Engineering Optics

Lecture 27

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by

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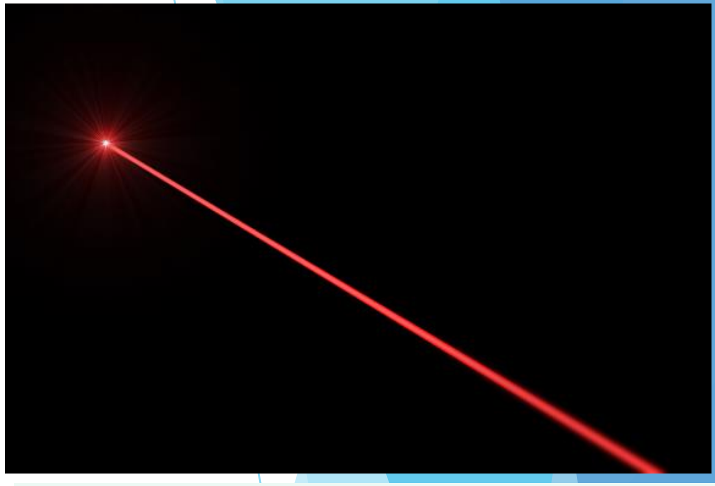
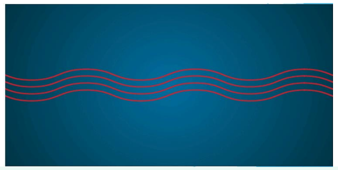
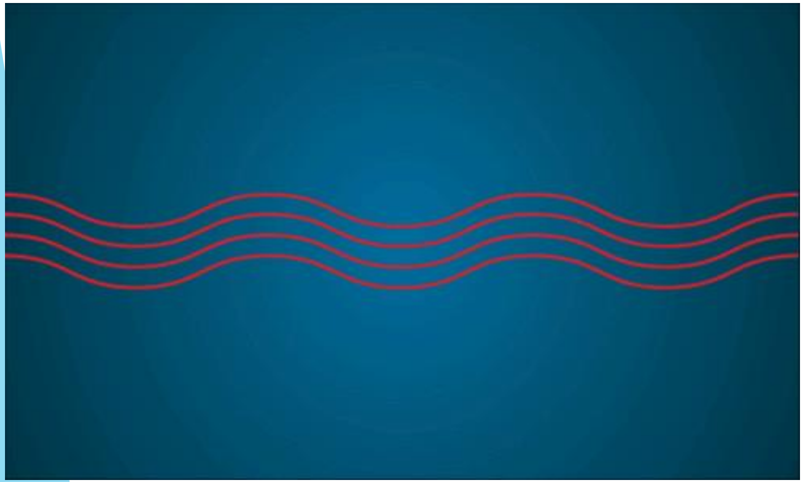
Coherence in Spontaneous vs. Stimulated emission

- you can't create a laser beam by cleverly focusing regular light, no matter how hard you try.
- You create a laser beam using stimulated emission.
- Stimulated emission is what causes the light in a laser beam to be coherent, and coherence is what makes a laser beam so much more useful than regular light.
- you can visualize a beam of light as a bundle of many little sine waves traveling through space



A laser beam is coherent light
source: Christopher S. Baird





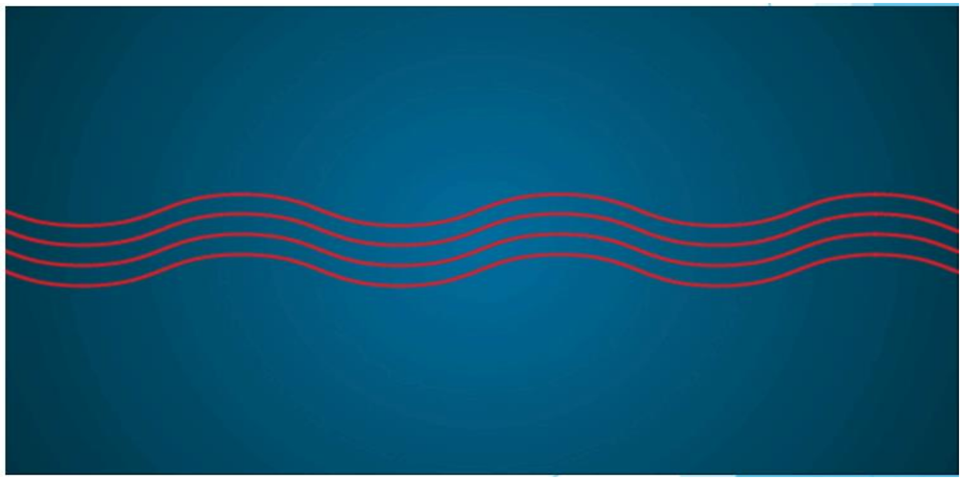
take a snapshot at a certain *t* the different wave components in a light beam, you would find that all the first peaks are at the same location in space, all the second peaks are at the same distance

When will that happen?? → What conditions to be satisfied??

