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A 20 Watt, C.W., Carbon Dioxide Gas Laser for Biological Studies

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Biologic Effects of Laser Radiation

SUMMARY

A 20 watt, C.W., CO_2 gas laser has been constructed at Northeastern University for biological experimentation. The experiments performed on this device include: incision of the abdominal skin and subcutaneous tissue of a dog utilizing a focused beam; biophysical threshold studies in rodent skin; experimental verification of models for threshold studies.

The laser cavity is composed of three sections: a mirror holder containing a spherical gold mirror; the laser gas tube containing Brewster angle windows, and electrodes; a second mirror holder containing a dielectric mirror. Each of the sections is independently secured to the bench allowing the cavity to be extended to any desired length, and any number of additional laser tubes to be inserted in the cavity to yield additional power. There is adequate space between elements to insert auxiliary equipment within the cavity, such as shutters and apertures.

The laser tube is water cooled to increase efficiency. The electrodes are air cooled to prevent overheating. All associated gas and water system components are isolated from the laser bench to reduce vibrations of the laser tube.

The laser has been operated at about 20 watts A.C. with one active tube. Mode patterns corresponding to TEM_{00}, TEM_{01}, TEM_{01*}, have been observed. D.C. operation of the laser has been carried out.

To perform the abdominal incision of the dog, the laser was operated at 10 watts, and the beam focused with an Irtran II lens. No attempt was made to tune the laser into a recognizable mode pattern. For other biological experiments, the laser was tuned into an apparent TEM_{00} mode by placing an aperture within the cavity. The focused beam yielded a power density of about 35 watts/cm^2 at the irradiation site.

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TECHNICAL DESCRIPTION OF CARBON DIOXIDE LASER

Biological studies involving the CO_2 laser are characterized by a number of problems not necessarily critical to other investigations. Among these are: power and power density requirements; shape and size characteristics of the output beam; duration of output pulses; accessibility of irradiation sites; precise aiming of the beam; elimination of hazards such as electrical shock and accidental reflection of the laser beam in the region of the experiment.

A. Power

Preliminary investigations at the author's laboratory have indicated that satisfactory biological experiments at 10.6μ can be performed with a CO_2 laser whose total power output could be continuously varied up to 50 watts.

B. Power Density

This parameter is a function of the power, the size of the output beam, and the structure or mode pattern of the output beam. The power density is a parameter of importance in the development of analytical models of tissue. These models involve thermal calculations which may be simplified if radial heat flow can be neglected.

Studies at this laboratory indicate that at the center of the irradiation site, radial heat flow may be neglected in biological media for a 1 cm. beam diameter if the pulse duration is less than 10 seconds. Smaller spot sizes, $<$ 1 mm. require shorter irradiation time, $<$100 m sec, in order to permit radial heat flow to be neglected.

Thus for high power densities (small spot sizes), it is necessary to have a device to control the irradiation time, such as a shutter.

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In order to calculate the power density incident on a given area within the beam, it is necessary to know the distribution of power within the beam cross section. This distribution is well known if the laser is operating in a low order mode, TEM_{00}, TEM_{01}, or TEM_{01*}. The TEM_{00} mode has a Gaussian cross section. This mode is the simplest to perform calculations with and is therefore the most desirable mode pattern for biological experimentation.

C. Accessibility of Irradiation Sites

Since the CO_2 laser is usually aligned horizontally, reflective optics is usually needed for vertical irradiation of animals and liquids. Gold coated glass or metal flats serve to alter the beam direction. Gold coated lenses act as converging mirrors for simultaneously focusing the beam and changing its direction.

D. Precise Aiming of the Beam

In order to align the irradiation site in the beam, a technique has been devised utilizing a He-Ne laser. This technique is discussed below.

E. Elimination of Hazards

All hazardous electrical components have been isolated from the region of the experiment. Marinite and asbestos are used to stop the beam. Metals are kept out of the beam path to prevent reflections from the experimental area.

