Introduction to Laser Theory

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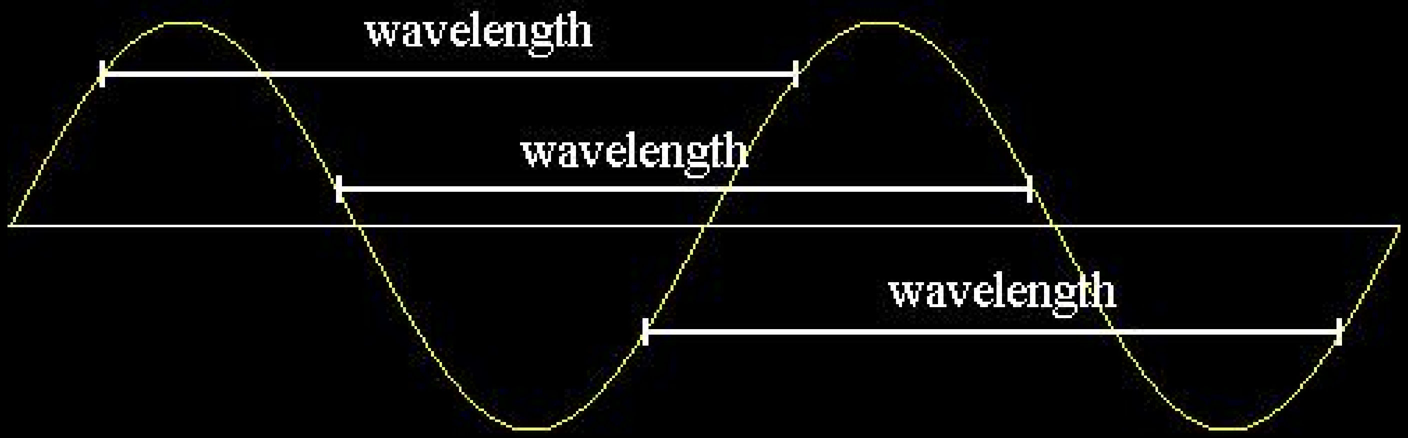
What we'll talk about . . .

- Light amplification by stimulated emission of radiation
- Electronic energy levels
- Energy transfer processes
- Classifications of lasers and properties of laser beams
- Detecting and characterizing very fast laser pulses

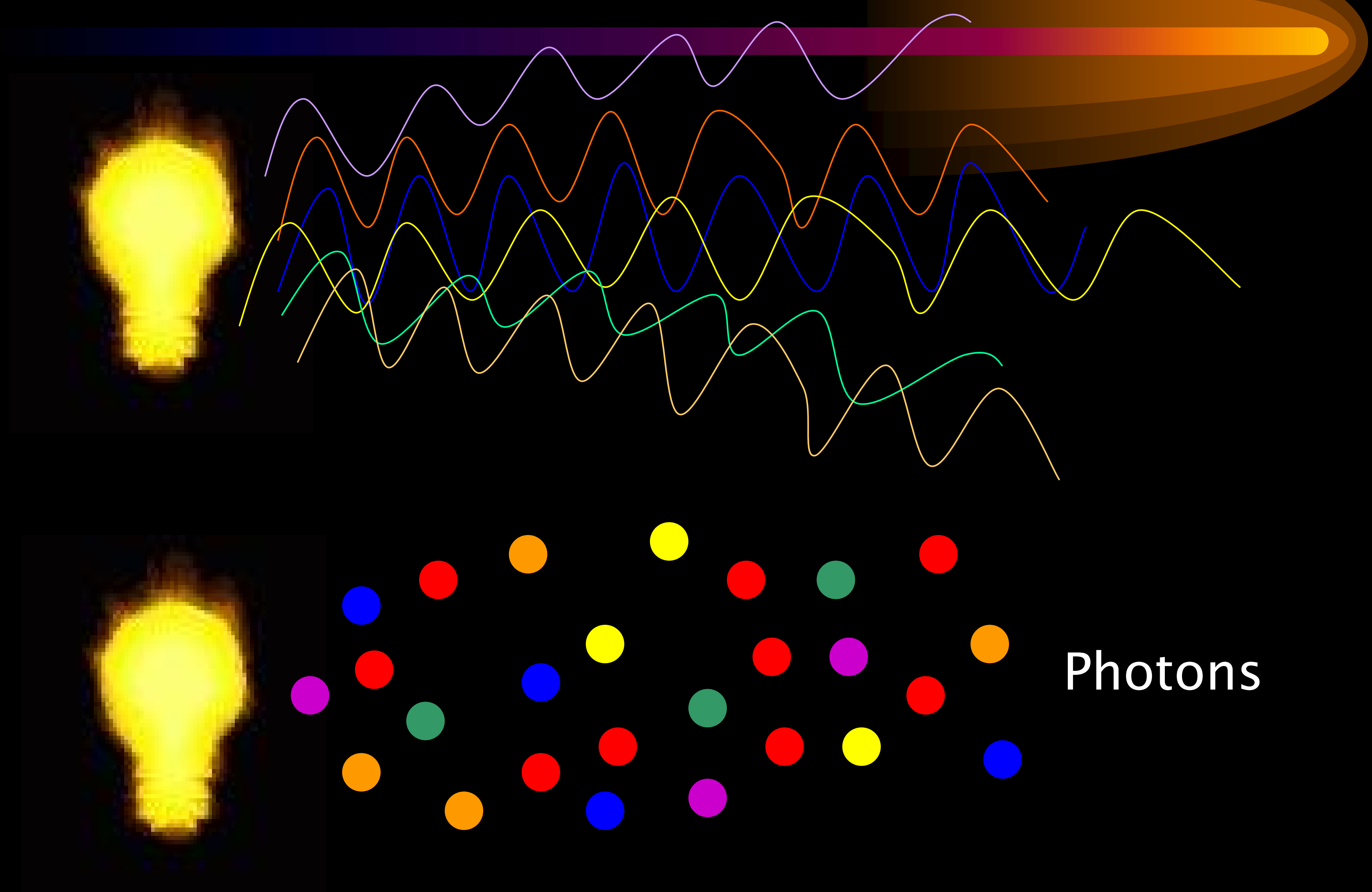
The Invention of the Laser

- Invented in 1958 by Charles Townes and Arthur Schawlow of Bell Laboratories
- Was based on Einstein's idea of the "particle-wave duality" of light, more than 30 years earlier
- Originally called MASER (m="microwave")