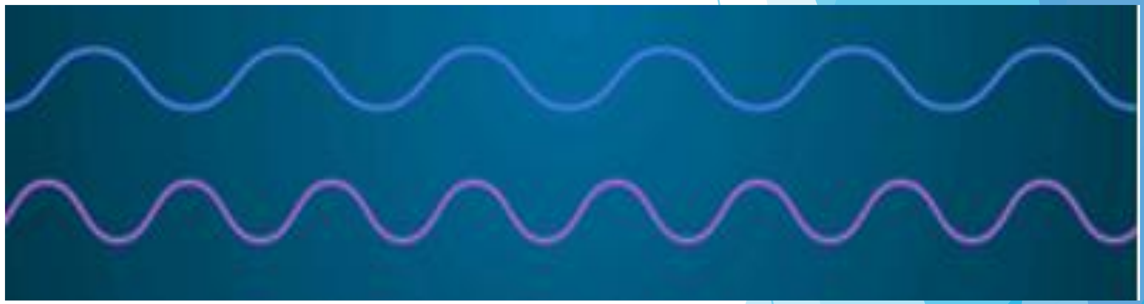
https://wtamu.edu/~cbaird/sq/faqs/

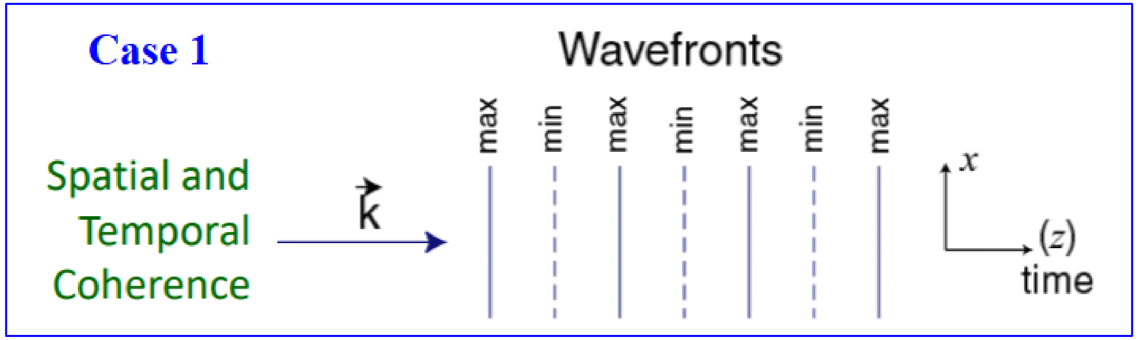
Conditions to be satisfied

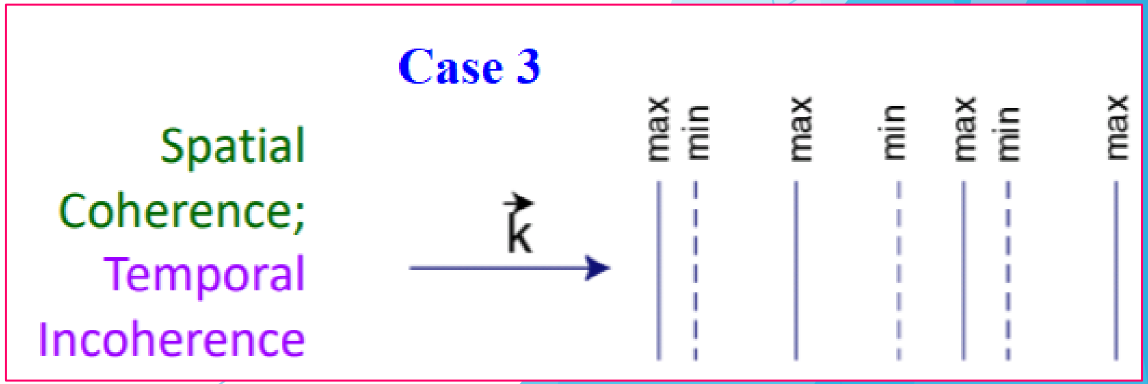
1. waves have to have the same wavelength (**Temporal coherence**): LASER → almost monochromatic $\Delta\lambda \sim 10^{-6}$ Å



