Related topics

Molecular vibration, exitation of molecular vibration, electric discharge, spontaneous emission, vibration niveau, rotation niveau, inversion, induced emission, spectrum of emission, polarization, Brewster angle, optical resonator.

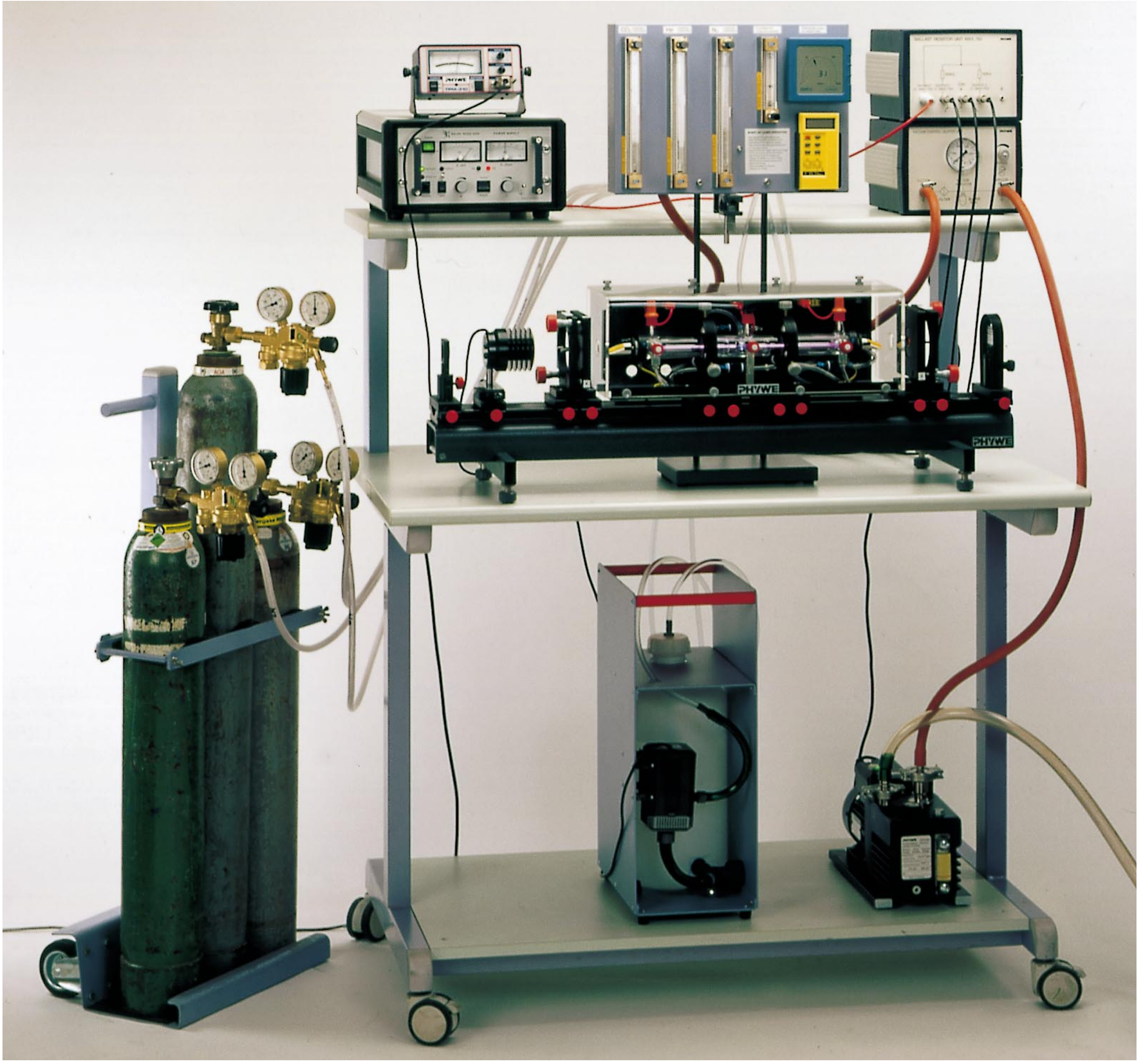
Equipment

CO_2-laser tube, detachable, 8 Watt	08596.00	1
Modul-box for CO_2-laser tube	08597.00	1
Set of laser mirrors, ZnSe and Si	08598.00	1
Opt. bench on steel rail l 1.3 m	08599.00	1
HV-power supply \5 kV/50 mA DC	08600.93	1
Ballast resistor unit	08601.00	1
Cooling water unit, portable	08602.93	1
Vacuum pump, two-stage	02751.93	1
Gas filter/buffer unit	08605.00	1
He/Ne-laser/adjusting device	08607.93	1
Screen/diaphragm f. adj. CO_2-laser	08608.00	2
Powermeter 30 mW/10 Watt	08579.93	1
Support for power probe	08580.00	1
Protecting glasses, 10.6 micro-m	08581.00	1
Cleaning set for laser	08582.00	1
ZnSe biconvex lens, d 24 mm, f150 mm	08609.00	1
Digit.thermom., NiCr-Ni	08583.00	1
HV-isolated temperature probe	08584.00	1
Control panel w. support, 1 gas*	08606.00	1
Pressure contr. valve 200/3 bar*	08604.00	1
Laser gas in bottle, 50 l/200 bar*	08603.00	1