The Electromagnetic Spectrum

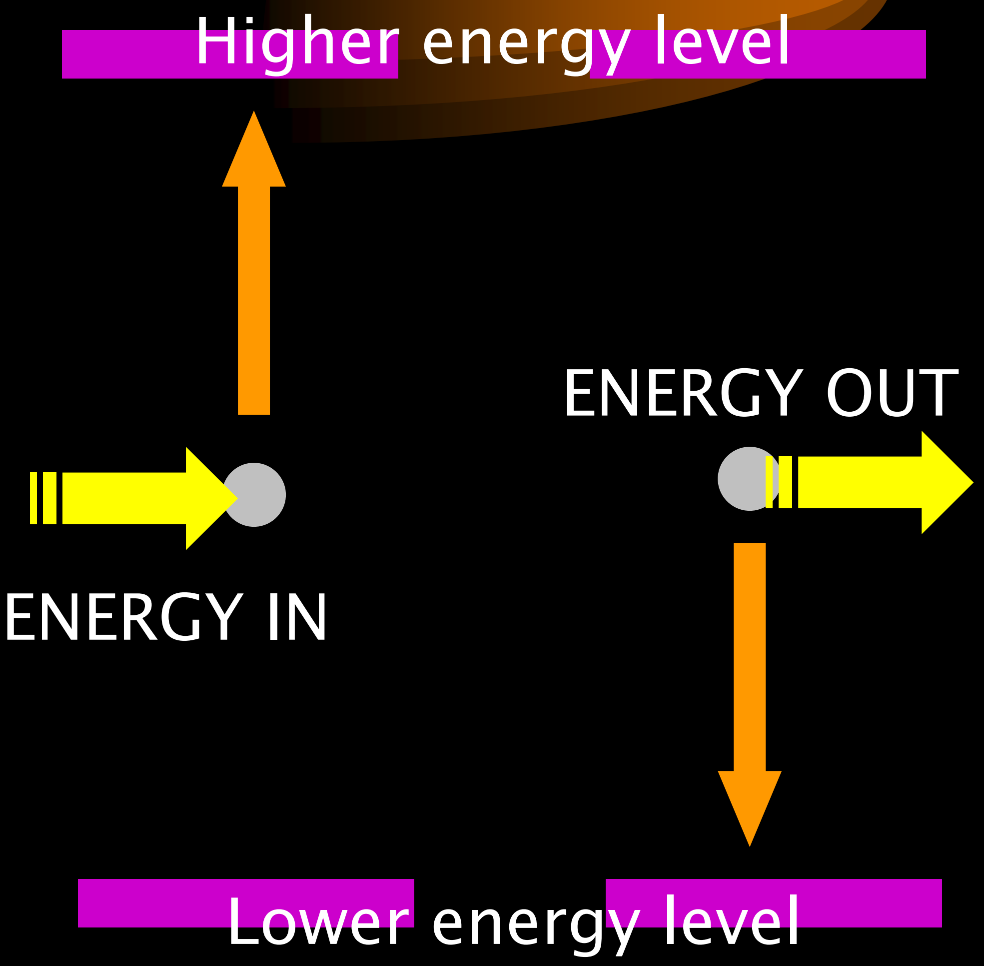


Particle-Wave Duality of Light



Energy is "quantized"

- To raise an electron from one energy level to another, "input" energy is required
- When falling from one energy level to another, there will be an energy "output"
- Theoretically: infinite number of energy levels.

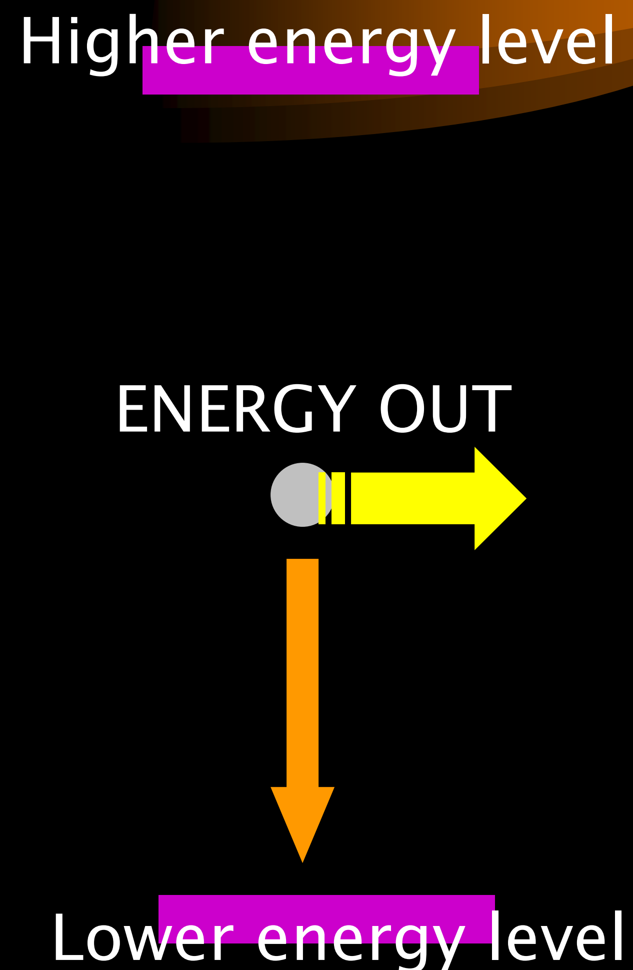


Spontaneous Emission

Electron initially in level 2 “falls” to level 1 and gives off energy (just happens spontaneously)