Slight change in λ will change temporal coherence







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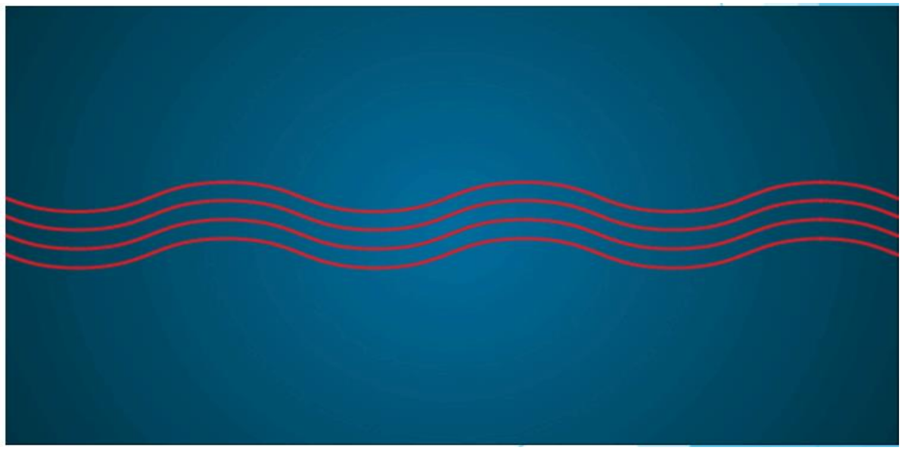
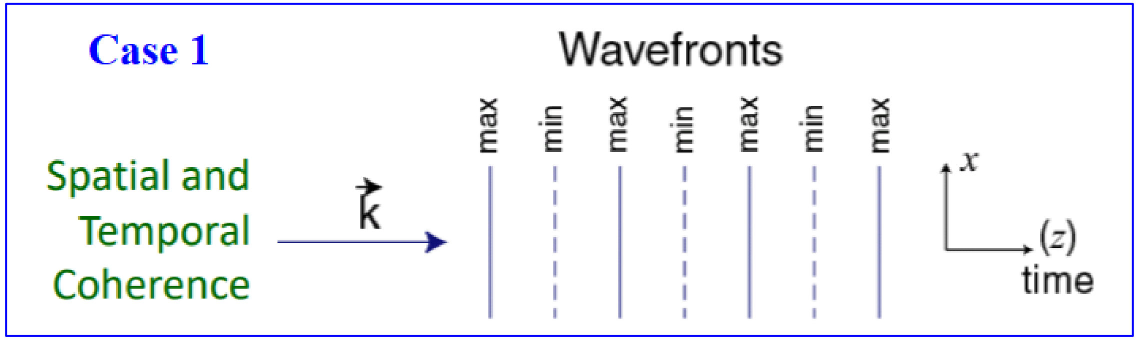
Conditions to be satisfied

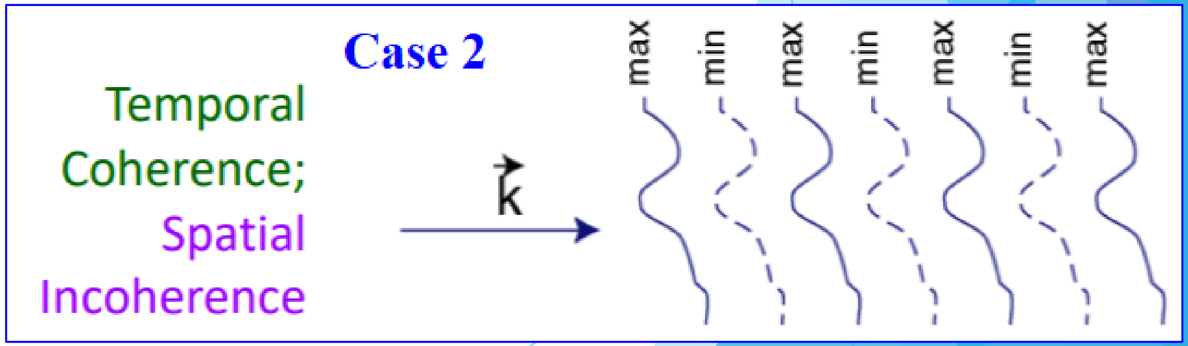


If you take one wave traveling north and another wave traveling north-east

then their peaks can not be lined up.

2. The waves have to travel in the same direction (**spatial coherence**)





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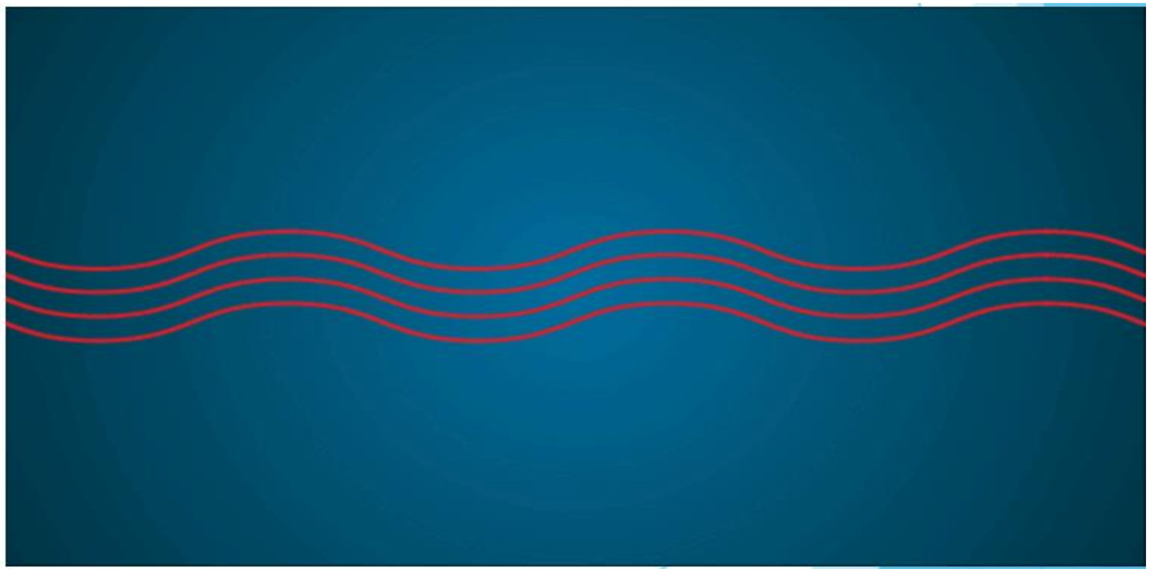
Conditions to be satisfied



