The Laser at 50: Past, present and future

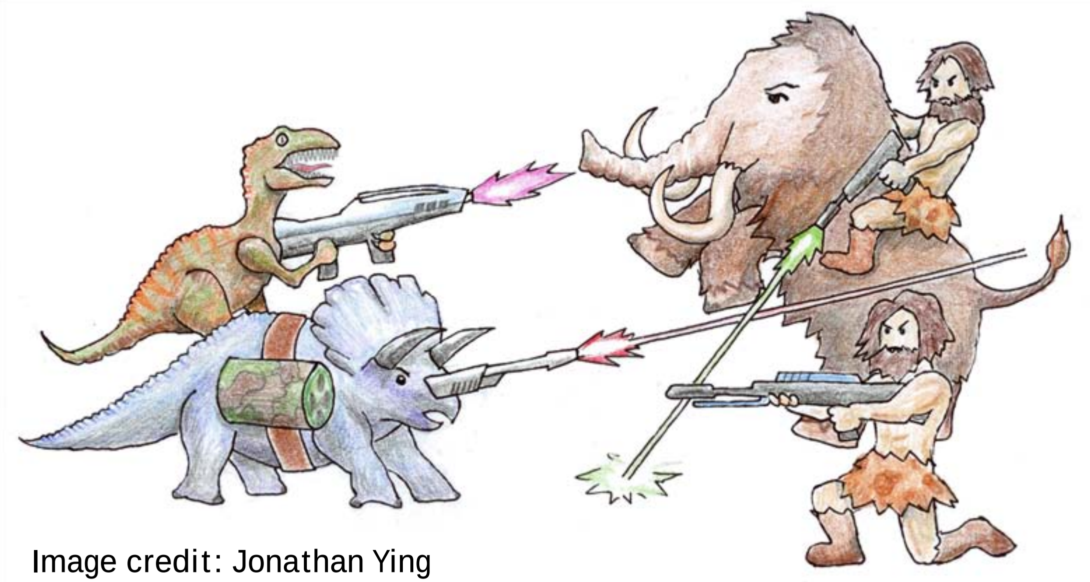

Image credit: Jonathan Ying

Lasers

Mikhail Kats — How Lasers Work

Romain Blanchard — Our Information Age

Ted Feldman — Power for the Future

LASER

Light
Amplification by
Stimulated
Emission of
Radiation

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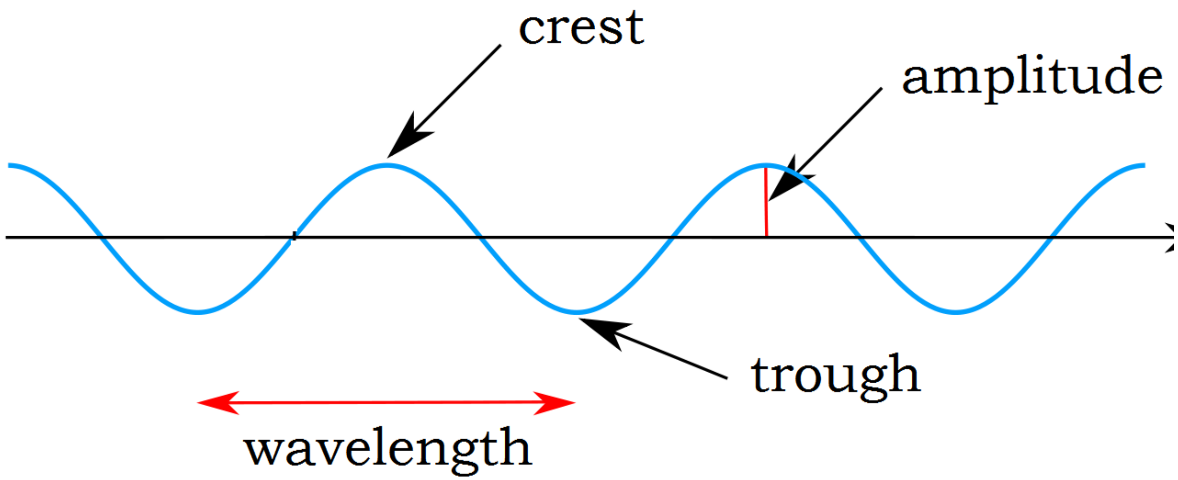
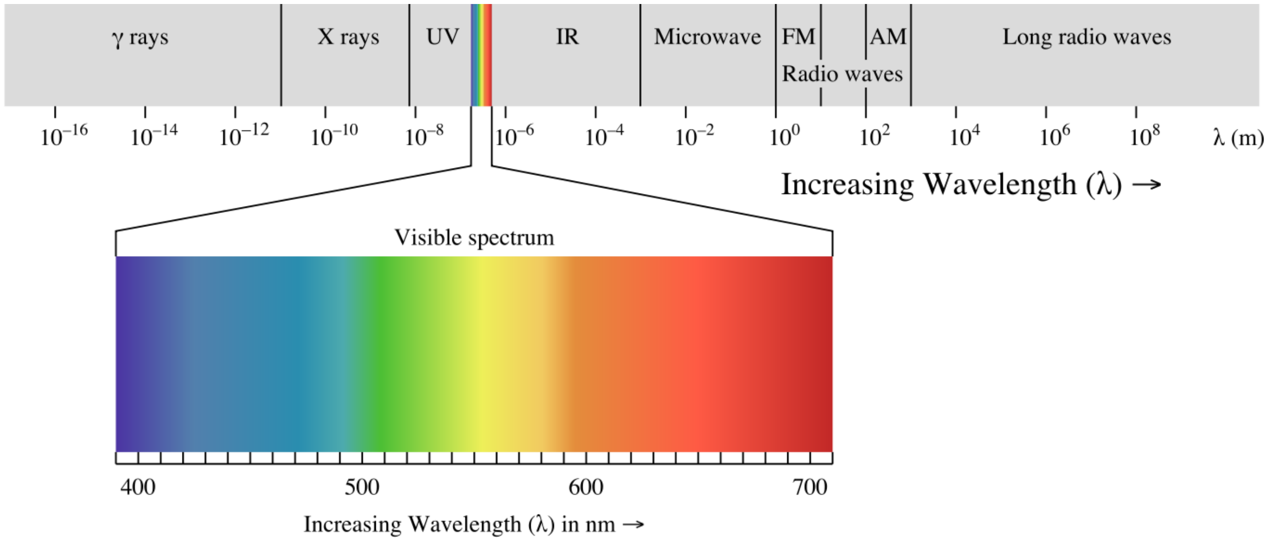
Light
Amplification by
Stimulated
Emission of
Radiation

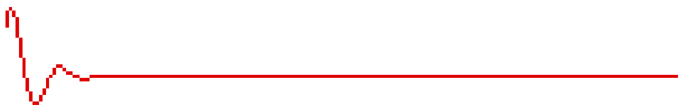
Light: electromagnetic wave



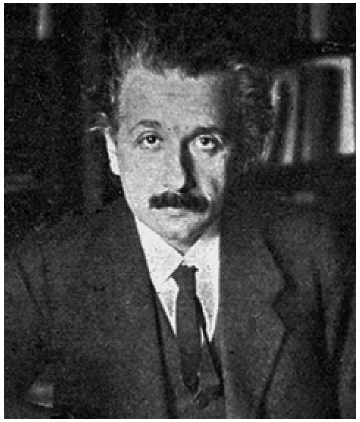


Photons: bits of light

- A single packet of light: a photon



Smaller wavelength ← → larger photon energy



- "Wave – particle duality"
- Helps understand interaction between light and atoms

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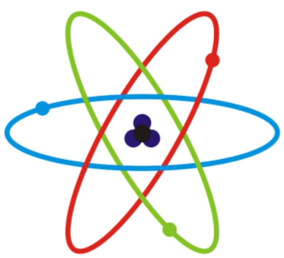
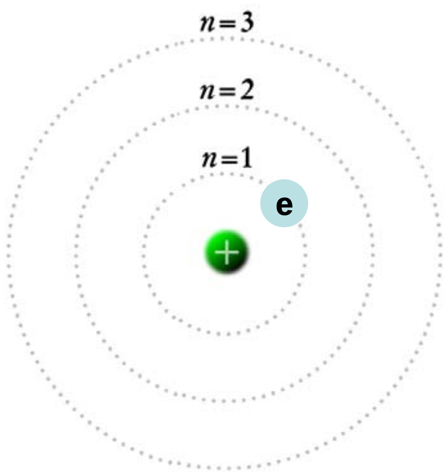
But first… atoms!



Atoms and atomic levels

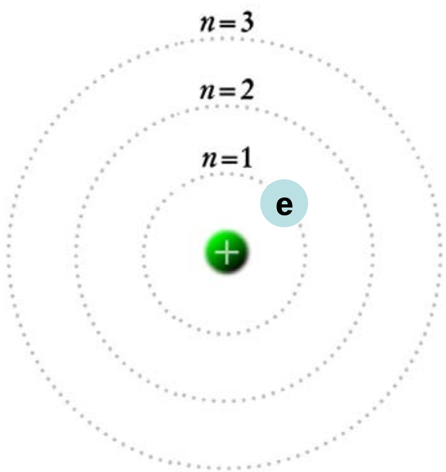
- Atom: positively charged nucleus surrounded by negatively charged electrons



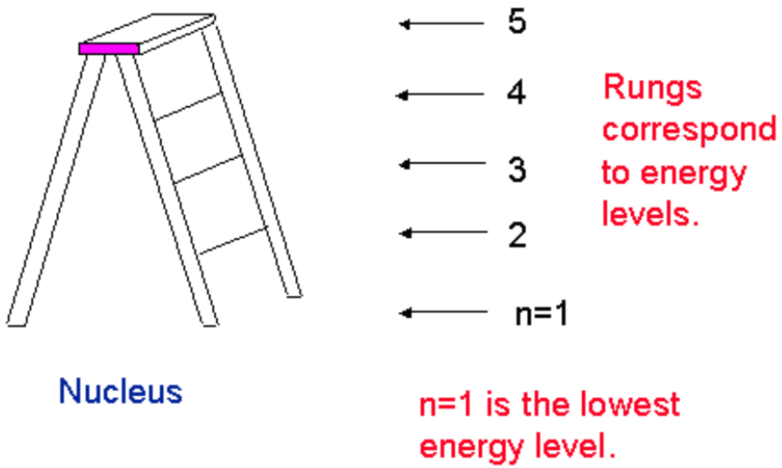
Simplistic orbit picture

Atoms and atomic levels

- Atom: positively charged nucleus surrounded by negatively charged electrons

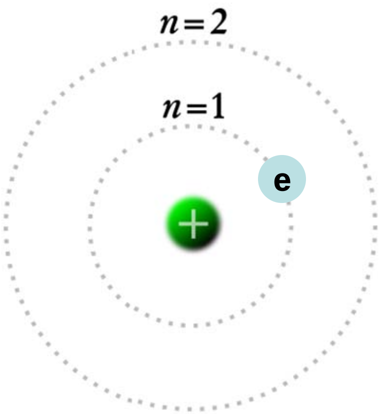


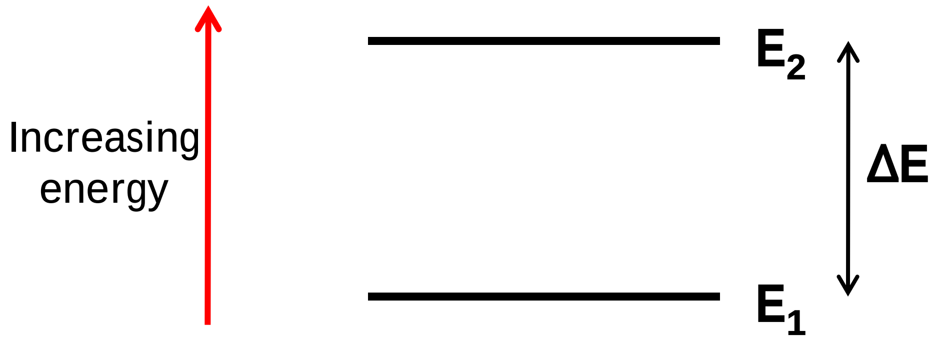
Simplistic orbit picture



A helpful analogy:
The quantum stepladder

2 level atom

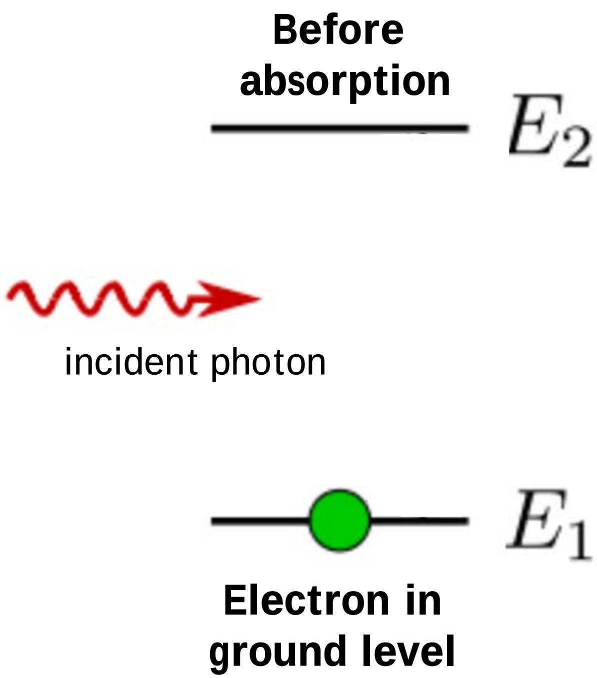


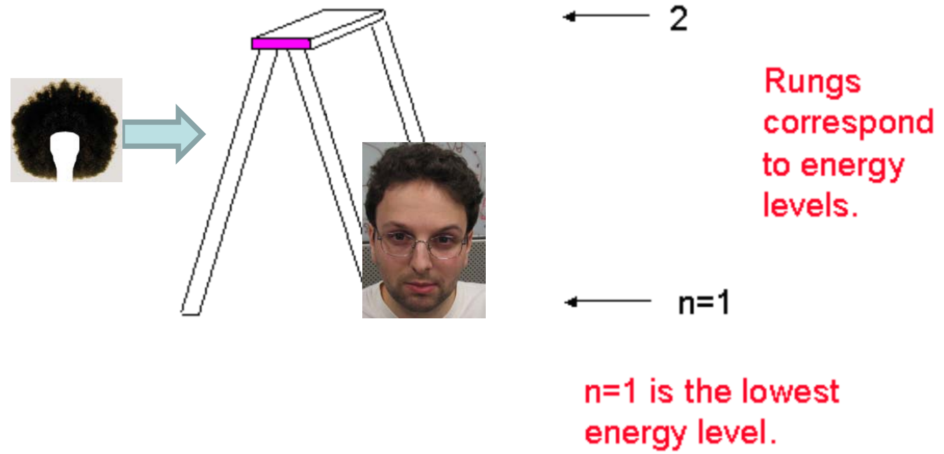


- Simplest model atom
- 2 discrete energy levels – one lower energy, one higher energy

