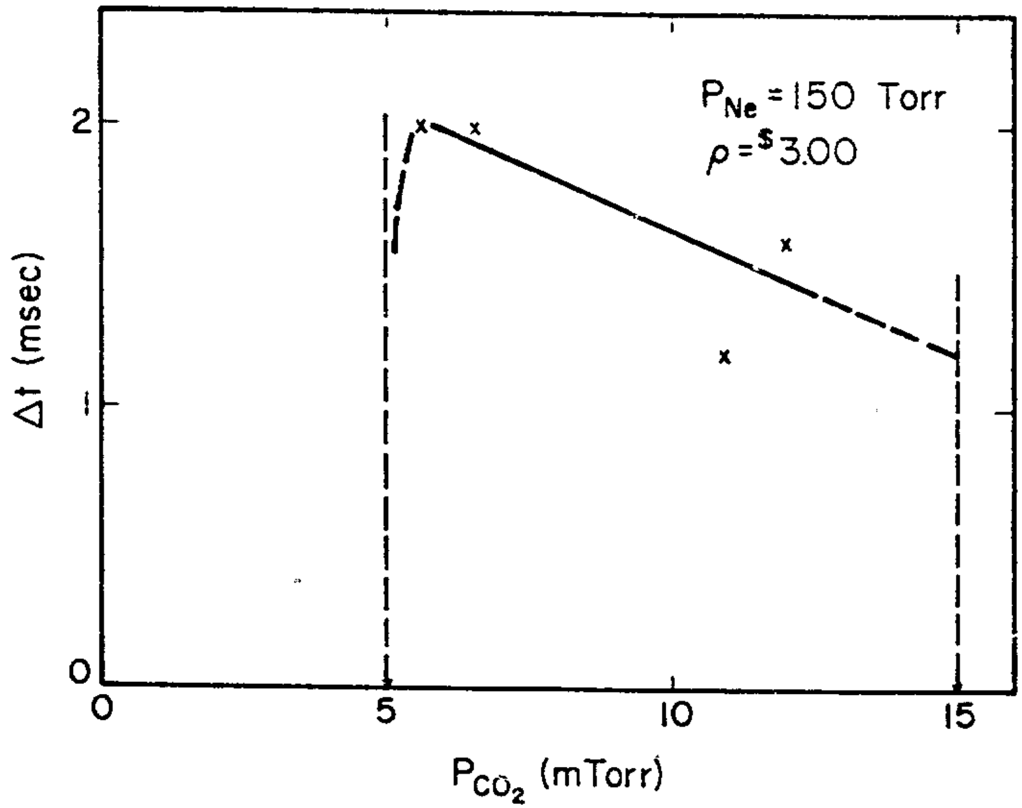

Figure 7. Time delay vs. partial pressure of CO_2 in 150-T N_e.