To construct the laser (see Figures in appendix), a 2 cm. i.d. double walled glass tube 80 cm. long was placed on a Benelex slab, 6' x 4' x 2". The tube was held in place by two x-y microscope stages which were modified and oriented to support the tube rigidly. The ends of the tube were female T 34/45 ground glass

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connectors into which a mating end piece was inserted. The end piece is a single walled glass tube, ~ 6" long, the end of which is cut at a 33.6° angle, the Brewster angle for sodium chloride. A second tube containing a high voltage electrode is fused into the side of the end piece. NaCl windows, flat to 1μ, were sealed to the end pieces with silicone rubber. The jacket of the tube is water cooled and a gas cock is fused into each end piece. Small venturi fans were used to circulate room air around the electrode holders. The laser cavity was formed with a 4.7m radius spherical gold mirror as a ~99% reflector at one end and a flat dielectric 88% reflector at the other end, 150 cm apart, forming a hemispherical resonator.

For this configuration the spot size on the flat mirror is ~2.7 mm. in lowest order (TEM_{00}) mode operation. For higher order modes, larger spot sizes occur. Calculations indicate if the cavity were enlarged to 4 meters, a 2 mm. TEM_{00} spot size would be expected. Preliminary experiments have shown that the 4 meter cavity yields a 2mm, single spot. This was demonstrated by achieving a TEM_{01} mode of operation, followed by fine tuning to produce a single spot. Further studies are required to determine that the power output is Gaussian and thus verify that a TEM_{00} mode has been achieved. The mirrors were supported by Lansing mirror mounts which are adjustable to 0.1 seconds of arc and resettable to 0.6 seconds. These gimbal mounts are adjustable about two axes.

The cooling system is composed of a heat exchanger capable of cooling the laser for 4 hours without externally cooled water and indefinitely with externally cooled water. The gas flow system consists of a mixing manifold into which the gases enter through needle valves for fine control. The mixture than flows through a metering valve before entering the laser tube, where it is evacuated by a vacuum pump.

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The laser is capable of operating both A.C. and D.C.. The A.C. supply is simply a neon sign transformer controlled by an autotransformer. The D.C. supply is capable of delivering 100 ma at short circuit, at 10 kv across the tube. To-date, A.C. operation has been adequate for the biological experiments performed.

To expedite initial lasing of the device, a tank of special gas mixture was obtained consisting of 80% helium, 15% N_2, and 5% CO_2. This mixture has been known to lase in other units. Using this mixture, only the pressure, voltage, and mirror alignment need to be adjusted. Approximate values for the pressure and voltage were known to be 5 Torr and 8 kv, A.C., respectively. To aid in initial operation, a pre-alignment procedure, as given in the appendix, was devised utilizing a He-Ne laser.

After initial lasing was demonstrated by a chromel-alumel thermocouple, the alignment of the laser tube and mirrors was varied until maximum output was achieved. The pressure and voltage were then adjusted until the output power was maximized, and the optimum values noted. The premixed gas tank was disconnected and tanks of He, N_2, and CO_2 were inserted. The gases were adjusted until the mixture in the tube glowed with the same color as did the premixed gases. This color was retained while the pressure was adjusted. When the color and pressure are correct, the voltage across the tube corresponds to that required for lasing with the premixed gases. The mixture was adjusted until maximum output was achieved. The gas mixture, voltage, and pressure are related. Maximum power was achieved by maximizing one parameter, going on to another, etc., until all parameters were adjusted. Then the sequence was repeated until the power output did not increase significantly with the variation of any parameter.

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The maximum power output observed with this instrument to-date is 20± 2 watts. This output was measured with a thermocouple in contact with a heat sink. This power meter was calibrated against a cone calorimeter by measuring the energy absorbed by the cone during a time interval measured by a stopwatch, thus obtaining the power. The cone calorimeter had been calibrated using an N.B.S. standard light source. Recent studies of heat sinks in this laboratory and the acquisition of an Eppley thermopile should lead to more accurate and more reproducible power measurements. Power output decreased as the quality of the NaCl Brewster angle windows decreased due to humidity and dust attacking the surfaces. This situation has been alleviated somewhat by placing plastic bags over the windows when the laser is not being used.