Image source: Wikimedia Commons (modified)

Absorption





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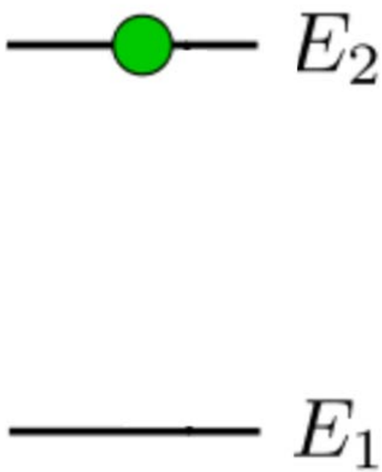
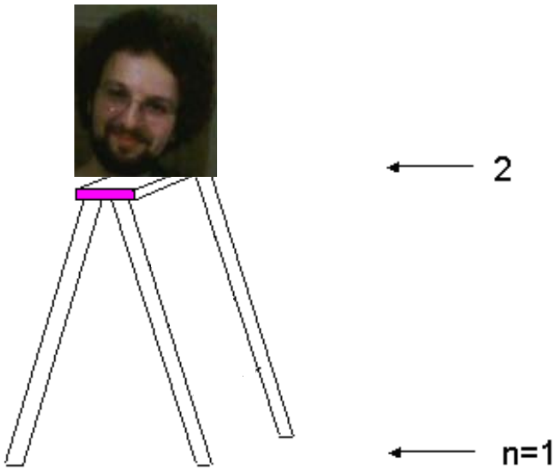
Absorption

After absorption



Electron in excited level



Rungs correspond to energy levels.

n=1 is the lowest energy level.

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Amplification by

Stimulated

Emission of

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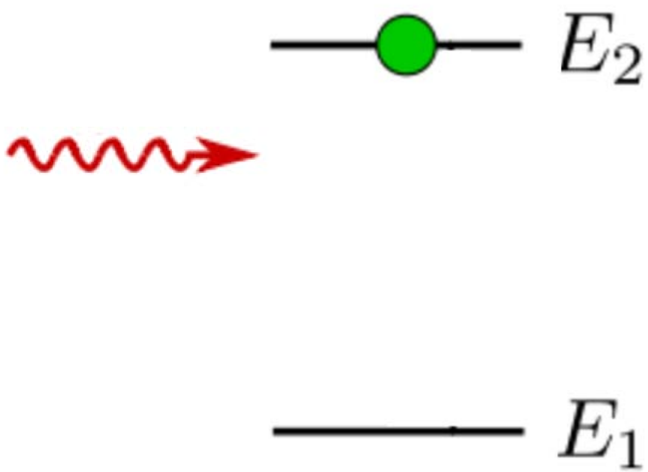
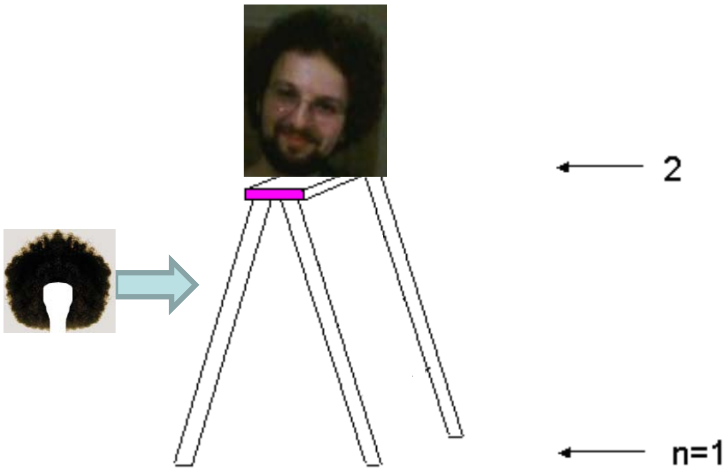
Stimulated Emission



Electron in an excited level

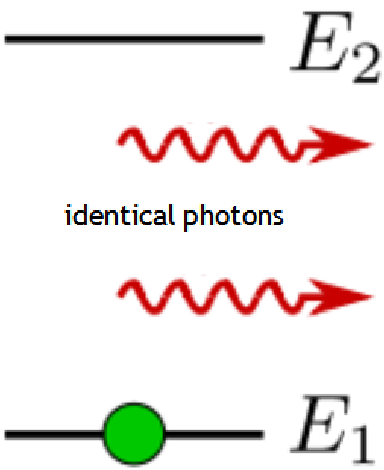


Rungs correspond to energy levels.

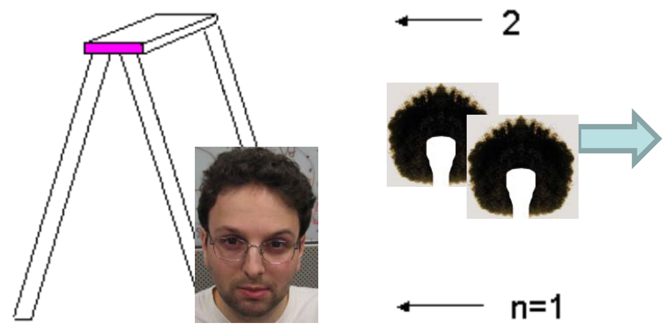
n=1 is the lowest energy level.

- A photon is hits an already excited atom…

Stimulated Emission



Electron back to ground level



n=1 is the lowest energy level.

- The two resulting photons are identical in every way! (wavelength, direction, and they wave in sync)

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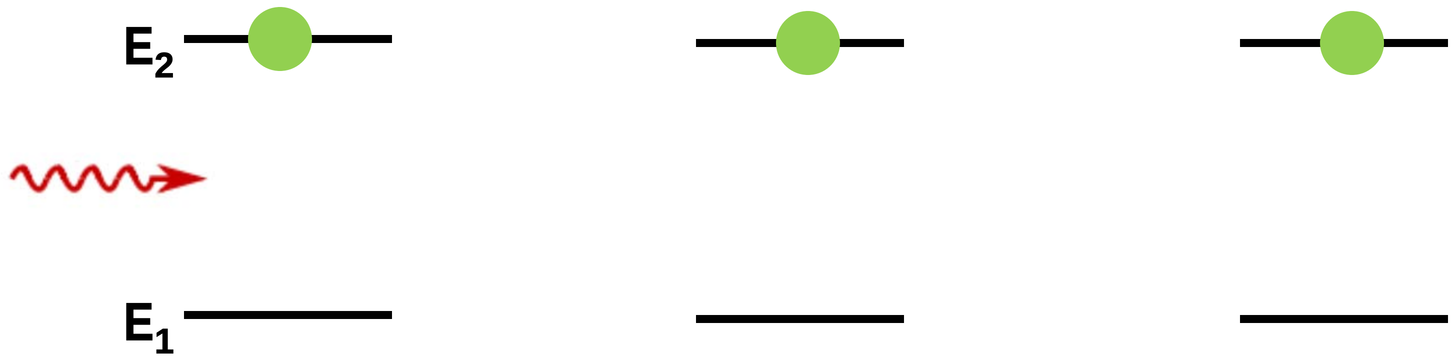
Amplification by
Stimulated
Emission of
Radiation

Light Amplification

- Take a piece of material with many two-level atoms, with all electrons in level 2
- A single photon traveling through this crystal will result In many photons (and put all electrons in the ground level)!



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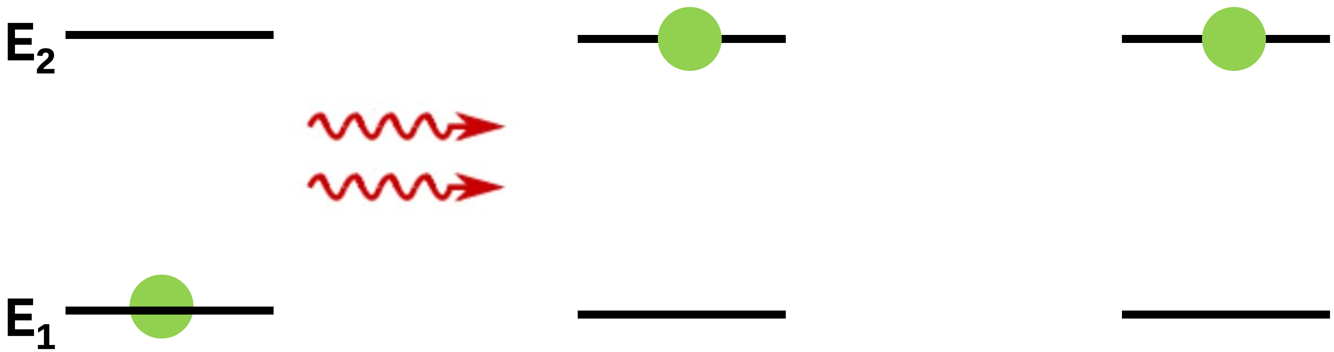

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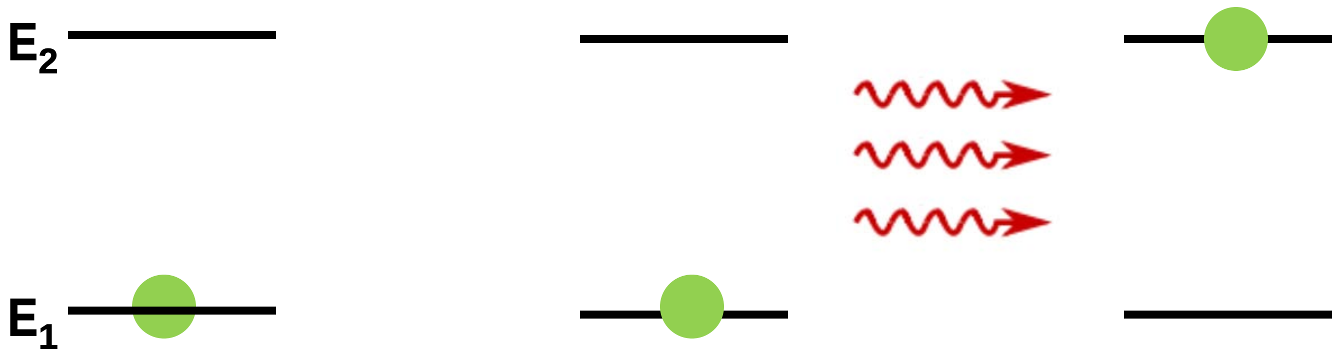

