17: Specific LASER Systems

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- Helium-Neon
- Ar^+ ion
- Ruby
- Nd:YAG
- Ti:sapphire

Recap

We need:

1. A material with optical gain:

$$\gamma(\nu) = \left(N_2 - \frac{g_2}{g_1} N_1 \right) \frac{c^2}{8\pi \; n^2 \nu^2 \tau_{sp}} g(\nu)$$

2. A means of inducing population inversion (i.e. pumping):

$$\left(N_2 - \frac{g_2}{g_1} N_1 \right) > 0$$

3. A cavity or resonator, to provide feedback and spectral filtering.

Hence a threshold gain: $$\gamma_{th} = \alpha_i + \frac{1}{2L} \ln\left(\frac{1}{R_1 R_2} \right)$$

Classes of Laser

Gas lasers

- Atomic (e.g. He:Ne)or ionic (e.g. Ar^+) species
  - Electronic transitions: wavelengths from visible to near-infrared
- Molecular species (e.g. CO_2)
  - Vibrational transitions: wavelengths in mid- to far- infrared
- Typically have:
  - Narrow linewidth
  - Low power / CW operation with stable, high-quality beams
  - Recirculating gain medium (replenish or cool)

'Liquid' lasers – organic dyes (e.g. Rhodamine 6G)

- Efficient emission over range of visible wavelengths
- Broad emission due to rotational transitions → tunable
- Typically optically-pumped, pulsed operation
- Being supplanted by solid-state lasers

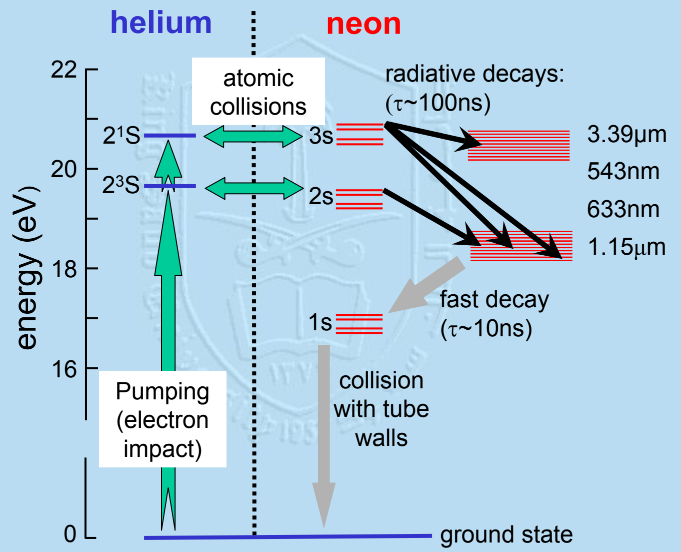
Solid-state lasers

- Crystal or glass host doped with paramagnetic ion (e.g. Ruby, Nd:YAG, Ti:sapphire)
- broad absorption → optical pumping
- high powers, CW and pulsed

Helium-Neon LASER

- Common type of laser
- Lasing transitions between excited state of Ne
- Pumping by excitation of He atoms via electron collisions in discharge tube
- Fortuitious coincidence between energy levels:
  - He 2^1S ↔Ne 3s ($2p^5$ 5s) [just labels, don't worry!]
  - He 2^3S ↔Ne 2s ($2p^5$ 4s)
- "4-level" laser: rapid depopulation of lower laser level
- 1s decay enhanced by collisions with narrow-bore discharge tube
- Lasing lines include 543nm (HeNe green), 633nm (HeNe red), 1.15 μm, 3.39 μm.
- Narrow laser linewidth → high coherence
- Low power (0.5 – 10mW)
- Excellent beam quality
- Many applications, e.g. laser interferometers