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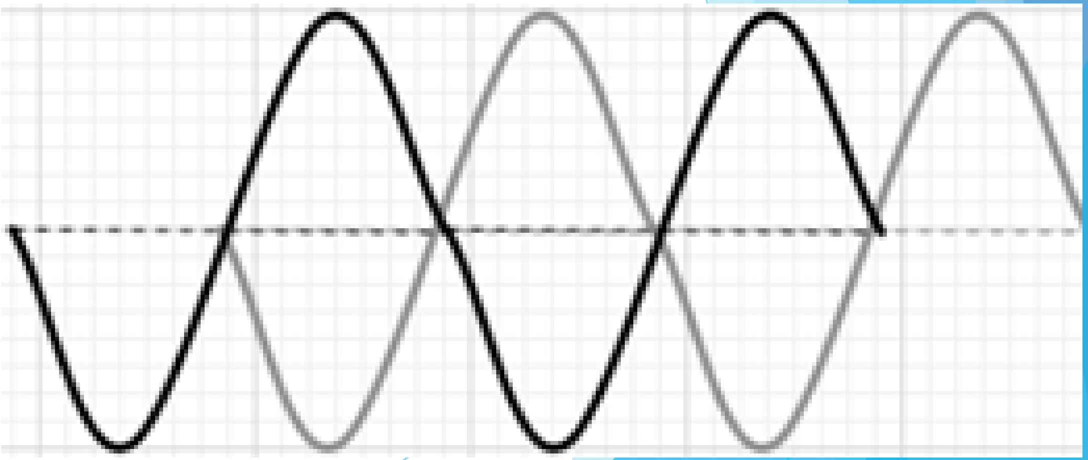
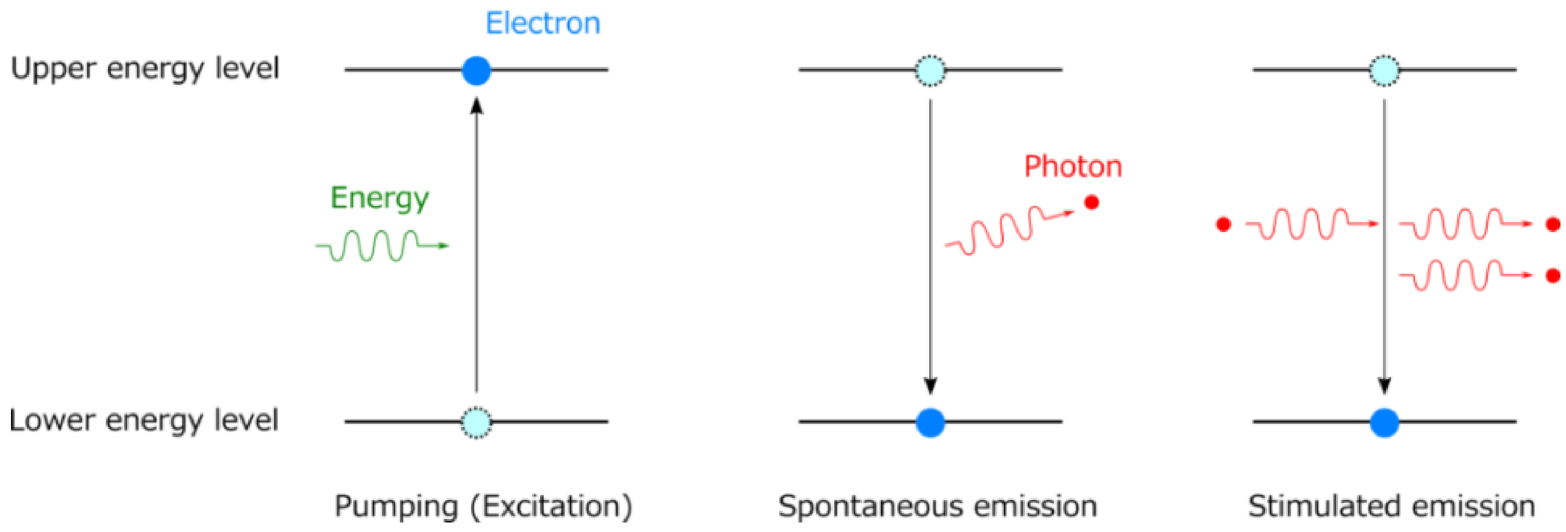
3. The waves have to be in phase (**spectral coherence**): if one wave peaking at the same point in space and the other wave is bottoming out? → ***out of phase***
4. The waves have to be the same polarization (**polarization coherence**)

Even if two waves have the same wavelength, if one wave is shifted forward a bit relative to the other wave, their peaks will not be aligned.



https://support.spectrasonics.net/manual/Omnisphere/edit_page/oscillator/page14.html

Coherence in Spontaneous vs. Stimulated emission



There is a degree of coherence in sources like the mercury green line and some other useful spectral sources, but their coherence does not approach that of a laser.

