9-Laser Laser is the acronym for Light Amplification by Stimulated Emission of Radiation.The spectrum of a helium-neon laser is therefore "monochromatic" in the sense that only one colour is visible to the naked eye as the line is very narrow. Other types of laser have a much wider transition (for example, several hundreds of nanometres for the titanium-doped sapphire, which has a spontaneous emission spectrum ranging from 700 to more than 1000 nm) and consequently emit a spectrum that cannot be defined as monochromatic. 3- Q-switching In order to store many atoms in an upper level, the flow to a lower level must first be limited. Thus, stimulated emission must be prevented by placing an attenuator in the cavity to stop light from travelling back and forced (note: this attenuator is usually a light modulator, rather than a mechanical shutter, which reduces the amplitude or power of the light beam). In this case, for a radiative transition, the only decay to a lower level is due to spontaneous emission. When the pumping system supplies more atoms per second than lose energy by spontaneous emission, the population in the upper level can become very large (Figure 10). Figure 10: Accumulation of atoms in the upper level when the optical cavity is blocked. This operating condition is much easier to achieve with media that have a low rate of spontaneous emission. This is true for solid state ion-doped lasers but not for gas (neon or argon) or semiconductor lasers. After a certain time, the energy losses in the cavity are suddenly reduced so that laser oscillation becomes possible. As there is a very large population in the upper level, stimulated emission becomes very probable and the laser is suddenly triggered. The flow due to stimulated emission is much greater than the other flows (filling by pumping and emptying by spontaneous emission): all the atoms stored in the upper level fall sharply, emitting stimulated photons (starting with the spontaneous emission trapped in the cavity). Thus, the laser cavity fills with stimulated photons at the same time as the upper level empties (Figure 11). Figure 11: Laser effect once the optical cavity is suddenly opened. Eventually, the upper level is completely empty. There is no further stimulated emission and the cavity will also empty due to the losses created by the output mirror (in general, the cavity empties after only a few round trips) (Figure 12). Figure 12: Depletion of the optical cavity once all the atoms have returned to the ground state. This process gives rise to a dramatic variation in the number of photons in the cavity (first by a significant amplification due to stimulated emission then by the complete emptying of the cavity at the end). The net result is the emission of a short pulse of light via the output mirror. Generally, several round trips are needed to completely depopulate the upper energy level and several more round trips to empty the optical cavity so the duration of the pulse is greater than one round trip. It should be noted that Q-switched lasers never reach a steady state as they stop functioning after several round trips of the light in the cavity. 4- Mode-locking The second operating technique is completely different. This time, the laser oscillator is left to reach a steady state and the oscillation in the cavity is not blocked. However, the cavity is prevented from filling with photons everywhere at the same time: only a packet of photons is allowed to propagate in the cavity. This pulse lasts for a shorter time than a round trip in the cavity. The method used to obtain these operating conditions consists in using a rapid light modulator that can chop the light in the cavity into periods of exactly the same length as a round trip. Thus, only those photons allowed to pass through the modulator in its on-state will be amplified and will always find the modulator in this state after each round trip. The other photons elsewhere in the cavity will be subject to losses when they travel through the modulator (Figure 13). Figure 13: A pulse propagating in the optical cavity of a mode-locked laser. Generally, the pulses last for a much shorter time than a round trip in the cavity. They are limited by the Fourier transform of the spectrum emitted by the laser: the wider the spectrum, the shorter the pulse. This means that if the amplifying medium is exceptionally wide (for example the titanium-doped sapphire has a spectral width greater than 300 nm), then the pulse generated will be only several femtoseconds long. The term mode-locking comes from the analysis of the various frequencies. Different types of laser: The different types of laser can be classified according to the nature of the amplifying medium: gas, liquid (dye) or solid state. The types of laser are: 1- Gas laser. 2- Chemical laser. 3- Dye laser. 4- Metal - vapour laser. 5- Solid state laser. 6- Photonic crystal lasers. 7- Semiconductor lasers. 8- Other types of lasers. 1- Gas laser: Gas lasers all have in common the same pump source: electricity. The gaseous species enter the excited state either directly, by collision with electrons, or indirectly, by collision with other gases, themselves electrically excited. Gas lasers cover the whole optical spectrum, from the ultraviolet to the far infrared. However, the spectrum is not continuously covered: gas lasers emit very narrow spectral lines. The most common gas lasers (from the UV to the far IR) include: a) excimer lasers (ArF:193 nm, KrF:249 nm, XeCl:308 nm) b) argon-ion lasers (blue and green wavelengths) c) helium-neon lasers (the neon is used for the laser effect) 632.8 nm, 543.3 nm, 1.15 um, 3.39 um d) CO2 lasers: a large number of wavelengths around 9.6 um and 10.6 um. Only CO2 lasers are really efficient (15 to 20%). They are used in industry for processing materials. The efficiency of the others is mostly less than 1%. Gas lasers are often bulky and need a great deal of water-cooling (almost all the energy provided by the pump is lost as heat). Even though those operating in the