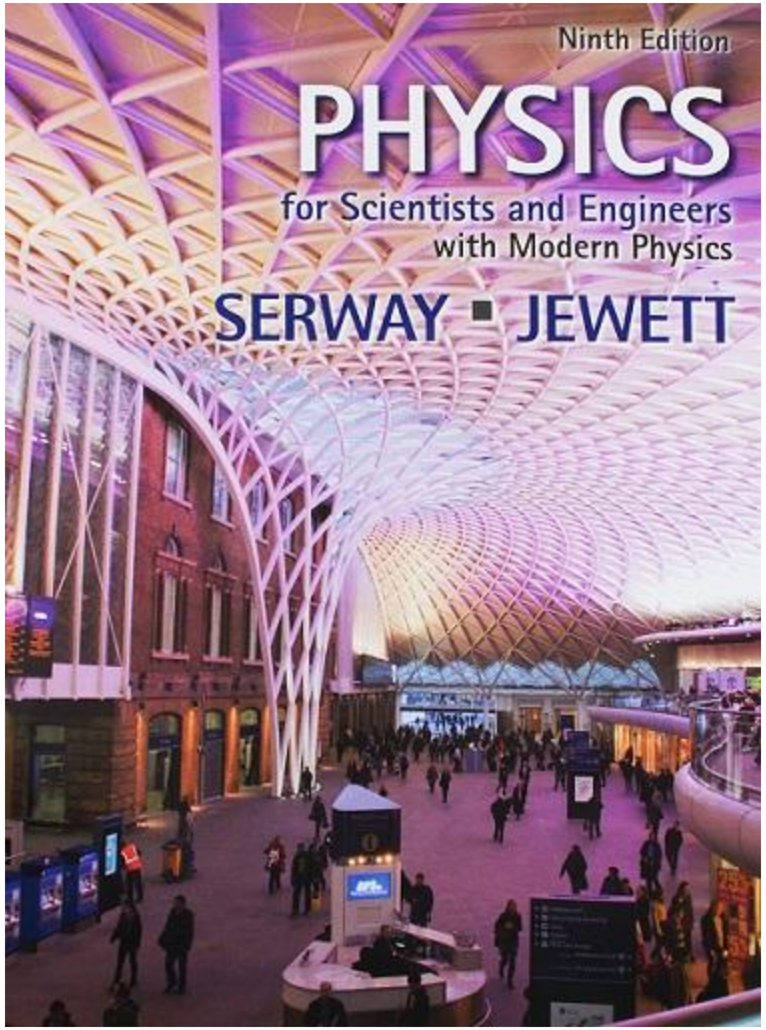
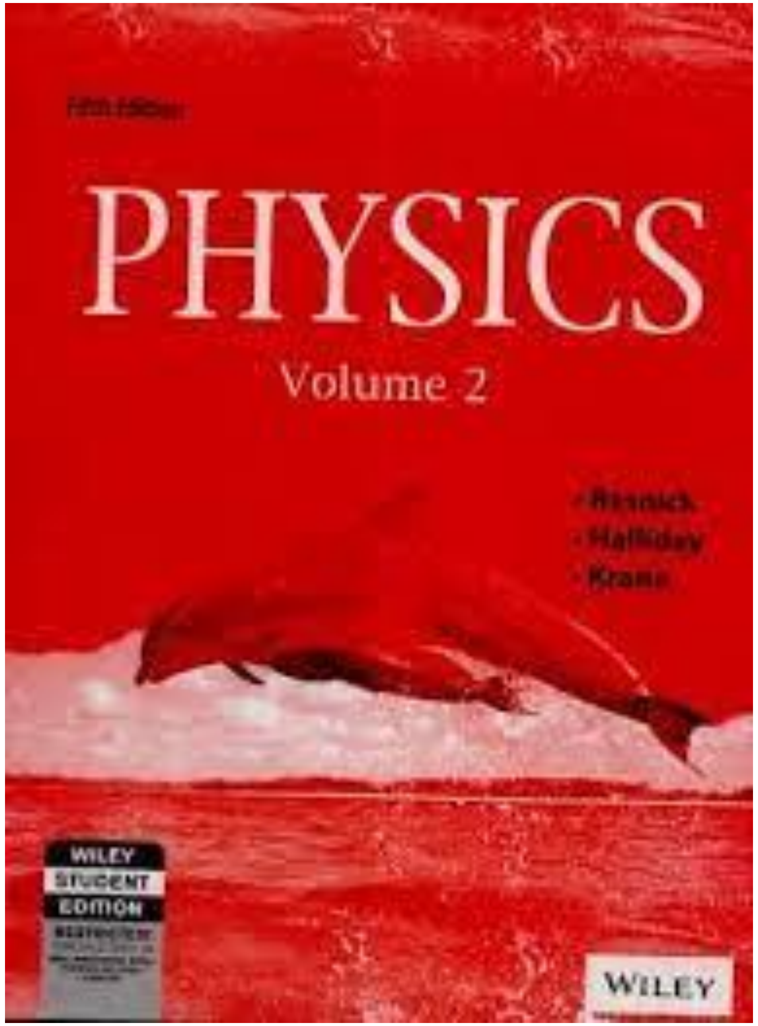
PHYSICS