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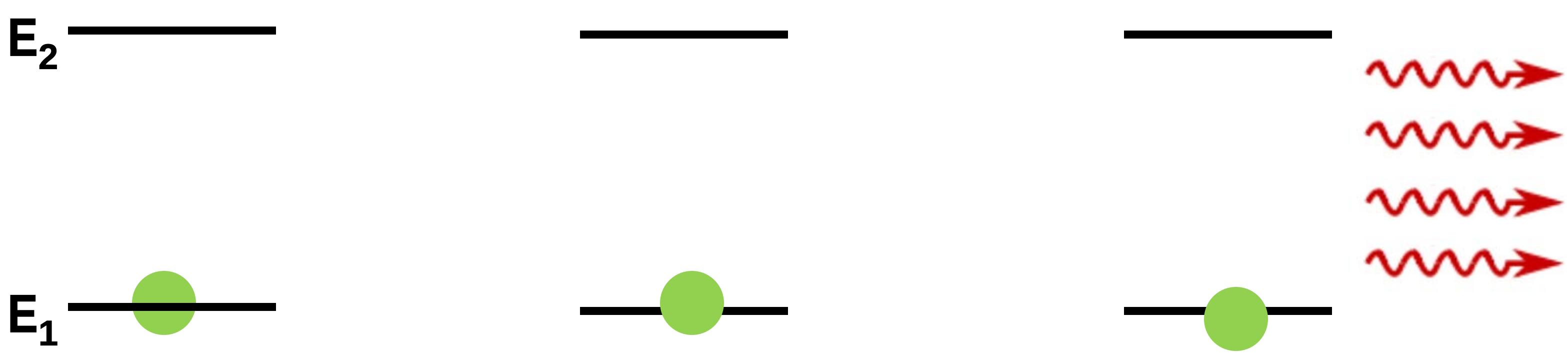
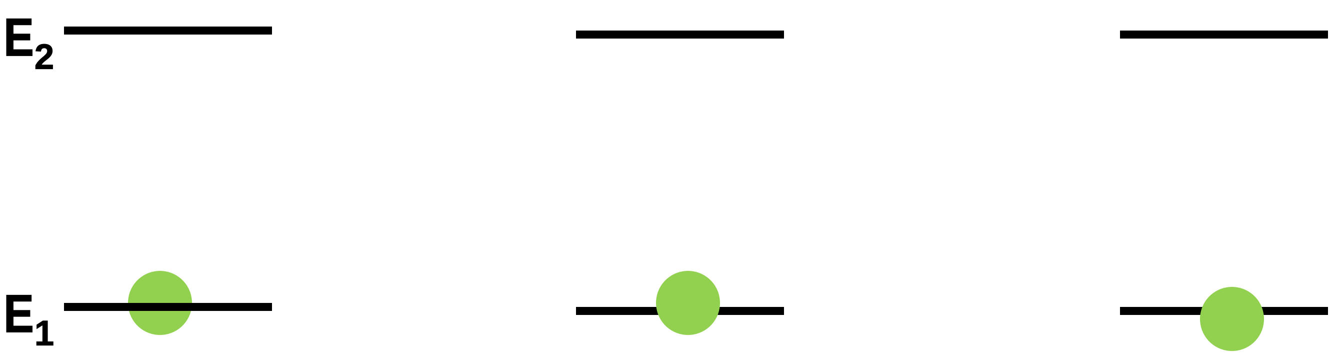


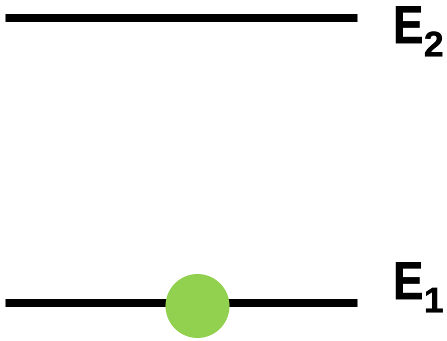
Light Amplification?



- But now… all of the electrons are in the ground level! No more amplification ☹

Constant amplification

- All electrons in our crystal need to constantly be re-excited to level 2
  - How do we get there? Add a third level!



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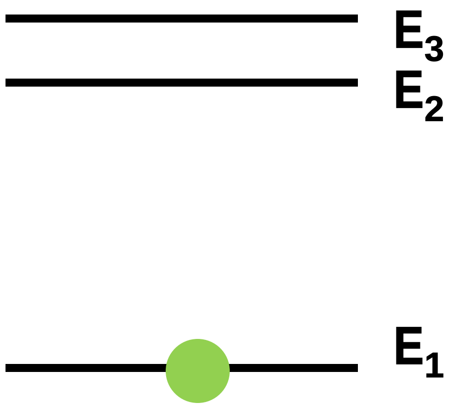
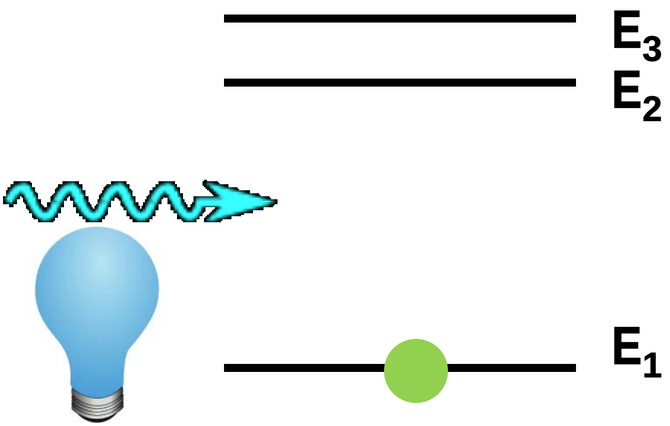


Constant amplification

- All electrons in our crystal need to constantly be re-excited to level 2
  - How do we get there? Add a third level!
  - Constant pumping by absorption of a different frequency!



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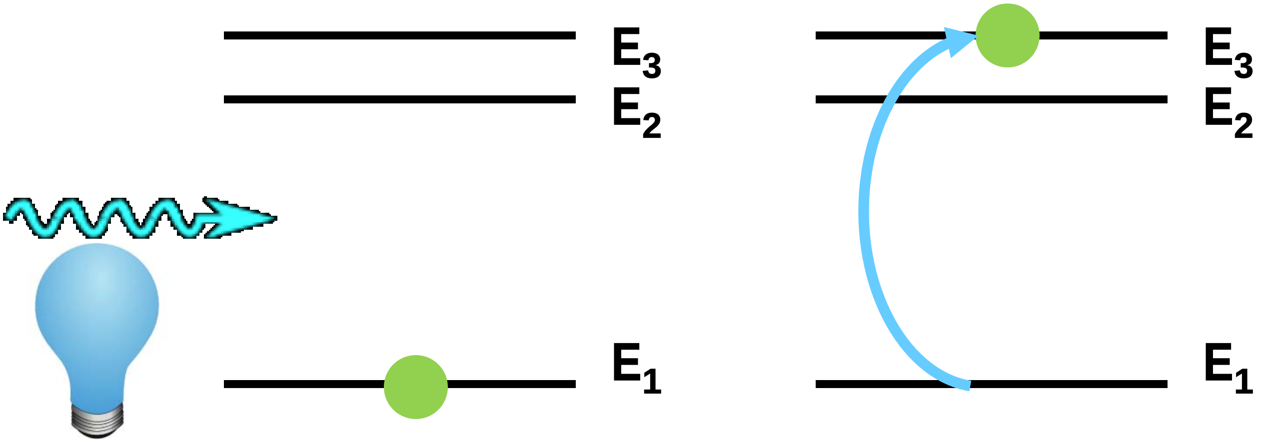

Constant amplification

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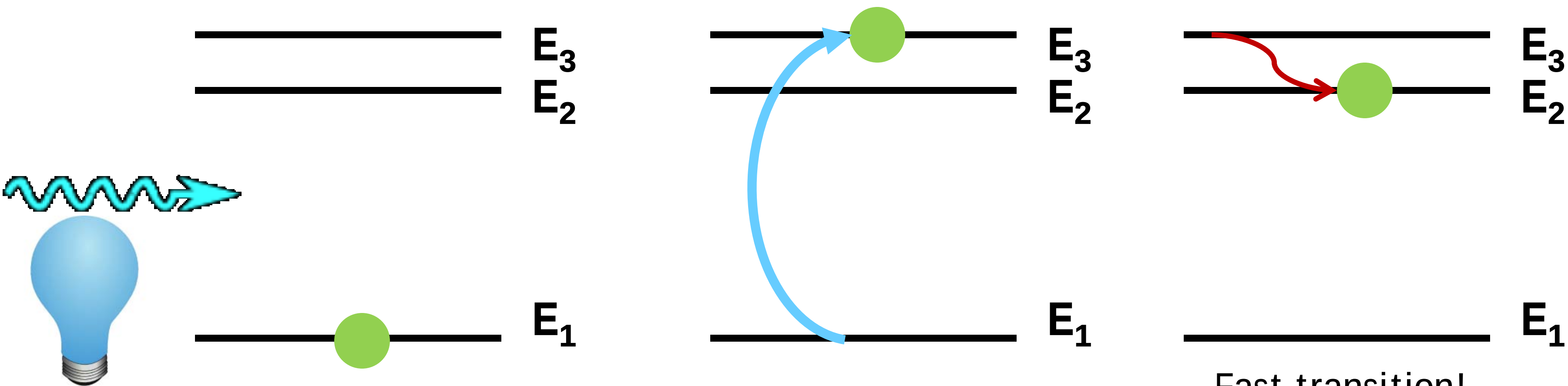
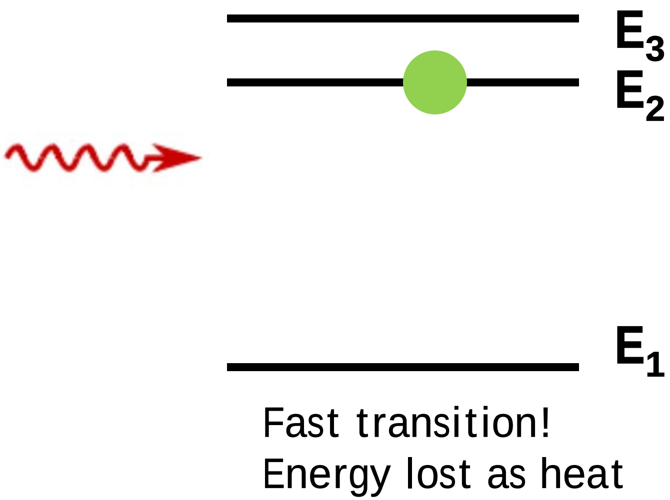


Fast transition!
Energy lost as heat

Constant amplification

- All electrons in our crystal need to constantly be re-excited to level 2
  - How do we get there? Add a third level!
  - Constant pumping by absorption of a different frequency!



Constant amplification

- All electrons in our crystal need to constantly be re-excited to level 2
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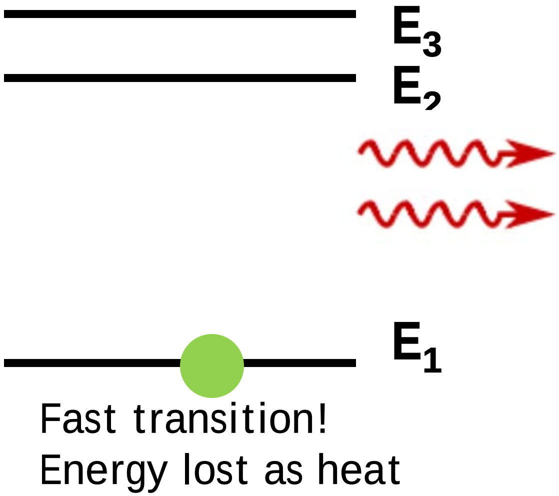

Constant amplification

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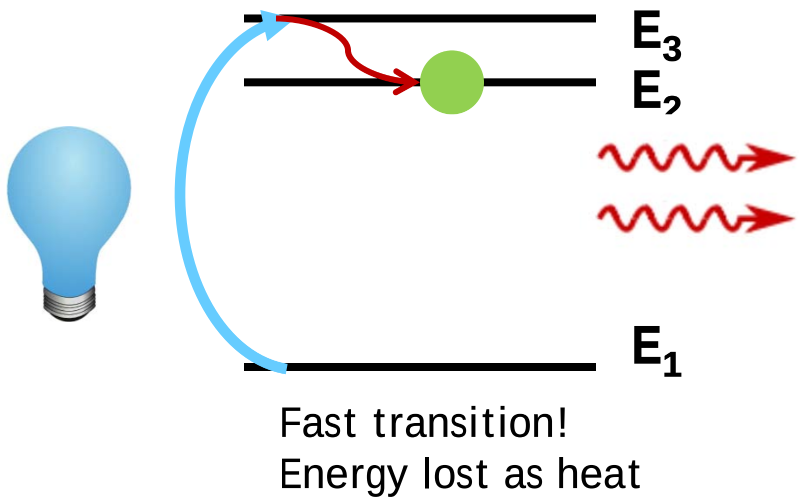
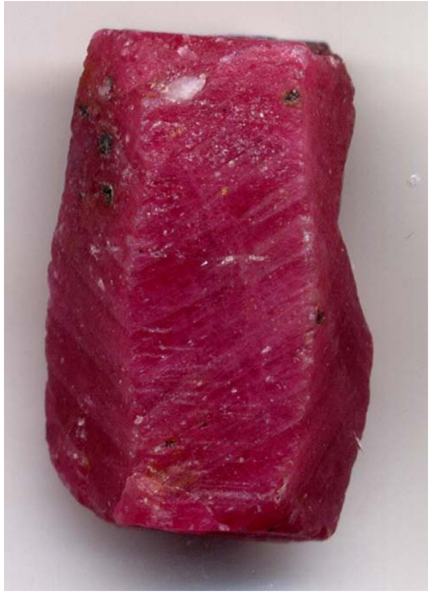
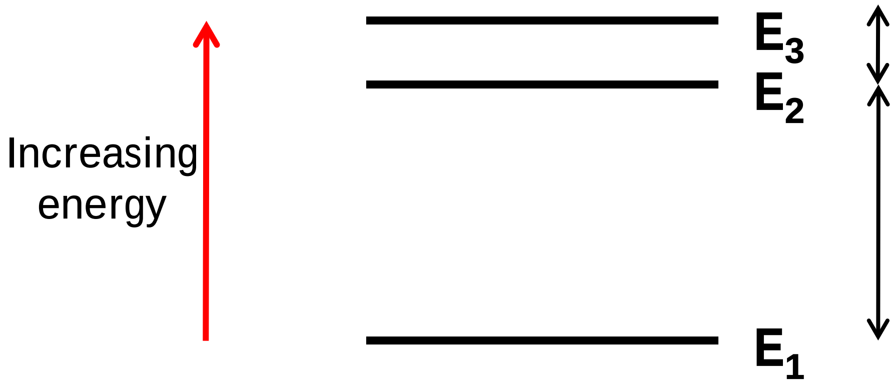


Atomic levels: ruby

- Ruby: Sapphire (Al_2O_3) crystal with 0.5% chrome atoms replacing aluminum



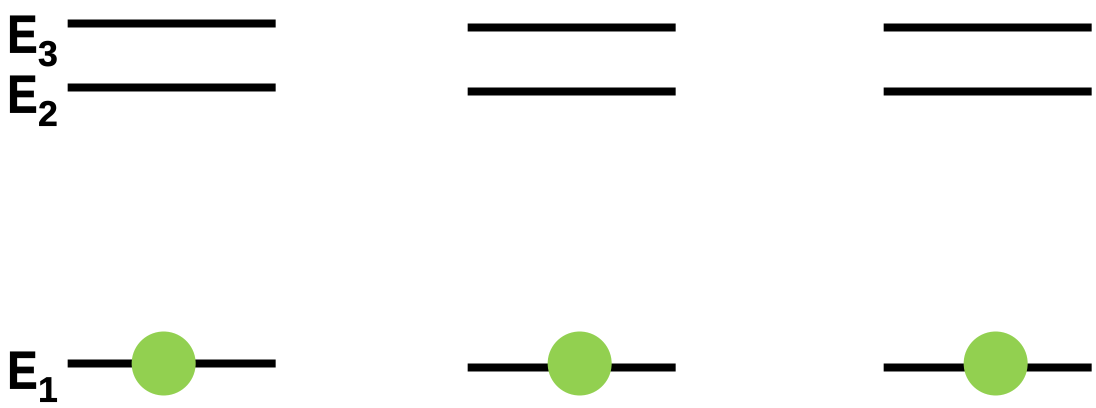


(very) simplified energy level diagram

- Each chrome atom in the crystal acts like a 3 level system!