***Alternative to:**

Laser gas mixing unit, 3 gases	08606.88	1

Fig. 1: Experimental set-up of the CO_2-laser system with laser gas mixing unit (Output power: max. 8 W CW).



CO_2-laser

Principle and task

Among molecular lasers, the CO_2-laser is of greatest practical importance. The high level of efficiency with which laser radiation can be generated in continuous wave (cw) and pulse operation is its most fascinating feature.

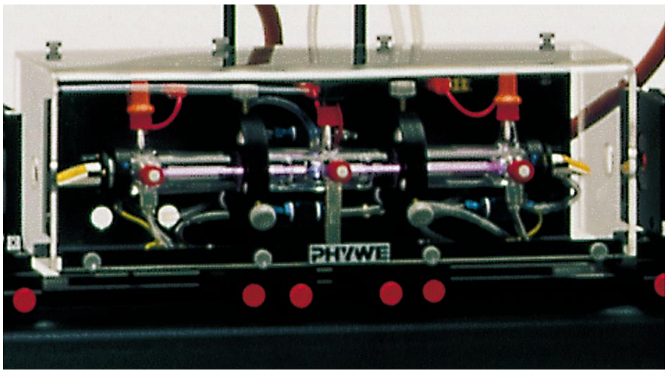
If a gold coated diffraction grating (with, e.g., 700 lines per cm) and a diaphragm are used, it is possible to select higher energy laser lines and to use them for spectroscopic purposes. If this diffraction grating is mounted in such a manner that it can be moved, then a CO_2-laser can be tuned to a band width of 9.2 μm to 10.8 μm. CO_2-lasers of this type are used for spectroscopic analyses in the intermediate IR region (RAMAN and FIR spectroscopy, environmental analytics). For, e.g. measurement of atmospheric pollutants the CO_2-laser is employed on the basis of photoacustic spectroscopiy or that of the LIDAR principle.

In the field of medicine this laser is used e.g. in surgery as a laser scalpel, in the ablative treatment of skin areas and as a source of light for the heat treatment of deep-lying tissue layers (e.g. neurostimulation).

As a result of the good thermal coupling of CO_2-laser radiation in high-temperature plasmas, this laser is used for cutting, welding and surface-hardening processes in the metal technology (power range: 100 W to 50 kW).

The experimental equipment set is an open CO_2-didactic laser system of max. 8 W power output. Since it is an “open” system, all components of the system can be handled individually and the influence of each procedure on the output power can be studied. One very primary and essential target in learning is the alignment of the CO_2-laser by means of a He/Ne-laser.

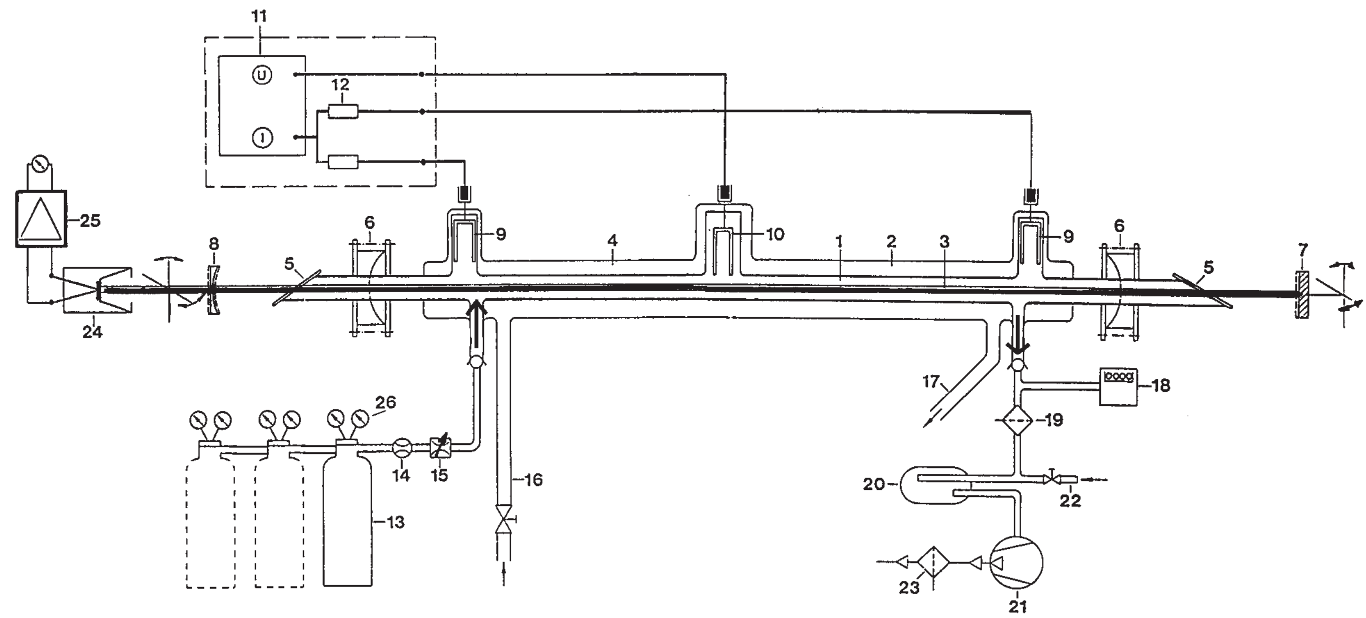
Fig. 1a: CO_2-laser tube in tri-point laser tube holder.



