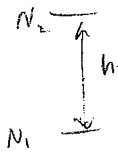
Einstein A + B



hf from (ω) black body mode interacting w/ material inside

three ways for this transition to occur

(1) photon produced by decay ↓ → $\frac{\text{prob of decay}}{\text{time}} = A$ "spontaneous decay" $P_{2\to1}: A_{21}$

(2) photon absorbed

→↑ (needs photon present!)

rate

$\frac{\text{prob of abs.}}{\text{unit time}} = B_{12} \times \rho_f$

"stimulated absorption"

(3) stimulated emission

→↓ → → needs photon present!

$\frac{\text{prob.}}{\text{time}} = B_{21} \times \rho_f$

rate eqns

$$\frac{dN_1}{dt} = +A N_2 + B_{21}\rho_f N_2 - B_{12}\rho_f N_1$$

(first two terms: increasing from (1) and (3); last term: absorbing from (2))

$$\frac{dN_2}{dt} = -A N_2 - B_{21}\rho_f N_2 + B_{12}\rho_f N_1 = -\frac{dN_1}{dt}$$

Thermal equilibrium: $N_1, N_2 = \text{const}$

$$0 = A N_2 + B_{21}\rho_f N_2 - B_{12}\rho_f N_1$$

$$\rho_f = \frac{A N_2}{B_{12} N_1 - B_{21} N_2} \times \frac{1/N_2}{1/N_2}$$

Consider thermal equilibrium ✓ Planck radiation law:

$$= \frac{A}{B_{12}\frac{N_1}{N_2} - B_{21}}$$

Boltzmann: $\frac{N_1}{N_2} = \frac{e^{-E_1/kT}}{e^{-E_2/kT}} = e^{+\Delta E/kT} = e^{+hf/kT}$ Assuming no degeneracies

(ħ?)

$$\frac{8\pi h f^3}{c^3(e^{hf/kT}-1)} = \frac{A}{B_{12}e^{+hf/kT} - B_{21}}$$

Must have $\boxed{B_{12} = B_{21}}$ $\boxed{A = \frac{8\pi h f^3}{c^3} B_{21}}$

even though derived using thermal equilibrium, there's no reason why A or B should change when not in equilibrium, so these are generally valid.

Fix h/ħ error ★

Eq 40 pg 2

Laser implication: if natural lifetime is long (A small)

then $\frac{dN_1}{dt} = B_{21}\rho_f N_2 - B_{12}\rho_f N_1$

$= B_{21}\rho_f (N_2 - N_1)$ also = rate at which photons are generated

(one photon for each new electron in state 1)

(where spontaneous emission ... is ... of the ... energy ...)

Thermal equilibrium: $N_2 < N_1$, a net absorption of photons

But if $N_2 > N_1$ can be maintained "population inversion" ⇒ nonthermalized! can use previous relation between A and B_{21}

then get net production of photons!

i.e. more out than you put in.

"gain"

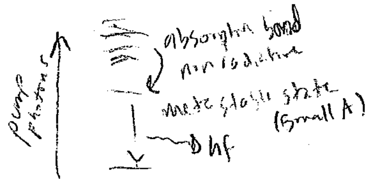
~~(...)~~

Ways to obtain population inversion

- diode laser: electrons electrically injected (directly) via voltage applied to p-n junction

] Note, if only optical, pop. inversion not possible w/ 2 level

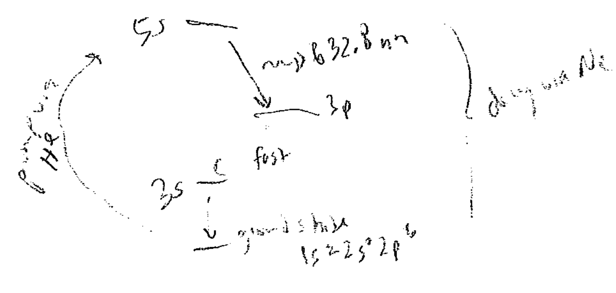
- Optically-pumped laser (eg ruby)



ruby: pump = green or blue

emission hf = 694.3 nm (red)

- HeNe laser
voltage creates free electrons + ions which are accelerated by an applied field and (via collisions) cause further ionization+excitation of gas



day 40 43

Lasers !

