Engineering Optics

Lecture 30

26/05/2023

by

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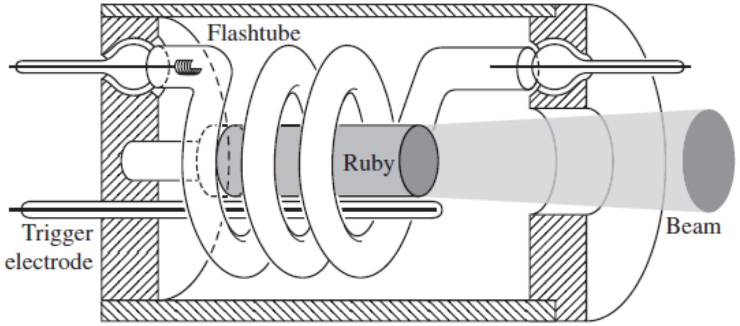
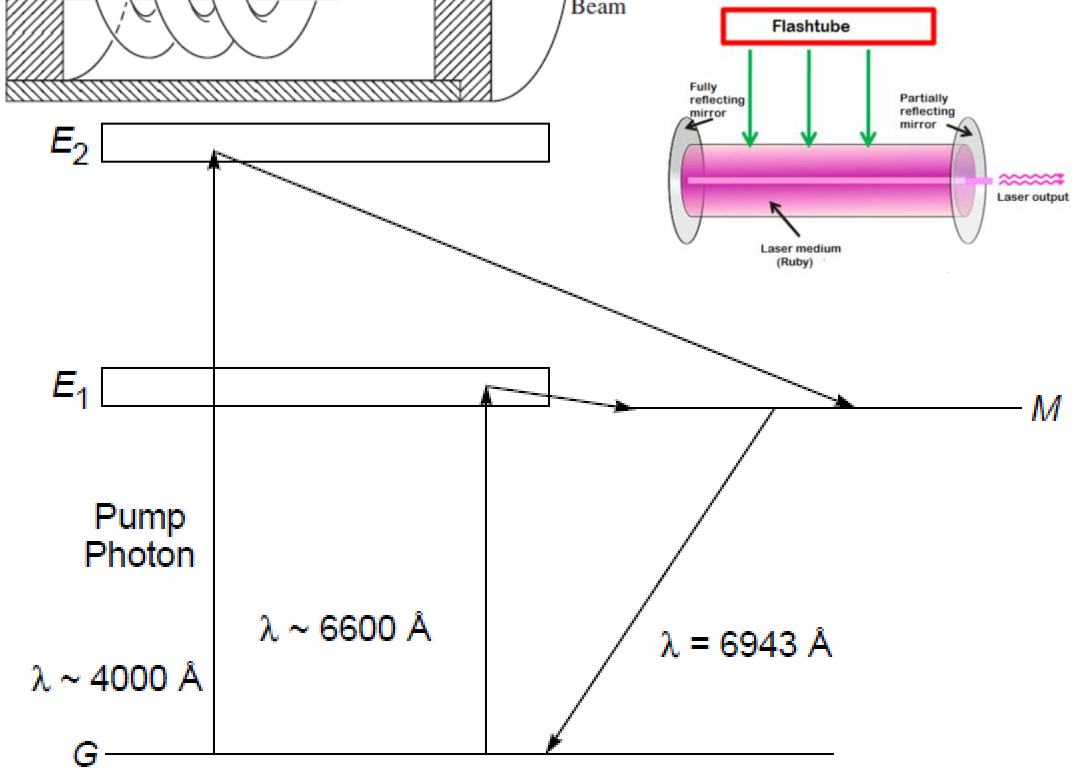
Working principle





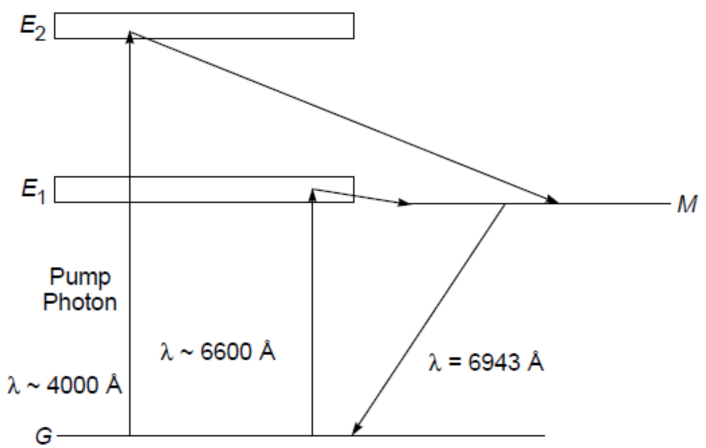
The energy levels of the chromium ion; G and M represent the ground and metastable states, respectively.