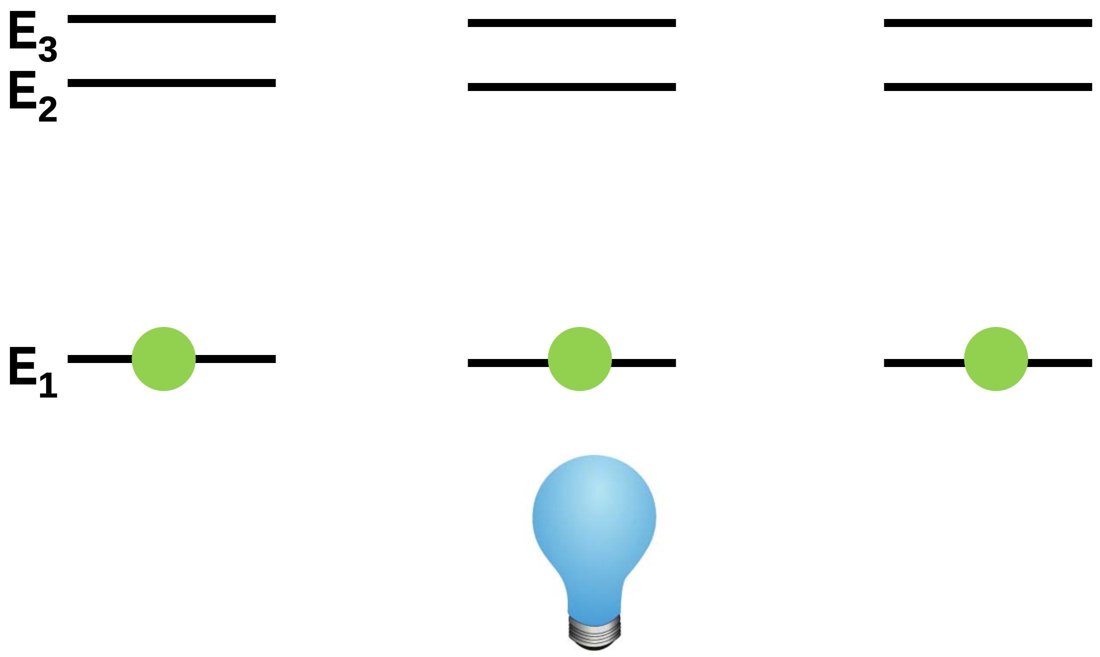
Laser cavity

- Start with a Ruby with all electrons in the ground state…



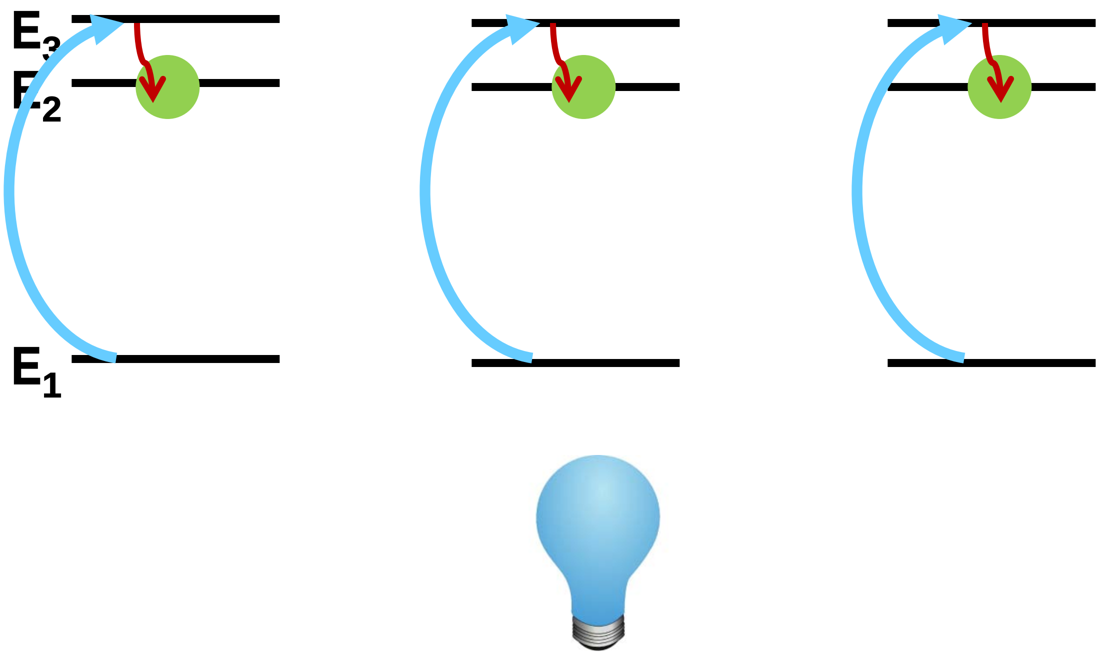
Laser cavity

- Turn on the pump light!