Problems

1. Align the CO_2-laser and optimize its power output.
2. Check the influence of the Brewster windows position on the power output.
3. Determine the power output as a function of the electric power input and gasflow.
4. Evaluate the efficiency as a function of the electric power input and gasflow.
5. If the gas-mixing unit is supplied the influence of the different components of the laser gas (CO_2, He, N_2) to the output efficiency of the CO_2-laser are analyzed.
6. Measurement of temperatures differences for the laser gas (imput / output) for study of conversion efficiency.

Fig. 2: The CO_2-laser system, schematic.



1 Laser tube
2 Cooling jacket
3 Lasing medium
4 Cooling water
5 Brewster window
6 Brewster window mount
7 Si-plano mirror
8 Zn/Se plano/concave mirror
9 Electrodes, positive
10 Electrode, mass
11 HV-DC power supply
12 Ballast resistor
13 Laser gas in bottle
14 Flow regulating valve
15 Flowmeter
16 Water inlet
17 Water outlet
18 Four-digit vacuum gauge
19 Oil-vapor trap
20 Woulff’s bottle
21 Vacuum pump
22 One-way sto-cock
23 Oil-vapor trap
24/25 Power meter
26 Gas supply (1 or 3 gases)

Set-up and procedure

The experimental set-up is shown in Fig. 1. To assemble the complete functional CO_2-laser system, the following components are needed (see Fig. 1a and Fig. 2).

a) The laser tube

- It channels the lasering media, e.g. the CO_2-laser gas, along the laser light propagation. A typical CO_2-laser gas mxiture consists of 4.5 % CO_2, 13.5 % N_2 and 82 % He.
- It provides three electrodes for DC pumping of the laser gas from a high voltage source. The source is both current and voltage-stabilized.
- Its waer jacket allows the two electrodes to cool (for safe operation) and the gas to be excited.
- The inner tube that carries the gas is extended out at either side of the outer jacket to facilitate the mounting of Brewster windows to linearly polarize the output beam.

b) Hardware

- Tri-point laser tube holder. This device holds the glass laser tube firmly and is surrounded by an acrylene-covered steel-housing mounted on an optical bench by means of two 80 mm wide slide mounts. The optical bench is fixed to the rigid surface of a U-shaped steel rail. The steel housing bears the fittings for the inlet and outlet of water and gas as well as safety sockets for the HV-supply.
- Adjustable mirror mounts. Two are needed. The mounts provide micrometer screws for fine adjustment on two axes and can be fixed to the optical bench by slide mounts of a width of 100 mm. The stability of the mirror mounts will directly affect the stability of the systems alignment.
- Brewster window mounts. Brewster windows polarize the output of the laser linearly. Reflection losses caused by windows placed on the tube ends at an angle of incidence other than the Brewster angle would prevent lasering.
- Optical bench. This bench is designed to carry the laser tube in its tube holder, the two mirror mounts and whatever components necessary external to the laser cavity, such as power meter, He/Ne-laser for alignment etc. The optical bench is mounted to a U-shaped heavy steel rail to ensure sufficient rigidity and stability.

c) Optics

The laser cavity contains one Si-plano mirror and one ZnSe-plano/Concave partial reflector, relfecting 95 % of the incoming light at 10.6 μm. The Si-plano mirror has an enhanced silver and dielectric coating whose flatness is 1/10 λ for 10.6 μm. Mirror diameter = 25.4 mm, parall. = 3 arc sec.
The ZnSe-plano/concave mirror has the same flatness and diameter as the Si-plano mirror. Its radius of curvature is 1 m or 10 m. The coating is dielectric on both sides. Mirror diameter = 25.4 mm, thickness 3 mm, AR coated.
For the Brewster windows ZnSe is the preferred material because of its high transmission at 10.6 μm. The Brewster window mounts include sealed ZnSe windows of 2 mm thickness. The angle of inclination of the Brewster windows with respect to the laser tube axis is 23.6°. Flatness = λ/10, parall. = 1 arc sec.

