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RATE EQUATIONS FOR THREE ENERGY LEVEL LASER SCHEME

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ABSTRACT

Almost everyone probably knows that the police use laser when they measure speed. Atleast many drivers that have exceeded the speed limit know about it, but how many know that you also use laser several times in a day? You will find its use in cd players and in laser printers. You often find laser in action movies where the hero has to escape the laser beams when he's trying to solve a thrilling problem. The power contained in laser is both fascinating and frightening. There is nothing magical about a laser. It can be thought of as just another type of light source. It certainly has many unique properties that make it as a special source of light, but these properties can be understood without the knowledge of sophisticated mathematical techniques or complex ideas .The concepts, as they are developed, will be applied to all classes of laser frequencies and laser materials, so that we will develop a sense of broad field of lasers. Furthermore, we may also understand that how a laser light differs from ordinary light.

INTRODUCTION

If light (photons) of frequency ν_{21} pass through the group of atoms, there is possibility of light being absorbed by atoms which are in ground state, which will cause them to be excited to higher energy state. The probability of absorption is proportional to the radiation intensity of light and also to the number of atoms currently in ground state, N_1.

In order to describe the process of absorption, let us consider an enclosure containing atoms. The energy of atom can take on only definite (discrete) values, these are the discrete energy states or levels .The transition of an atom from one energy level say level-1 to another say level-2 occurs in jump and is called quantum transition. Quantum transition may be induced by various causes, such as through collision with other particles. In particular transition can also occur through the absorption of electromagnetic radiation of proper frequencies. Here the two level could be any two out of infinite set of levels.

(i) Absorption or Induced Absorption: Suppose N_1 and N_2 represents the number of atoms per unit volume in levels 1 and 2 : the levels corresponding to energies E_1 and E_2.Here E_2 is larger than E_1 and normally N_2 is smaller than N_1.

Further assume that the atom is initially lying in level 1.The atom will remain in this level unless some external stimulus is applied to it. An electromagnetic wave of frequency ν is incident on the material .The atom excited to higher level 2.The excitation process, therefore occurs in the presence of radiation and the radiation that acts an external stimulus to cause the process.

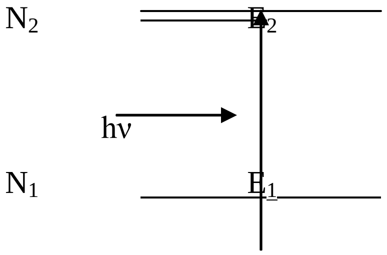

Fig 1.1: Absorption or Induced Absorption

Such a process is called 'Stimulated Absorption' or simply as Absorption as shown in fig. 1.1.

(ii) Spontaneous Emission: An atom in the excited state i.e. level 2 tend to decay to level 1.It emits the corresponding energy difference (E_2-E_1) when comes to level 1.

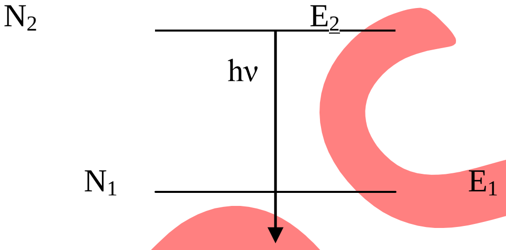

Fig 1.2: Spontaneous Emission

The processes occur even in the absence of any incident radiation it is thus not stimulated by any incident signal but occurs spontaneously or own its own. This process is called Spontaneous Emission. If the atom is in the excited state, it will spontaneously decay to the ground state at the rate proportional to N_2, where N_2 are the number of atoms in the excited state. The energy difference between the two states ΔE is emitted from the atom as a photon of frequency ν_{21} as shown in fig. 1.2.

(iii) Stimulated Emission: The process in which an incident signal of appropriate frequency triggers an atom lying in the excited state(level 2) to emit radiation and come to ground state energy level (level 1) is called stimulated emission. In this case the energy difference (E_2-E_1) is delivered in the form of electromagnetic radiation which adds to incident radiation.

