STUDIES ON THE SPECTRAL LINE SHAPE OF A LASER BEAM

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By

Abo El-Azim Abd El-Gowad Hemida

Physics Dept.

Faculty of Science

HELWAN UNIVERSITY

25135

TO

Physics Dept.

University College For Women

AIN SHAMS UNIVERSITY

1987

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SUPERVISORS

Signature

Prof. Dr. M.A. KENAWY

Head of Phys. Dept.
University College for women
Ain-Shams University.

M. A. Kenawy

Prof. Dr. M.M.HASSAB EL-NABY

Universisy College for women
Ain-Shams University

M. M. Hassab El. Naby

Prof. Dr. K.A. EL-DEHEMY

Dean of Faculty of Science
Helwan- Univeristy.

El Deheny 16/7/1987

Prof. Dr. M.M. EL-NICKLAWY

Head of Phys. Dept.
Faculty of Science
Helwan-University.

M. El-Nicklawy

Approved
Head of Phys. Dept.
M. A. Kenawy
Prof.Dr. M.A. KENAWY

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بسم الله الرحمن الرحيم

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Beside the present work in the thesis, the candidate has attended and passed successfully post graduate for the partial fulfilment of the requirements of the degree of Master of Science in Physics during the academic year (1977-1978).

1. Theoretical Physics
2. Electronic and Radiation Physics.
3. Solid State and Nuclear Physics.
4. German Language.

Post Graduate Office

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ABSTRACT

The present work represents a review on the physical characteristics of the laser emission, showing the different methods for producing the population inversion between the energy excited levels.

The sharpness of the laser spectral line profile makes it important in several fields of laser application.

The spectral half-width of a laser single mode is too small such that, till now, it is impossible to be measured directly.

Mathematical expressions are derived for the spectral half-width of a laser beam in terms of the population densities of the laser energy levels, transition probability of the spontaneous emission and the spectral half-width of a Lorentz-and a Gauss-gain line profile.

It is concluded that, for a Gaussian and Lorentzian distribution of the gain line, a new approach has been used for determining the spectral half-width of a radiated laser longitudinal mode $\delta_m(\nu)$ by measuring the spectral half-width of the spontaneous emission " $\Delta\nu$ " and that of the envelope of the radiated spectral laser half-width $\delta_L(\nu)$, and calculating the spectral half-width of the

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passive Fabry-Perot resonator δ_F.

In addition an important result,is concluded:if the gain line has a Lorentz profile, then the spectral distribution of the emitted spectral laser radiation is of the same profile. In the case of a Gaussian gain line profile the spectral distribution of the laser beam is found, with a very good approximation, to be also of a Lorentz profile.

The spectral half-width of the laser beam, in both cases, are slightly different from each other.

Also, a mathematical formula for the general case is obtained indicating that the laser spectral line profile behaves a differential form like that of its gain line profile.

A scanning confocal spectral analyzer (model 470) with a free-spectral-range of 8 GHZ and finesse 150 is used to analyse the spectral profile of the laser beam to its longitudinal modes. The analyzer is calibrated by using a single mode stablized He-Ne laser (moodel 117-spectra physics) at the National Institute for standards. The possible error in calibration amounts ± 0.43%.

The experimental work is carried out using two He-Ne laser sources, one of type (PL-693), and the power 0.5 mW. The other was of the type (157-2 spectra physics),

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and of power 3 mW. A scanning deriver model 476 was used to supply a scanning saw tooth voltage to the Piezoelectric spacer in the analyzer. From the obtained mode structure of He-Ne laser beam, Plate (3-2) and figure (3.6), the following physical parameters of the laser beam could be calculated:

The spectral half-width of the laser beam $\delta_L(\nu)$ and its longitudinal mode $\delta_m(\nu)$, difference between the atomic population densities (n_2-n_1) of the upper and lower laser transition energy levels.

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CHAPTER I

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I. Introduction and previous work:

Until 1917, no one was conceived that there is a basic process that would allow light to be amplified as it is in a laser. In that year, Albert Einstein[1] showed that the atomic emission can occur in two ways:

(i) The atoms changing spontaneously to the lower energy state creating photons with a random phase, which is known as spontaneous emission.

(ii) A photon with an energy equal to the energy difference between the two levels interacting with the atom in its higher state, causing it to change to the lower state with the creation of a second photon. This process is known as stimulated emission. On the other hand, Einstein showed that the atomic absorption process can take place only in an inverse way of the stimualted emission process.

There are two important facts about stimulated emission upon which the properties of laser light depend. First of all the photon produced by stimulated emission is of almost equal energy and direction to that stimulated emission. Hence the light waves associated with

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them must be of nearly the same frequency. Second, the light waves associated with the two photons are inphase, i.e. they are coherent. In case of the spontaneous emission, the random creation of photons results waves of random phase and the light is said to be incoherent.

Microwave amplification by stimulated emission of radiation(MASER)was proposed during the early 1950's independently by Weber[2] and by Townes[3] in the United States and by Basov and Prokhorov[4-9] in the Soviet Union. Considerable analytical work proceeded the successful construction of the first light amplifier, or laser in 1960. Most notable was the work of Schawlow and Townes[10] who explored the general physical conditions necessary for the operation of a laser in either the gaseous or the solid state.

In 1959 Sanders[11] and Javan[12] explored the effectiveness of electron excitation and exchange of excitation as a means of producing negative absorption. This work led to the development of the helium neon laser in the fall of 1960, shortly after the ruby laser was discovered by Maiman[13,14,15]. Subsequently, Basov[16] carried out mathematical analysis of the conditions under which the exchange of excitation in a mixture

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of different gases can lead to negative absorption. Sorokin and Stevenson(17) announced the operation of a four-level solid laser.

Many such lasers were discovered during the years between 1961 and 1962.

For most lasers to operate, three basic conditions must be satisfied: First, the presence of medium (solid, liquid or gas) that emits radiation in the optical region of the electromagnetic spectrum. Second, the existance of population inversion between certain energy levels of that medium. This condition is highly abnormal in nature, since at thermal equilibrium the population of the energy levels obeys the Boltzmann distribution i.e. the population of the lower energy level is greater than that of the higher energy level. Boltzmann's equation shows that even if the temperature is infinitely high, the populations in the energy excited level are equal, hence for the population of the upper energy level to be more than that of the lower, which is known as a population inversion, the temperature would have to be negative, which is practically impossible.

Population inversion can be achieved at normal temperatures but only under nonequilibrium conditions to which Boltzmann's law do not apply.

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In a laser it is created by an excitation process known as pumping. There are three energy level systems for inversion.

(i) Two level system:

Which could be accomplished only in a pulsed device[18] or by spatial separation of the various excited molecules in molecular beam as in the ammonia maser[19].

(ii) Three level system

In which a suitable three-level system is selected and atoms from the bottom level E_1 to the top level E_3 are pumped. From there, they decay to an intermediate level E_2. With sufficient intense pumping, a significant number of ground-state atoms could be pumped to level E_2. A population inversion then occurs when the population of E_2 exceeds that of the ground state E_1. For population inversion to be achieved easily, it is necessary to have rapid transition from E_3 to E_2 (i.e. the transition($3\rightarrow2$) to have a very short life time) and the energy state E_2 has to be metastable.

If these two conditions are satisfied, ground

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