General Physics I (PHYS 101)





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LASER

Course Outline

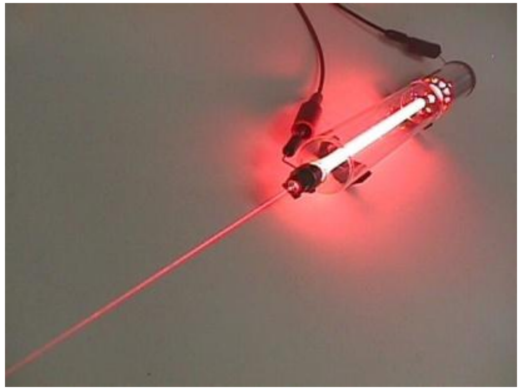
- Introduction
- Properties of Laser Radiation
- Stimulated or Induced Absorption
- Spontaneous Emission and Stimulated Emission
- LASER, Population Inversion, Optical and Electrical Pumping
- Applications of Laser

LASER and Laser Light

- In the early 1960s, quantum physics made one of its many contributions to technology: the laser.
- The **laser** is a light source that produces a beam of highly coherent and very nearly monochromatic light as a result of cooperative emission from many atoms.
- The name "**LASER**" is an acronym for "Light Amplification by the Stimulated Emission of Radiation".
- The laser operates on the principle of stimulated emission, by which many photons with identical wavelength and phase are emitted. Laser operation requires a nonequilibrium condition called a population inversion, in which more atoms are in a higher-energy state than are in a lower energy state.
- Laser light, like the light from an ordinary lightbulb, is emitted when atoms make a transition from one quantum state to a lower one. However, in a lightbulb the emissions are random, both in time and direction, and in a laser they are coordinated so that the emissions are at the same time and in the same direction.

Characteristics of Laser Light:

- Laser light is highly monochromatic.
- Laser light is highly coherent.
- Laser light is highly directional
- Laser light can be sharply focused.



These are the properties of laser light that make it useful in the present technological applications.

EINSTEIN AND THE LASER

EINSTEIN AND THE LASER

LASER

- In 1917 Einstein introduced into physics a new concept, that of stimulated emission.

  The stimulated emission is the key to laser operation.

- Even though the first operating laser did not appear until 1960, the groundwork for its invention was put in place by Einstein's work. The importance of stimulated emission is indicated by the name " laser," which is an acronym for light amplification by the stimulated emission of radiation.

- **What was Einstein working on when the concept of stimulated emission occurred to him?** Nothing other than the cavity radiation problem, which in the hands of Planck and others established the new science of quantum mechanics. In 1917 Einstein succeeded in deriving the Planck radiation law in terms of beautifully simple assumptions and in a way that made quite clear the role of energy quantization and the photon concept.

- It is interesting that Einstein was also thinking deeply about this same fundamental cavity radiation problem when, in 1905, he first proposed the concept of the photon and realized that the photoelectric effect could be explained with its use. We learn from both o f these examples that practical devices of major importance can flow from a concern over problems that seem to have no relevance to technology. When you next see a photoelectric elevator door opener or listen to a compact-disc stereo system, think of Einstein.