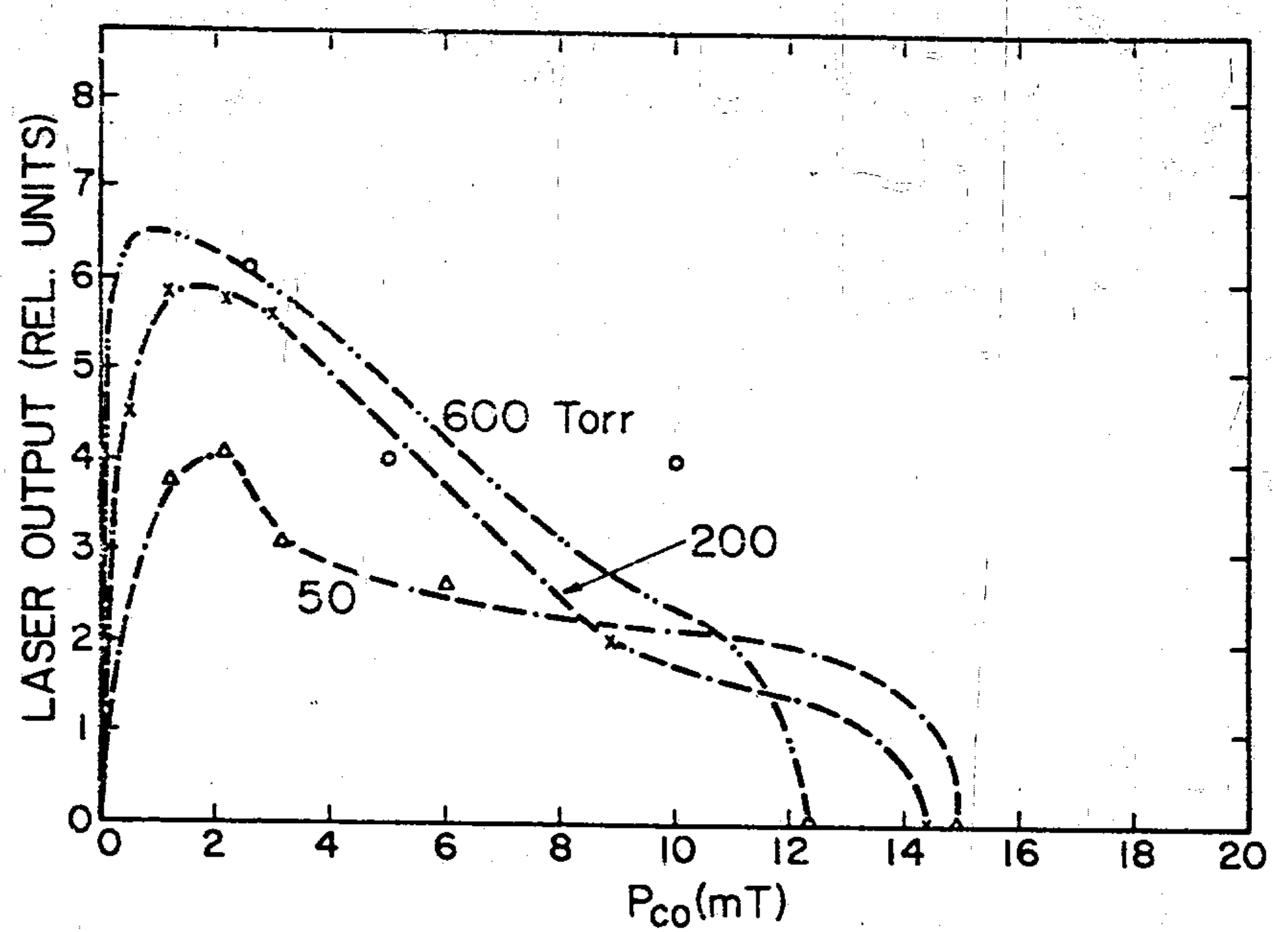

Figure 8. Laser output vs. partial pressure of CO at He pressures of 600, 200 and 50 Torr.