Spatial Coherence Length, x_c

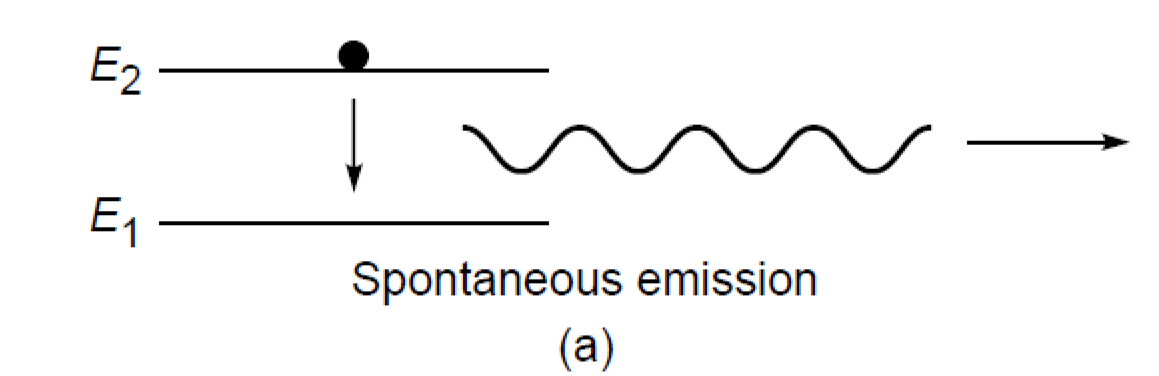
Temporal Coherence Time, τ_c

Spontaneous and Stimulated Emissions

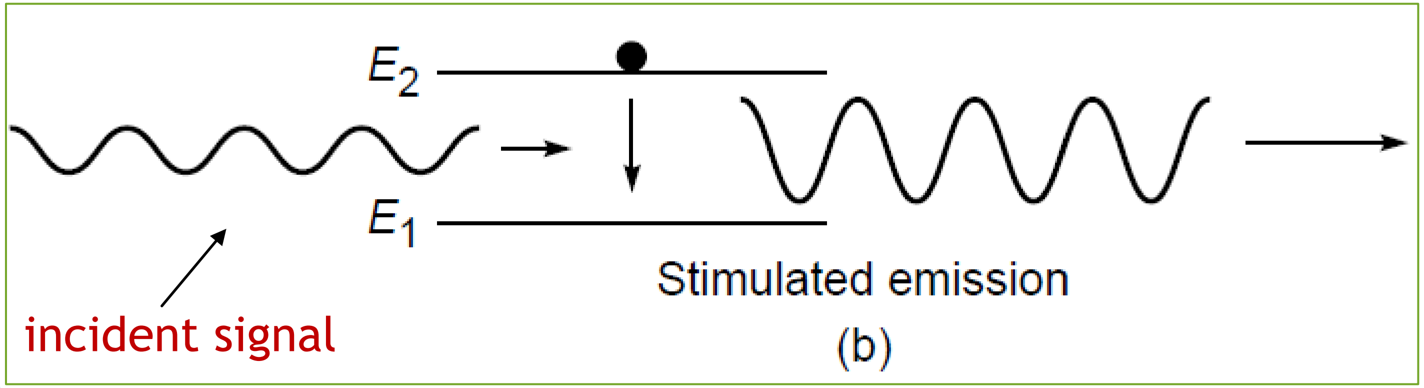
$$\omega = \frac{E_2 - E_1}{\hbar}$$

$$\hbar = \frac{h}{2\pi} \approx 1.0546 \times 10^{-34}\ \text{J s}$$

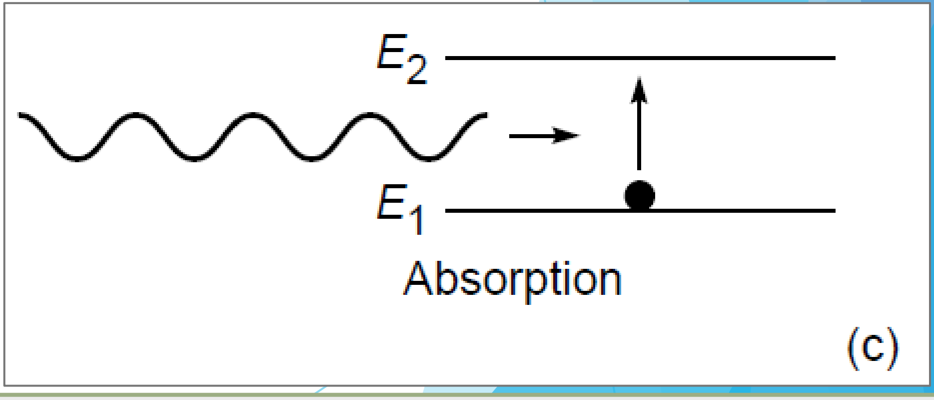
- Atoms → discrete energy states
- **Q: How does an atom interact with electromagnetic radiation??**
- Ans: according to Einstein → 3 different ways