Atomic Transitions -Three Process

Atomic Transitions can be described with three Process

- Atomic transitions can be described with three processes:

1. Stimulated absorption, in which an incoming photon raises the atom to a higher energy state
2. Spontaneous emission, in which the atom makes a transition to a lower energy state, emitting a photon, and
3. Stimulated emission, in which an incident photon causes an excited atom to make a downward transition, emitting a photon identical to the incident one.

Stimulated Absorption

- When radiation is incident on the atom, only those photons whose energy hf matches the energy separation ΔE between two energy levels can be absorbed by the atom as represented in Figure T-1. This process is called **stimulated absorption** because the photon stimulates the atom to make the upward transition.

The atom is transferred from the ground state to the excited state when the atom absorbs a photon of energy $hf = E_2 - E_1$.

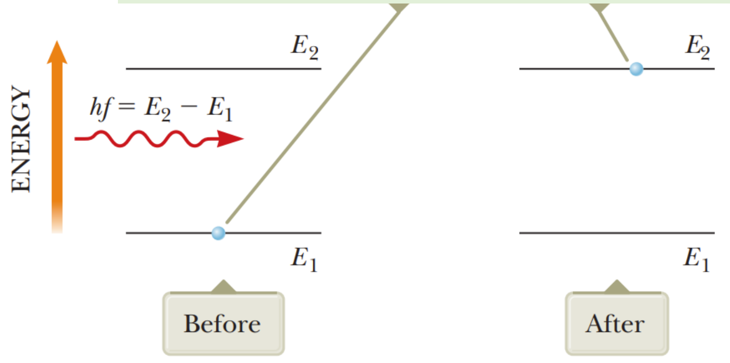


Figure T-1 Stimulated Absorption

LASER

Spontaneous Emission

Spontaneous Emission

- Once an atom is in an excited state, the excited atom can make a transition back to a lower energy level, emitting a photon in the process as in Figure T-2. This process is known as spontaneous emission because it happens naturally, without requiring an event to trigger the transition.
- Typically, an atom remains in an excited state for only about 10^{-8}s .

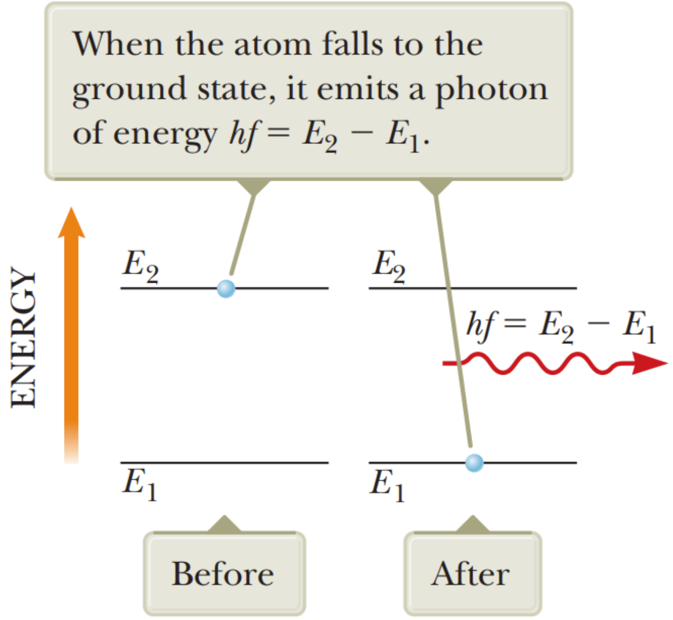


Figure T-2 Spontaneous Emission

In such a case:

(i) The emitted photon can move in any random direction.

(ii) The photons emitted from various atoms in the assembly have no phase-relationship between themselves.

Normally the mean life τ for spontaneous emission by excited atoms is of the order of 10^{-8}s. However, there are some states for which t is much longer, perhaps 10^{-3}s . We call such states metastable; they play an essential role in laser operation.

The light from a glowing lamp filament is generated by spontaneous emission. Photons produced in this way are totally independent of each other. In particular, they have different directions and phases

Stimulated Emission

Stimulated Emission

- Suppose an atom is in an excited state E_2 as in Figure T-3. If the excited state is a metastable, —the time interval until spontaneous emission occurs is relatively long. Let's imagine that during that interval a photon of energy $hf = E_2 - E_1$ is incident on the atom. One possibility is that the photon energy is sufficient for the photon to ionize the atom. Another possibility is that the interaction between the incoming photon and the atom causes the atom to return to the ground state and thereby emit a second photon with energy $hf = E_2 - E_1$.