Helium-Neon LASER: energy levels



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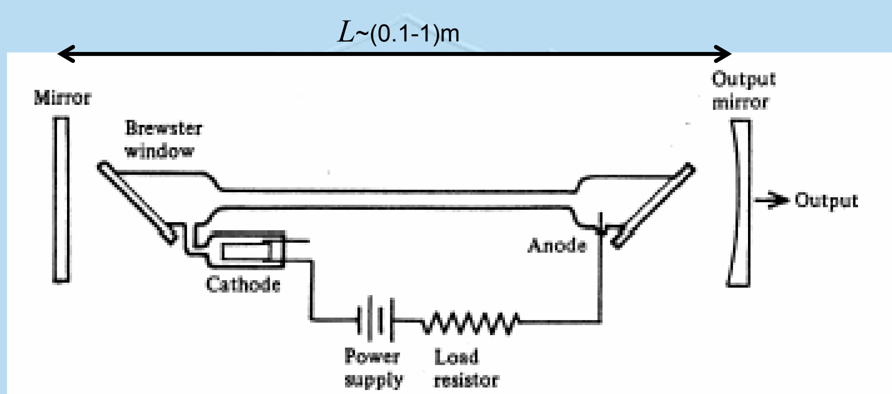
Helium-Neon LASER: construction



Relatively low gain coefficient, hence:
- Long cavity length
- High reflectivity mirrors needed
- Low output powers

Contents:
- 10He: 1Ne gas mixture
- Pressure ~10 torr
- Current density ~ (0.1-1)Acm^{-2}

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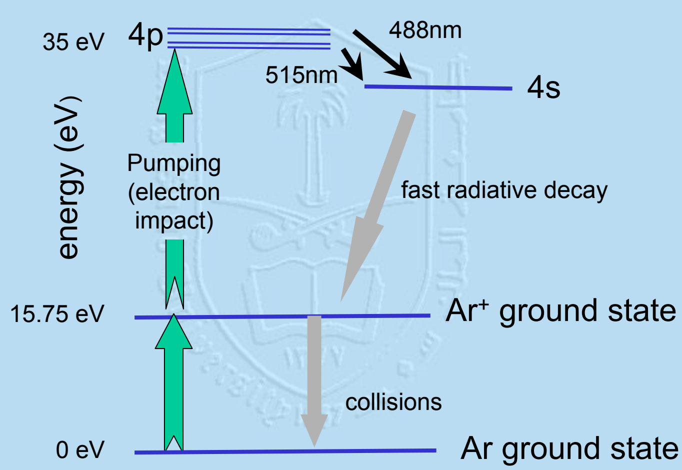
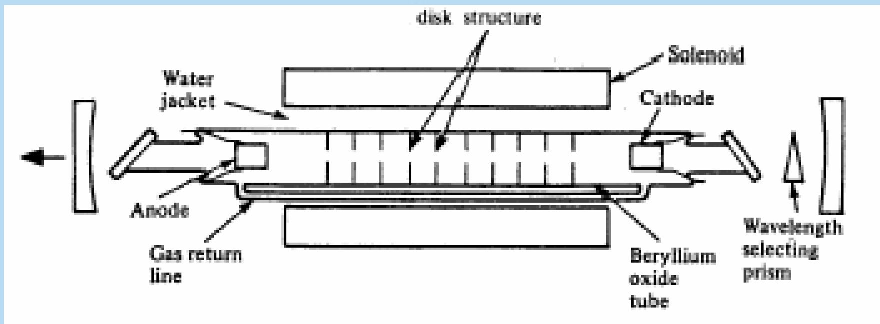
Ar^+ ion LASER

- Transitions between highly-excited states of Ar^+ (also Kr^+, Ne^+, Xe^+, etc)
- LASER lines between 350nm (UV) and 520nm (blue/green)
  - Hence used for LASER light shows!
  - 488nm and 514nm are strongest lines
  - Colour selected by intracavity prism
- Many important applications (but being supplanted by diode-pumped solid-state lasers)
  - Pumping tunable dye or Ti:sapphire LASERs
  - LASER surgery
  - Scientific applications, e.g. Raman spectroscopy
- 'pure' discharge – only Ar^+ present
- High ionisation energy (to make Ar^+) and excitation energy (to generated excited state)
  - Hence low efficiency (~10^{-2} %)
  - Hence water cooling
  - High output powers available (tens of Watts CW)