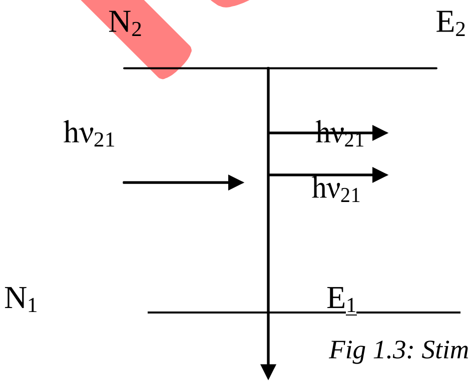

Fig 1.3: Stimulated Emission

If an atom is already existed in the excited state, it may be perturbed by the passage of a photon which has the frequency ν_{21} corresponding to the energy gap ΔE of the excited state to the ground state transition. In this case, the excited atom relaxes to the ground state and is induced to produce a second photon of frequency ν_{21}.The original photon is not absorbed by the atom and so the result is that to have two photons of same frequency in the same direction as shown in fig.

This process is called Stimulated Emission. The rate at which stimulated emission occurs is proportional to the number of atoms N_2 in excited state and the radiation density of incident radiation.

The critical detail of stimulated emission is that induced photon has the same frequency and phase as inducing photon. In other words, the two photons are coherent. It is this property that allows optical amplification and the production of a laser system. During the operation of a laser, all the three processes of light matter interactions described above are happening. Initially, atoms are energized from the ground state to the excited state by a process of pumping. Some of these atoms decay through spontaneous emission, releasing incoherent light as photons of frequency ν .These photons are fed back into the laser medium, usually by optical resonator. Some of these photons are absorbed by the atoms in ground state and thus the photons are lost. However some photons stimulate the atoms in excited state and releasing another coherent photon.

REVIEW OF STUDIES

The high rate of technology advancement in today's world is astounding. These technological advances are having an enormous impact on all aspects of life and their impact on the practice of medicine is not to be underestimated. One area of medicine that is undergoing extremely rapid development is the adaptation and integration of imaging into the process of cancer detection, diagnosis, and intervention. Radiation therapy is a prime example of this change. The role of the medical physicist in the radiation therapy process accelerates the development and introduction of these technologies into the clinical setting. As a result, imaging is now a pervasive component of radiation therapy with all major imaging modalities represented and numerous examples in which these modalities have been adapted to the treatment machine to allow increased accuracy and precision in the delivery of dose. While the objectives of these developments are clear, they raise numerous issues regarding the skills and resources that ensure these technologies are appropriately integrated and applied. Specifically, these developments place enormous pressure on the clinical staff to extend their knowledge base and their scope of responsibility.

In 2007, the IAEA assembled a team of medical physicists with experience in radiation therapy and imaging and charged them to examine the increasing role of imaging in the radiation therapy process and make recommendations related to their observations. A report was commissioned that should achieve the following objectives.

- *Review the status of mature imaging modalities currently employed in radiation therapy practice. These include pre-treatment imaging for target definition to in-room imaging for improved precision and accuracy of delivery.*

- *Review the availability and applicability of existing practice and quality assurance guidance documents related to the use of imaging information in the radiation therapy process.*

- *Identify of shortcomings in these documents while being cognizant of the broad range of needs found in the IAEA Member states.*

- *Develop a set of recommendations to the IAEA related to the needs and opportunities for further development with respect to imaging in radiation therapy. These recommendations may take the form of either detailed, prescriptive recommendations (e.g. formation of a CRP, preparation of a TECDOC) or broader recommendations regarding future directions.*

The resulting report was to be employed for internal use by the Agency, providing a perspective on the issues related to imaging in radiation therapy and assisting the Agency in accommodating these issues in the years ahead.

IMAGING IN THE RADIOTHERAPY PROCESS

In the developed countries, radiation therapy is employed in over 50% of cancer patients at some point in the management of their disease. As a local therapy, radiation therapy seeks to exploit technology to conform the treatment to the targeted structure while avoiding surrounding critical normal tissue. Overall, the process of radiation therapy has become increasingly complex as the technology for its delivery advances. Recent developments in radiation collimation (e.g. multi-leaf collimators), computation (inverse planning), and imaging (target definition and targeting) have resulted in a far more complex radiation therapy process which promises higher quality of intervention, dose escalation, and/or reduced toxicity. The radiation therapy process contains many steps with imaging distributed throughout the process.