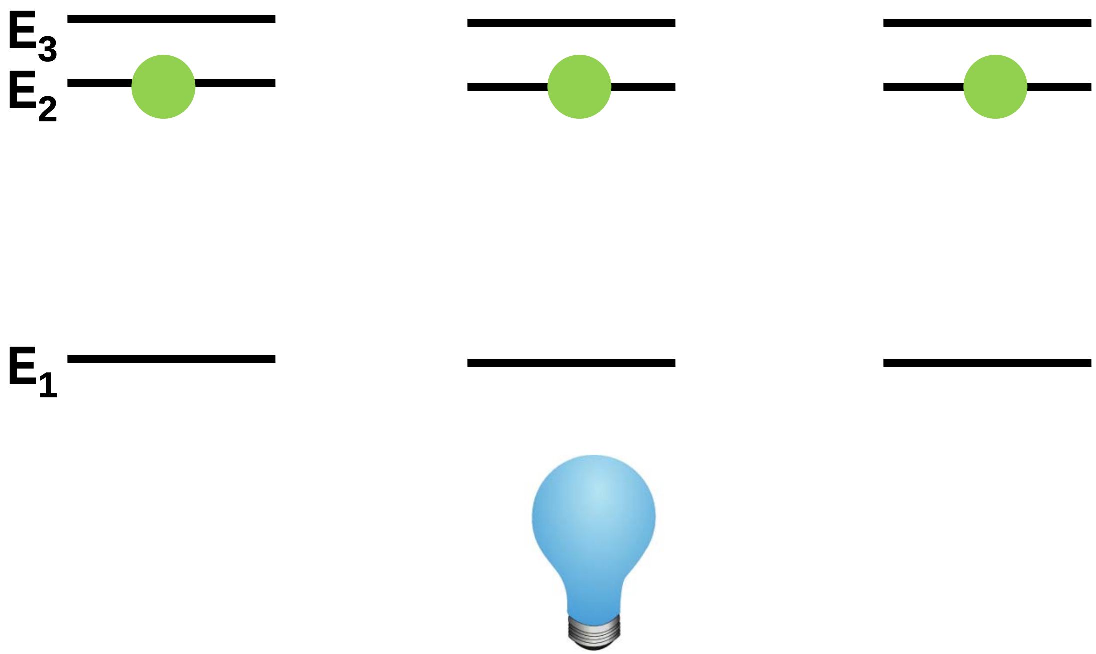
Laser cavity

- Pump light ensures all electrons are in state 2



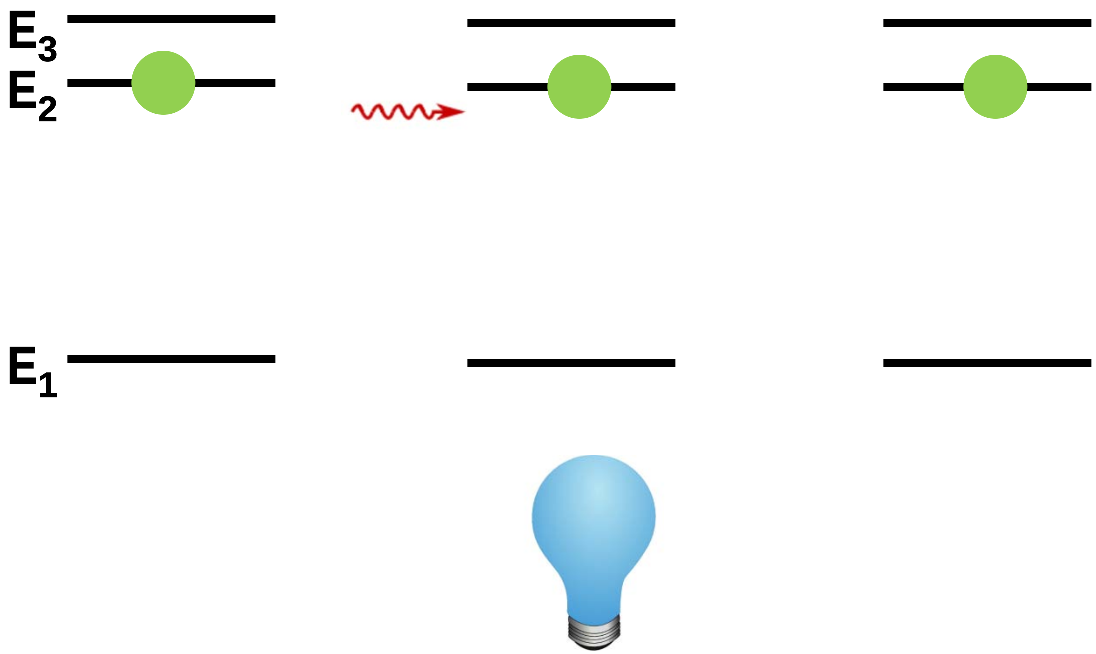
Laser cavity

- Pump light ensures all electrons are in state 2



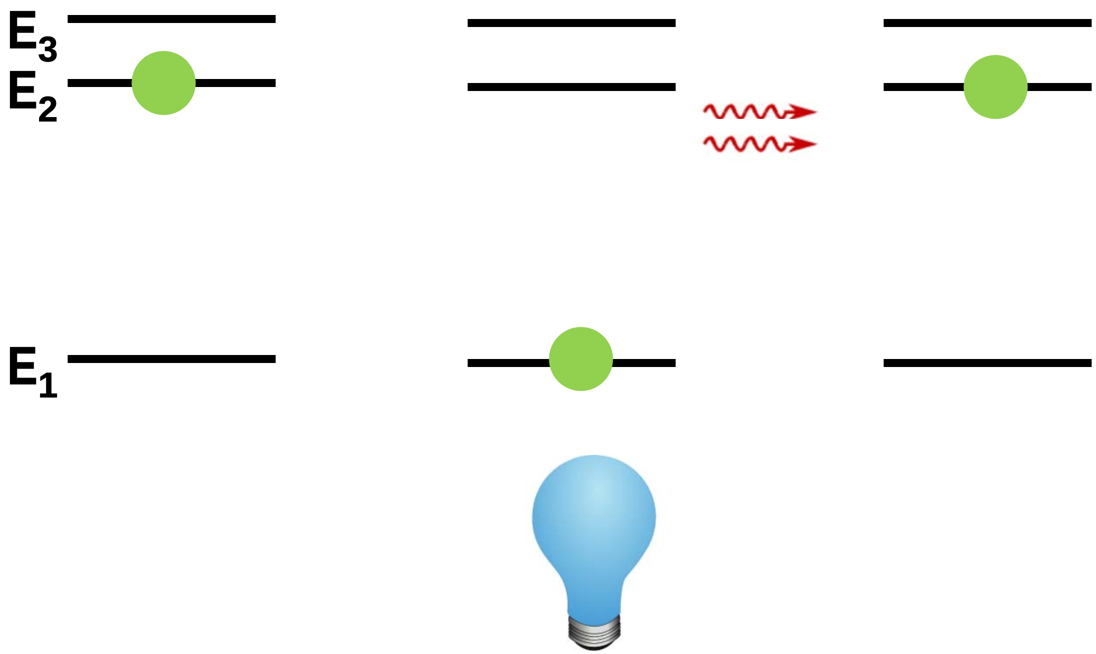
Laser cavity

- Start with just one photon somewhere in the Ruby…



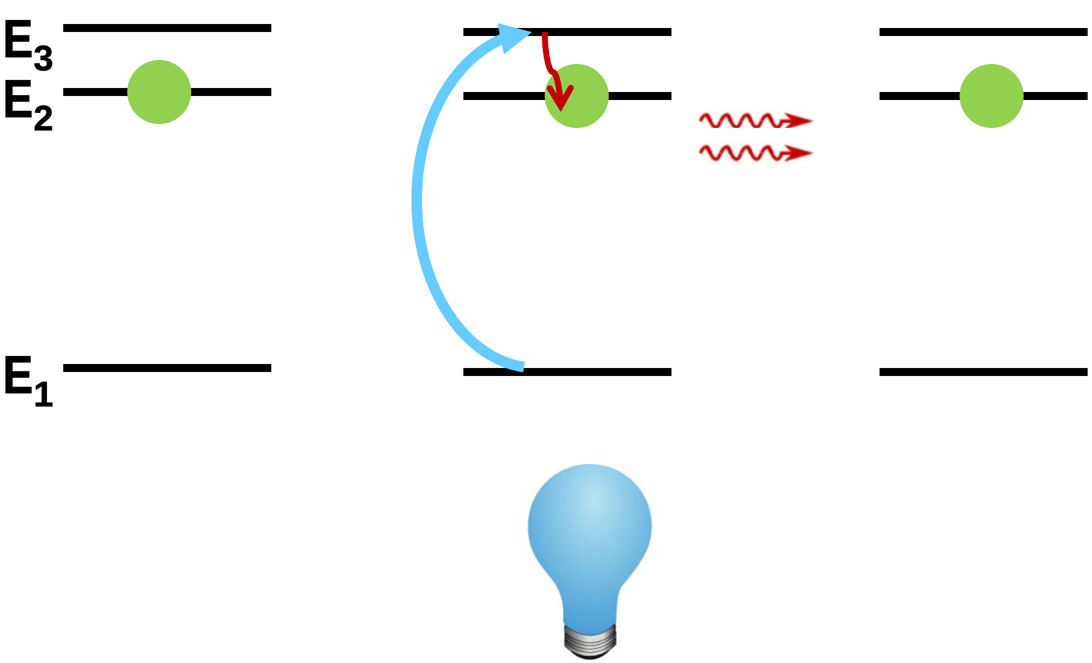
Laser cavity

- Stimulated emission!

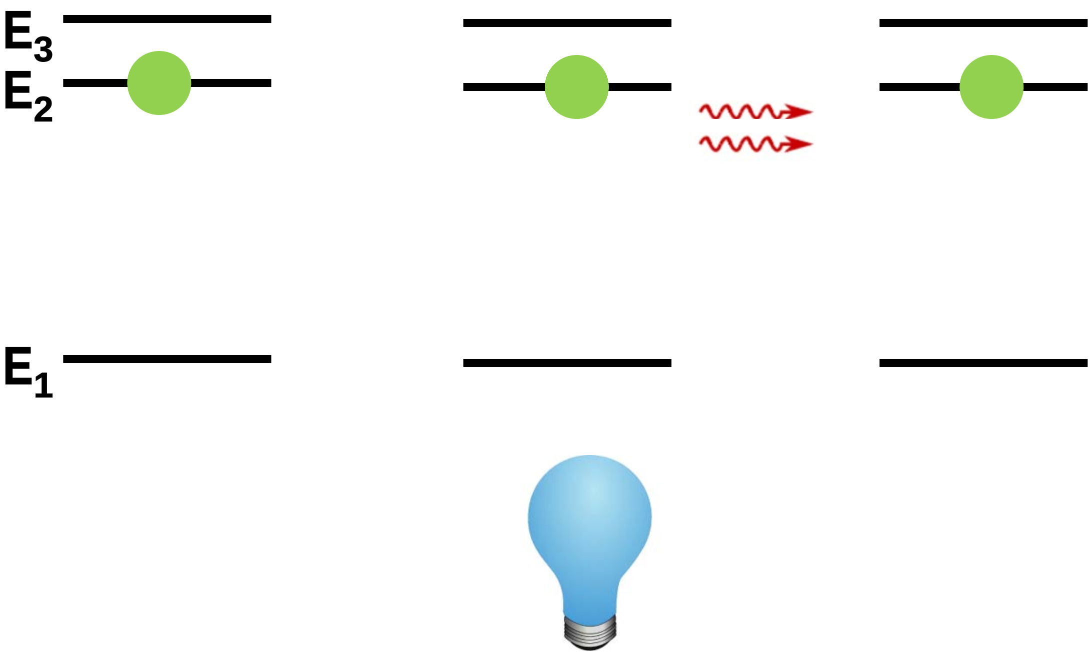


Laser cavity

- Pumping: Absorption and fast relaxation!

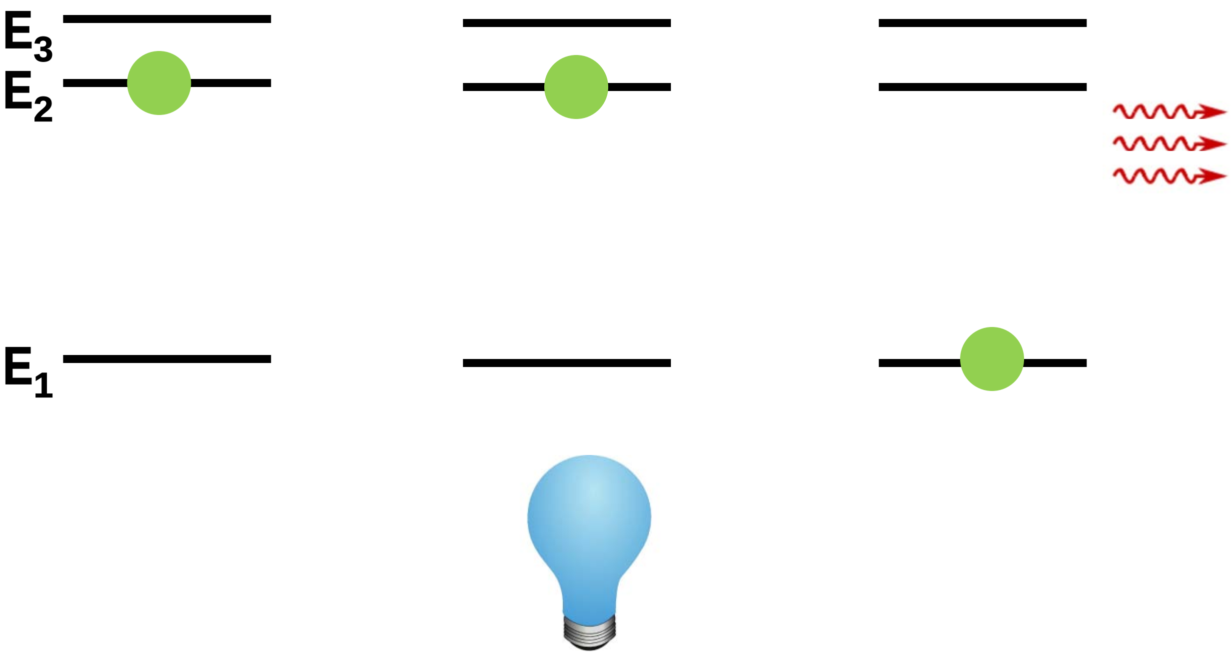


Laser cavity



Laser cavity

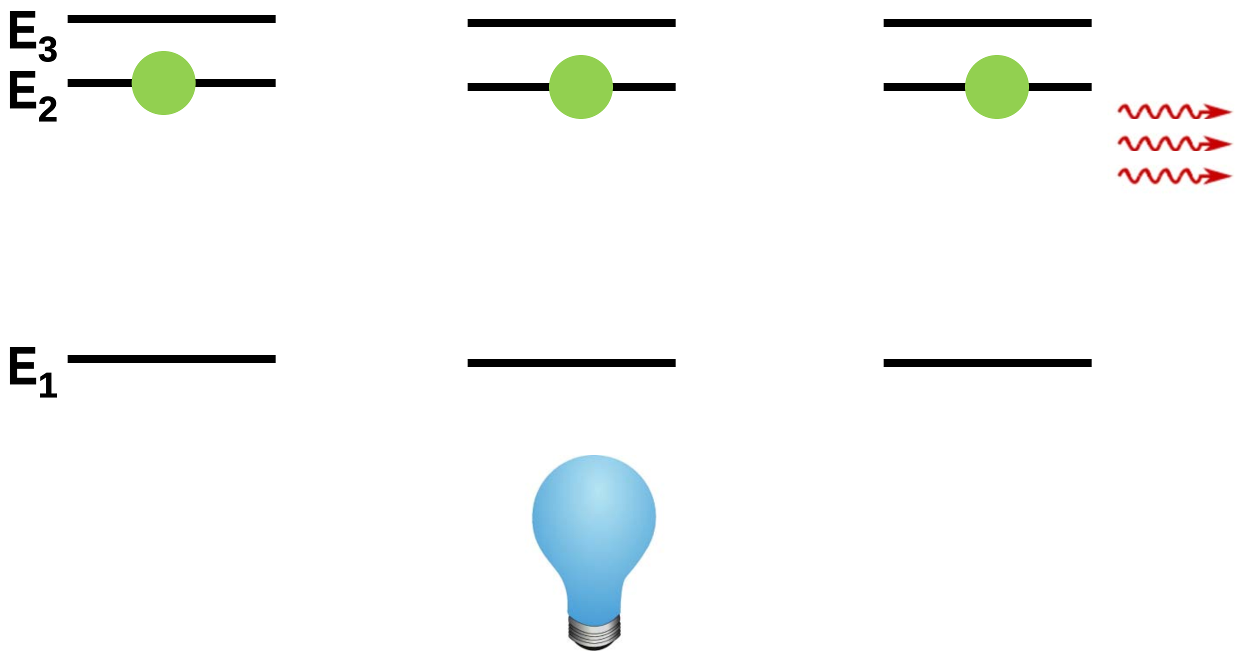
- Stimulated emission!



Laser cavity

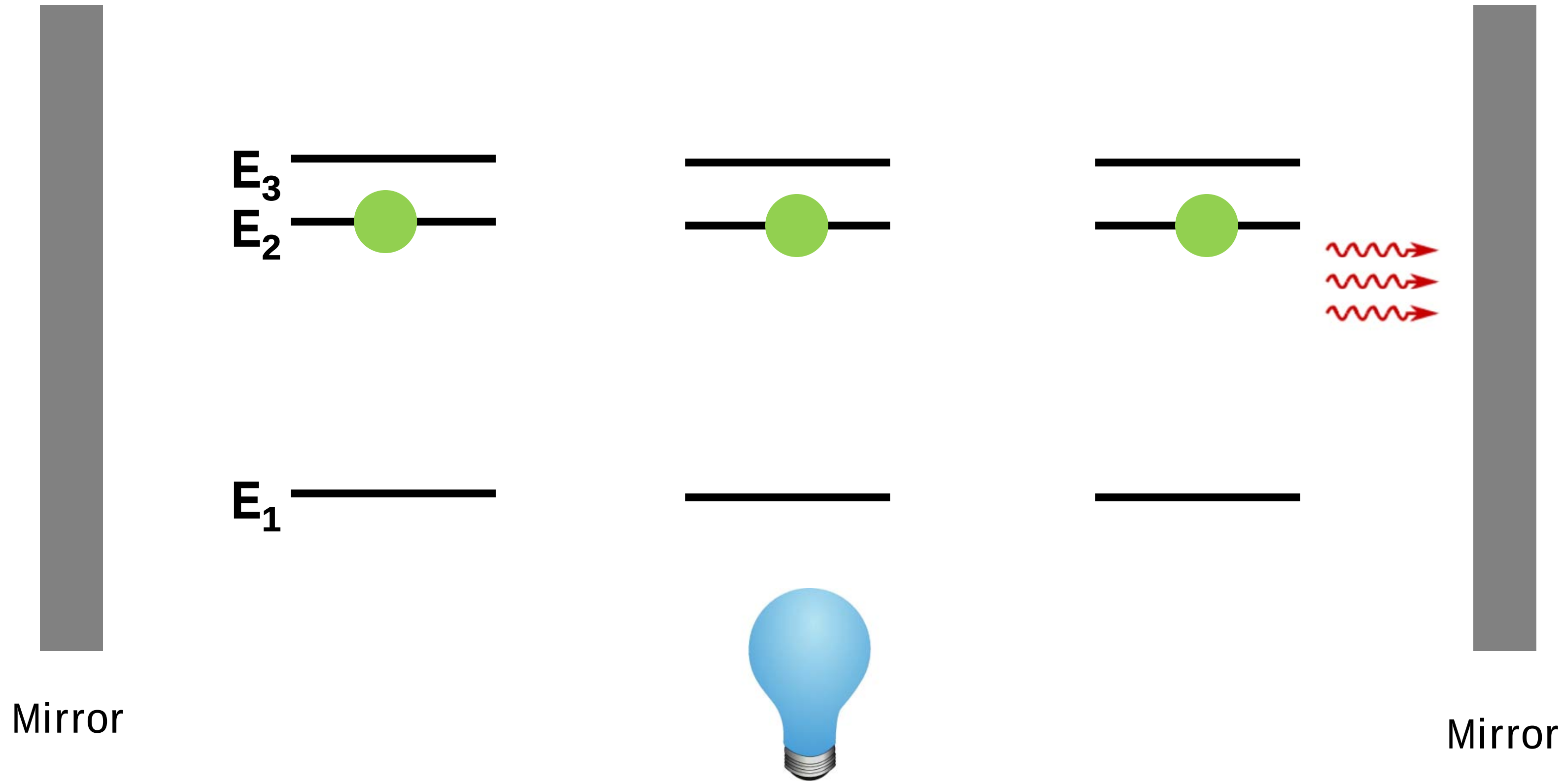
- Pumping: absorption and fast relaxation!