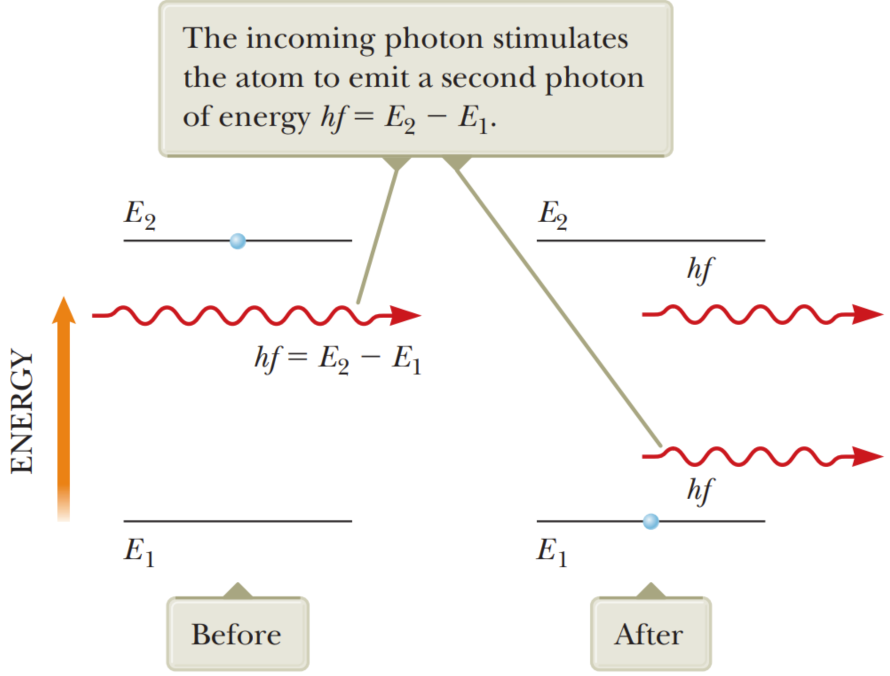


Figure T-3 Stimulated Emission

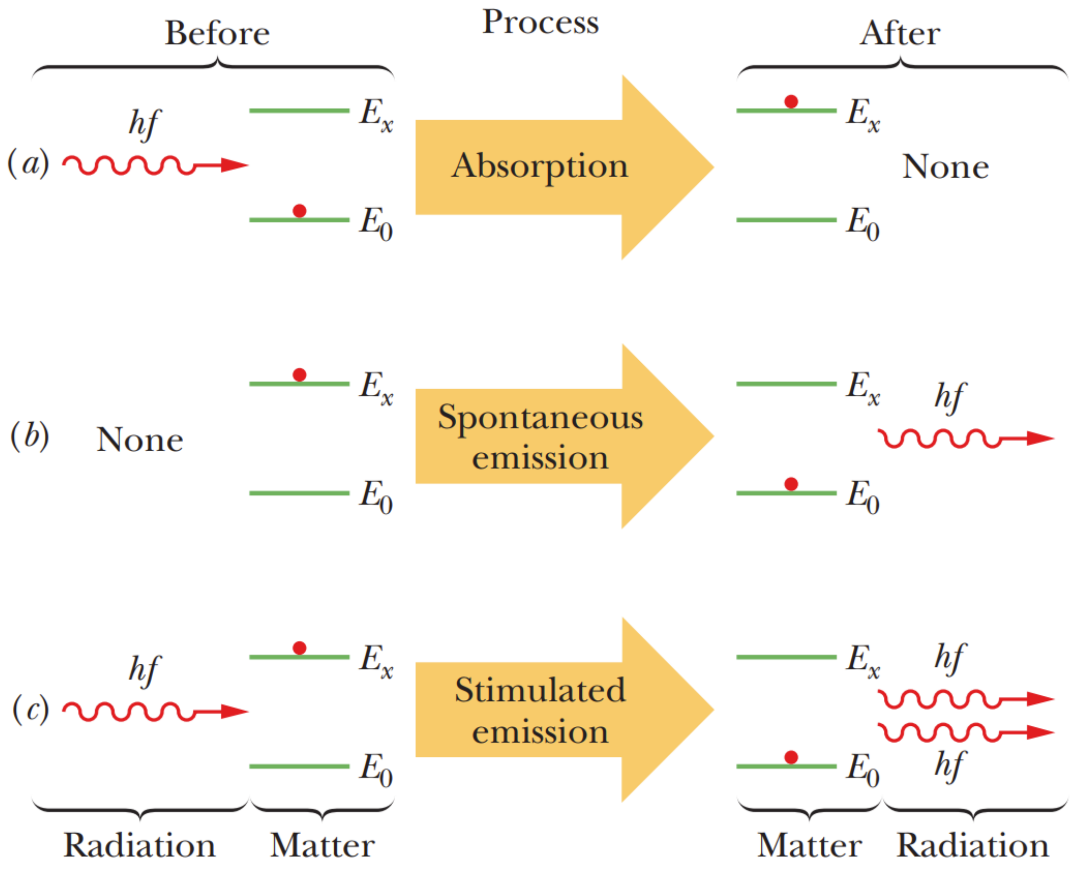
- In this process, the incident photon is not absorbed; therefore, after the stimulated emission, two photons with identical energy exist: the incident photon and the emitted photon. The two are in phase and travel in the same direction, which is an important consideration in lasers.