The rate of spontaneous emission is proportional to the number of atoms in the excited state



The rate of stimulated emission depends on both the intensity of the external field and the number of atoms in the excited state



The rate of stimulated absorption depends both on the intensity of the external field and on the number of atoms in the lower energy state.

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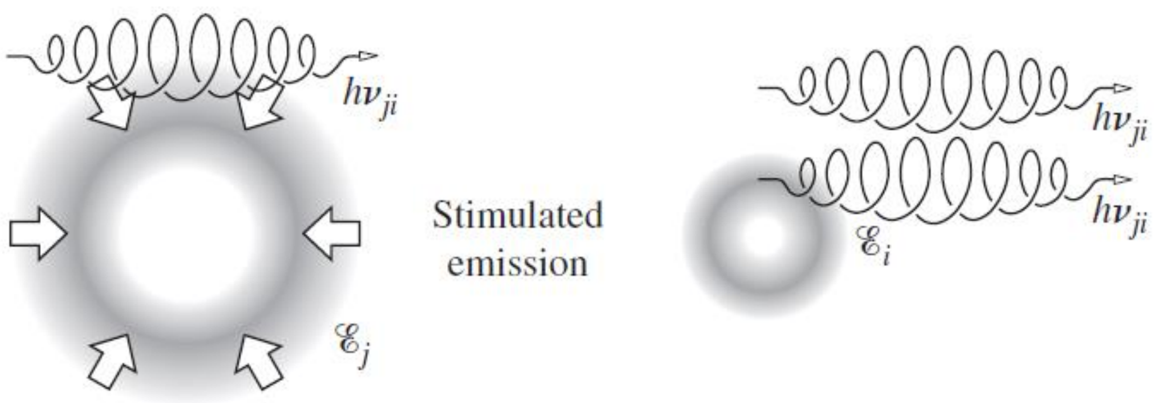
Stimulated Emissions

- If a photon in an incident beam is to trigger one of these excited atoms into stimulated emission, it must have the frequency ν_{ji}
- A remarkable feature of this process is that the emitted photon is in-phase with, has the polarization of, and propagates in the same direction as, the stimulating radiation. The emitted photon is said to be in the same radiation mode as the incident wave and tends to add to it, increasing its flux density.
- Friedberg and Einstein

Where is the problem then?



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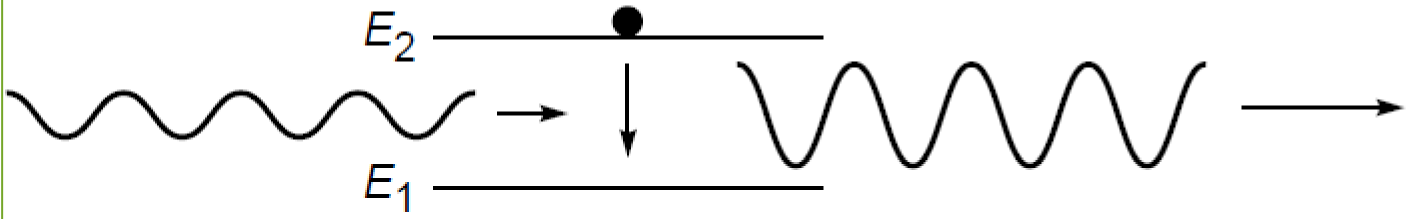

Stimulated emission

(b)

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Stimulated Emissions

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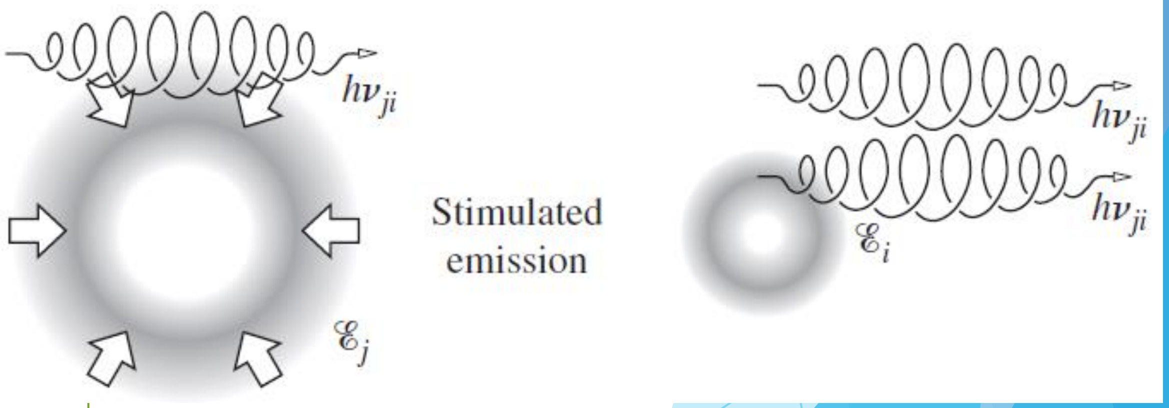
since most atoms are ordinarily in the ground state, absorption is usually far more likely than stimulated emission.