Ar^+ ion LASER energy levels



Ar$^+$ ion LASER construction



- Metal disks for heat conduction
- Solonoid magnet keeps Ar ions away from walls (where they would de-excite)
- 1-2 m length
- High current: ~10Amm^{-2}

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Ruby LASER

- First demonstrated LASER ('optical MASER', Mainman 1960)
- 0.05% Cr-doped Al_2O_3, or Cr^{3+}:sapphire
- Example of a 3-level LASER
- Strong absorption bands in green and blue
- Optically pumped by flashlamp
- Laser emission at 694.3nm and 692.9nm
- Long lifetime of upper lasing level →high storage capacity
- Typically operated pulsed as high as 100J per pulse (Q-switching)

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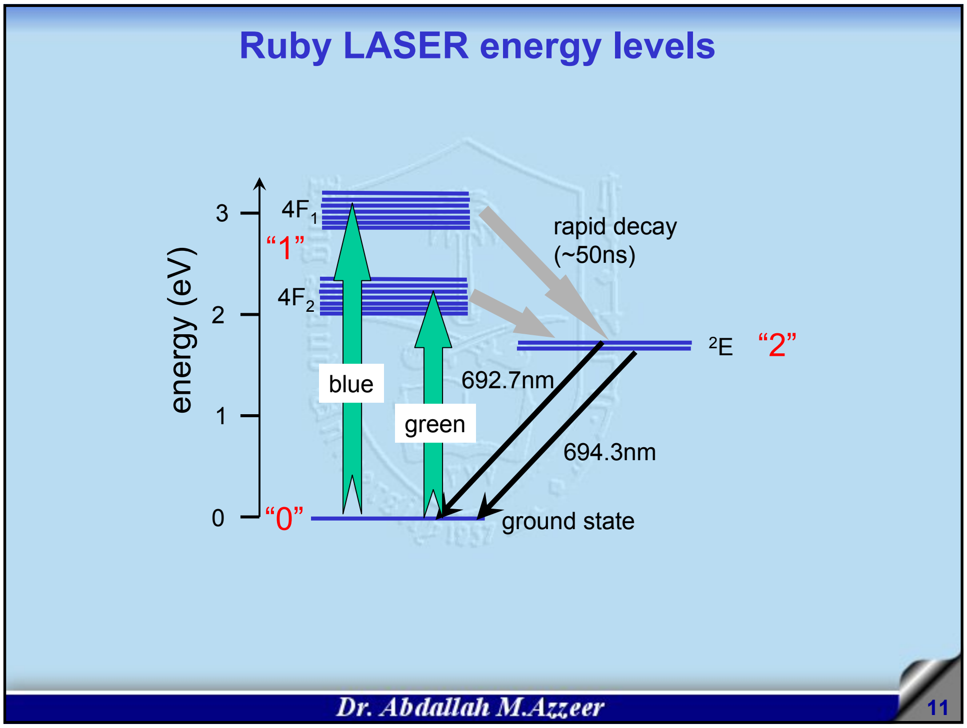
Ruby LASER energy levels
energy (eV)
0
1
2
3
4F1
4F2
"1"
"0"
"2"
rapid decay
(~50ns)
blue
green
692.7nm
694.3nm
2E
ground state
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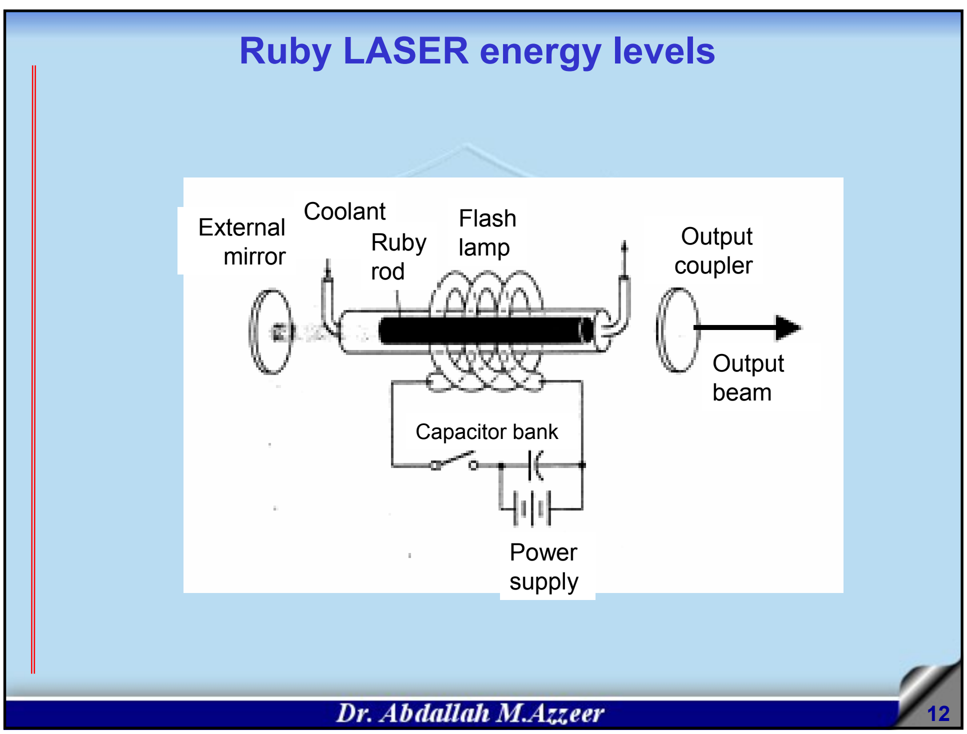
Ruby LASER energy levels
External
mirror
Coolant
Ruby
rod
Flash
lamp
Output
coupler
Output
beam
Capacitor bank
Power
supply
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Nd:YAG LASER