Imaging has become the primary source of information in the design of radiation therapy. As such, it is of critical importance that (i) the signal contained in these images is well understood, and, (ii) the spatial distribution is precise and accurate. Failure in this aspect to do so can result in serious deleterious effects including failure to control the disease and/or induction of unforeseen toxicities.

IMAGING FOR TARGET DETERMINATION

The use of imaging to define the cancer target is, in many ways, ideal, however, it is important to understand the limits of the imaging signal if it is to be appropriately applied. As with any measurement, it is useful to consider the precision and accuracy of the reported signal. The precision relates to the minimum quantity that can be detected by the system and the accuracy of its spatial resolution. In the context of cancer, this is highly relevant when considering the desire to treat not only the gross tumor volume (GTV) but also deliver a dose to the surrounding clinical target volume (CTV), which may contain microscopic extension of the disease and is by definition not visible on the available images. Incorrect interpretation of the imaging signal can result in either underestimating or overestimating the extent of these volumes. It can be anticipated that this problem will persist regardless of the specific imaging modality being employed. The complex nature of the disease makes complete characterization of the radiation target via imaging somewhat unlikely. As a result, the imaging systems effectively provide surrogate signals of the disease (e.g., a mass on a CT image). These surrogates are often referred to as 'the target' although they are clearly not a precise or accurate representation. It is important to emphasize that the image signal is, therefore, only a surrogate of the target and must not be over-interpreted. In fact, the traditional practice of treating to bony anatomy recognizes that the bones are reasonable surrogates of the adjacent disease targets.

MATERIAL & METHODS

The simple basic ideas and processes used for laser physics are presented below. They did not need any complex mathematical methods.
There are three basic types of interactions between a system of atoms and light that are of interest in the present context.

(i) Absorption or Induced Absorption
(ii) Spontaneous Emission
(iii) Stimulated Emission

RESULTS

On the basis of these theoretical results we conclude that as we move from IR-lasers to UV, x-ray and γ-ray lasers the difficulty in their operation increases.

Important Properties of Laser

The beam of light generated by a typical laser can have many properties that are unique. When comparing laser properties to those of other light sources, it can be readily recognized that the values of various parameters for laser light either greatly exceed or are much more restrictive than the values for many common light sources. We never use lasers for street illumination or for illumination within our houses. We don't use them for search lights or flashlights or as headlights in our cars. Lasers generally have a narrower frequency distribution or much highest intensity or much greater degree of collimation or much shortest pulse duration than that available from more common type of light sources. Therefore we do use them in compact disc players, in supermarket check out scanners, in surveying instruments and in medical applications as a surgical knife or for welding detached retinas. We also use them in communications systems and in radar and many other areas. A laser [8] is a specialized light source that should be used only when its unique properties are required.

Directionality

The conventional light sources emit in all directions. When we need a beam for a particular experiment, we get in with the help of an aperture in front of source. Lasers on the other hand emit only in one direction. The directionality of laser is usually expressed in terms of the full angle beam divergence, which is twice the angle that the outer edge of the beam makes with the axis of the beam. How do we determine the outer edge of the beam? This is defined as the point at which the strength of the beam has dropped to1/e times its value at centre. When a beam with planar wave front radiates from an aperture of diameter d, the beam propagates as a parallel beam for a distance of about d^2/λ, which is sometimes called Rayleigh range and then begins to spread linearly with distance because of the unavoidable effects of diffraction as shown in fig. 1.4.