But now what? How do we get even more photons?



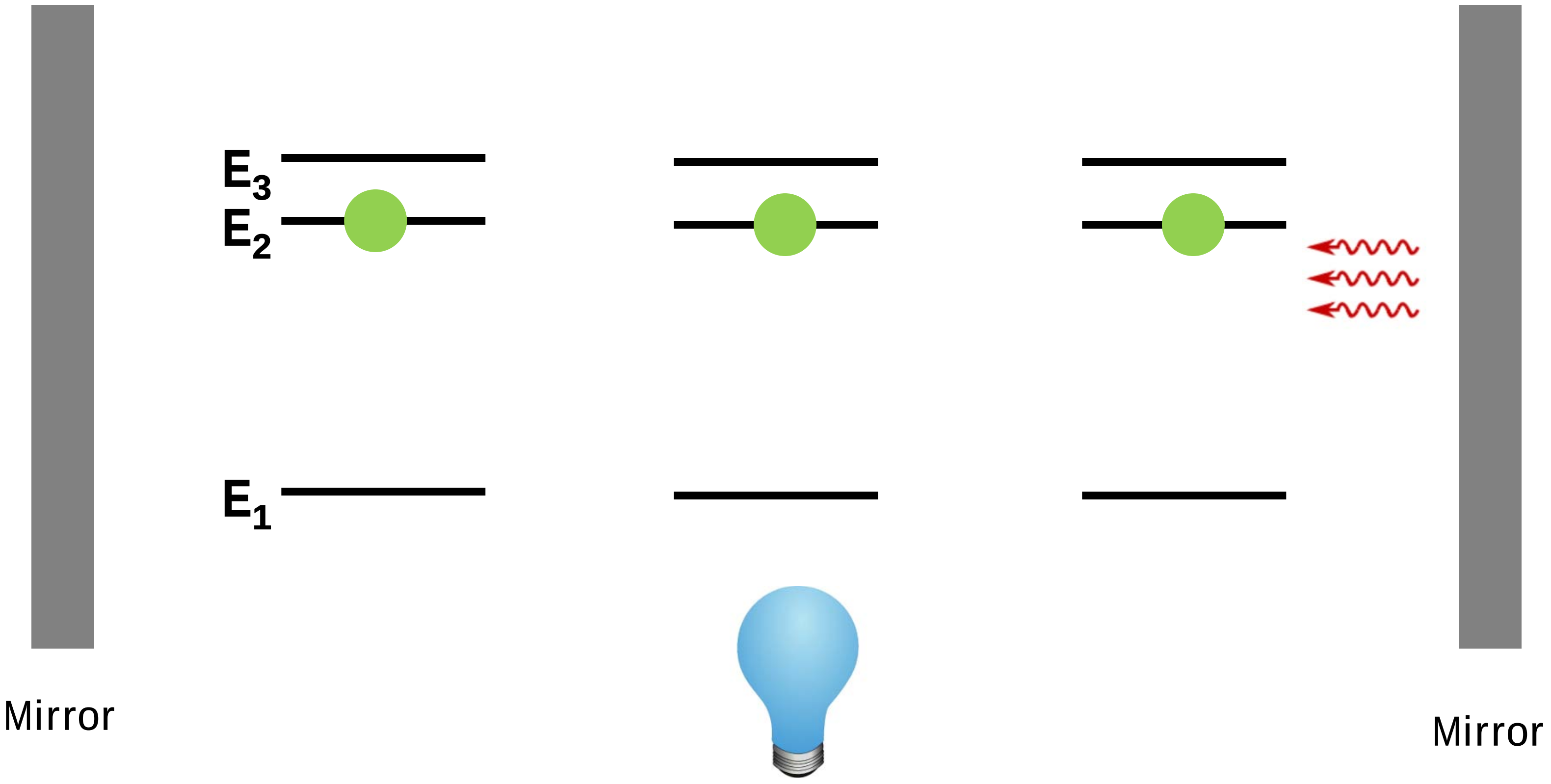
Laser cavity

- Add mirrors! This makes a "laser cavity"

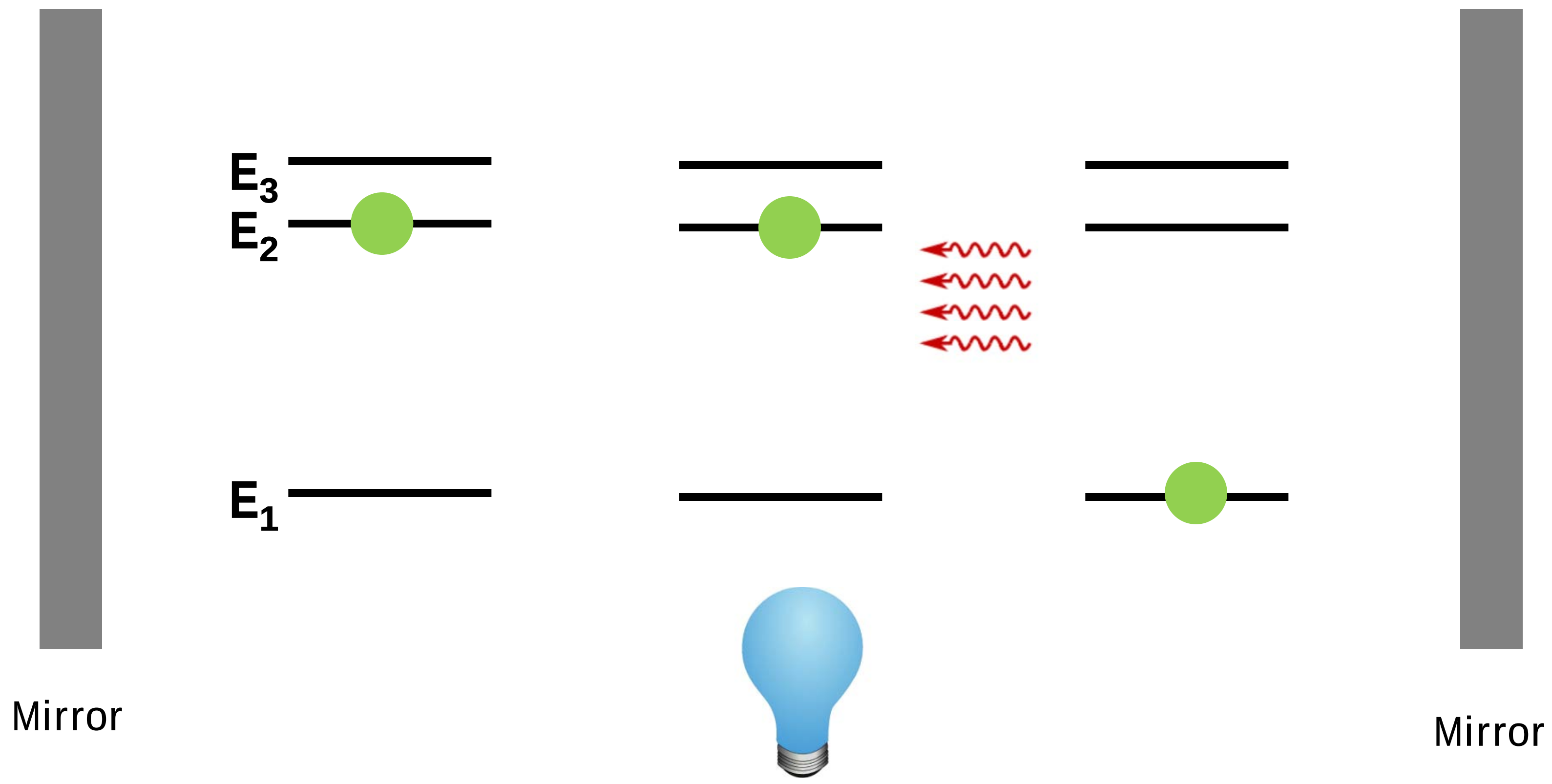


Laser cavity

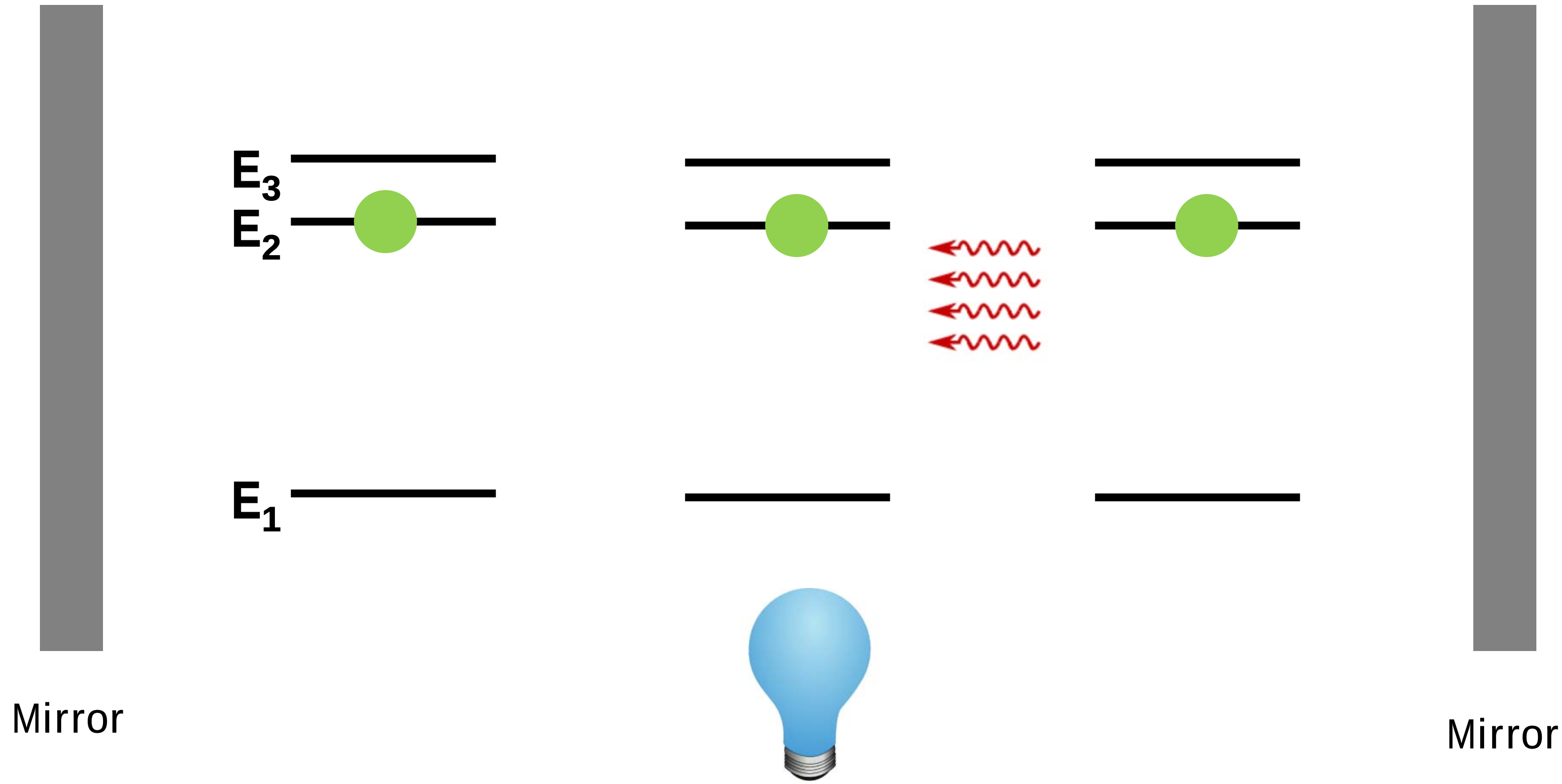
- Reflection!