- Nd^{3+} ions (also Er^{3+}, Ho^{3+}, etc, up to 1/5% concentration) in various hosts: Yttrium Aluminium Garnet (YAG), YLF, vanadate, glass, ….
- 4-level laser, 75x higher gain than ruby
- Long upper state lifetime (0.2 – 0.3ms)
- High power in CW (up to ~100W) and pulsed operation (e.g. 1J ni 10ns).
- Efficiency is 0.1 – 2%
- YAG has high thermal conductivity, strength, optical; quality
- Main transition at 1064nm
- Can be efficiently frequency-doubled to 532nm
- Optically-pumped by flashlamp or, increasingly, semiconductor diode laser, giving compact rugged high-power laser
- Used in industry (machining), medicine (laser surgery)
- Used as pump for tunable lasers

Nd:glass

- Higher [Nd] → higher gain
- Broader absorption lines → high pumping efficiency (~5%)
- BUT: poor thermal conductiviity → restricted to pulsed operation
- Pulse energies of ~10 kJ, peak powers of 10^{12} W (e.g. for nuclear fusion research).

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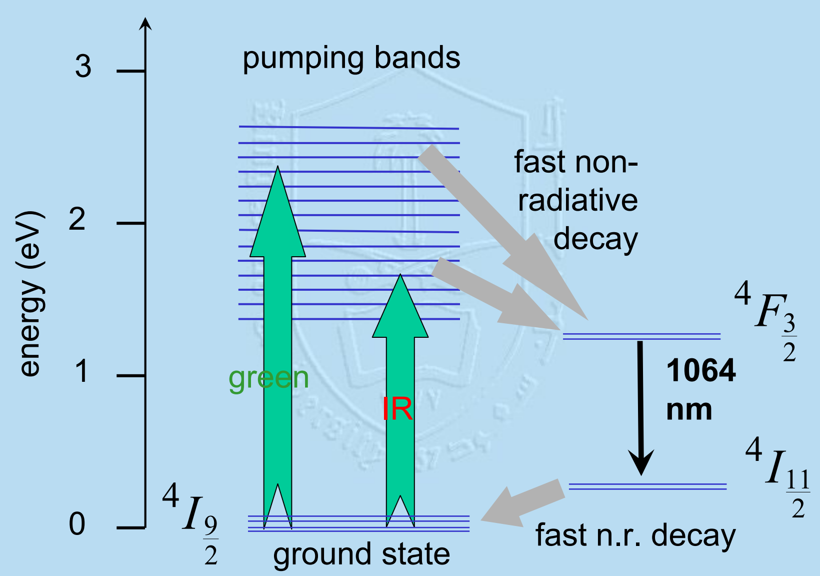
Nd:YAG LASER