When an atom in an excited state E_2 interacts with an incident photon of right frequency f and is thereby induced to move to the ground state E_1 by emitting the difference of energy E_2-E_1 as a photon of same frequency f , the process is known as Stimulated Emission.

In such a case: (i) The emitted photon travels in the same direction in which the incident photon is moving.
(ii) The two photons are in phase with each other.

Three Ways – Radiation Interact with Matter

- Figure I shows the interaction of radiation and matter in the processes of (a) absorption, (b) spontaneous emission, and (c) stimulated emission.



These are three ways that radiation (light) can interact with matter. The third way is the basis of lasing.

An atom (matter) is represented by the red dot; the atom is in either a lower quantum state with energy E_0 or a higher quantum state with energy E_x .
In (a) the atom absorbs a photon of energy *hf* from a passing light wave.
In (b) it emits a light wave by emitting a photon of energy *hf*.
In (c) a passing light wave with photon energy *hf* causes the atom to emit a photon of the same energy, increasing the energy of the light wave. The emitted photon is in every way identical to the stimulating photon.

LASER

- When light is incident on a collection of atoms, a net absorption of energy usually occurs because when the system is in thermal equilibrium, many more atoms are in the ground state than in excited states. If the situation can be inverted so that more atoms are in an excited state than in the ground state, however, a net emission of photons can result. Such a condition is called **population inversion.**
- Population inversion is the fundamental principle involved in the operation of a laser.
- One of the requirements for laser light: to achieve laser action, the process of stimulated emission must occur.
- Suppose an atom is in the excited state E_1 as in Figure L-1 and a photon with energy $hf = E_2 - E_1$ is incident on it. The incoming photon can stimulate the excited atom to return to the ground state and thereby emit a second photon having the same energy *hf* and travelling in the same direction. The incident photon is not absorbed, so after the stimulated emission, there are two identical photons: the incident photon and the emitted photon. The emitted photon is in phase with the incident photon. These photons can stimulate other atoms to emit photons in a chain of similar processes. The many photons produced in this fashion are the source of the intense, coherent light in a laser.