Laser cavity

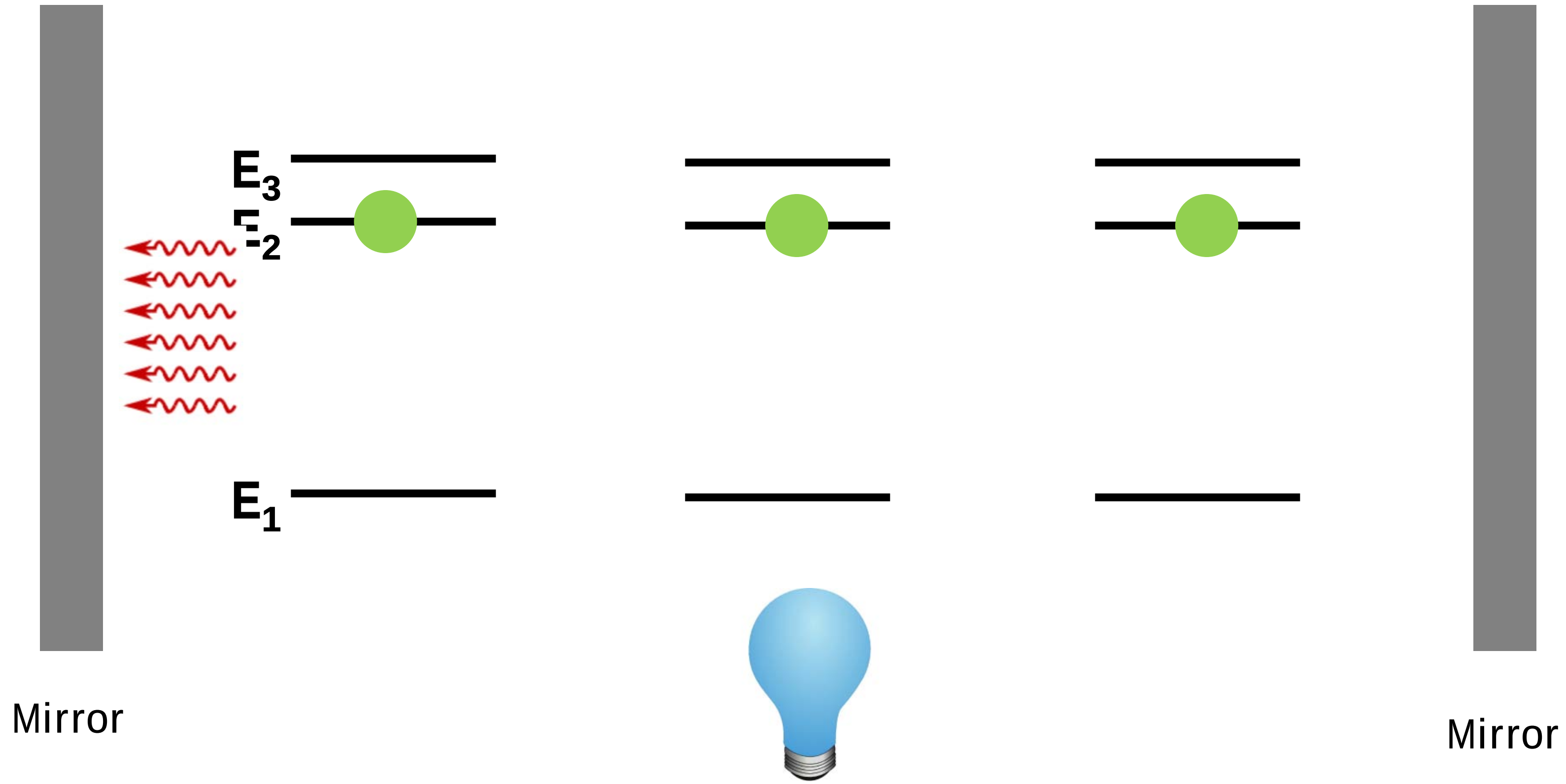


Laser cavity



Laser cavity

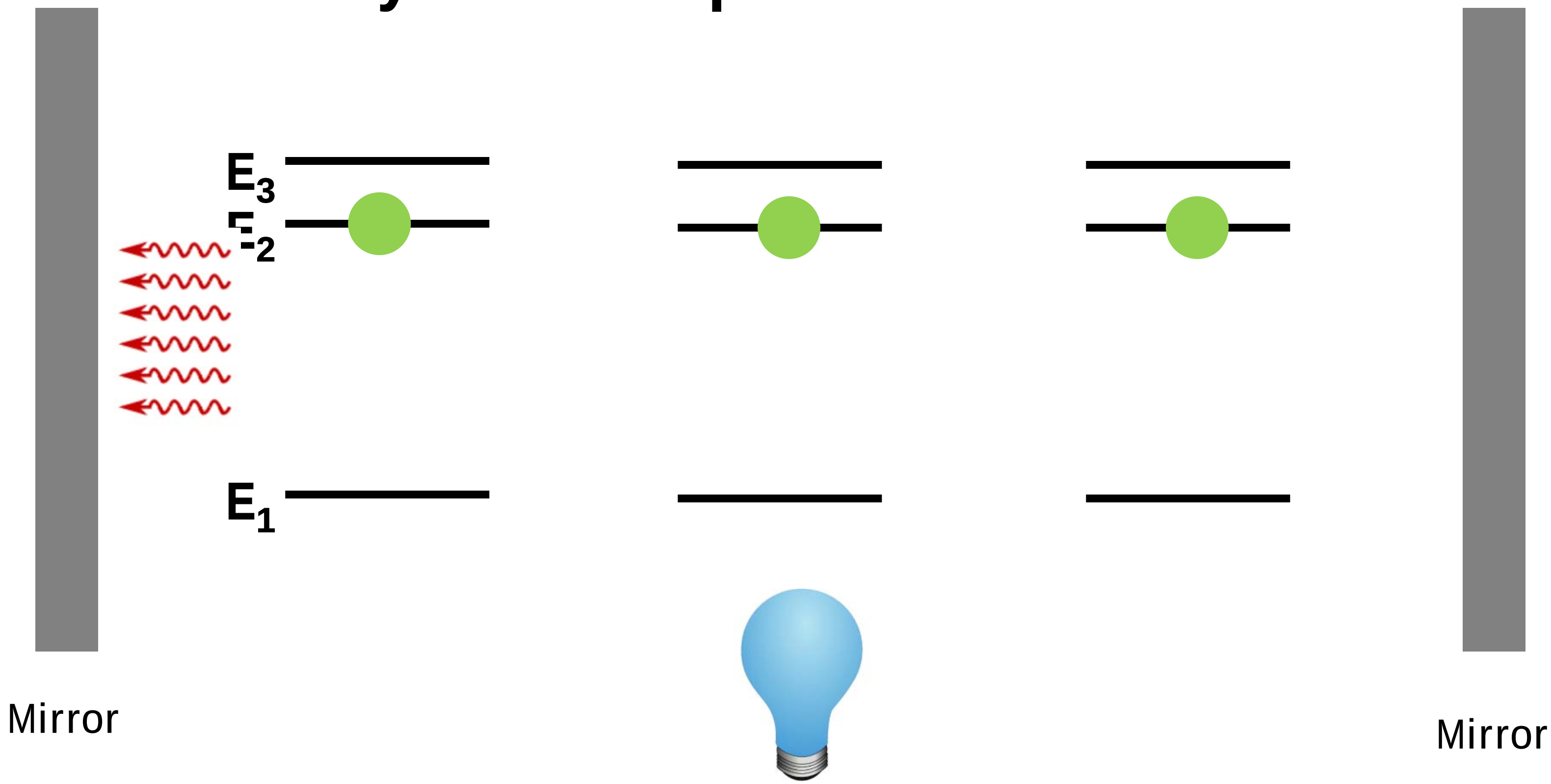
- Skipping a few steps!



Laser cavity

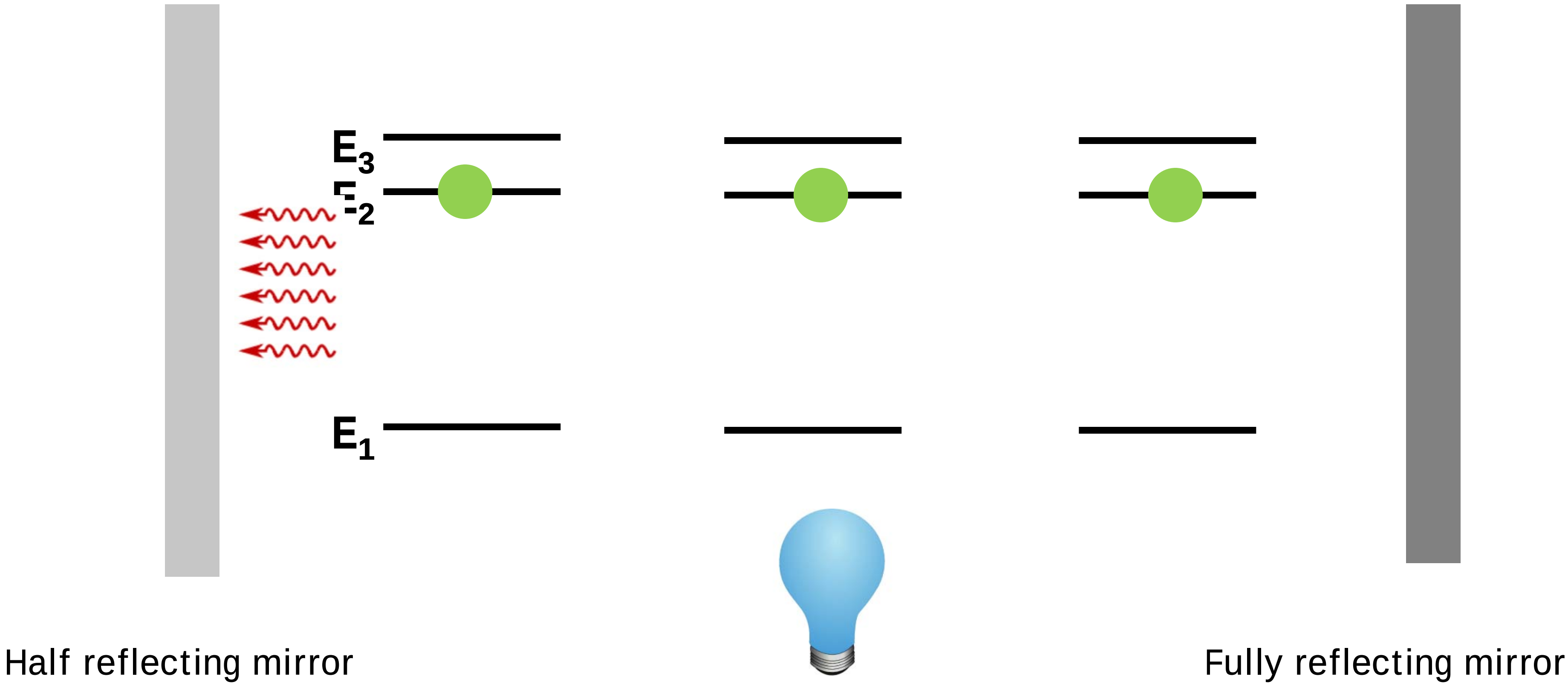
- Skipping a few steps!

Does anyone see a problem with this laser?



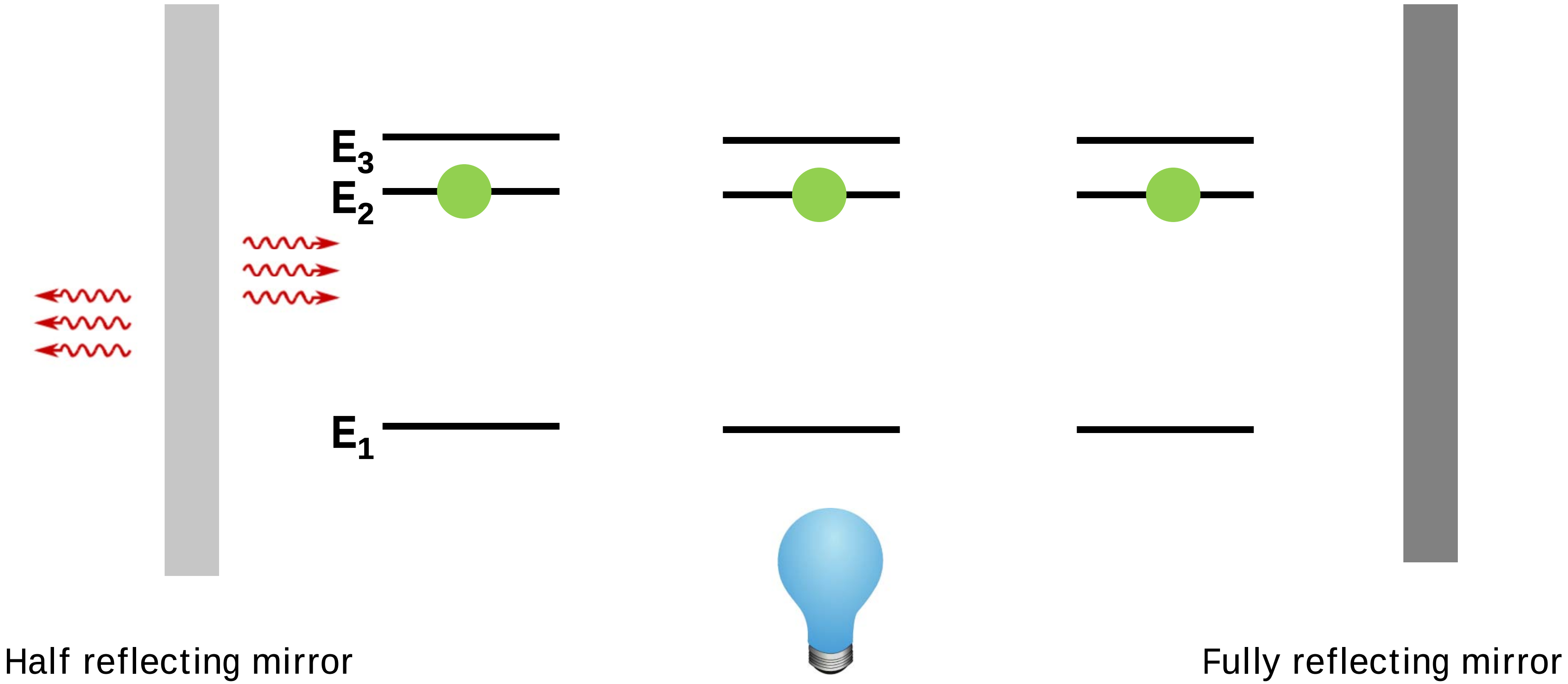
Laser cavity

- Use a partially reflecting mirror!