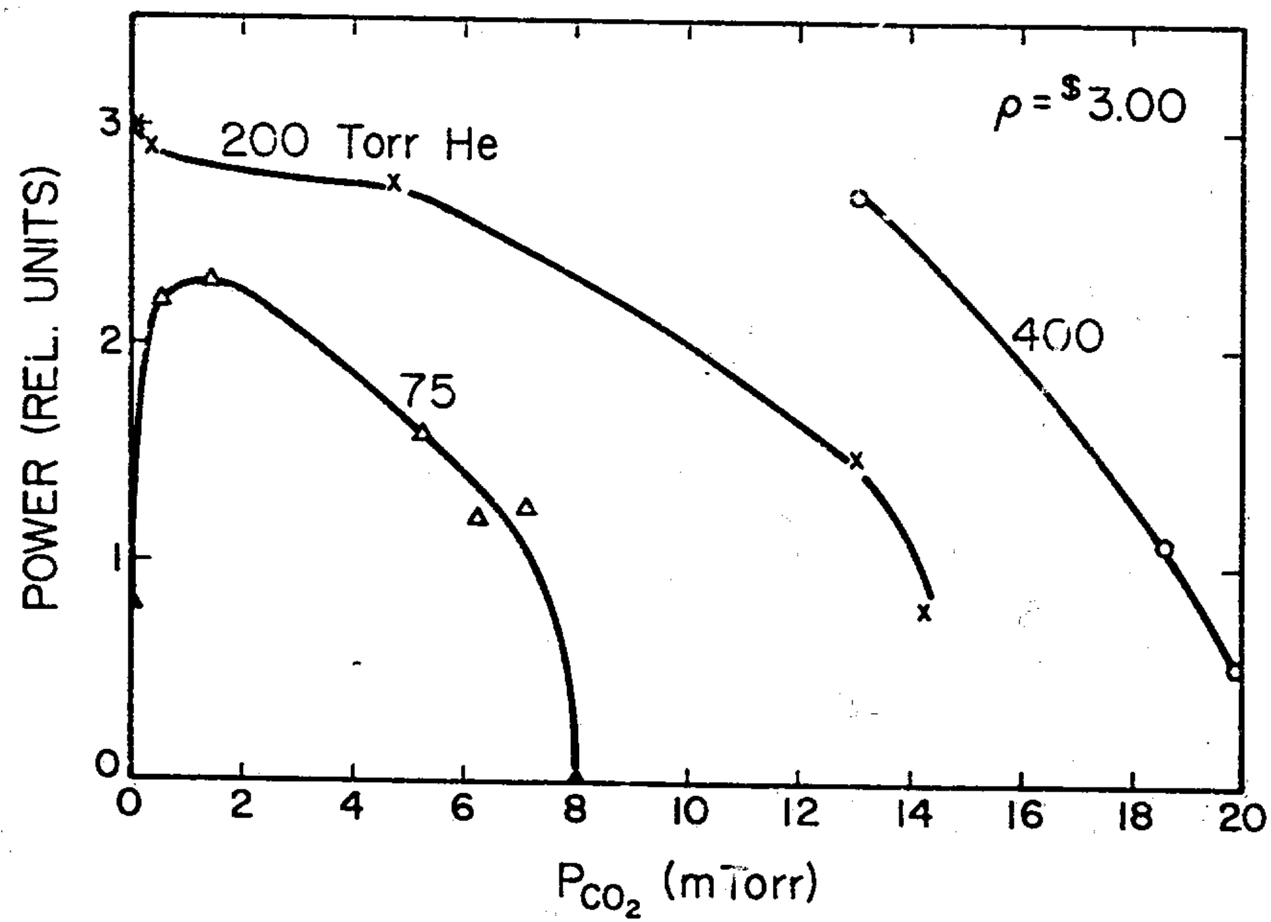

Figure 9. Laser output vs. partial pressure of CO_2.