Energy is emitted in the form of a photon:

$$E = hf$$

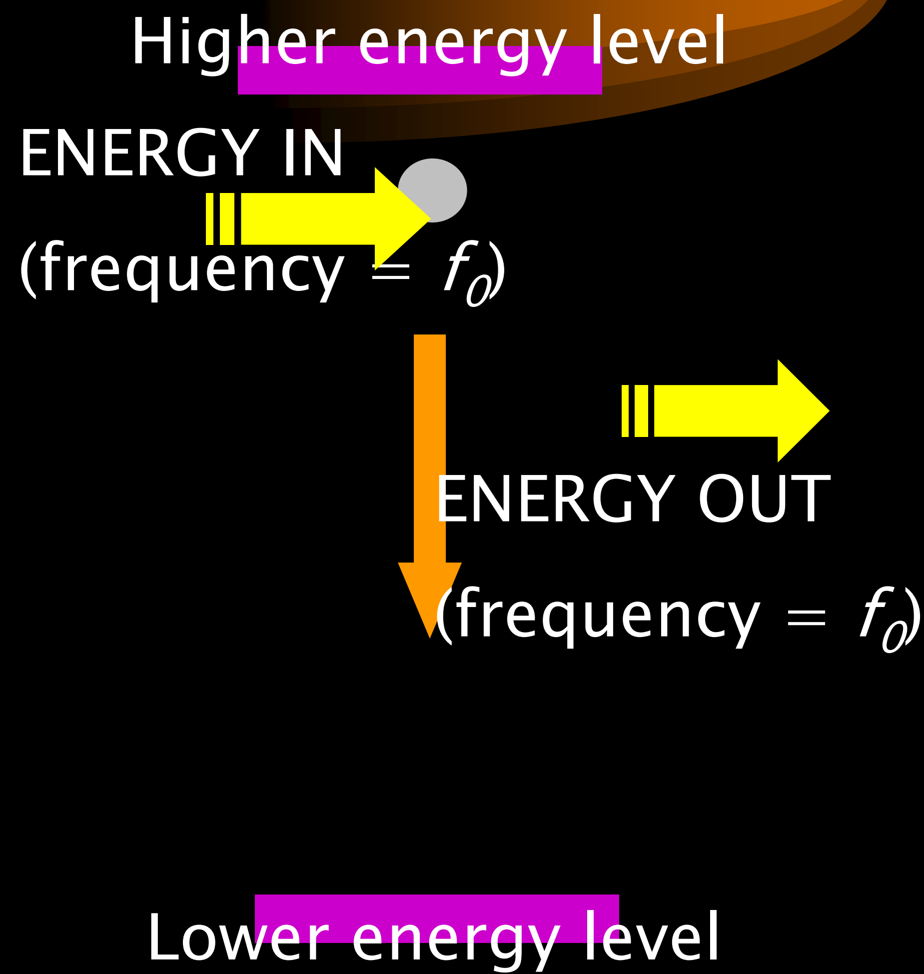


Stimulated Emission

Same idea as spontaneous emission except we MAKE it happen by sending in an EM wave of frequency f_0

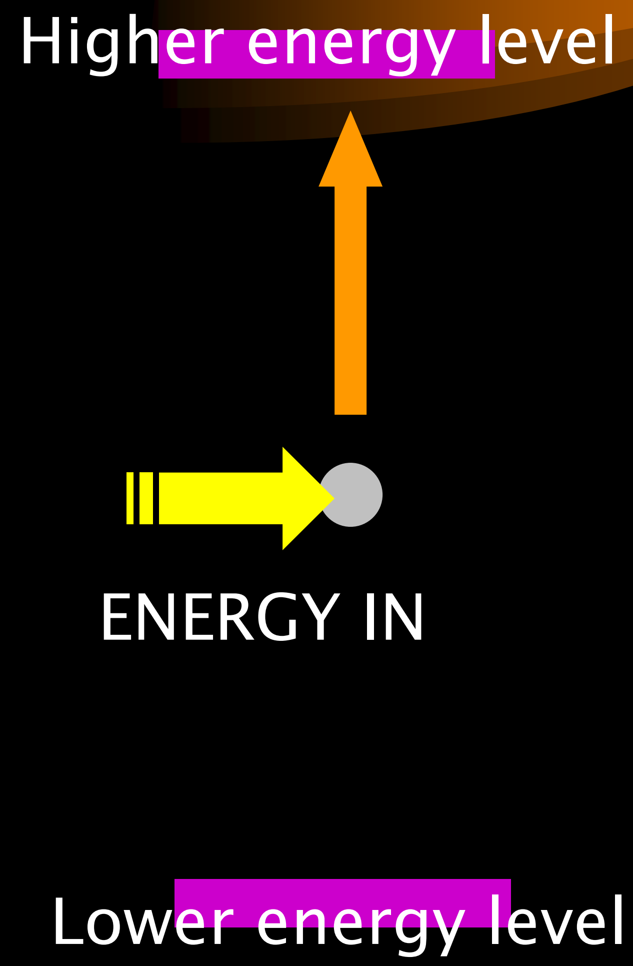
A photon is given off with the energy

$$E = hf_0$$



Stimulated Absorption

Electron is initially in level 1. We send in an EM wave and the electron goes UP from level 1 to level 2.