d) Electronics

A high voltage power supply is required to "pump" the laser tube by discharging. The current and voltage electronically highly stabilized DC power unit has a nominal output of 50 mA and 5 kV. Two ballast resistors absorb about 50 % of the total supply output power. Pumping under optimal conditions (maximum laser output), a current of approx. 18 mA at 3.01 kV is observed. The discharging process within the tube takes place from the outside electrodes to the central point (mass) along two equal distances. The power supply unit has a visible power-on indicator.
The ballast resistors serve two functions. When configured as shown in the system diagram, they split the output of the high voltage supply and compensate for the negative plasma resistance of the tube during discharge. The ballast resistors which are incorporated in the supply unit consist of two 100 kΩ resistors with a 150 Watt rating.

e) Vacuum

The typical operating pressure for the CO_2 mixture is from 30 to 40 mbar. Therefore, a vacuum pump is required. A rotary vane pump capable of approximately 67 litres/min which establishes a maximum final pressure of about 2 mbar suffices and is included in the equipment set. Diaphragm pumps are not recommended, due to their pulsing flow. Pressure fluctuation will result in a power instability of the laser output.
To prevent oil-droplets or oil vapor from entering the laser tube, Woulff-bottle and a micro-filter are inserted into the circuit between the vacuum pump and the laser tube. A high precision four-digit vacuum gauge at the outlet of the laser tube provides precise information about the quality of the vacuum. Initially, before introducing the laser gas, a vacuum with a final pressure of equal to or less than 2 mbar has to be established in the tube. Needless to say, all vacuum fittings and connections have to be established with utmost care using vacuum grease and stiff plastic tubing.

f) Gas

The CO_2-laser gas mixture is supplied in a quantity of 50 l at a pressure of 200 atm. Consequently, a pressure regulator is needed to reduce the outlet pressure to one atmosphere above normal. Before entering the laser tube, the gas passes a flowmeter with a measuring range up to 1.5 l/min and flow-regulating needle valve. The laser works under continuous flow conditions to match the unavoidable CO_2 dissociation.
Alternatively, it is possible to mix an individually variable gas mixture from the required laser gas components (CO_2, N_2, He). An adjustable dose and mix system (No. 08606.01) allows the production of a laser gas from commercial gases with a technical purity grade.

g) Cooling circuit

The laser tube requires permanent cooling to reach higher inversion densities. This is ensured by a closed cooling circuit which consists essentially of a circulating pump, and a 10 litre tank with dest. water from the cooling jacket. Since relatively little heat dissipates from the laser tube, the 10 litres of water do not need to be replaced or artificially cooled down unless the system is operated for a long period. The water flow rate approx. (0.5 l/min) is controlled by a flow meter.

h) Power meter

The power output of the laser, e.g. the intensity of the infrared beam is measured using a power meter whose most sensible range allows the instantanous detection of a change in power of 1 mW. The maximum measurable power is 10 Watt with mounted heat sink.
During operation, the power meter is put on the optical bench and placed next to the plano/concave ZnSe-partial reflector outside of the cavity. In this way it acts simultanuously as a perfect absorber for any outcoming infrared radiation thus fullfilling an important safety requirement.

The CO_2-laser system should only be assembled and operated by experienced persons. The operating voltages are lethal, and its output can burn or cause eye damage in a fraction of a second. Consequently, the precautions and safety measures must be observed to ensure safe operation of this device.

After assembling the CO_2-laser system as described and after alignment (see chapter below) you can proceed to fire the laser.

Firing procedure

1. Turn on coolant water and verify its proper flow (approx. 0.5 l/min)
2. Close the needle valve on the gas flowmeter and the valve of the gas filter / buffer unit.
3. Turn on the vacuum pump and allow the system to pump down to a pressure of approx. 2 mbar.
4. Open the main valve of the gas supply.
5. Adjust the regulator on the tank to 1 bar outlet pressure.
6. Gradually raise the output voltage until both sides of the tube have fired. This should occur between 3 kV and 4 kV. Adjust the voltage to the maximum (5 kV) and set the current to 20 mA.
7. Gradually open the needle valve of the flowmeter until the dial gauge reads approximately 36 mbar (for a gas flow of approx. 1l/min)
8. Verify that all persons in the area including yourself are waring the proper safety glasses and that the power meter is in place.
9. Using heat sensitive paper, such as that used on thermal printers, check for the presence of the output beam in front of the power meter. For quantitative statements, the power meters can be used straight away in its most sensible range (0 to 30 mW).
10. If no lasering is detected, apply gentle hand pressure to the mirror mounts in the x and y directions or make fine adjustments on the mount itself while looking for the presence of the output beam.
11. If lasering still does not occur,check the alignment procedure.