Optics, Ghatak; Hecht

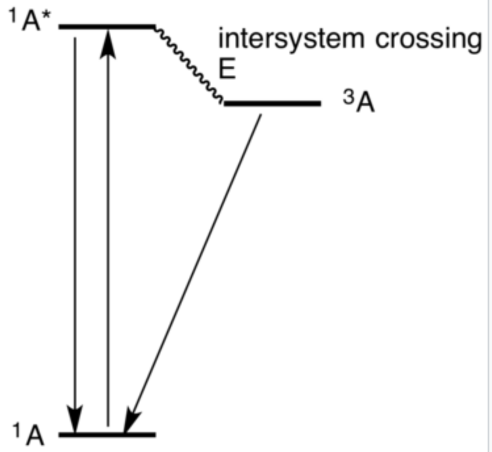
1. photons are produced by the flash lamp
2. The chromium ion in its ground state can absorb a photon (~ 4000 Å) and make a transition to E_2 → by optical pumping OR to E_1 (6600 Å)
3. Once in E_2 or E_1 → it immediately makes a **nonradiative transition** (in a time ~ 10^{-8} s) **to the metastable state *M*** *(3 ms lifetime)*
4. the excess energy (transition from E_2/E_1 to M) is absorbed by the lattice and does not appear as EM radiation.
5. *M* has a very long life, the number of atoms in this state keeps increasing and one may achieve population inversion between states *M* and *G*.
6. Once population inversion is achieved, light amplification can take place, with two reflecting ends of the ruby rod forming a cavity.

- The ruby laser is an example of a three-level laser.
- Applications: medical and cosmetic procedures, holography

Working principle



The energy levels of the chromium ion; G and M represent the ground and metastable states, respectively.



A Jablonski diagram showing the excitation of molecule A to its singlet excited state ($^1A^*$) followed by intersystem crossing to the triplet state (^3A) that relaxes to the ground state by phosphorescence.

Wikipedia

The chromium ion in its ground state can absorb a photon (whose wavelength is around 6600 Å) and make a transition to one of the states in the band E_1. It could also absorb a photon of $\lambda \sim 4000$ Å and make a transition to one of the states in the band E_2—this is known as optical pumping, and the photons which are absorbed by the chromium ions are

produced by the flash lamp (see Fig. 26.16). In either case, it immediately makes a nonradiative transition (in a time ~ 10^{-8} s) to the metastable state M—in a nonradiative transition, the excess energy is absorbed by the lattice and does not appear in the form of electromagnetic radiation.

Also since state M has a very long life, the number of atoms in this state keeps increasing and one may achieve population inversion between states M and G.

Once population inversion is achieved, light amplification can take place, with two reflecting ends of the ruby rod forming a cavity. The ruby laser is an example of a three-level laser.