Energy Transfer Processes

- Spontaneous emission
  - electron “naturally” falls down from level 2 to level 1

Send in an electromagnetic (EM) wave:

- Stimulated emission
  - electron can be knocked down from level 2 to level 1
- Stimulated absorption
  - electron can be raised from level 1 to level 2

Energy Transfer Processes: Quantitatively

- Define N_i, the <u>population</u> of level *i*
- $N_i(t)$ = the # of electrons, per unit of volume, occupying energy level *i* at time *t*

Energy Transfer Processes: Quantitatively

Level 2

For spontaneous emission:

$$\frac{dN_2}{dt} = -AN_2$$

For stimulated emission:

$$\frac{dN_2}{dt} = -W_{2\text{ to }1}N_2$$

For stimulated absorption:

$$\frac{dN_2}{dt} = +W_{1\text{ to }2}N_1$$

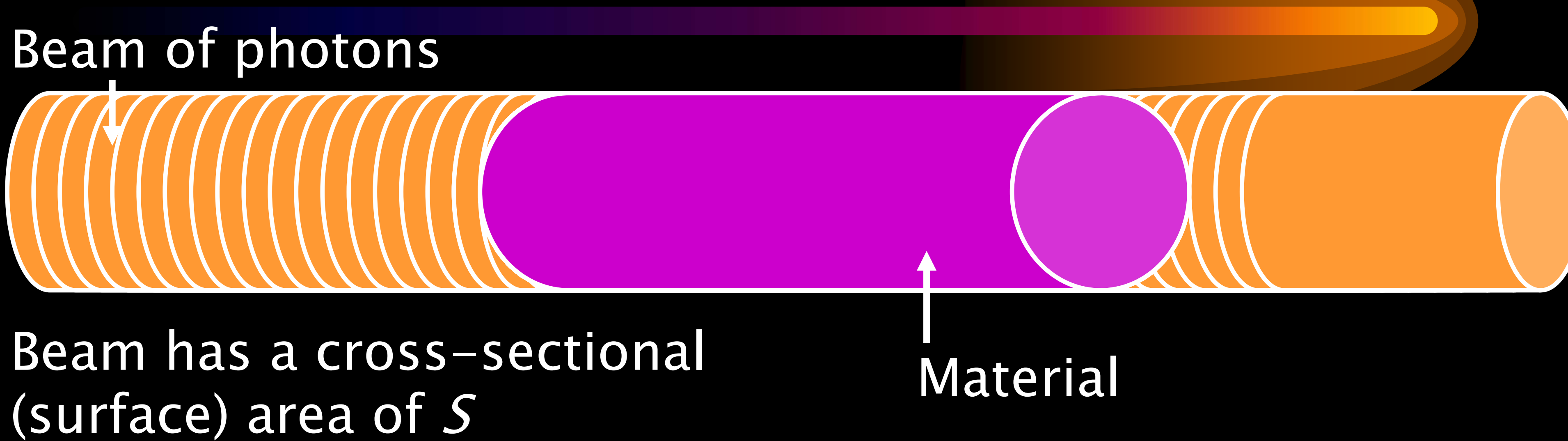
$$W_{2\,\mathrm{to}1} = \sigma_{2\,\mathrm{to}1}\Phi_{\mathrm{photon}}$$