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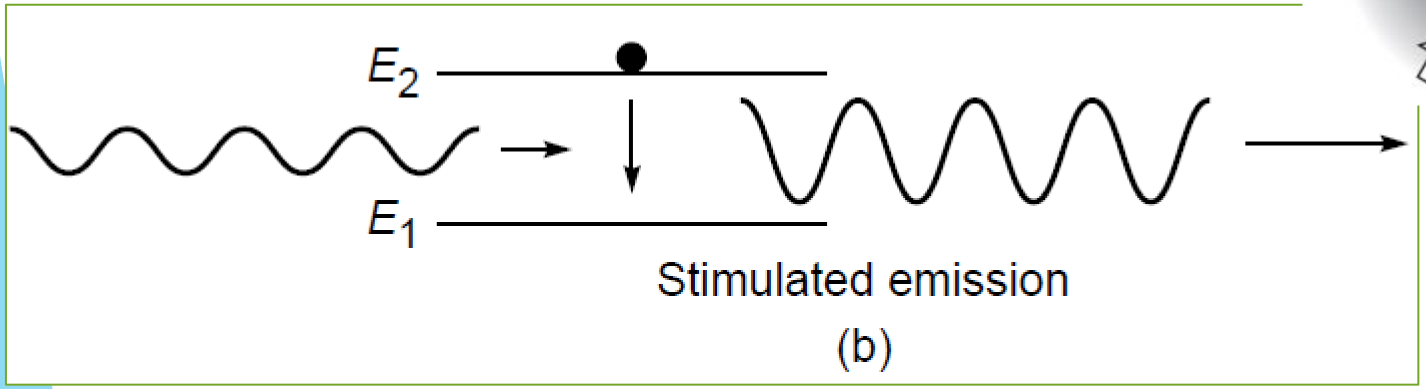

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Population inversion

When the atoms are in thermodynamic equilibrium, there are larger number of atoms in the lower state → absorptions

For **Stimulated emission** → more and more atoms need to be in the excited state ← ***Problem***

Solution → create a state of **population inversion** in which there are larger number of atoms in the upper state