The observed spot size of this laser, unfocused, is of the order of 1.5 cm diameter with hot and cold spots distributed irregularly over the beam cross section. This observation was made by heating a piece of Marinite to incandescence. Noting the calculated 2.7 mm spot size mentioned above, and with observations of the mode pattern as seen in the glowing Marinite, it has been decided that the laser is not operating in a recognizable mode. With the insertion of a 0.5 cm diameter aperture in the cavity, a mode pattern apparently corresponding to TEM_{00} or lowest order mode, has been observed with the cavity extended to 4 meters.

This TEM_{00} mode of operation has been used in biological experiments. Under these conditions the spot is circular and the power output should have a Gaussian distribution across the beam face. Preliminary observations of the power across the beam using thermofax paper, appear to corroborate the Gaussian distribution. The power density was measured to be 35 ± 4 watts/cm^2 in this mode with the total power output ~ 2 watts. This power and power density is expected to increase when the laser is operated D.C. Modification of the NaCl windows is expected

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to increase the power output. Addition of active tubes will also increase power output.

As mentioned above, a spot size this small requires a short exposure time to insure that radial heat flow can be neglected. To control exposure time, a shutter has been constructed and placed in the cavity which can reliably yield a range of exposures from 100 msec. to one second. The reproducibility of the instrument is 1%, whereas commercial camera shutters are usually specified as accurate to 10% in some ranges. Two shutters tested at this laboratory have, however, been shown to be 50% inaccurate at some settings. A second instrument which should yield exposure times of 20 msec. is now under construction.

For continuous monitoring of the output, a beam splitter for 10.6μ is being constructed to be used with the aforementioned detectors. To irradiate difficult anatomical sites and liquids, mirrors of both flat and concave configurations have been employed for low or high power density irradiation, and a lens of Irtran II has been used to yield power densities sufficient to attempt surgical incisions.

Considerable spatial variation of the mode pattern was observed which seemed to be related to vibrations of a vacuum pump on the floor near the laser. When this pump was put on a platform fastened to a brick wall of the building, these variations were eliminated except when personnel moved near the laser bench. It was decided that vibrations were transmitted through the floor to the laser. These vibrations were noted to affect the output of the laser. To minimize vibrations which affected the apparatus, the laser was removed from the Benelex and replaced on a wooden table top. The table top was placed on another table, and 3/4" of rug padding was inserted between the two table tops. The table was placed on the Benelex slab and the whole system was"floated" on three partially

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inflated bicycle inner tubes. This technique has not been entirely successful in eliminating vibration. We have observed, however, that although a given mode pattern and power output may vary while there is movement around the laser, when the movement ceases, the system reverts to the mode pattern and power output that had been observed before the disturbances occurred. The problem of vibration is expected to be further reduced when the laser is moved to a building with solid concrete floors.

To precisely align the laser for biological experiments, a mock-up of the experiment is set up. The irradiation site of the laser is noted and a He-Ne laser is then aligned in such a way that its beam strikes the target at the same place as the CO_2 beam. The exact irradiation site is then indicated by the He-Ne laser beam. This system has been used with both focusing mirrors and lenses where the high power density precludes trial and error aiming.

The experimental procedures are performed on a table separate and distinct from the laser bench. The A.C. power supply is beneath the laser bench and the D.C. supply is housed in a cabinet at the other end of the laser. There is always an absorbent barrier between the experimental site and other parts of the room so that stray radiation cannot cause accidents.