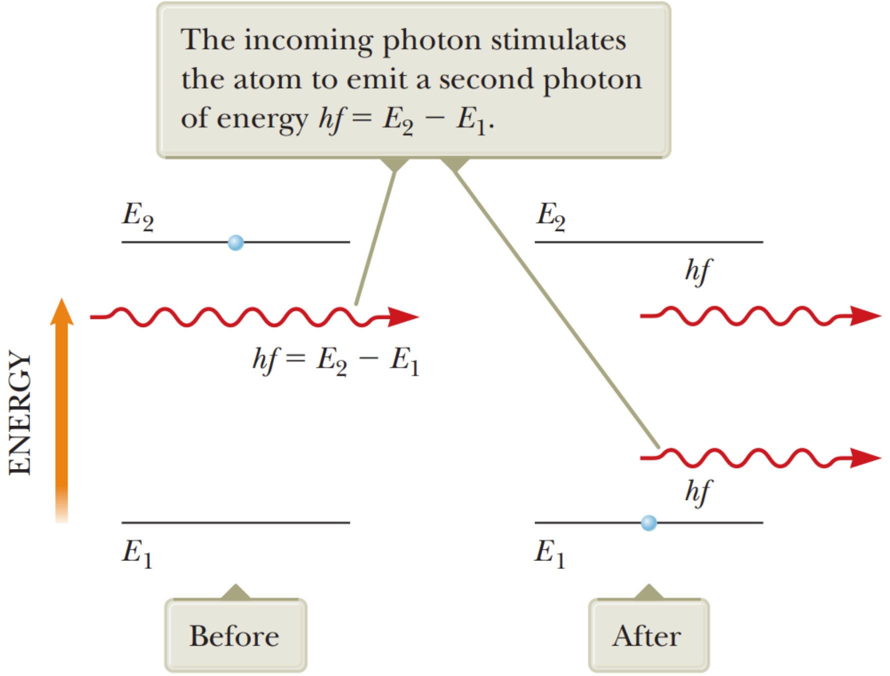


Figure L-1

LASER

For the stimulated emission to result in laser light, there must be a buildup of photons in the system.

The following three conditions must be satisfied to achieve this buildup:

- The system must be in a state of population inversion: there must be more atoms in an excited state than in the ground state.
- The excited state of the system must be a metastable state, meaning that its lifetime must be long compared with the usually short lifetimes of excited states, which are typically 10^{8} s. In this case, the population inversion can be established and stimulated emission is likely to occur before spontaneous emission.
- The emitted photons must be confined in the system long enough to enable them to stimulate further emission from other excited atoms. That is achieved by using reflecting mirrors at the ends of the system. One end is made totally reflecting, and the other is partially reflecting. A fraction of the light intensity passes through the partially reflecting end, forming the beam of laser light.

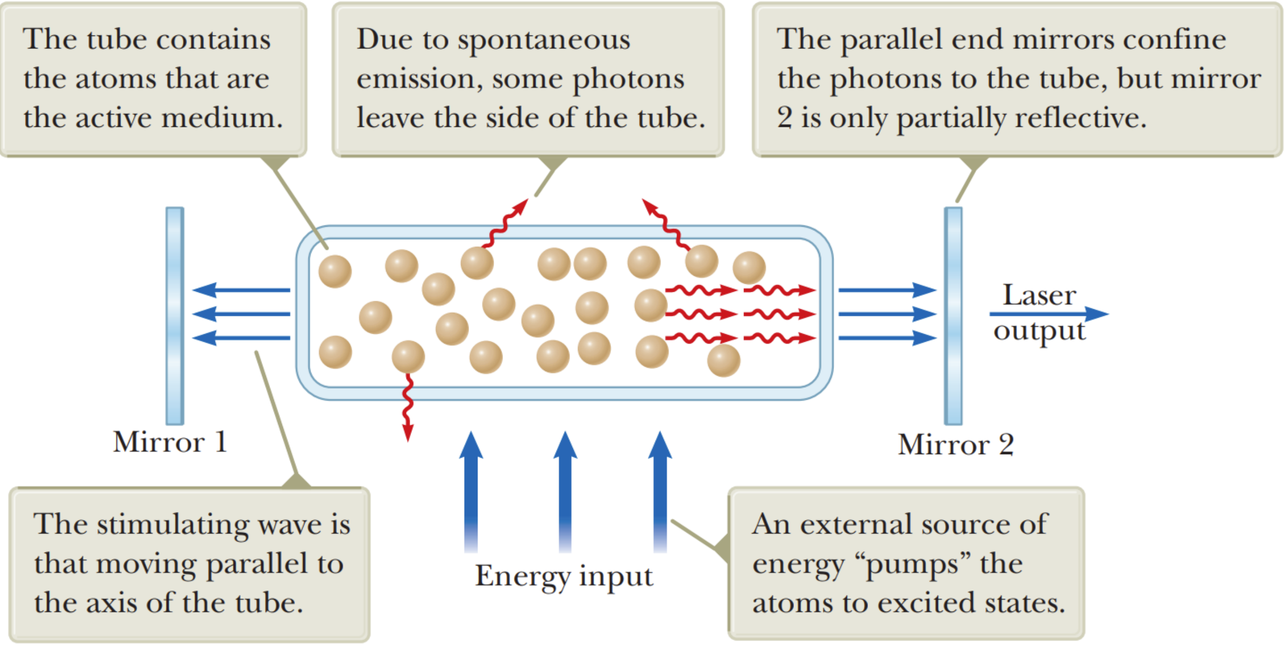


Figure L-2 Schematic diagram of a laser design.