Optics, Ghatak

Spike in Ruby LASER

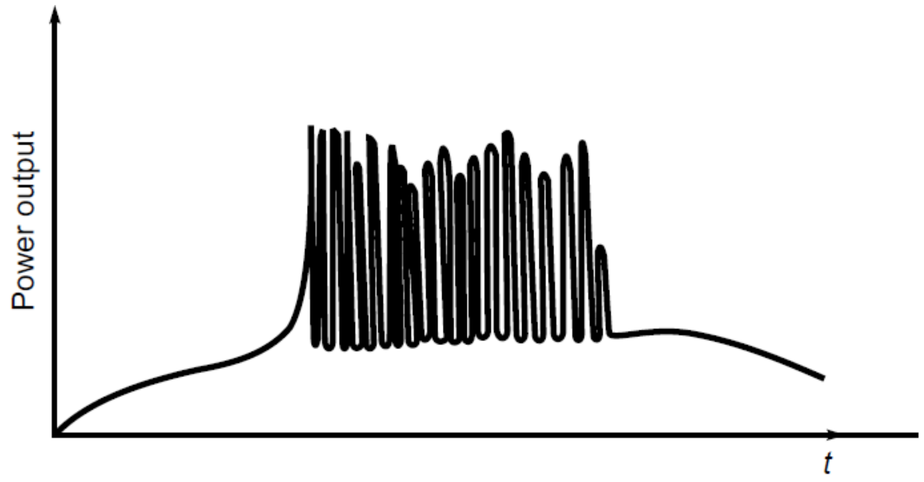
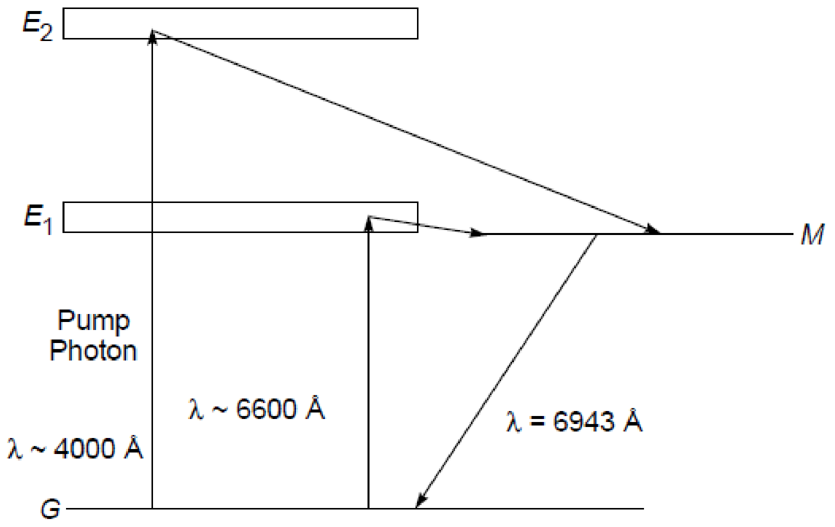


Fig. 26.19 The characteristic spiking of a ruby laser.



The energy levels of the chromium ion; *G* and *M* represent the ground and metastable states, respectively.

Optics, Ghatak

- Sometimes one finds that the emission is made up of spikes of high-intensity emissions → spiking
- Steady state of Lasing → steady pumping rate
- If the pump is suddenly switched on to a value > threshold, the population inversion > threshold value
- photon number builds up rapidly to a value much higher than the steady-state value.
- Output > the steady-state value,
- the rate of stimulated transitions > much higher than the pump rate.
- Consequence? → the population inversion decreases → output decreases
- the emission stops for a few microseconds, within which time the flash lamp again pumps the ground-state atoms to the upper level, and laser oscillations begin again. This process repeats itself till the flash lamp power falls below the threshold value and the lasing action stops

Ruby laser

- https://physicswave.com/ruby-laser-construction-and-working/

Solid-State Lasers

- Along with **ruby**, great many other solid-state lasers whose outputs range from 170 nm to 3900 nm.
- lasers use a glass or crystal rod doped with ions capable of supplying the needed energy states.
- Recall that ruby is corundum doped with chromium.
- The trivalent rare earths Nd^{3+}, Ho^{3+},Gd^{3+} Tm^{3+}, Er^{3+}, Pr^{3+}, and Eu^{3+} undergo laser action in hosts, such as $CaWO_4$, Y_2O_3, $SrMoO_4$, LaF_3, yttrium aluminum garnet (YAG for short), and glass.
- Nd:YAG ($Nd:Y_3Al_5O_{12}$) lasers are among the most widely used solid-state laser.
- Applications in surgery, target designation, range finding, frequency doubling, and material processing, among others.