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PARTS LIST

Benelex Slab

48" x 72" x 2"
Gilfoy Distributing Co., Cambridge, Massachusetts
This material is rigid and easily drilled and tapped

Double Walled Glass Tubes

80 cm long, female 34/45 without connector ends.
Macalaster Scientific Co., Nashua, New Hampshire
Double wall allows continuous cooling

Window and Electrode Holders

Cut to 33.6°, pyrex
Macalaster Scientific Co., Male 34/45 connector

Mirror Mounts

2, GS-253 Gimbal Suspensions: one mounted on a TR112 translation stage, one on a GS-002 height adaptor
Lansing Research Corp., Ithaca, New York
These mounts allow precise control and reproducibility

Cavity Mirrors

1 spherical mirror, 2" diameter, 4.7 m radius, coated in gold (≈99% reflector)
1 1" diameter, 2mm thick Irtran II flat, dielectric coated 12% transmission and AR. coated on back surface at 10.6μ
Orion Optics, Stamford, Connecticut

Microscope Stages

x-y mounts, modified by addition of a screw to give more stable support
Lafayette Radio Electronics, Natick, Massachusetts

Vacuum Pump

Kinney KC-8
Kinney Vacuum Division, Natick, Massachusetts

Vacuum Gauge

0-50 mm Hg. in 0.5 mm gradations
Catalogue No. FA 160030 -Wallace & Tiernan, Inc., Belleville, N.Y.

Transformer

15 kv. neon sign transformer
New England Sign Supply Co., Boston, Massachusetts

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End Windows

2 15/64" x 1/4" thick polished NaCl, n=1.5 ± 1% at 10.6μ.
Harshaw Chemical Co., Cleveland, Ohio
Frank Cook Optical Co., North Brookfield, Massachusetts

Special Gas Mixture

85% He, 10% N_2, 5% CO_2
E.D.Cook Co., Boston, Massachusetts

Focusing Lens

Irtran II f/10, 1" focal length
Eastman Kodak Co., Rochester, New York

Water and Gas Fittings

Swagelok Fittings, Cambridge Valve and Fitting Co.,
Wayland, Massachusetts

This type fitting holds both pressure and vacuum well and the connection can be broken and remade several times and not lose its tightness

Fans

Muffin Venturi fan made by Rotron Cooling Equipment Co.,
Cramer Electronics Inc., Boston, Massachusetts

The fans were supported by Tygon tubing used as legs to minimize vibration.

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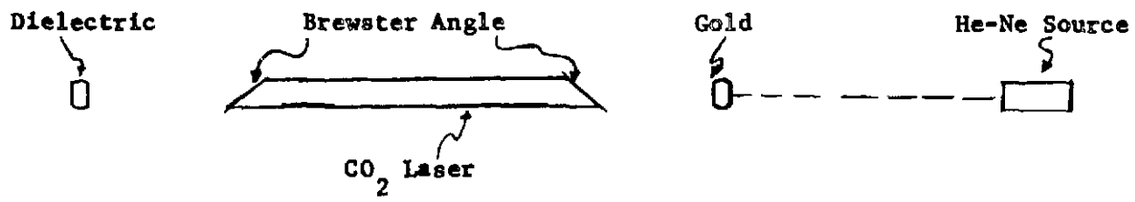
PRE-ALIGNMENT PROCEDURE FOR CO_2 LASER



The procedure utilized a He-Ne gas laser beam as a reference line.

1. Remove the gold reflector.
2. Align CO_2 laser by eye so that a line passing through the center of both Brewster angle windows intersects the center of the dielectric mirror.
3. Set up He-Ne source as far from the CO_2 tube as possible (the longer the lever arm, the more accurate the alignment.)
4. Aim He-Ne beam down tube, intersecting the center of dielectric mirror.
5. Check to be sure the beam is not bouncing in the CO_2 tube.
6. Translate the He-Ne laser until the beam, pivoted at the center of the dielectric, also passes through both Brewster angle windows and is centered as well as possible in the windows.
7. Adjust the CO_2 tube until the beam is centered in both windows, again checking to be certain the beam does not bounce within the tube.
8. Adjust the dielectric until reflected beam coincides with incident beam.
9. Replace the gold reflector, gold side toward CO_2 laser and reflect He-Ne beam off the center of the rear of this mirror.
10. Adjust the gold mirror until the reflection from the rear surface of this mirror coincides with the incident beam.