$$W_{1\,\mathrm{to}2} = \sigma_{1\,\mathrm{to}2}\Phi_{\mathrm{photon}}$$

$$g_2 W_{2\,\mathrm{to}1} = g_1 W_{1\,\mathrm{to}2}$$

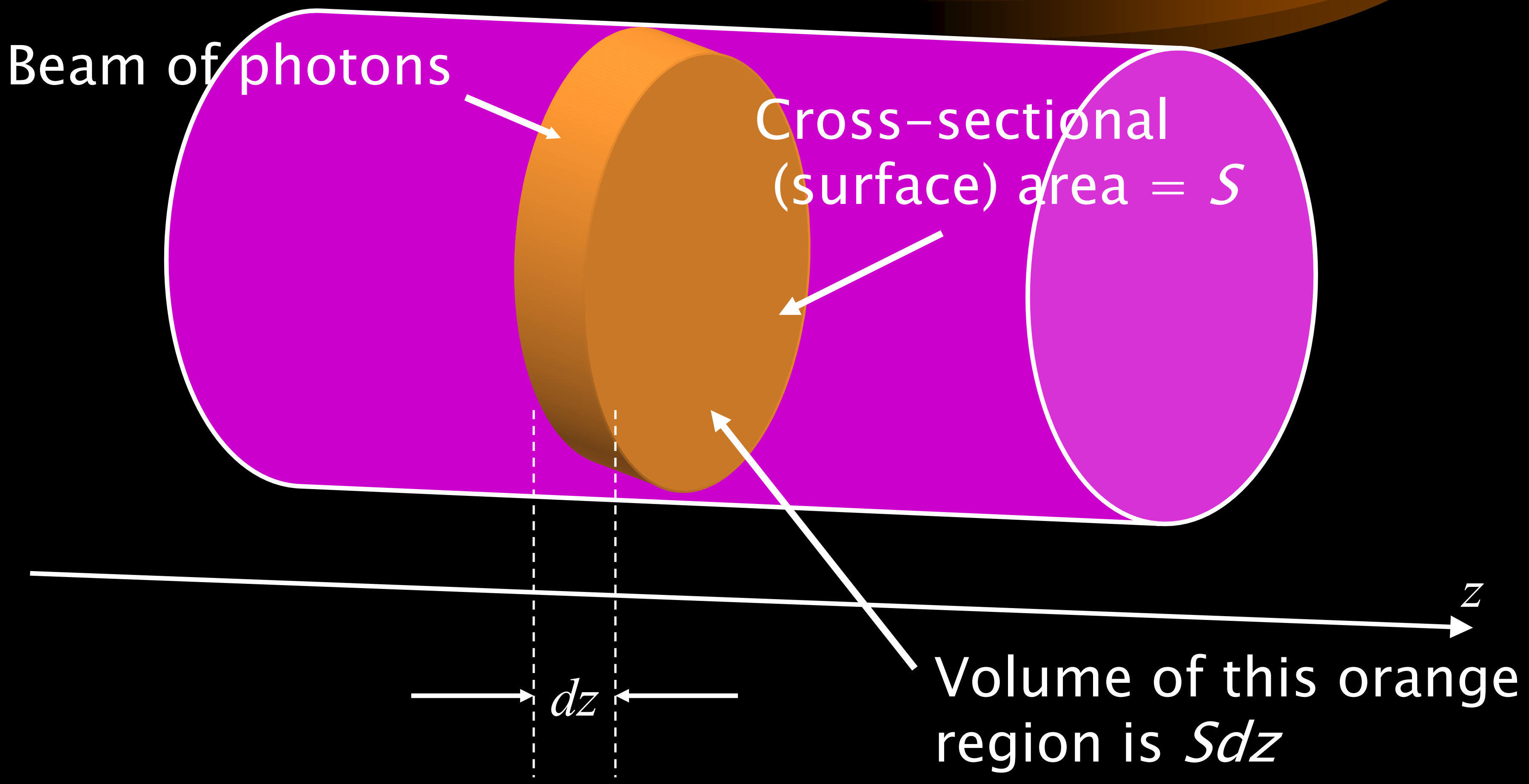
Level 1

The Laser Concept



As the beam travels, it will cause stimulated emission and absorption within the material.

The Laser Concept



The Laser Concept

How would we express the incremental change in photon flux ($d\Phi$) in the material due to the photon beam?

$$S d\Phi = \left(\left| \begin{matrix} \text{change in \# of photons} \\ \text{due to stim. emission} \\ \text{(per unit of time)} \end{matrix} \right| - \left| \begin{matrix} \text{change in \# of photons} \\ \text{due to stim. absorption} \\ \text{(per unit of time)} \end{matrix} \right| \right) S dz$$

$$S d\Phi = \left(\left. \frac{dN_2}{dt} \right|_{\text{stim. emiss.}} - \left. \frac{dN_2}{dt} \right|_{\text{stim. absorp.}} \right) S dz$$

$$W_{2\text{ to }1} = \sigma_{2\text{ to }1}\Phi_{\text{photon}}$$

$$W_{1\text{ to }2} = \sigma_{1\text{ to }2}\Phi_{\text{photon}}$$

$$g_2 W_{2\text{ to }1} = g_1 W_{1\text{ to }2}$$

The Laser Concept

$$Sd\Phi = \left(\left|\frac{dN_2}{dt}\right|_{\text{stim. emiss.}} - \left|\frac{dN_2}{dt}\right|_{\text{stim. absorp.}} \right) Sdz$$

$$Sd\Phi = \left(W_{2\text{ to }1}N_2 - W_{1\text{ to }2}N_1\right)Sdz$$

$$\frac{d\Phi}{dz} = \left(W_{2\text{ to }1}N_2 - W_{1\text{ to }2}N_1\right)$$

$$\frac{d\Phi}{dz} = \left[\sigma_{2\text{ to }1}\left(N_2 - \frac{g_2}{g_1}N_1\right)\right]\Phi$$

The Laser Concept

$$\frac{d\Phi}{dz} = \left[\sigma_{2\text{ to }1} \left(N_2 - \frac{g_2}{g_1} N_1 \right) \right] \Phi$$

$$\frac{d\Phi}{dz} > 0 \Rightarrow \textit{amplifier}$$

"Population inversion"