The laser can be shut down in the following way:

Shut down procedure

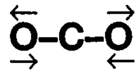
1. Set the power supply output to zero.
2. Shut off the power and gas supply.
3. Shut off the vacuum pump and allow the tube pressure to reach atmospheric pressure by opening the valve on the gas filter / buffer unit.
4. Close the needle valve.
5. Shut off the coolant water.

Theory and evaluation

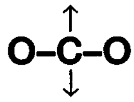
In atom and ion lasers, laser radiation is the result of the electron transistions close to the limit for single or double ionization i.e. far from the electron ground state. The infrared radiation of the CO_2-laser, on the other hand, is the result of the energy exchange between rotational-vibrational levels within the electron ground level.

Owing to its O-C-O structure, the CO_2 molecule can oscillate in three basic forms:

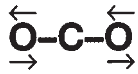
a) symmetrical vibration where the two oxygen atoms oscillate against each other:



b) flexural vibration where the carbon atom oscillates through the oxygen atom:



c) asymmetrical vibration where the two oxygen atoms oscillate in the same direction:



Both the modes of vibration and the energy states of the atoms are quantized. A three-digit number is used to characterize the different energy states of a molecule with three modes of vibration:
the first digit is the quantum number for the symmetrical vibration. The second digit-represents the flexural vibration and the third digit indicates the asymmetrical vibration.

A zero is used to indicate the ground state, ascending numbers signifiy the higher vibrational energy levels (excited states).

Consequently, a 000 for a carbon dioxide molecule indicates that the molecule is in the ground state. The first excited vibrational energy level with the lowest energy for CO_2 is the 010 state i.e. an oscillation of the carbon atom.

The problem with molecules is that they can occur in all combinations of modes of vibration as, for example, the 111 mode of vibration. However, for the CO_2-laser it is sufficient to

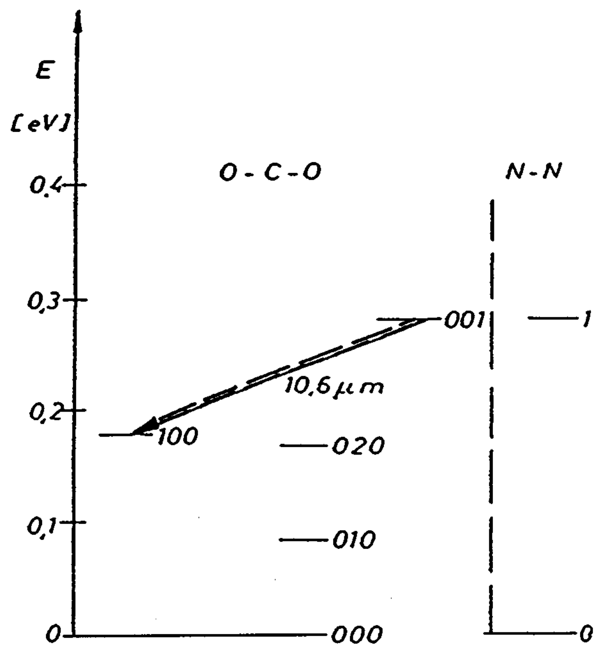
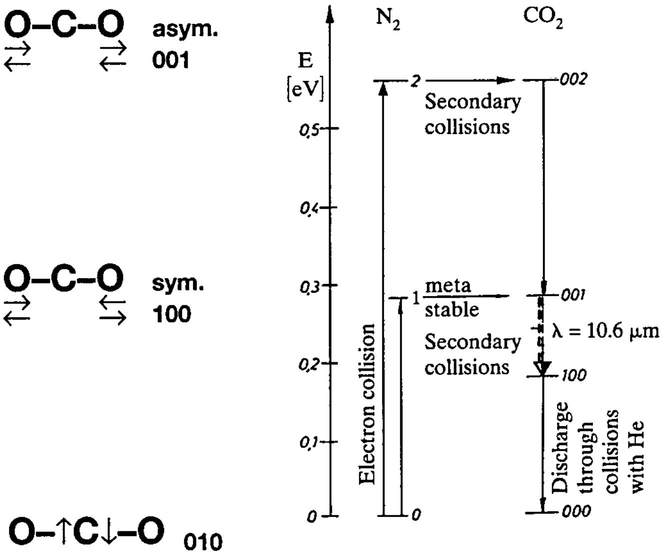


Fig. 3: Energy levels for the modes of vibration of the CO_2 and N_2 molecules.

Fig. 4: Energy level scheme of the CO_2-laser.



understand the ground states and the transitions occuring there. The fact that every vibrational energy level is split into many discrete levels through the rotation of the molecule certainly increases the variety of transitions (more than 100 lines) but is irrelevant for an understanding of how the CO_2-laser works and thus can be ignored here.