The laser should now be well enough aligned so that with an appropriate flow rate of the three gases in the tube, appropriate voltage to the electrodes, proper pressure and cooling, the device will lase.

When lasing is observed, the alignment can be optimized by adjusting both mirrors and the tube until maximum output is achieved.

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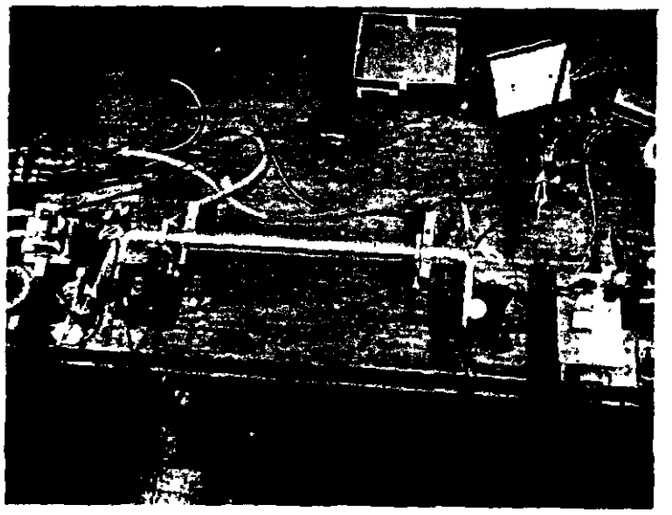

Fig. 1. Top view of CO_2 laser bench showing the water cooled laser tube with air cooled electrodes and Brewster angle windows, and the external mirror mounts. The two rotary solenoid operated blades compose the internal shutter.

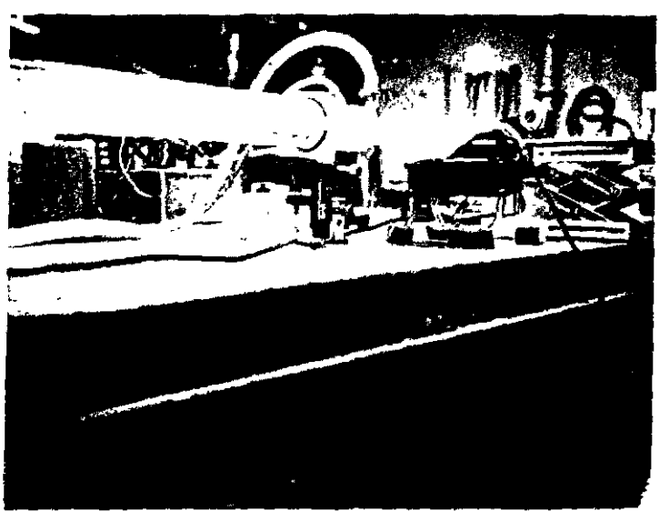

Fig. 2. Modified x-y tube mounts, electrode, and fan on Tygon "legs".

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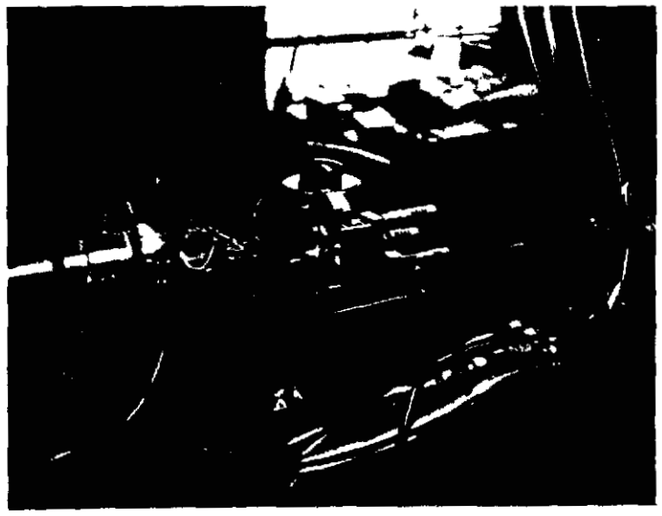

Fig. 3. Brewster angle NaCl windows on tube and gold reflector in mirror mount.