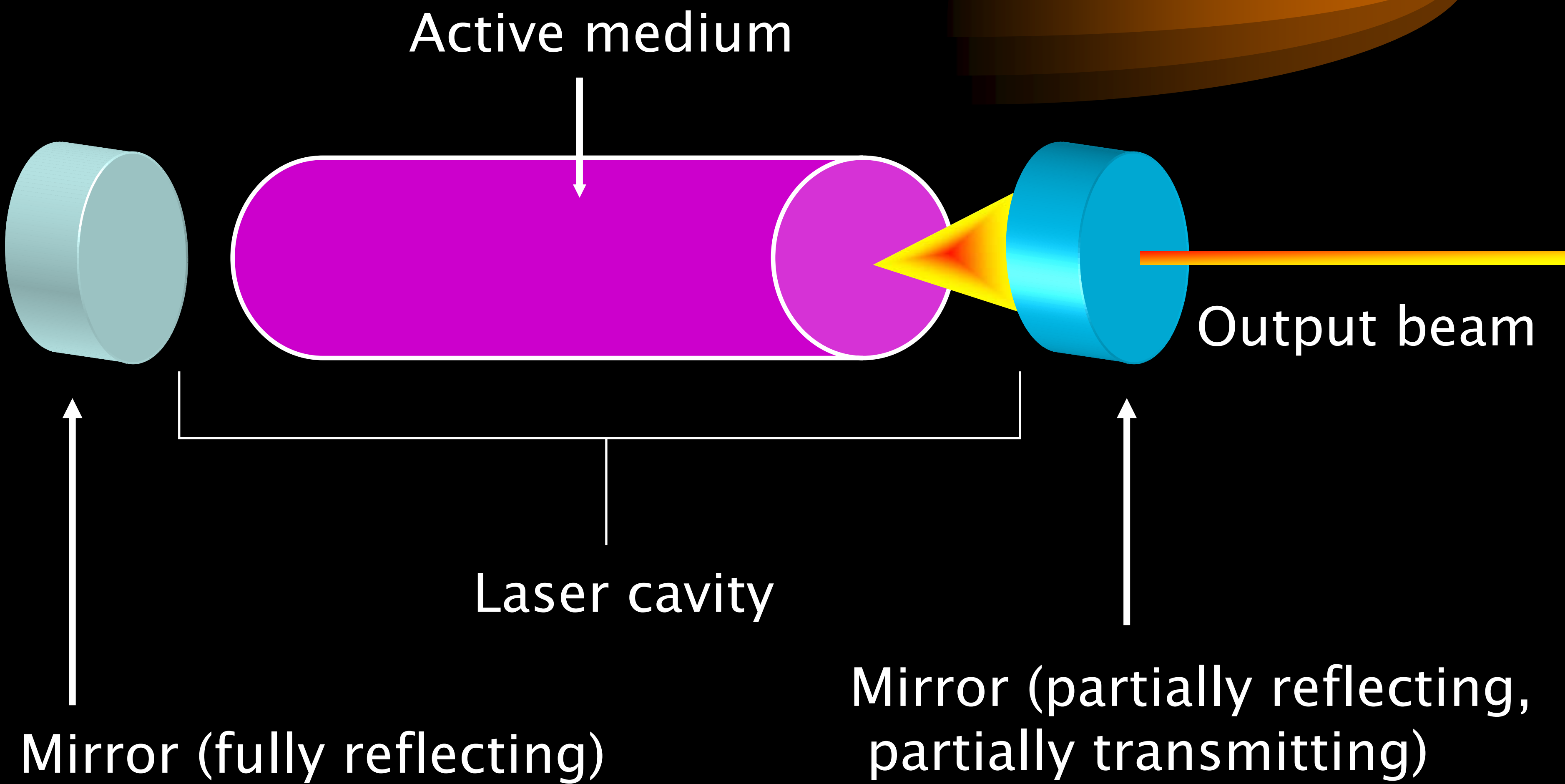
In thermal equilibrium: material acts as an absorber

