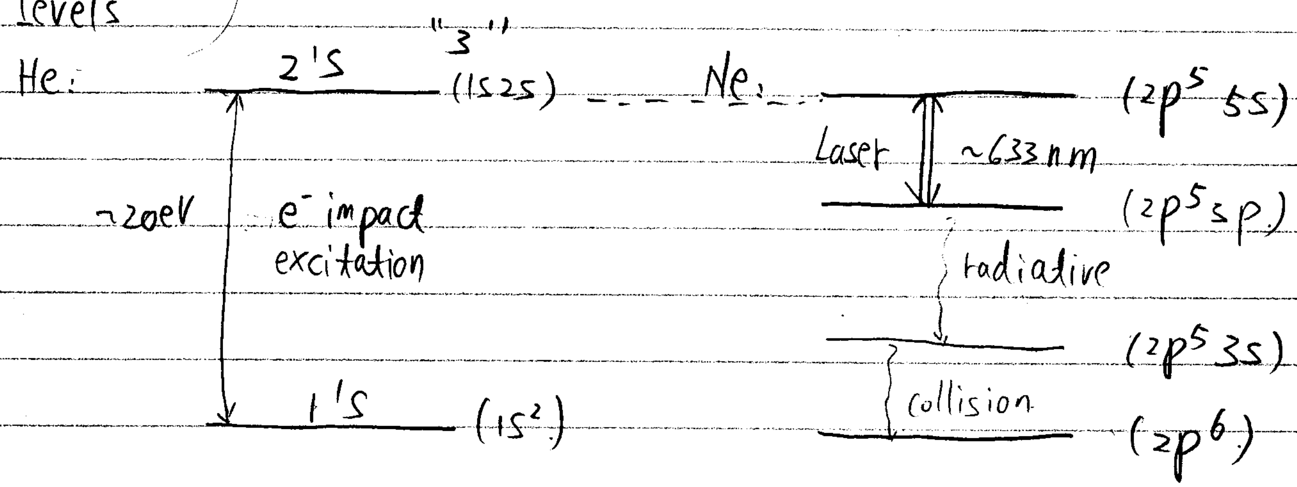
03/23/05 lecture 21 ①

Common gas lasers.

He Ne:

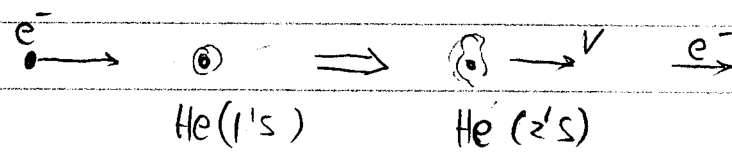
Gas cell containing 1 torr He, $N = 3\times10^{16}\ cm^{-3}$
0.1 torr Ne, $N = 3\times10^{15}\ cm^{-3}$

levels



Turns out 2'S state of He and 5s ($2p^5$) state of Ne are almost degenerate.
2'S state of He is also long lived $\tau \sim 5\mu s$

Pumping: ① use electron discharge to excite He atoms



② He (2'S) is metastable, pump Ne (5s) state through resonant energy transfer collision.
collision rate $\sim 10^7/s$

Pumping Ne (5s) state through collision with He (2^1s) turns out to be very efficient, and dominant in producing population inversion in the He-Ne laser, although direct electron-Ne collisions also contribute to the pumping.

5s state of Ne is upper laser level:

lifetime: $t_s \approx 10^{-7} s$

linewidth Doppler broadened to $\Delta\nu = 1 GHz$

homogeneous line width: $f_{collision} = 10^7 s^{-1}$

$\frac{1}{\tau_2} = 10^7 s^{-1}$

But 3p lower level lifetime is $10^{-8} s$

$\Delta\nu_{homo} \approx \frac{1}{2\pi\tau_1} = 15 MHz$

So expect gain $\gamma = \frac{\lambda^2}{8\pi} \frac{1}{t_s \Delta\nu} \Delta N$

$\lambda = 633 nm$, $t_s = 10^{-7} s$, $\Delta\nu = 1 GHz$

Effectively a four-level system: "3" is He 2^1s state

So $\Delta N \approx R\tau_2$

R = excitation rate, estimate

Typical electron current is $5 mA = 8 \times 10^{16} e^-/s$

Voltage is 1000V, while excitation energy is 20eV.
in one collision, only transfer 20eV.