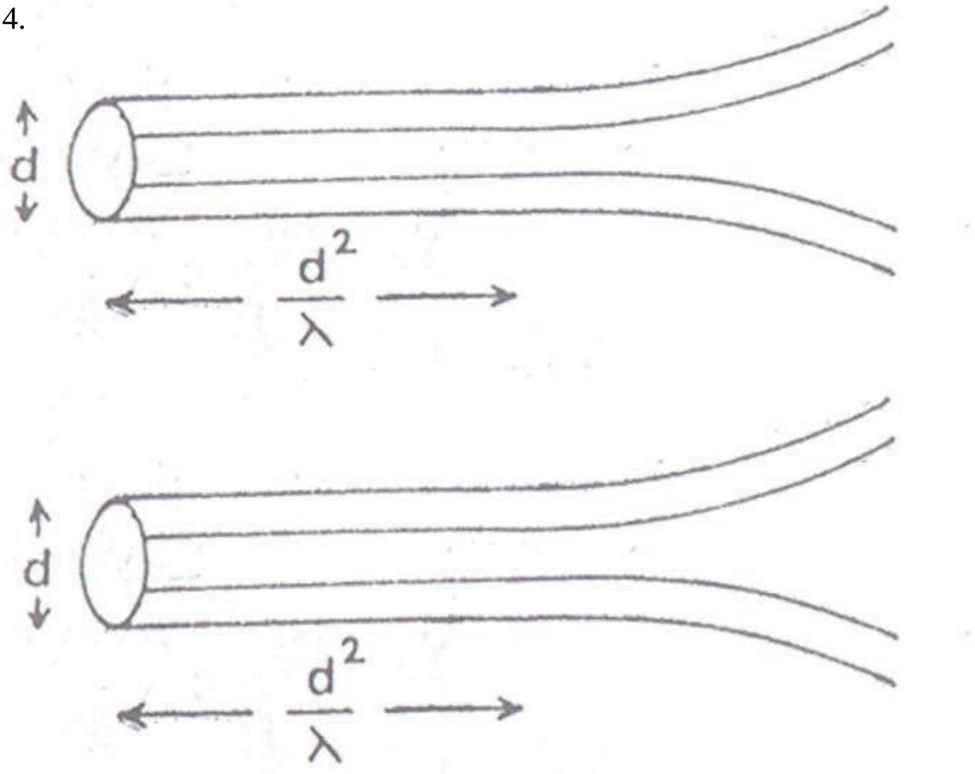

Fig. 1.4: Directionality of the Laser Beam

The angular speed $\Delta\theta$ of the far field beam is related to the aperture diameter d by

$$\Delta\theta=\lambda/d$$

For a typical laser, the beam divergence is less than 1 milliradian. That is, the beam spreads less than 1mm for every meter. Output in laser beam is many millions of times more concentrate than the best search light available. The beam from the latter spreads to about a kilometer in diameter for every kilometer that the light traverses .One can imagine its spread on the surface of moon, which is at a distance of 384,400km, if it ever reaches the moon.

DISCUSSIONS

X-rays lasers are one of the most recently developed types of lasers and are not so far commercially available. The x-ray lasers produced to date operate at a pulse repetition rate of only a few pulses per day and are expensive to operate. Thus, applications are currently limited to those that can justify the expense. One such application is x-ray holography of living biological materials. With a laser pulse of a few hundred picoseconds duration, this process can generate a ‘stop action’ three dimensional image of living species with high resolution possible with short illumination wavelength. Other applications include x-ray microscopy, crystallograph, medical radiology, atomic physics studies, radiation chemistry, x-ray lithography in the fabrication of microcircuits and structures, material research etc.

In the interaction of electromagnetic radiation with matter, the ratio of spontaneous emission to stimulated emission as given by Einstein is

$$\frac{8\Pi h v^3}{C^3}$$

In this equation the frequency *v* appeared in numerator with cube power clearly makes spontaneous emissions very high for short wavelength. Hence making of short wavelength laser is far more difficult. The frequency of ultra violet rays and x-rays is very high and it makes stimulated emission very difficult unlike in infrared region where it is just opposite. In 1917 without realizing the invention of laser and Einstein had predicted difficulty in the making of x-ray lasers [15]. However the importance of short wavelength of x-rays brings out the importance of x-ray laser [16]. Shorter wavelengths can be focused more tightly than light, offering much better resolution than possible in the ultraviolet and optical region.