Like the CO_2 molecular, the nitrogen molecle can also oscillate. However, the N_2 molecule can only oscillate symmetrically, thus allowing one-digit characterization.

Fig. 3 shows the energy levels for the modes of vibration of the CO_2 and N_2 molecules in part.

Fig. 4 shows the enery level scheme for the CO_2-laser. The actual laser transition occurs at the transition from the asymmetrical 001 to the symmetrical 100 mode of vibration.
The energy difference of this transition corresponds to the wavelength of 10.6 μm.

Therefore, to attain lasering, the 001 state has to be inverted compared to the 100 state because stimulated emissions are only possible with inversion.

Just as with non-ionized atoms, with molecules too it is not possible to produce inversion directly via electric discharge. A "détour" via the N_2 nitrogen molecule is necessary. As can be seen in Fig. 4, level 1 of nitrogen and level 001 of the carbon dioxide correspond in energy so that the energy can be transferred to the carbon dioxide by secondary collisions. Level 1 of nitrogen is metastable (0.1 sec.) as the transition to the ground state is forbidden. The resulting long-life of the level contributes considerably to increasing the probability of collisions with CO_2 molecules and to considerable over-population.

The over-population of the CO_2 level 001 is also increased by the transitions from level 002. The helium, which is present in the laser tube, does not participate in the actual excitation process; it is only required to aid in the rapid discharge of the CO_2 level 100. Consequently, discharge does not occur in every case, only through collisions with the wall. Collisions with omnipresent helium also occur. This makes it possible to use a large-diameter laser tube for a CO_2-laser. The output power of the CO_2-laser is greater, the greater the volume available to participate in the gain.

Due to the fact that the mirrors and the laser tube, in spite of their rather rigid suspensions, are subject to thermal expansion, the active volume of the laser tube participating in the gain may change. This results in a change of the laser's working mode respectively its output power. A slight adjustment of the mirror positions will bring the laser back into its original mode.

1. The CO_2-laser can be aligned as follows:

A He/Ne-laser of 1 mW and two 1 mm pin-hole screens in front of the He/Ne-laser and at the end of the optical bench are used to align the laser tube and the mirrors perfectly – a prerequisite for oscillation (see Fig. 5).

The He/Ne-laser with the pin-hole screen in front initially replaces the power meter on the optical bench. The pin-hole of the pin-hole screen is 95 mm above the top of the optical bench. The centrer of the Si-plano/concave mirros must also

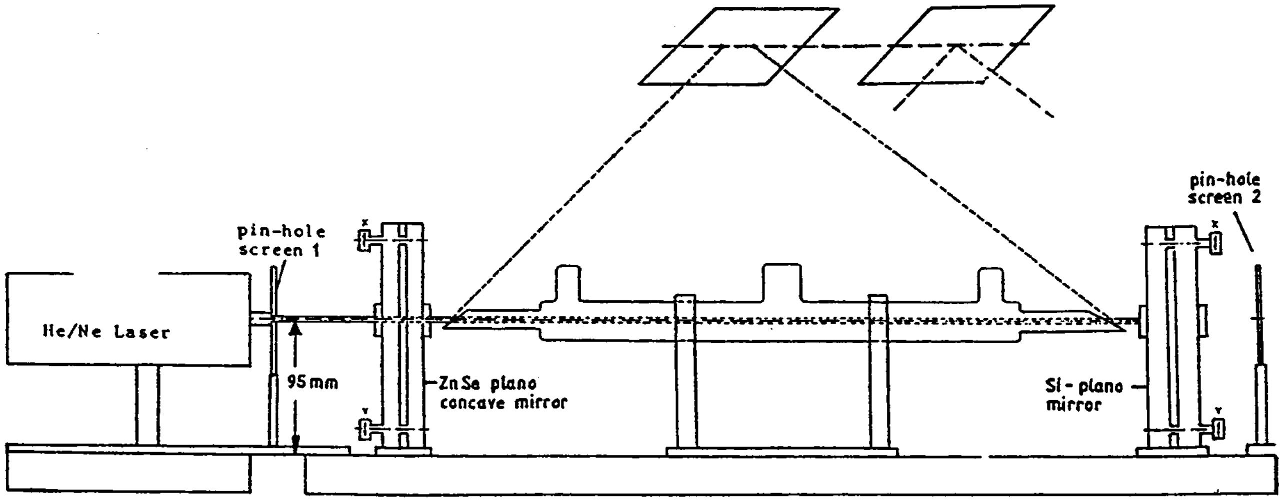


Fig. 5: Alignment of the CO_2-laser tube.

be 95 mm above the bench. The ZnSe-plano/concave miror, the Si-plano mirror and the laser tube with holder and metal housing are removed from the optical bench. The He/Ne-laser is now adjusted in its holder till the outcoming beam passes the pin holes of the first and second pinhole screen. The Si-plano mirror is then mounted and adjusted such that the reflected beam coincides with the incoming beam. Since that side of the first pinhole screen directed towards the cavity is white, it is easy to establish whether the reflected beam passes through the pin-hole again, it will definitely fall on the white part of the screen surrounding the pin-hole. Adjusting the micrometer screws of the Si-plano mirror holder will ensure that the reflected beam re-enters the He/Ne-laser.