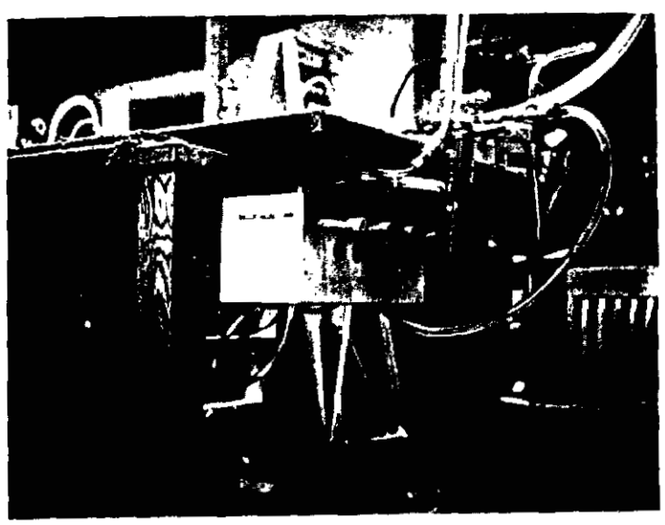

Fig. 4. Gas mixing manifold and metering valves.

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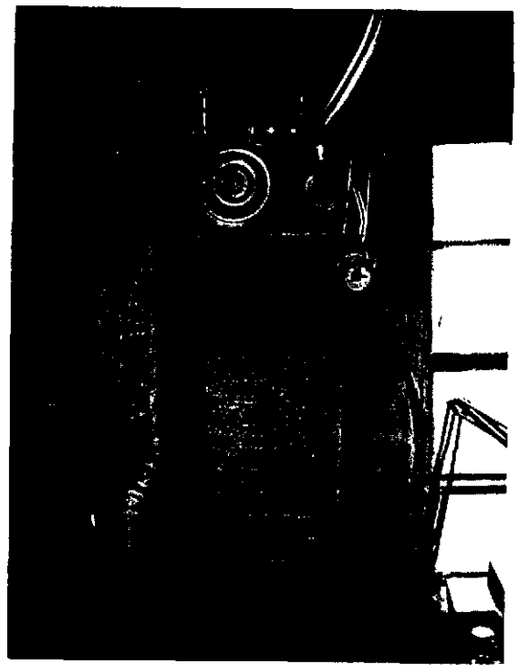

Fig.5. Isolated vacuum pump on wall mount.

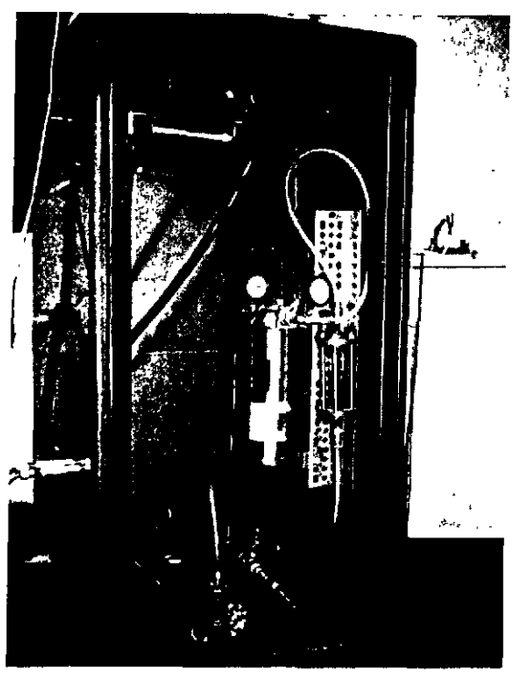

Fig. 6. Water system for gas tube cooling.