The production of x-ray photons occurs in much the same sort of way as the production of visible and ultraviolet photons. It this case, however, the electron involved is not an outer electron, but is one buried deep within one of the inner subshells of the atom. Excitation of this type requires something like 800eV instead of the few electron volts needed to move an outer electron to an excited state level. All the intervening layers between the energy levels such an electron normally occupies and the first unoccupied level, are filled with electrons and so a great amount of energy is released when it drops back to the ground state. The high energy photon released is, therefore, in the x-ray part of the electromagnetic spectrum. Besides many difficulties the Nova x-ray laser in USA is one of the successful step in this direction.

Structure of X-Ray Laser

A schematic picture of an XRL is shown in Fig. 4.1. The pumping source – which might be a focused laser beam or the x-rays produced by focusing a laser on a nearby high Z target – is swept along the lasing medium at the speed of light, in order to have a minimum pumping energy. It can be shown that in order to pump an XRL operating at wavelengths ≤ 10 A^0 the pumping laser must have a power $> 10^{12}$ W and the pumping laser beam must be focused to a spot less than 30 μm across. Such lasers are not now available commercially but soon will be as a result of laser fusion research. The x-ray lasers are specifically designed to produce a lasing plasma with as high a fraction of usable ions as possible to maximize the stability and hence the output energy of the laser.

The general configuration for producing x-ray lasers is that of generating a line focus of a powerful Nd:Glass laser onto a solid target material over a length of 1-5 cm and a width of a few hundred microns. This focusing arrangement and laser target are located inside an evacuated chamber. The circular mirror located in the front of the target. Intense plasma of the ions of the laser species is produced within the focal region of the initiating laser and the electrons are stripped to obtain the desired ionization stage [17]. When the desired ionization stage is reached, the plasma electrons produce excitation to the upper laser level.

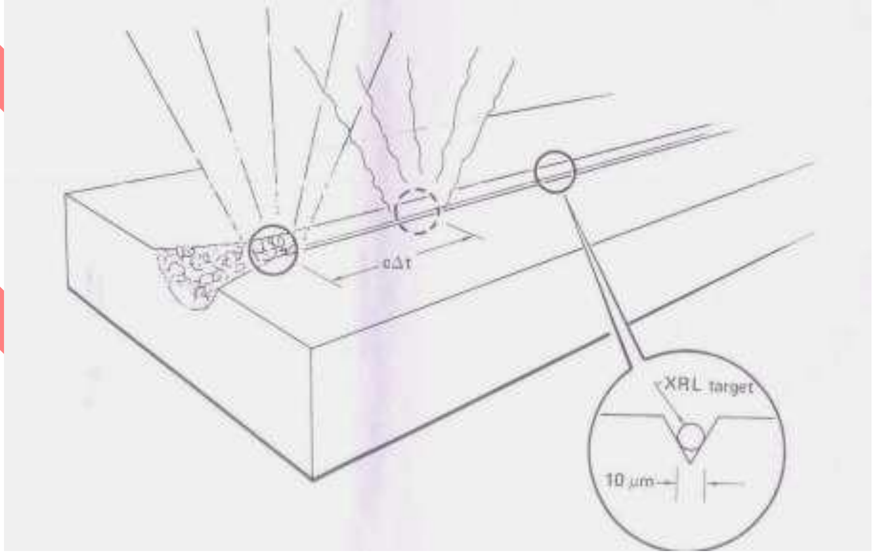

Fig. 4.1: X-Ray Laser

Optical cavities are not suitable for these lasers for several reasons.

1. The gain duration is so short that only a few passes will occur though the amplifying medium depending upon how close the mirrors are placed to the medium.

2. If the mirrors are placed too close while attempting to obtain more passes through the amplifier, the intense x-ray radiation from the plasma will damage the mirrors even before they have a chance to operate.
3. Mirrors are not available that can withstand the saturation intensities of these lasers.

PROPOSED RESEARCH WORK

"STUDY OF X-RAY & γRAY LASERS" The concepts, as will developed, will be applied to all classes of laser frequencies and laser materials, so that we will develop a sense of broad field of lasers. Furthermore, we may also understand that how a laser light differs from ordinary light.

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