The ZnSe-plano/concave mirror with its mount is now fixed to the optical bench directly next to the pin-hole screen. The Si-plano and the ZnSe-plano/concave mirros now form a kind of Fabry-Perrot interferometer and a pattern of dark and bright rings can appear on the white part of the pinhole screen around the pin-hole. The ZnSe-mirror is now adjusted with the micrometer screws on the ZnSe-plano/concave mirror holder until the beam reflected by its plane surface reenters the He/Ne-laser. During this procedure the Si-plano mirror should be covered.

The CO_2-laser tube is then re-inserted into the cavity between the two mirros and fixed on the optical bench. The Brewster windows are taken off.

The CO_2-laser tube in its tri-point holder is adjusted till the He/Ne-laser beam passes through the center of the tube without touching the walls. Then the Brewster windows are remounted and the laser tube in its tri-point holder is adjusted a final time till the beam of the He/Ne-laser passes approximately through the center of the Brewster windows.

If you are satisfied with the positioning of the laser tube, mount the transparent screen above it. With the Brewster windows positioned as shown in Fig. 5 you should catch the reflection of the He/Ne beam on the face of the two windows. By raising and lowering the transparent screen you can locate the point at which these two reflections cross. Above the center of the laser tube, the two spots should overlap precisely. If they do not, move one Brewster mount with respect to the other until they do. If the beam really passes the tube in an optimal way the two spots should be nearly equal in brightness.

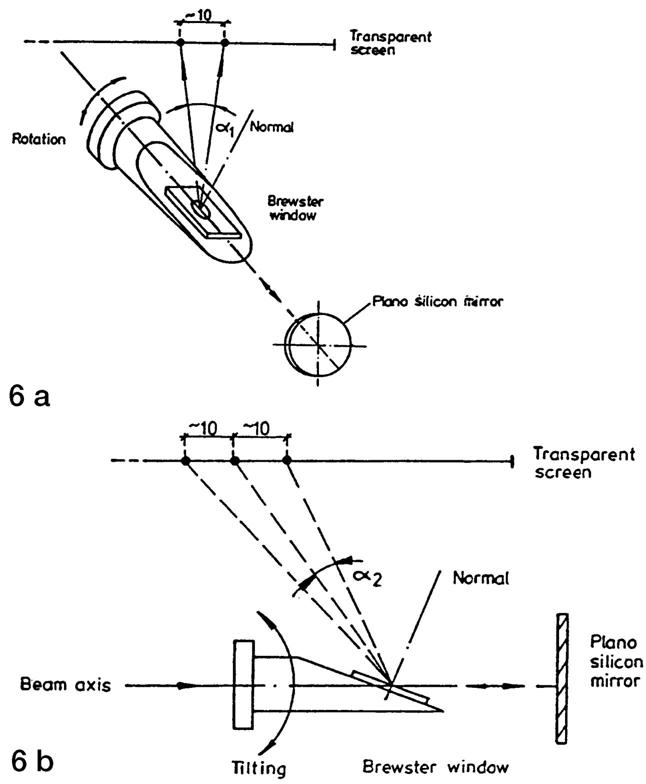
This alignment is just as important as the mirror alignment – if done carelessly, it can drastically reduce the power output or prevent lasering.

After this procedure, the He/Ne-laser with the pinhole screen in front is replaced by the power meter. After establishing the operating gas pressure in the tube, the laser can now be "fired" by switching on the electric power. If the alignment procedure has been carried out properly, it will burst into oscillations. It might be necessary to carry out a final adjustment of the Si-plano mirror. Normally at the very beginning of the lasering process the output power is still weak. It can be optimized by a final adjustment of the Si-plano mirror and a last extremely careful adjustment of the tube within its tripoint holder (ATTENTION: HIGH VOLTAGE!).

2. The influence of the Brewster window's position on the ower output can be verified as follows:

The right Brewster window is rotated or tilted around the laser tube axis in steps of two degrees as indicated in Fig. 6a and Fig. 6b.

Fig. 6: Rotation and titing of a brewster window.