POPULATION INVERSION, PUMPING

POPULATION INVERSION

- A nonequilibrium situation in which the number of atoms in a higher-energy state is greater than the number in a lower-energy state.

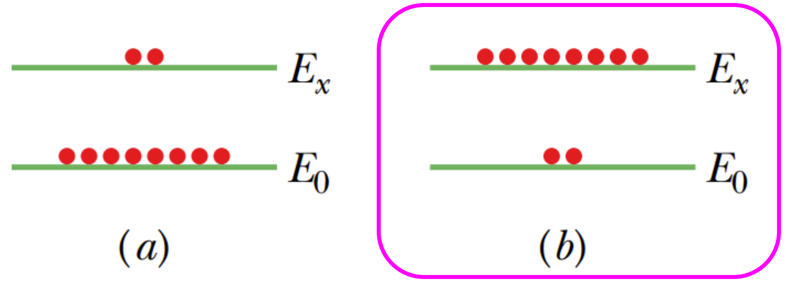


Figure P

(a) The equilibrium distribution of atoms between the ground state E_0 and excited state E_x accounted for by thermal agitation.
(b) An inverted population, obtained by special methods. Such a population inversion is essential for laser action

PUMPING

- The process of energizing the laser medium.

Optical Pumping:

which uses strong light source for excitation

$$hf + A \rightarrow A^*$$

$\uparrow$ atom at normal state

$\searrow$ the corresponding atom at excited state

Electrical Pumping:

which uses electron impact for excitation

Chemical Pumping:

which uses chemical reactions for excitation

HOW A LASER WORKS

HOW A LASER WORKS

- Atoms from the ground state E_1 are “pumped” up to an excited state E_3 , for example by the absorption of light energy from an intense, continuous spectrum source that surrounds the lasing material
- From E_3 the atoms decay rapidly to a state of energy E_2 . For lasing to occur this state must be metastable; that is, it must have a relatively long mean life against decay by spontaneous emission. If conditions are right, state E_2 can then become more heavily populated than state E_1 , thus providing the needed population inversion. A stray photon of the right energy can then trigger an avalanche of stimulated emission events, resulting in the production of laser light.

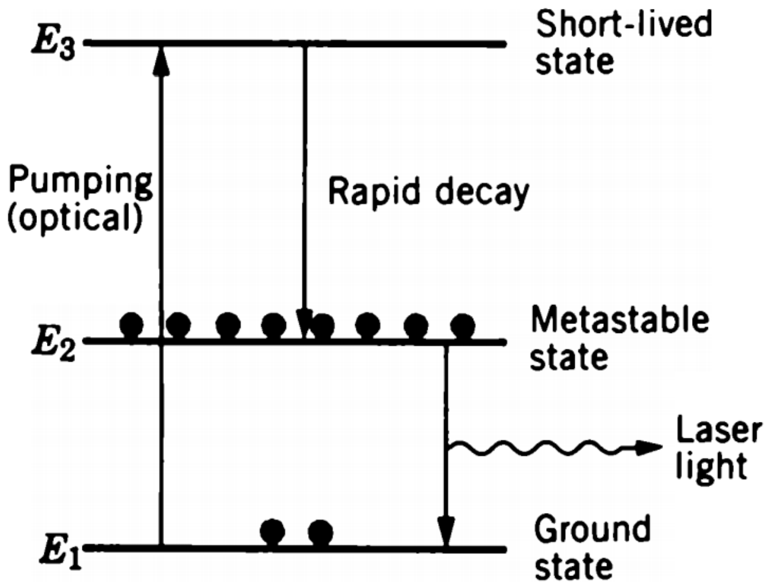


Figure T-3

The basic three-level scheme for laser operation.