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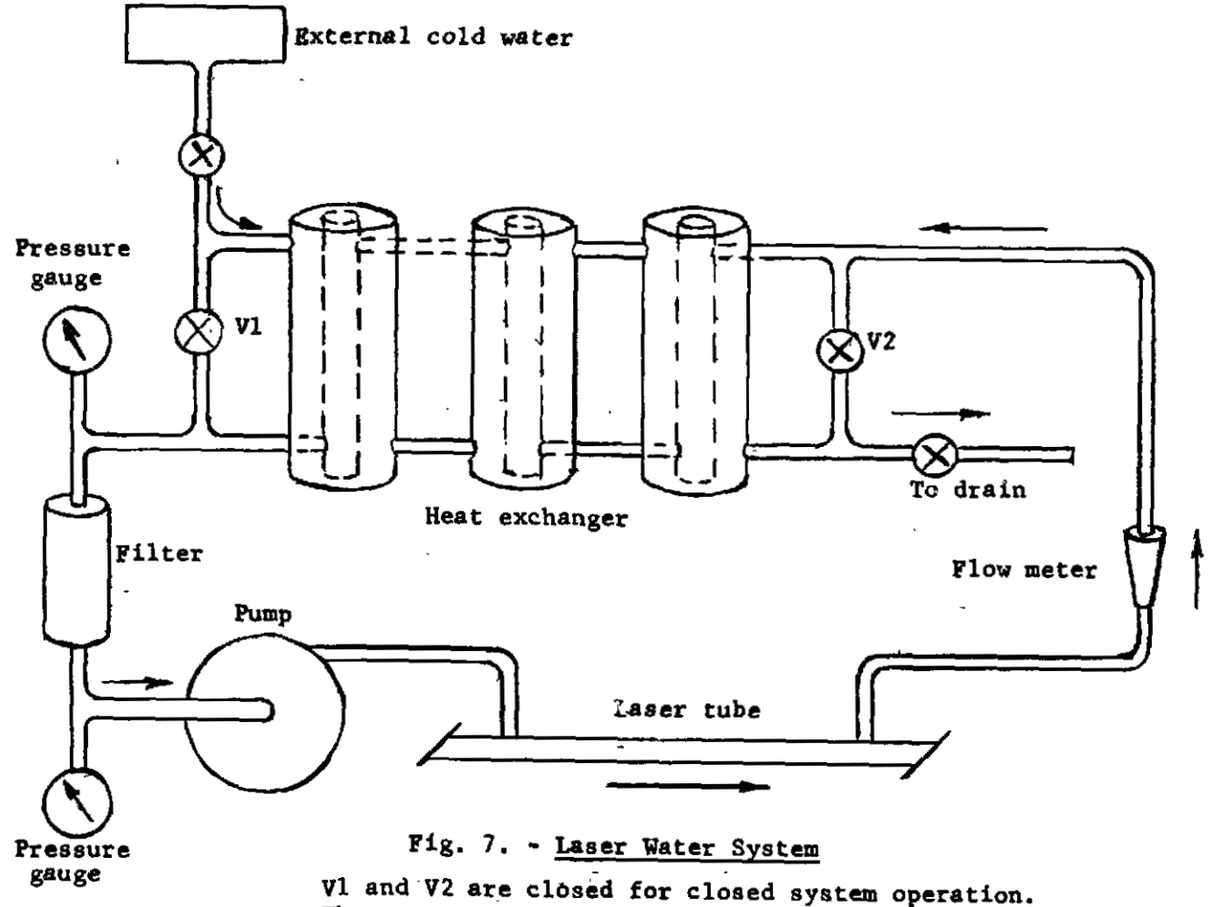

Fig. 7. - Laser Water System

V1 and V2 are closed for closed system operation. They are opened to allow direct cooling of the laser tube by externally cooled water.