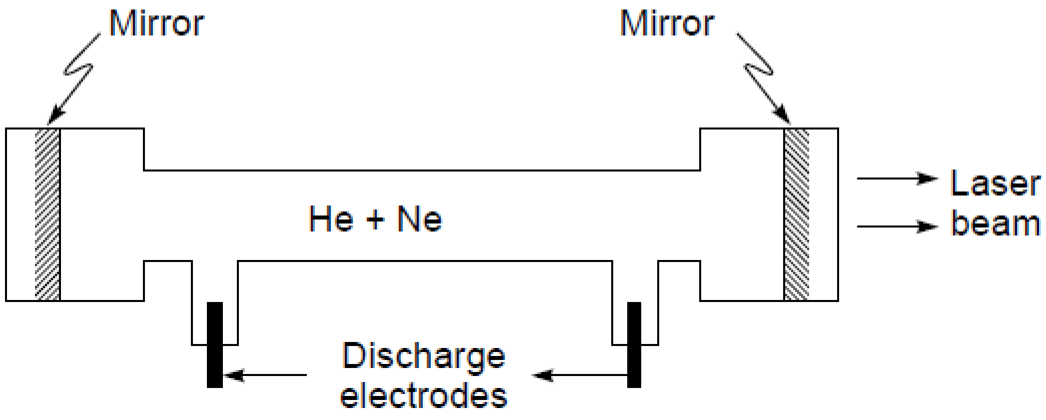
Optics, Hecht

Solid-State Lasers

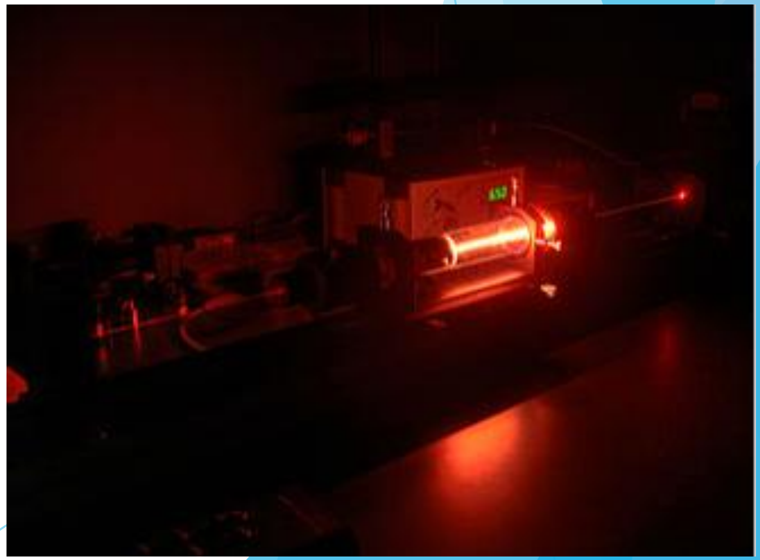
Type	Wavelengths (nm)
$Cr:Al_2O_3$ (Ruby)	694.3
$Cr:BeAl_2O_3$ (Alexandrite)	700–830
Cr:LiCaF	700–830
Cr:LiSrAlF	800–1050
Cr:ZnSe	2200–2800
Er:YAG	2940
Ho:YAG	2100
Nd:Glass	1080, 1062, 1054
Nd:YAG	1064.1, 266, 355, 532, 1320
Nd:YCOB	≈ 1060
Nd:YLF	1047, 1053
$Nd:YVO_4$	1064
Pr:Glass	933, 1098
$Sm:CaF_2$	708.5
Ti:sapphire	650–1180
Tm:YAG	2000
$U:CaF_2$	2500
Yb:Glass	1030
Yb:YAG	1030

He-Ne LASER

- He-Ne laser which was first fabricated by *Ali Javan* and coworkers at Bell Telephone Laboratory in the United States. → 1^{st} gas laser to be operated successfully.
- The He-Ne laser consists of a mixture of He and Ne (ratio ~10 : 1), placed inside a long, narrow discharge tube
- Fixed pressure inside the rube (1 torr).
- system → enclosed between a pair of plane mirrors → resonator



The helium-neon laser.



wikipedia

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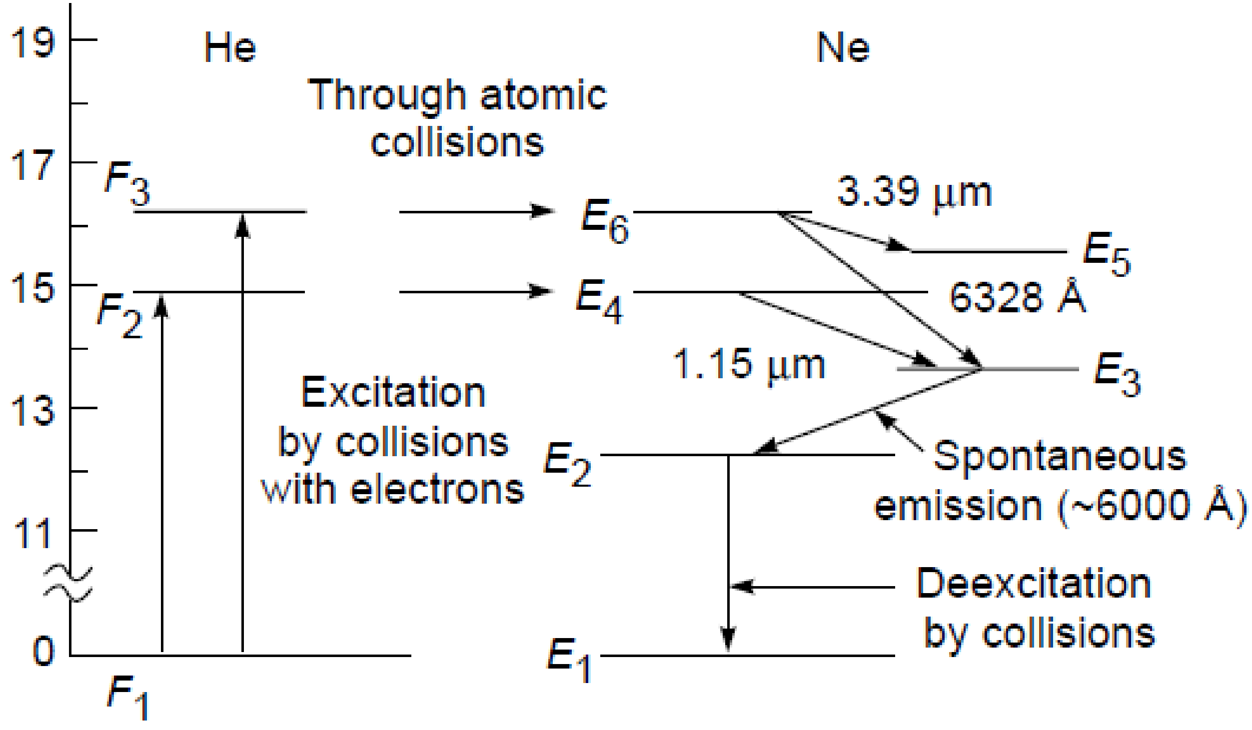
He-Ne LASER