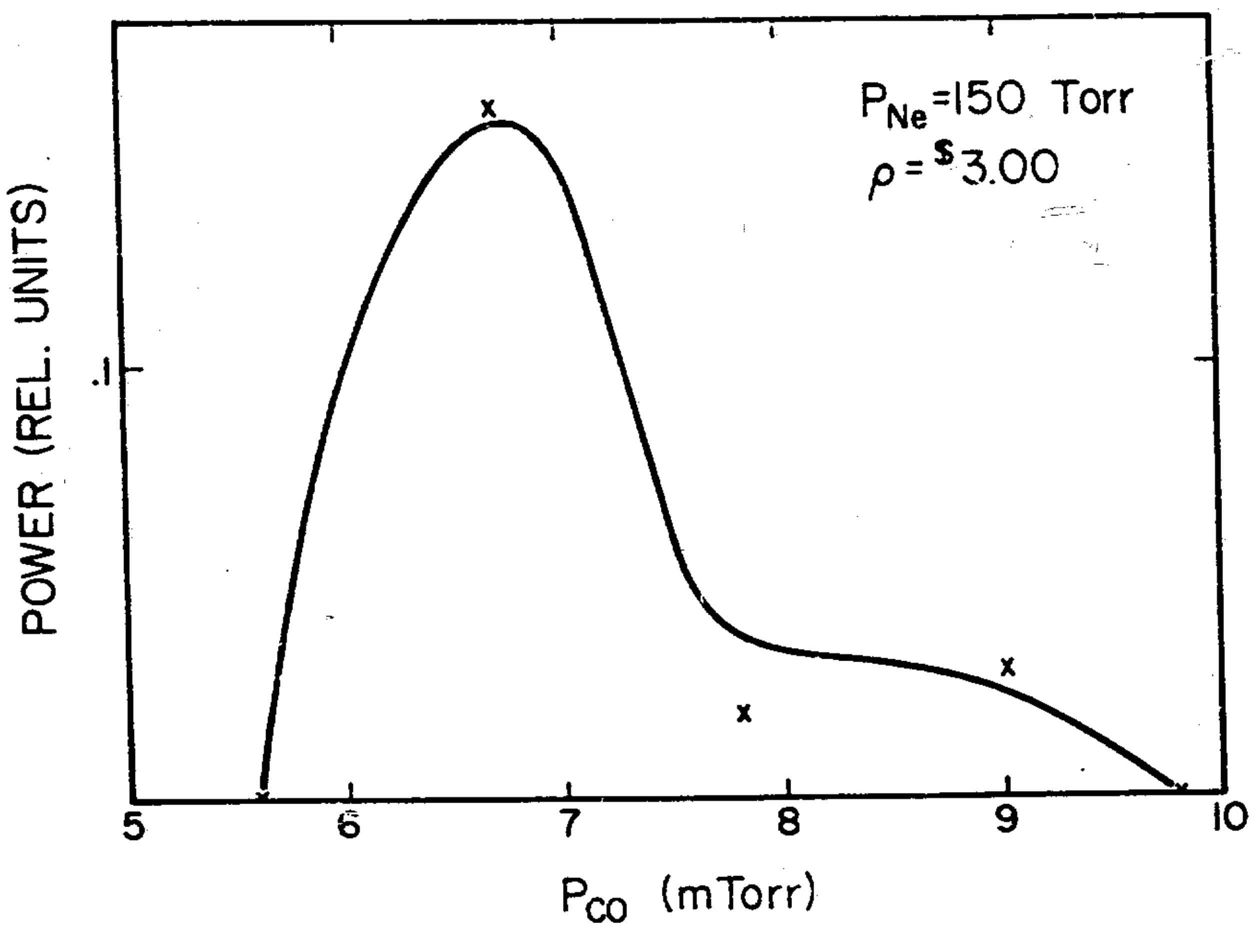

Figure 10. Laser output vs. partial pressure of CO.

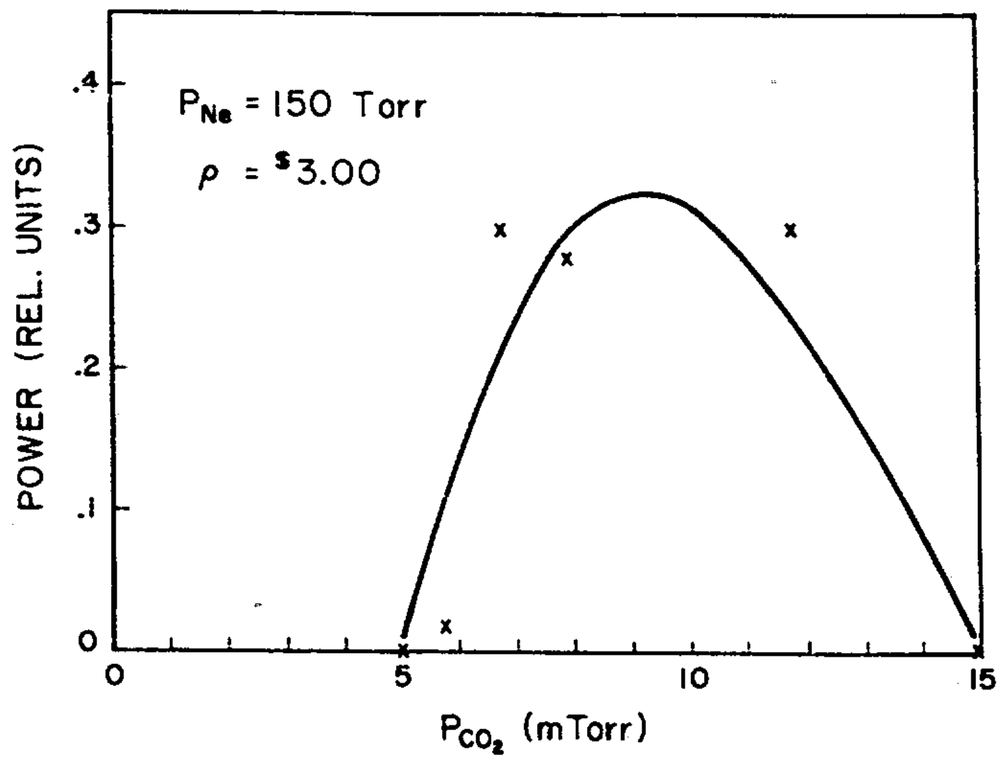

Figure 11. Laser output vs. partial pressure of CO_2.

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