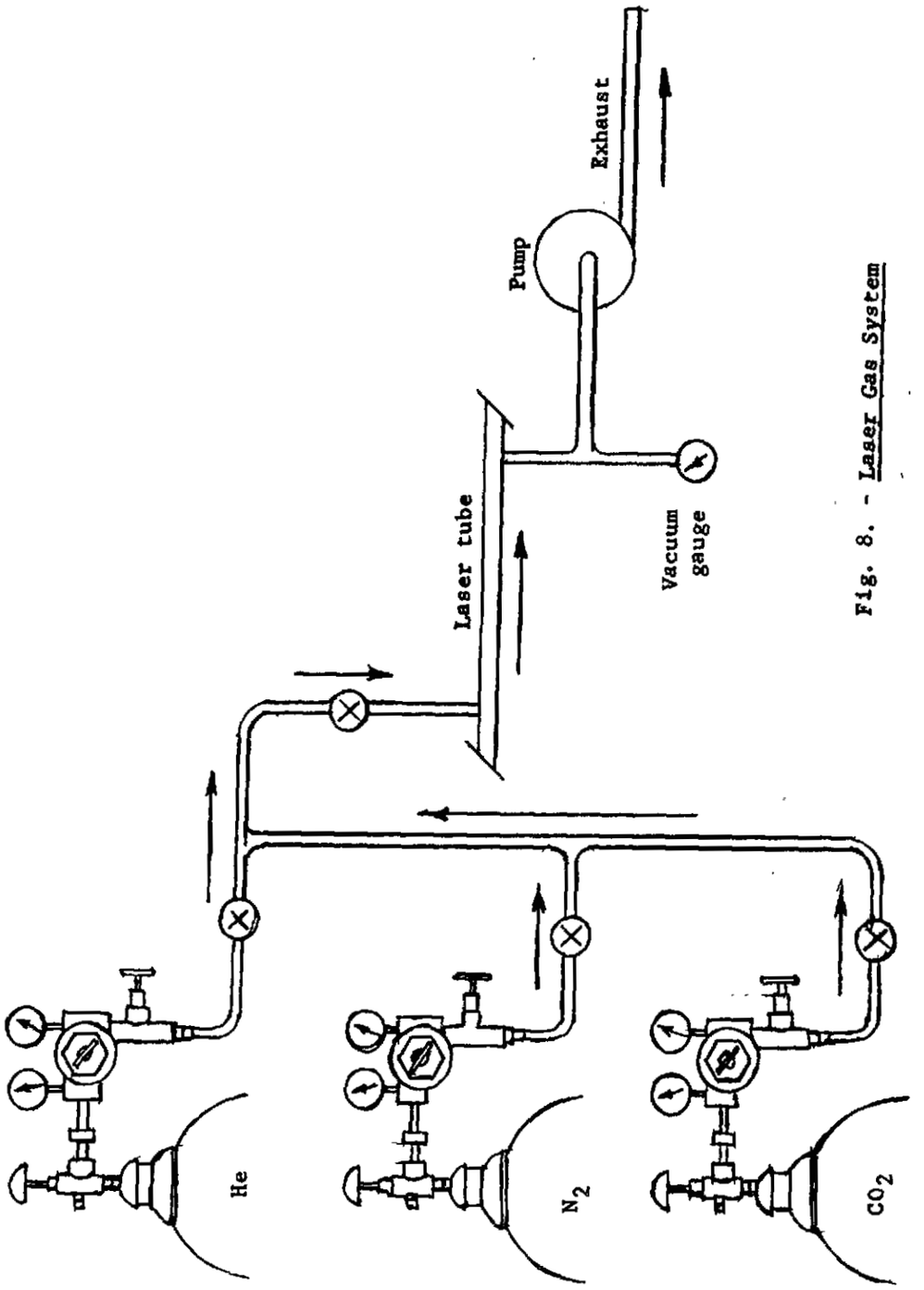

Fig. 8. - Laser Gas System

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