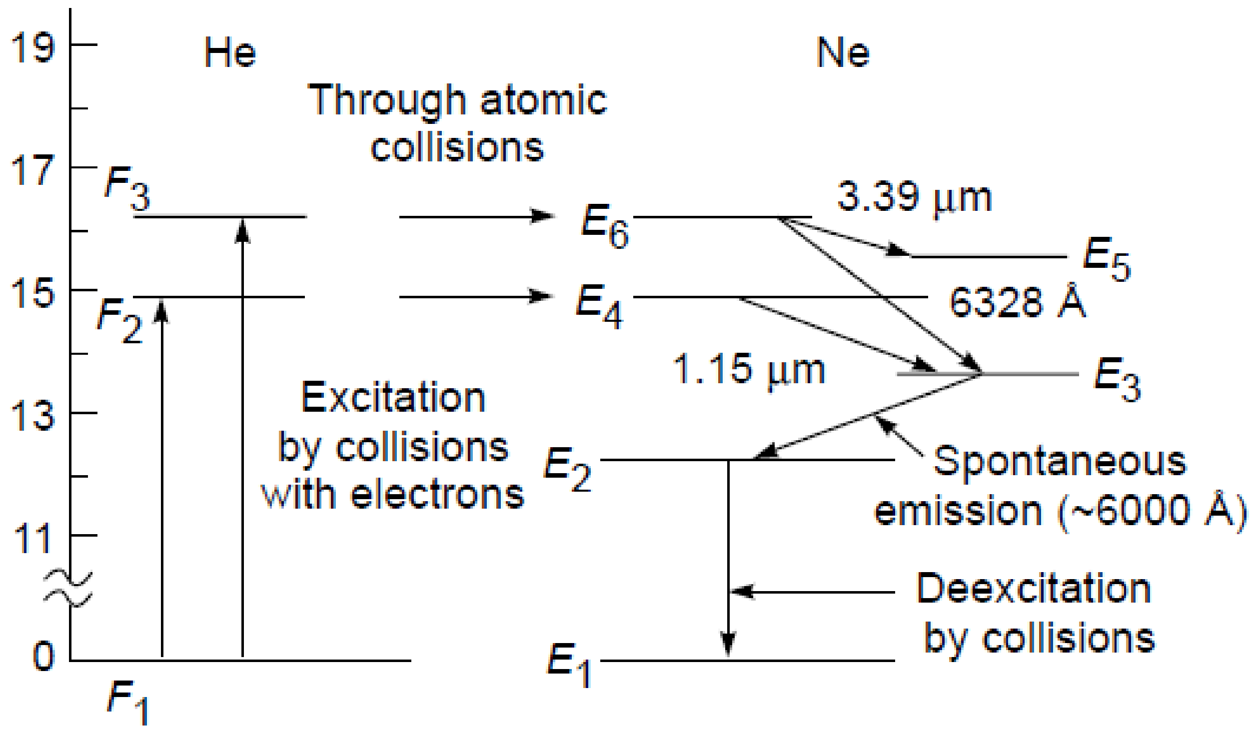


Relevant energy levels of helium and neon.