Some materials: amplifiers when not in thermal equilibrium

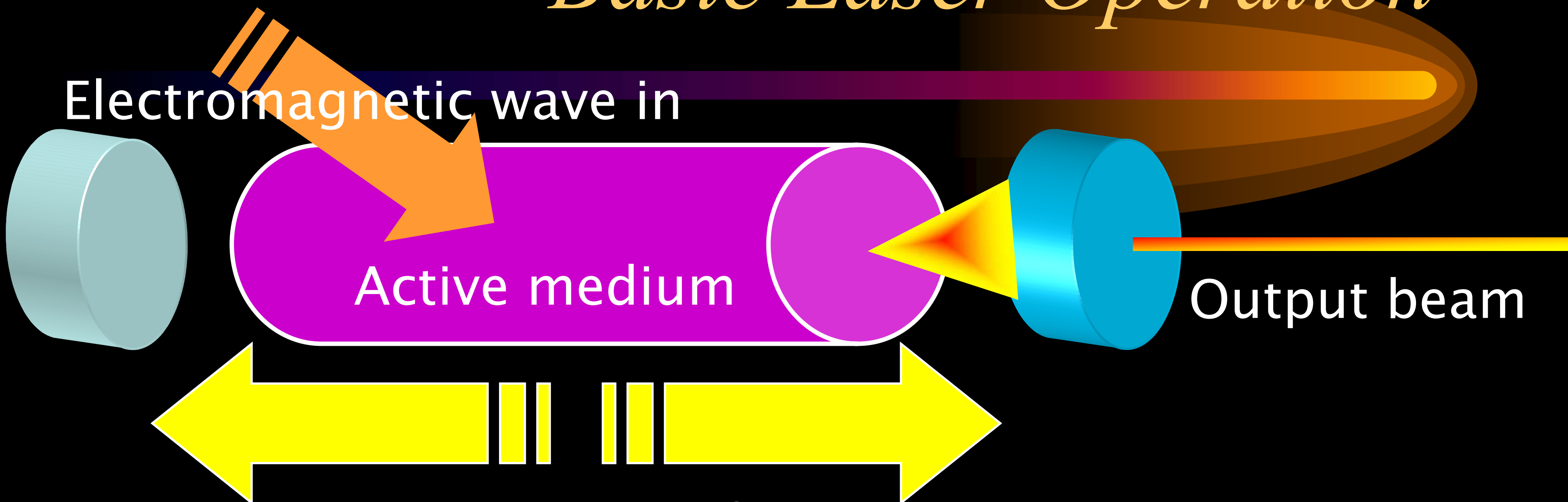
$\Downarrow$

ACTIVE MEDIUM

Components of a Laser



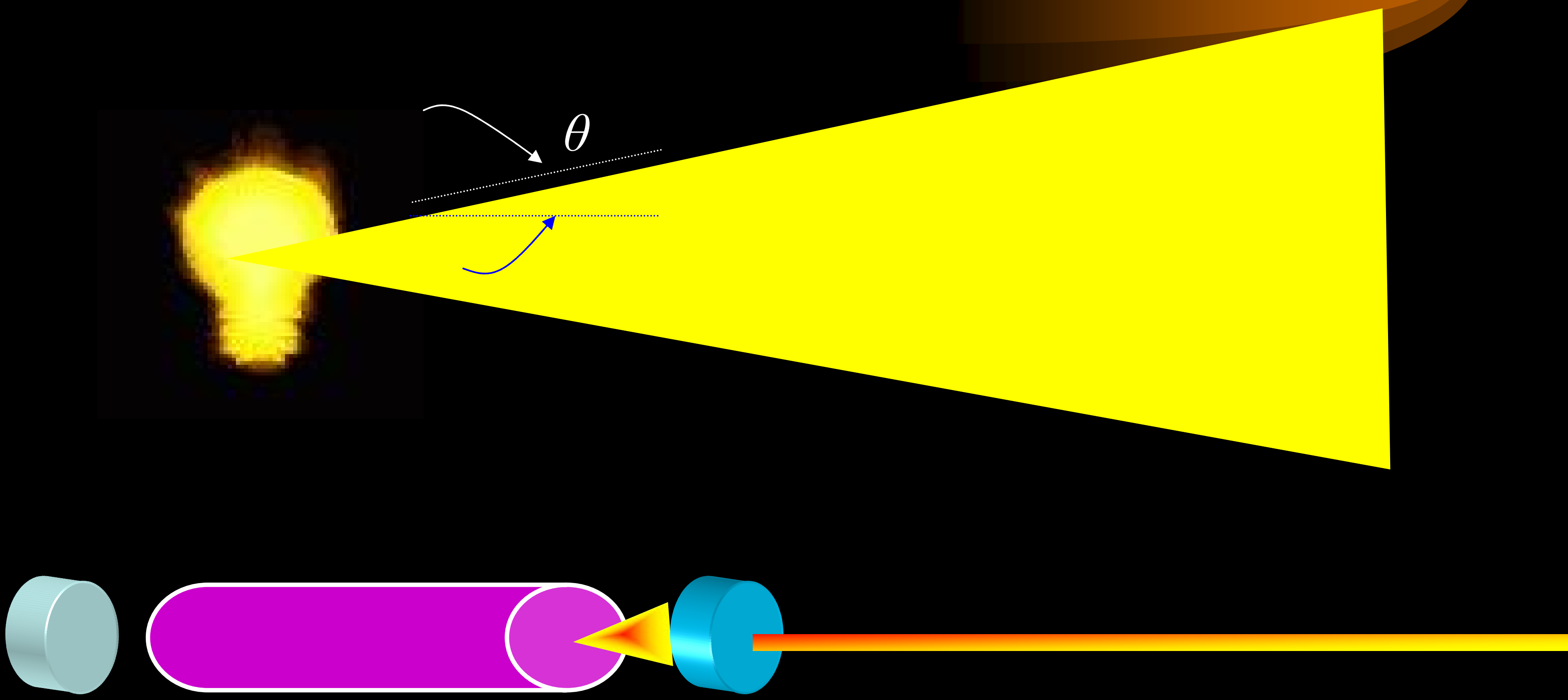
Basic Laser Operation



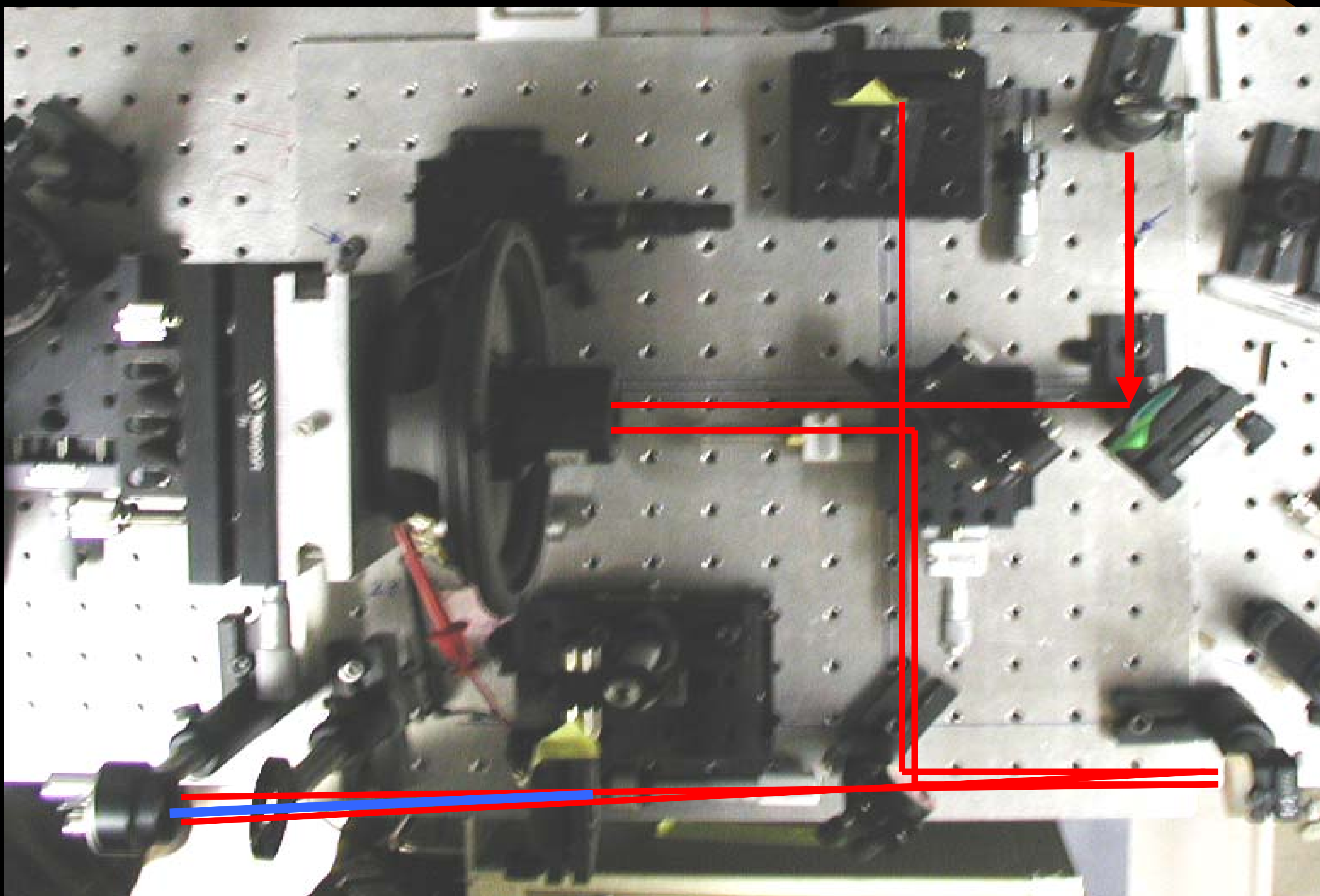
EM wave is repeatedly reflected within the laser cavity