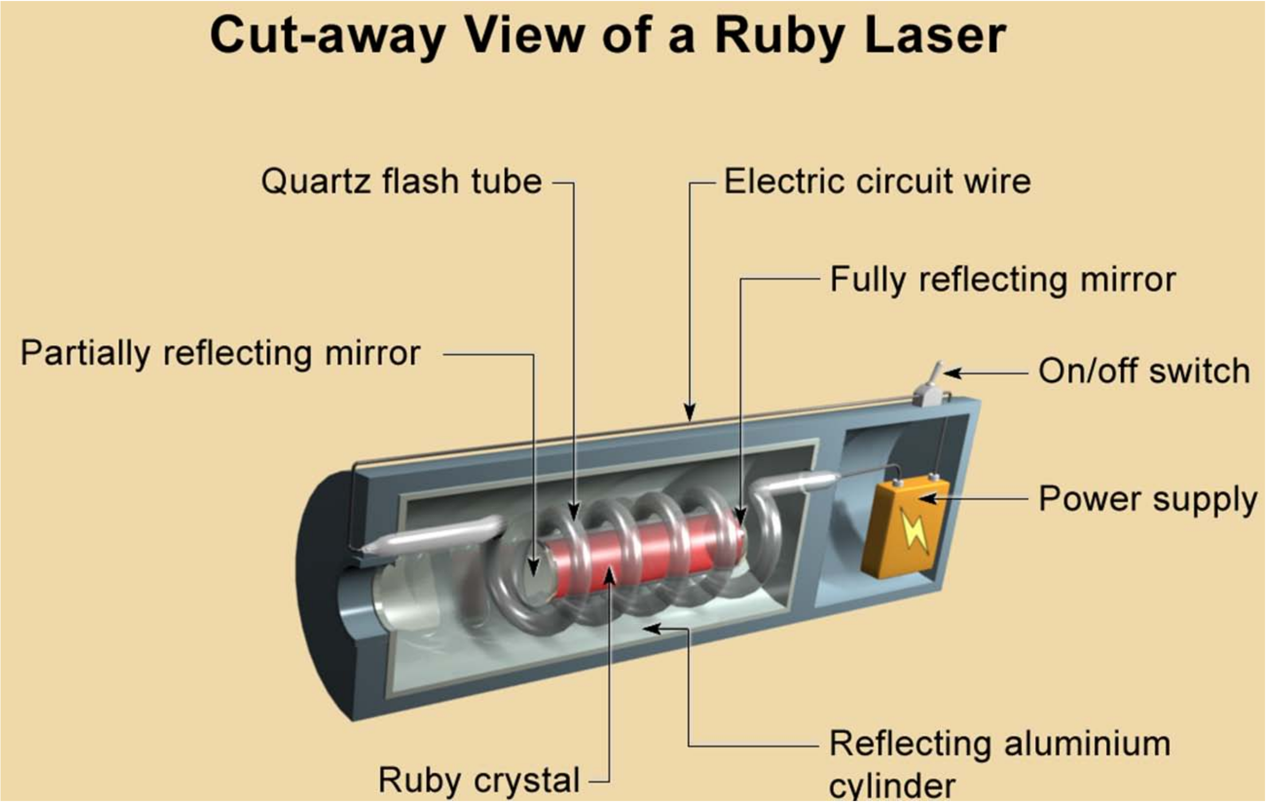


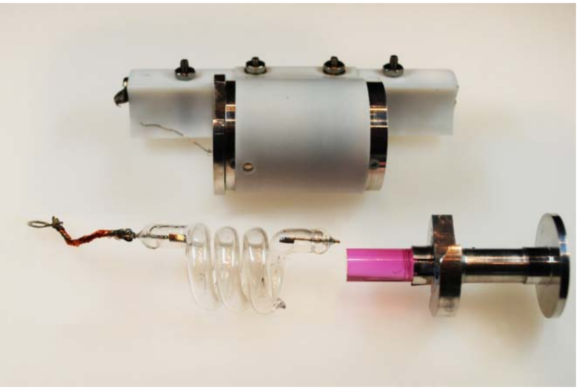
Laser cavity

- 50% transmission, 50% reflection!
- Now we have a laser!



The ruby laser





- Ted Maiman’s first laser: 1 ‘Gillette’ of power

The ruby laser

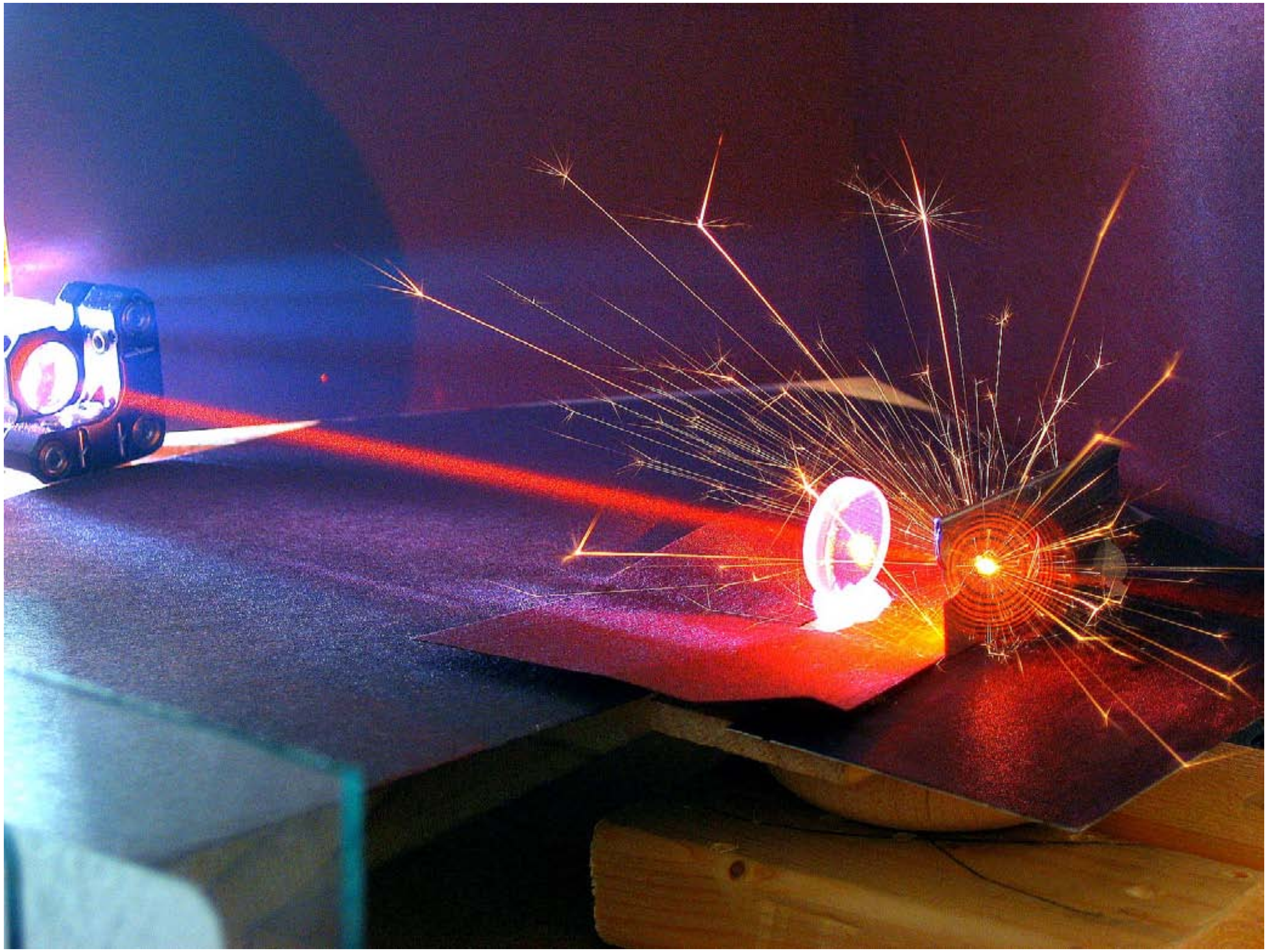
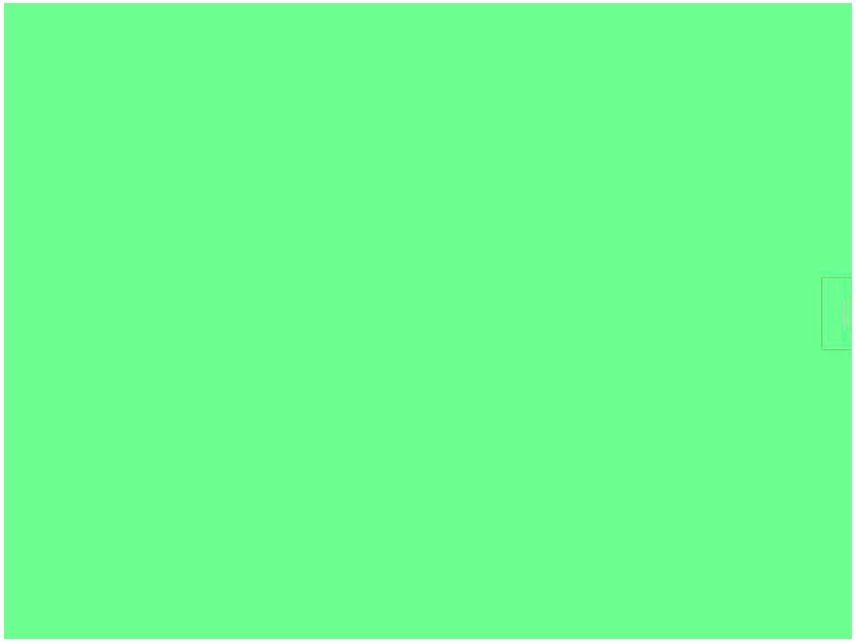
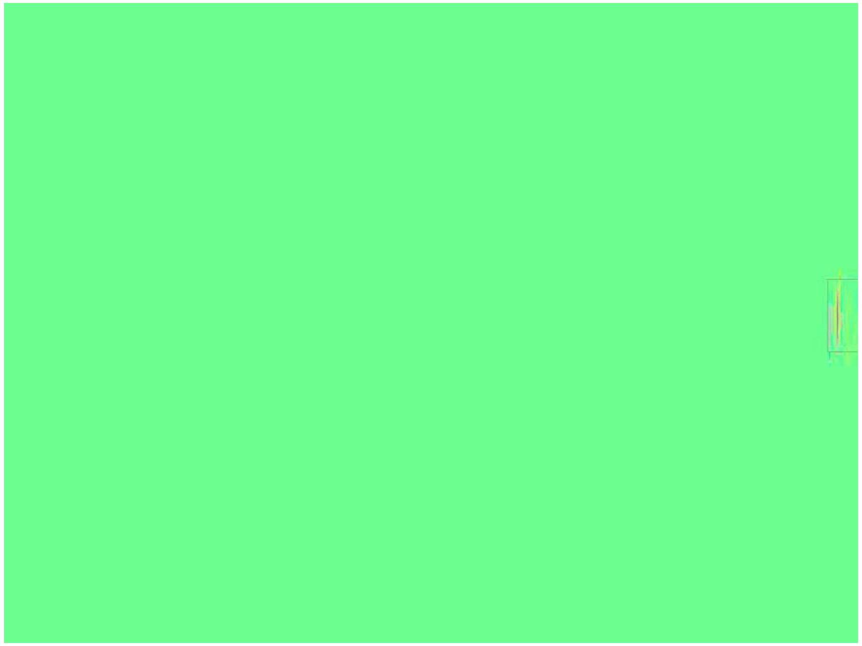


Image source: Retrotech on Flickr, reproduced with permission

What’s special about laser light?



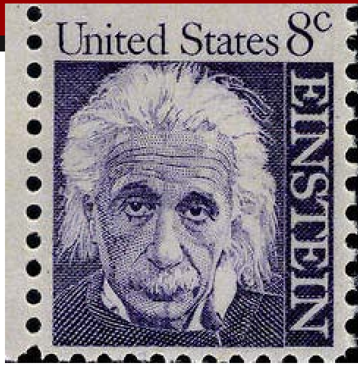
Fully coherent



Partially coherent

- Monochromatic: nearly single frequency
- Coherent: same polarization, phase – all photons in lock step

Brief Timeline



- 1917: stimulated emission explained by Einstein
- 1950s: Charlie Townes, Arthur Shawlow, Alexander Prokhorov and Nikolay Basov work out the theory of lasers

- 1959: Gordon Gould coins the term LASER, patents it
- 1960: Ted Maiman makes first working laser

Image source: Wikimedia Commons and APS (for Ted Maiman's picture)

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Thank you!

SITN would like to acknowledge the following organizations for their generous support:

- Harvard Medical School
  - Office of Communications and External Relations
  - Division of Medical Sciences
- The Harvard Graduate School of Arts and Sciences (GSAS)
- The Harvard Biomedical Graduate Students Organization (BGSO)
- The Harvard/MIT COOP
- Restaurant Associates

- SITN is a student organization at Harvard GSAS-

Laser cavity