- When an electric discharge is passed through the gas, the electrons → collide with the ***He atoms***
- ***He atoms excited*** *from the ground state F_1 to F_2 and F_3.*
- He atoms excited to these states stay in these levels before losing energy through collisions.
- Collisions with whom?? → Ne atoms present in the same tube
- Due to collision → these collisions, the Ne atoms are excited to E_4 and E_6
- Thus when the atoms in levels F_2 and F_3 collide with unexcited Ne atoms, they raise them to the levels E_4 and E_6, respectively.

Optics, Ghatak

He-Ne LASER

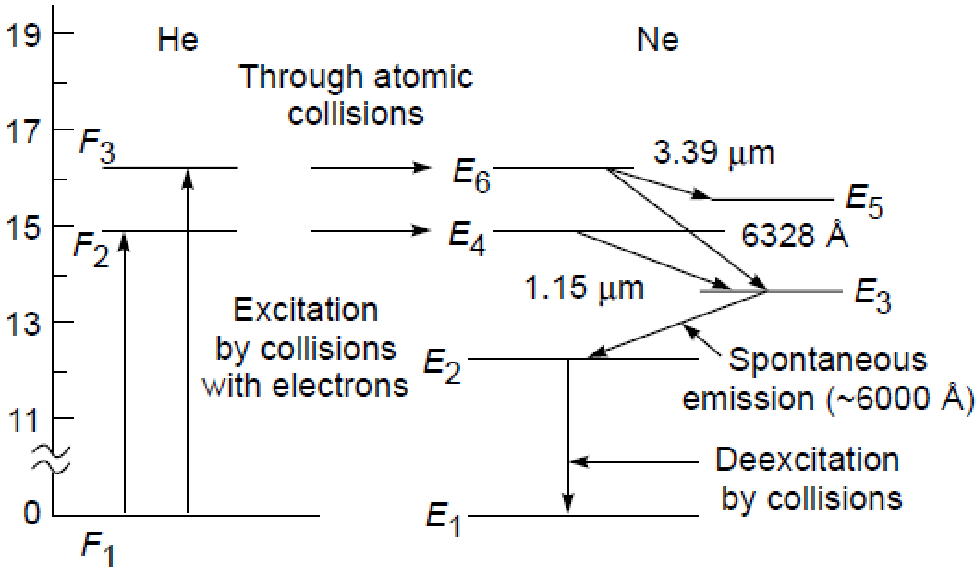


Relevant energy levels of helium and neon.

- ***What happens next?***
- He atom in excited state F_3 + Ne atom in ground state → He atom in ground state + Ne atom in excited state E6
- Similarly, He atom in excited state F_2 + Ne atom in ground state → He atom in ground state + Ne atom in excited state E_4
- **Consequence?** population of E_4 and E_6 >> E_3 and E5. → population inversion is achieved
- Light amplification can be achieved

Optics, Ghatak

He-Ne LASER



Relevant energy levels of helium and neon.

- **Possible transitions:**
- The transitions from $\mathbf{E_6}$ to E_5, $\mathbf{E_4}$ to E_3, and E_6 to E_3 result in the emission of radiation having wavelengths of 3.39 μm, 1.15 μm, and 6328 Å, respectively.
- Note that the laser transitions corresponding to 3.39 and 1.15 mm are not in the visible region→ infrared
- The 6328 Å transition corresponds to the well-known red light of the He-Ne laser.

https://www.sciencedirect.com/topics/physics-and-astronomy/laser-cavities

Wikipedia/ Optics, Ghatak

Few points to note

- Ne and not He is related to the lasing action. He → buffer
- Not optical but electrical pumping method is used
- The tube containing the gaseous mixture is made ***narrow*** so that Ne atoms in level E_2 can get de-excited by collision with the walls of the tube.
- There are a large number of levels grouped around E_2, E_3, E_4, E_5, and E_6. Only those levels are shown in the figure which correspond to the important laser transitions.
- **Advantages:** more directional and more monochromatic than solid-state lasers→ ***Why?*** This is so because of the absence of such effects as crystalline imperfection, thermal distortion, and scattering, which are present in solid-state lasers.
- A large group of gas lasers operate across the spectrum from the far IR to the UV (1 mm to 150 nm).
- Primary among these are helium-neon, argon, and krypton, as well as several ***molecular gas systems***, such as carbon dioxide, hydrogen fluoride, and molecular nitrogen (N_2).

Thank You