In this experiment the power supply is switched off briefly. The power meter is put aside and the He/Ne-Laser switched on. The reflections of the He/Ne-beam on the faces of the two Brewster windows are observed and systematically displaced on the transparent screen above the CO_2-laser tube as shown in Fig. 6a and Fig. 6b. A displacement of 1 cm corresponds to an angle of about 2 degrees.
After each displacement the power meter is brought back into its original position and the power supply is switched on.
The laser power output as a function of the displacement is shown in Fig. 7 for rotation and tilting. It is evident that tilting the Brewster window (equivalent to a wrong choice of the Brewster angle) is much more detrimental to the power output than a rotation.

3./4. Power output – efficiency:

In Fig. 8 the laser power output has been plotted versus the elctric laser power input. The electric power input can be calculated from the product supply-voltage times current minus the power dissipated by the ballast resistors. The product of "flow x pressure" was kept constant. It can be seen that the laser power output initially increases with the increase of the power input. But after passing a maximum, the power output decreases with further increase of the power input. The inversion becomes more and more disturbed by the increase in temperature. By extrapolating curve A it can be seen that a minimum power input of about 8 Watts (threshold power) is needed to start the lasering process. Fig. 8 shows also the efficiency as a function of the power output to power input. For the working mode chosen the maximum efficiency is 2.3 % at a power output of 0.7 Watts.

Fig. 7: Laser power as a function of the angle of inclination of the brewster window normal N.

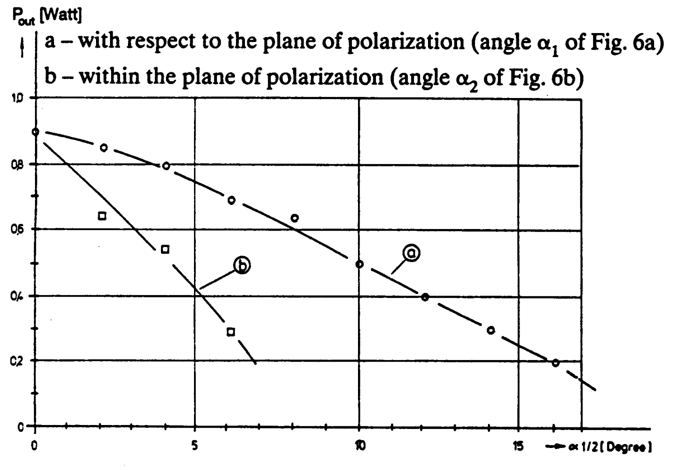
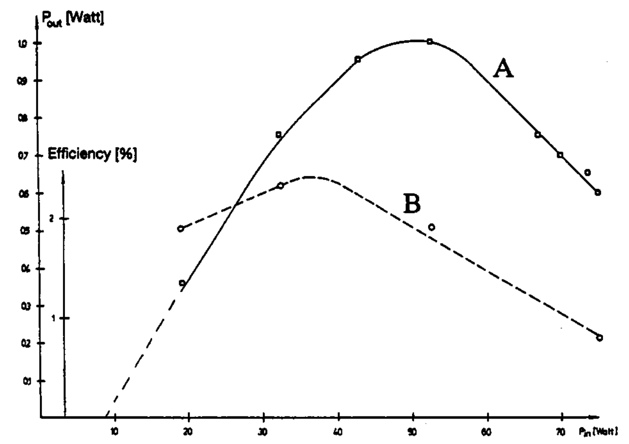


Fig. 8: A = Laser power output as a function of laser power input
B = Efficiency as a function of laser power input.



5. Influence of Laser Gas:

The optically active laser gas can be attained by mixing the individual gas components (CO_2, N_2, He).

Advantage: Possibility of study of the reaction and optimization of the gas components on the laser process and production of the laser gas from commercial gases, some with technical purity grades. This allows the operation of a CO_2 laser also in those countries where it is not possible to obtain industrially produced laser gas mixtures.

The following gases are required to produce the laser gas mixture.

CO_2, Gas, steel cylinder, 10 liters, purity grade: approx. 99%

N_2, Gas, steel cylinder, 10 liters/200 bar, purity grade: approx. 99%

He Gas, steel cylinder, 10 liters, 200 bar, purity grade: approx. 99,9%.

The gas components are channeled with an operating pressure of 1 bar via a 2-stage pressure reducer (200 bar/max. 3 bar) to a gas control unit. Three separate flow meters with adjustable needle vents allow an adjustment of the individual gas volume flow, independent of the operating pressure of the laser tube (approx. 30... 50 mbar). With the buffer with built-in bypass-needle vent found in the filter, a further, individual variation of the operating pressure of approx. 30 mbar can be undertaken independent of the adjusted volumetric flow of the gases.

This allows the determination of the essential laser parameters depending on the gas mixture, ignition behavior, plasma stability, variation of the flow/pressure values, performance optimization and stability of the laser output power in connection with the mechanical resonator adjustment.

The Laser Gas mixing unit, 3 gases (08606.88) includes 3 gas bottles (CO_2, N_2 and He), the necessary pressure controle valves and the control panel for 3 gases.