So each electron can excite ~ 50 He atoms as it passes through tube.

So excite $50 \times 8 \times 10^{16} = 4 \times 10^{18}$ He atoms /s

Suppose tube is 30 cm long, 4mm diameter.

$$\text{Then} \quad R = \frac{\text{atoms}/s}{\text{Volumn}} = 10^{24} \ \frac{\text{atoms}/s}{m^3}$$

So expect

$$\gamma = \frac{(633\,nm)^2}{8\pi} \frac{1}{(10^{-7}s)(10^{9}Hz)} \left(10^{-7}s \cdot 10^{24} \frac{\text{atoms}}{s \cdot m^3}\right)$$

$$= 16 \ m^{-1}$$

Actually get more like $\gamma = 1\,m^{-1}$
collisions only about 10% efficient
e^- hit Ne atoms
e^- hit walls
He^* atoms hit walls
other internal states
End up with relatively low gain, need fairly long tube
good mirrors.

Might try to increase gain. increase density, pump rate

Many issues:

* gas heating
* collisions cause broadening & depopulate 5s state
* population trapping: 3s state decay very slowly

Get output power from I_s

$$I_s = \frac{8\pi h\nu\, t_s \Delta\nu}{\lambda^2\, \tau_s} \approx \frac{8\pi hc}{\lambda^3} \cdot \frac{(10^{-7}s)(15\,MHz)}{(10^{-7}s)}$$

$$= 300\ W/m^2$$

$$P_{out} = \pi W^2 I_s \left(\frac{g_0}{L+T} - 1\right) T$$

if $g_0 \gg g_t$ and $T \gg L$ then

$$P_{out} \approx \pi W^2 I_s\, g_0 = \pi W^2 I_s\, 2\gamma_0 l$$

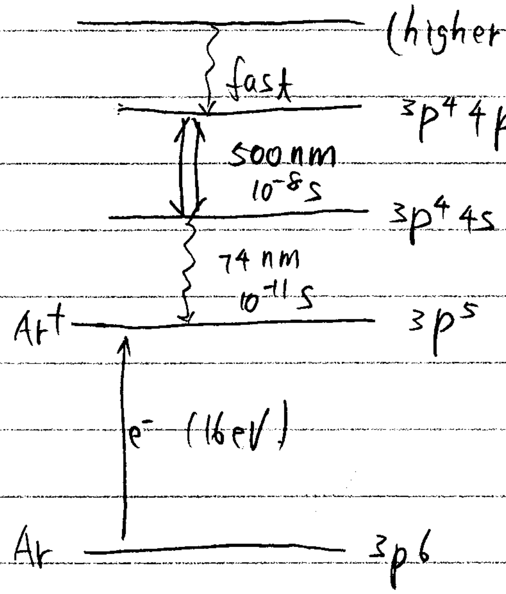
if $W = 1\,mm$, $l = 30\,cm$, $\gamma_0 = 1.6\,m^{-1}$ $\quad P_{out} = 1\,mW$, typical

Real picture more complicated. many levels can lase on other Ne lines as well.

Ar^+ : Ar ion laser.

powerful laser 100mW - 20W.

blue-green light, common pump laser for solid state & dye lasers used in light shows.



Two step excitation.

one e^- collision produces ions another excites.

Much population trapped in $3p^4 4p$ level (metastable)

Gas pressure ~ 300 mtorr, also higher pressure buffer gas to increase $\Delta\nu$

Why is Ar^+ more powerful than HeNe?

- Decay times + collision times faster (x 100 times)
  pump harder before saturating.
  $\Delta\nu$ bigger → I_s bigger.
  λ smaller → I_s bigger (λ^3)
  No trapping states. much higher inversion

Cost ~ \$10K for smaller laser (~100mW)
\$100 K for large one. (~1W)