visible (Argon, Helium, Neon) are tending to be replaced by solid state lasers, excimer lasers and CO2 lasers are still very frequently used. o A helium-neon laser or He Ne laser shown in figure 14, is a type of gas laser whose gain medium consists of a mixture of helium and neon (10:1) inside of a small bore capillary tube, usually excited by a DC electrical discharge. The pressure inside the tube is 1 mm of Hg. The best-known and most widely used He Ne laser operates at a wavelength of 632.8 nm in the red part of the visible spectrum. Figure 14 Energy level diagram of a He Ne laser. The mechanism producing population inversion and light amplification in a HeNe laser plasma originates with inelastic collision of energetic electrons with ground state helium atoms in the gas mixture. As shown in the accompanying energy level diagram, these collisions excite helium atoms from the ground state to higher energy excited states, among them the 23S1 and 21S0 long-lived metastable states. Because of a fortuitous near coincidence between the energy levels of the two He metastable states, and the 3s2 and 2s2 (Paschen notation) levels of neon, collisions between these helium metastable atoms and ground state neon atoms results in a selective and efficient transfer of excitation energy from the helium to neon. This excitation energy transfer process is given by the reaction equations: He*(23S1) + Ne1S0 -> He(1S0) + Ne*2s2 + ?E and He*(21S) + Ne1S0 + ?E -> He(1S0) + Ne*3s2 where (*) represents an excited state, and ?E is the small energy difference between the energy states of the two atoms, of the order of 0.05 eV or 387 cm-1, which is supplied by kinetic energy. Excitation energy transfer increases the population of the neon 2s2 and 3s2 levels manyfold. When the population of these two upper levels exceeds that of the corresponding lower level neon state, 2p4 to which they are optically connected, population inversion is present. The medium becomes capable of amplifying light in a narrow band at 1.15 um (corresponding to the 2s2 to 2p4 transition) and in a narrow band at 632.8 nm (corresponding to the 3s2 to 2p4 transition at 632.8 nm). The 2p4 level is efficiently emptied by fast radiative decay to the 1s state, eventually reaching the ground state. The remaining step in utilizing optical amplification to create an optical oscillator is to place highly reflecting mirrors at each end of the amplifying medium so that a wave in a particular spatial mode will reflect back upon itself, gaining more power in each pass than is lost due to transmission through the mirrors and diffraction. When these conditions are met for one or more longitudinal modes then radiation in those modes will rapidly build up until gain saturation occurs, resulting in a stable continuous laser beam output through the front (typically 99% reflecting) mirror. o Nitrogen laser: A nitrogen laser is a gas laser operating in the ultraviolet range (typically 337.1 nm) using molecular nitrogen as its gain medium, pumped by an electrical discharge. The population inversion in the laser is achieved by the following sequence: 1. Electron impact excites vibrational motion of the nitrogen. Because nitrogen is a homonuclear molecule, it cannot lose this energy by photon emission, and its excited vibrational levels are therefore metastable and live for a long time. 2. Collisional energy transfer between the nitrogen and the carbon dioxide molecule causes vibrational excitation of the carbon dioxide, with sufficient efficiency to lead to the desired population inversion necessary for laser operation. 3. The nitrogen molecules are left in a lower excited state. Their transition to ground state takes place by collision with cold helium atoms. The resulting hot helium atoms must be cooled in order to sustain the ability to produce a population inversion in the carbon dioxide molecules. In sealed lasers, this takes place as the helium atoms strike the walls of the container. In flow-through lasers, a continuous stream of CO2 and nitrogen is excited by the plasma discharge and the hot gas mixture is exhausted from the resonator by pumps. o Krypton laser A krypton laser is an ion laser, a type of gas laser using krypton ions as a gain medium, pumped by electric discharge. Krypton lasers are used for scientific research, or when krypton is mixed with argon, for creation of "white-light" lasers, useful for laser light shows.Krypton laser 416 nm, 530.9 nm, 568.2 nm, 647.1 nm, 676.4 nm, 752.5 nm, 799.3 nm Electrical discharge Scientific research, mixed with argon to create "whitelight" lasers, light shows. Xenon ion laser Many lines throughout visible spectrum extending into the UV and IR. Electrical discharge Scientific research. Nitrogen laser 337.1 nm Electrical discharge Pumping of dye lasers, measuring air pollution, scientific research. Carbon dioxide laser 10.6 um, (9.4 um) Transverse (high power) or longitudinal (low power) electrical discharge Material processing (cutting, welding, etc.), surgery, dental laser, military lasers. Carbon monoxide laser 2.6 to 4 um, 4.8 to 8.3 um Electrical discharge Material processing. Excimer laser 193 nm (ArF), 248 nm (KrF), 308 nm (XeCl), 353 nm (XeF) Excimer recombination via electrical discharge Ultraviolet lithography for semiconductor manufacturing, laser surgery, LASIK. 2- Chemical lasers: Chemical lasers are powered by a chemical reaction permitting a large amount of energy to be released quickly. Such very high power lasers are especially of 111 interest to the military, however continuous wave chemical lasers at very high power levels, fed by streams of gasses, have been developed and have some industrial applications. As examples, in the hydrogen fluoride laser (2700-2900 nm) and the deuterium fluoride laser (3800 nm) the reaction is the combination of hydrogen or deuterium gas with combustion products of ethylene in nitrogen trifluoride.

Laser gain medium and type Operation wavelength(s) Pump source Applications and notes Hydrogen fluoride laser 2.7 to 2.9 um for Hydrogen fluoride (