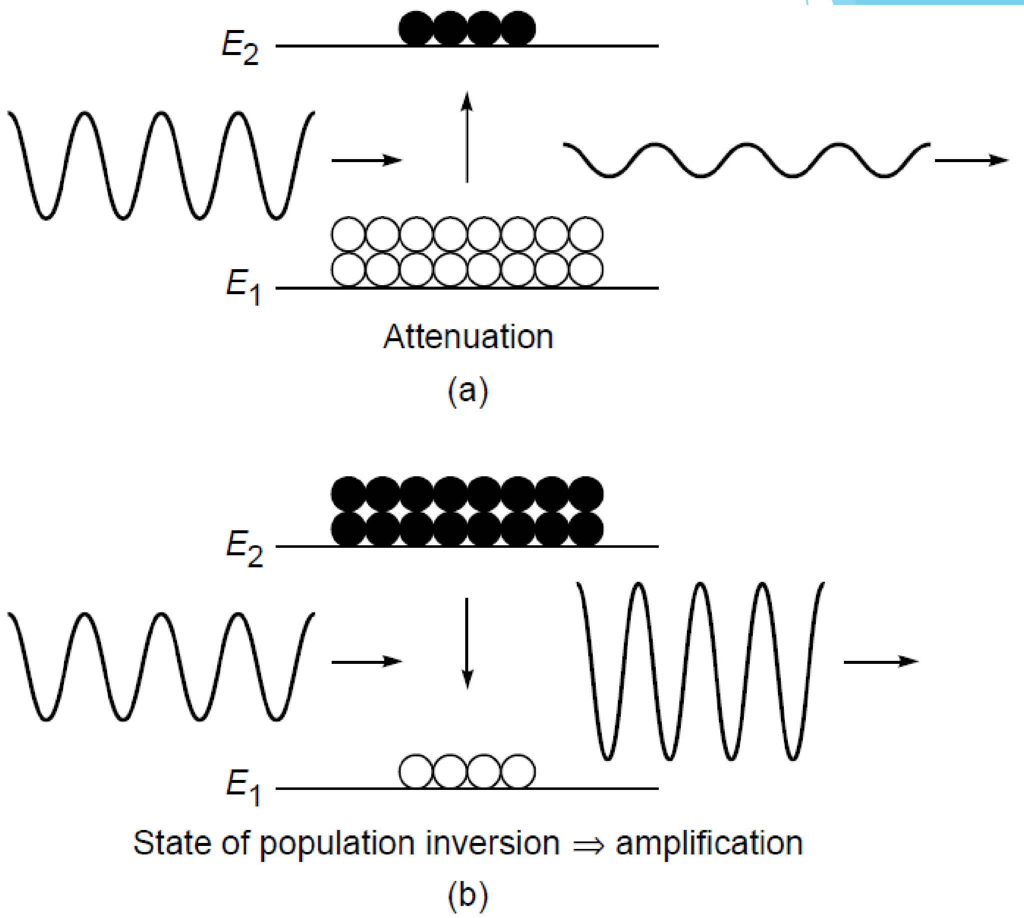

Fig. 26.2 (a) A larger number of atoms in the lower state result in the attenuation of the beam. (b) A larger number of atoms in the upper state (which is known as population inversion) result in the amplification of the beam.

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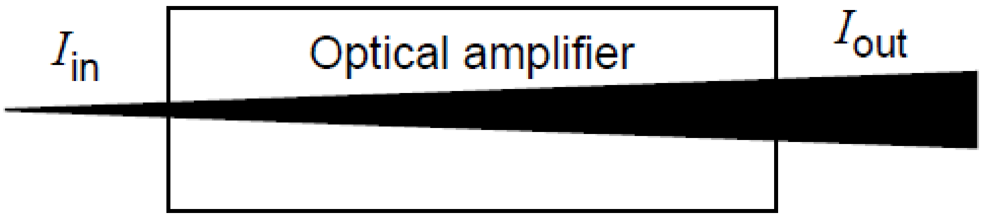
Mechanism

1. **Population inversion**
2. An incident photon of the proper frequency could then trigger an avalanche of stimulated photons—all in-phase → **amplified output**
3. The initial wave would continue to build, so long as there were no dominant competitive processes (such as scattering) and provided the population inversion could be maintained.

4. In effect, energy (electrical, chemical, optical, etc.) **would be pumped in to sustain the inversion**, and a beam of light would be extracted after sweeping across the active medium.



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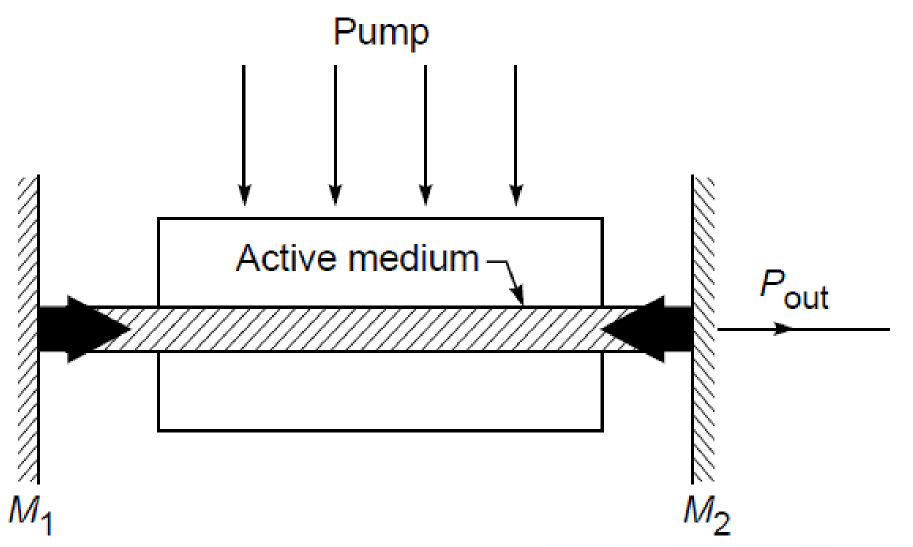
Main Components of the Laser

- Active medium: The active medium consists of a collection of atoms, molecules, or ions (in solid, liquid, or gaseous form) which is capable of amplifying light waves.
- Pumping source: The pump enables us to obtain such a state of population inversion between a pair of energy levels of the atomic system. When we have a state of population inversion, the input light beam can get amplified by stimulated emission
- Optical resonator: A medium with population inversion is capable of amplification; however, for it to act as an oscillator, a part of the output energy must be fed back into the system. Such feedback is brought about by placing the active medium in a resonator; the resonator could be just a pair of mirrors facing each other.



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Problem:1

A 10-mW laser is emitting at a mean wavelength of 500 nm. Determine the rate of occurrence of stimulated emission.

Answer:

We have that the laser puts out 10×10^{-3} J/s. We need to find out how much energy (E) each photon carries off. Since $E = h\nu$ and $c = \lambda\nu$

$$E = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34})(2.998 \times 10^{8})}{500 \times 10^{-9}}$$

$$E = 3.973 \times 10^{-19}\ \text{J}$$

Rate of photon emission = rate occurrence of spontaneous emission

$$\frac{10 \times 10^{-3}\ \text{J/s}}{3.973 \times 10^{-19}\ \text{J}} = 2.52 \times 10^{16}\ \text{photons/s}$$

Thank You