LASER

APPLICATIONS OF LASER

APPLICATION OF LASER

- **IN INDUSTRY**

  Precision cutting, welding and drilling of tiny holes into hardest materials can be performed by laser beam.

- **IN MEDIA**

  A very interesting application is the production of true three dimensional images called "HOLOGRAM".

- **IN SURGERY**

  In surgery, the laser has proved a more delicate and accurate instrument than the finest scalpel.

  It has been used for bloodlessly removing small humors, cutting and delicate operations.

  Laser can be used to fragment stones in kidney and eye-surgery.

- **AS RANGE FINDER**

  Laser beam is used as a range finder, lining up equipment accurately in surveying large distances.

- **IN ELECTRICAL DEVICES**

  Tiny solid state lasers are widely used in electrical devices. A laser beam replaces the phonographic needle in a compact disk audio system for music reproduction of extremely high fidelity. A laser can also be used for the photographic recording of output data of computer.

- **IN ENVIRONMENTAL STUDY**

  Laser can be used as a very sensitive detectors of pollutants in the atmosphere.

- **IN NUCLEAR FUSION**

  A high power laser is a potential source to induce nuclear fusion reaction.

APPLICATIONS OF LASER

Figure LA-1
The NOVA laser room at the Lawrence Livermore National Laboratory. These lasers, with a power of about 10^{14} W, are used in controlled thermonuclear fusion research.

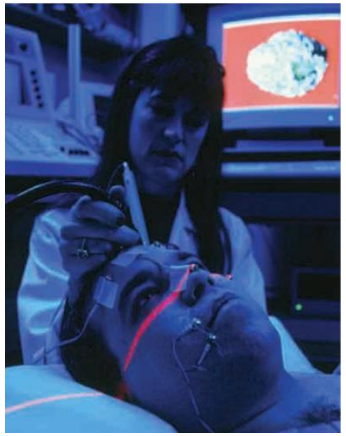


Figure LA-2
A patient's head is scanned and mapped by (red) laser light in preparation for brain surgery

Figure LA-3
This robot carrying laser scissors, which can cut up to 50 layers of fabric at a time, is one of the many applications of laser technology

Figure LA-4
Laser beams light up the sky.

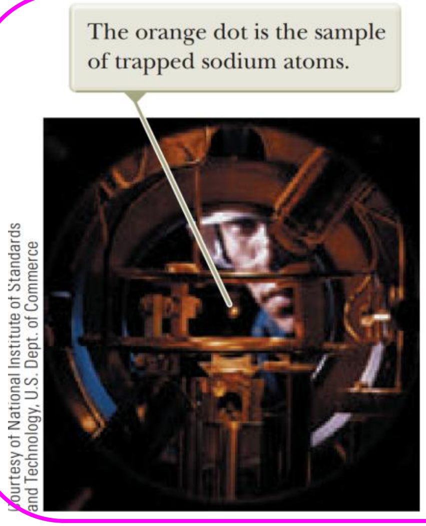


Figure LA-5
A staff member of the National Institute of Standards and Technology views a sample of trapped sodium atoms cooled to a temperature of less than 1 mK.

Chu shared the 1997 Nobel Prize in Physics with two of his colleagues for the development of the techniques of optical trapping

SUMMARY

Atomic Transition – Three process

- Atomic transitions can be described with three processes: stimulated absorption, in which an incoming photon raises the atom to a higher energy state; spontaneous emission, in which the atom makes a transition to a lower energy state, emitting a photon; and stimulated emission, in which an incident photon causes an excited atom to make a downward transition, emitting a photon identical to the incident one.

Laser and Laser Light

- The laser operates on the principle of stimulated emission, by which many photons with identical wavelength and phase are emitted.

  Laser operation requires a nonequilibrium condition called a population inversion, in which more atoms are in a higher-energy state than are in a lower energy state.

- Laser light arises by stimulated emission. That is, radiation of a frequency given by

$$hf = E_x - E_0$$

  can cause an atom to undergo a transition from an upper energy level (of energy E_x) to a lower energy level, with a photon of frequency *f* being emitted. The stimulating photon and the emitted photon are identical in every respect (such as wavelength, phase, and direction of travel) and combine to form laser light.

- For the emission process to predominate, there must normally be a population inversion; that is, there must be more atoms in the upper energy level than in the lower one.

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Thank you