See PPT file

Semiconductor

bandgap engineering → see PPT

and quote on next page

Band Gap Engineering day 40 pg 4

From http://www.tf.uni-kiel.de/matwis/amat/semi_en/kap_5/backbone/r5_1_4.html

There is a tremendous amount of information in this diagram (note that "X-gap" and L-gap" both denote indirect band gaps a the respective positions in the band diagram):

- Most III-V compounds radiate at wavelengths above the visible region, i.e. in the infrared. However, adding some Al to GaAs producing AlxGa1-xAs, will shift the wavelength into the red region of the spectrum - here are our red luminescence diodes and Lasers!
- Very fortunate: GaAs and AlAs have almost the same lattice constant; we can thus combine any combinations of these materials without encountering mechanical stress.
- Very unfortunate: There are no III-V compounds in the diagram that emit blue light - this is a severe problem for many potential applications. While SiC could be used to some extent, it was only with the recent advent of GaN that this problem was solved. SiC and GaN crystals, however, are not of the "zinc-blende" type common to all the III-Vs in the diagram but have a hexagonal unit cell. They therefore do not easily mix with the others!
- If we want to radiate at 1.3 μm or 1.5 μm - infrared wavelength of prime importance for optical communications - we should work with combinations of InAs, GaAs, and AlSb.
- Most interesting: The II-VI compounds are all direct semiconductors and span a much larger range of wavelengths than the III-V's. The fact that they are not much used for products tells us that there must be big problems in utilizing these compounds for mass products.

Obviously need lasing medium

Other laser requirement

- cavity (⟵⟶) (curved mirrors as we discussed!)

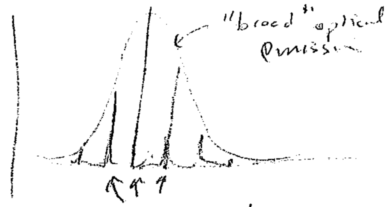
need to trap photons long enough for them to cause stim. emission → partial reflector, lets photons leak out every so often

Slides: cavity can be the crystal itself

cavity like F-P interferometer → maxima at $L = n\frac{\lambda}{2}$

$\lambda = \frac{2L}{n}$

↳ λ inside cavity, frequently = λvac



F.P.: $T = \frac{T_{max}}{1+F\sin^2\frac{\Phi}{2}}$

$\Phi = 2k_2 d\cos\theta_2$ + shifts

max T when $\sin\frac{\Phi}{2} = n\pi$ ... $\frac{\Phi}{2} = n\pi$

$\Phi = 2n\pi$

$2\frac{2\pi}{\lambda} d\cos 0 = 2\pi n$

$\frac{4d}{\lambda} = 2n$, $\lambda = \frac{2d}{n}$

Yay! same answer

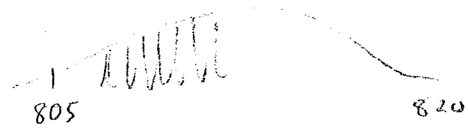
→ in this figure, about ~5 laser freqs possible

typically laser selects out one of them
→ or you can insert wavelength selecting element like a prism

→ change the length of cavity, get different FP mode structure, and then diff output λ

Tunable lasers: very broad natural emission

my laser:



- wavelength selective device (like prism) to pick approx. λ
- mode tuning (like change cavity length) to fine-tune λ

Note: F.P. recall large R → sharp resonances

~~[illegible]~~

Transverse modes: already discussed (briefly) TEM_{00} gaussian normally preferred