If the frequency (f) of the output beam is . . .
microwave region (1 GHz – 30 THz) . . . MASER
optical region (430 THz – 750 THz) . . . LASER

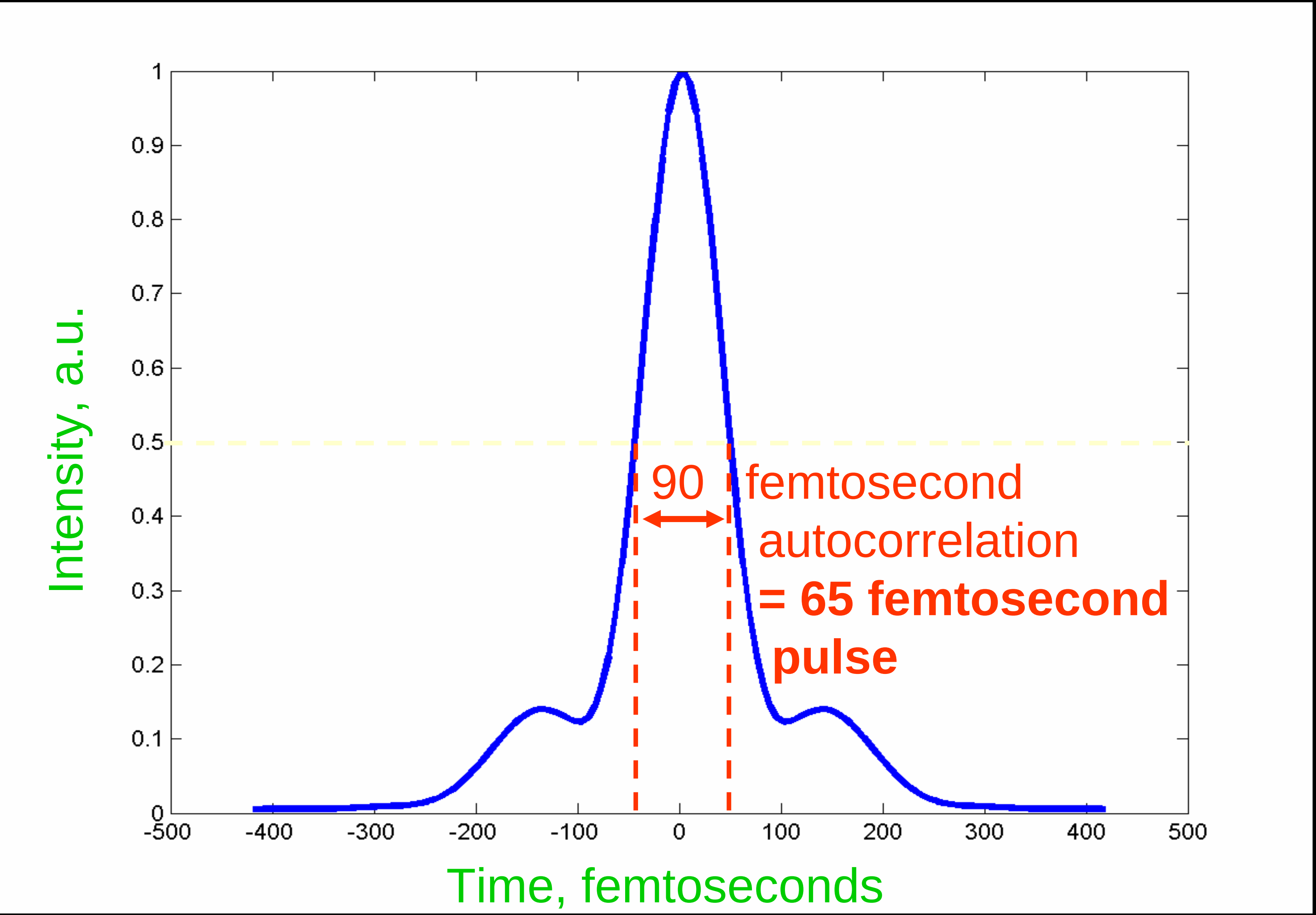
Properties of Laser Beams



Characterizing Fast Laser Pulses: Autocorrelation



Characterizing Fast Pulses: Autocorrelation



Summary

- The electromagnetic spectrum
- Energy level diagram representation
- Spontaneous and stimulated emission, absorption
- The laser concept: rate equations, population inversion, amplification
- Properties of laser beams
- Autocorrelation: characterizing femtosecond laser pulses

Thank You

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