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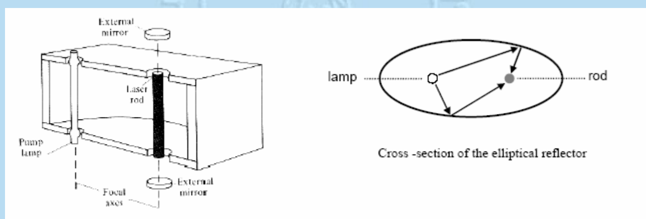
Nd:YAG LASER



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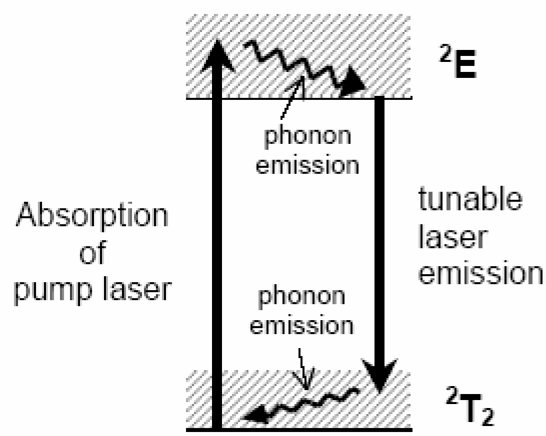
Ti:sapphire LASER

- Strong electron-phonon interaction → broad vibronic band
- Strong absorption in green-blue for optical pumping
- Broad tuning range fro 690 -1080nm
- Mode-locked Ti-sapphire lasers produce <10fs pulses
- Current state-of-the-art



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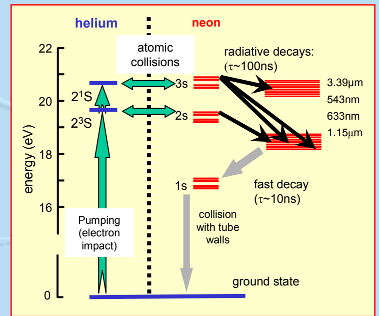
What U need 2 know: Specific LASERs 17.1

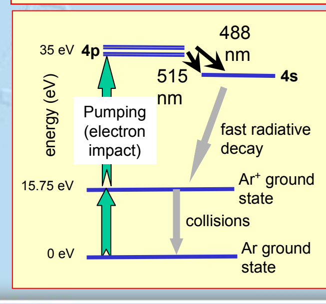
Acquaintance with the **basic properties** and **energy level diagrams** for the lasers listed below.

You do NOT need to learn the numbers or memorise the diagrams in detail, but SHOULD be able, if given the diagram, to describe the processes in terms of the pumping mechanism and lasing transitions, and to relate the energy levels to general 3- and 4-level systems, and to mention the most important features of the laser.

helium-neon laser:

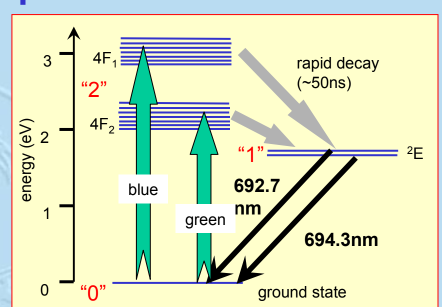


Ar-ion laser:



What U need 2 know: Specific LASERs 17.2

ruby laser:



Nd:YAG laser:

(and: note the particular features of Nd:glass lasers)