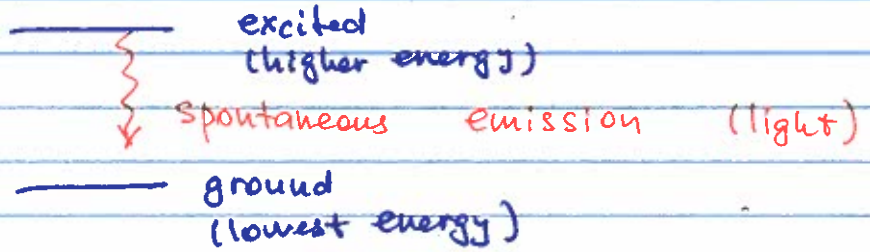
Light sources (cont)

(thermal)

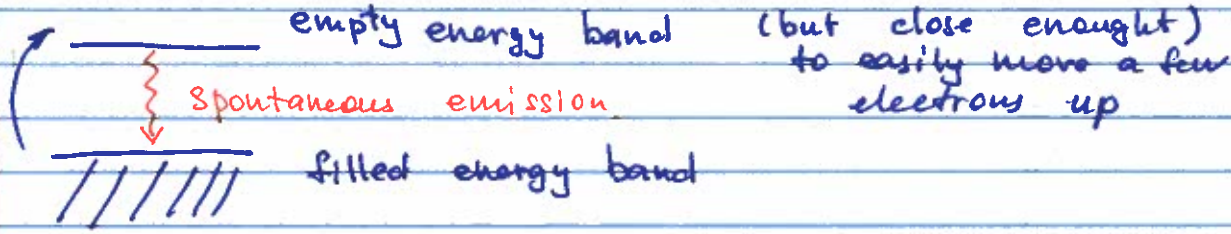
Classical motion of atoms/electrons → very broadband radiation

Quantum systems → unique structure of well-defined energy levels for electrons to occupy (atoms, simple molecules)



Semiconductors

Instead of energy levels they have bands of energies that electrons can occupy, and energy gaps that they cannot



In LED (light emitting diodes) we can use electric current to "pump" electrons in the empty (conduction) band. When these electrons "jump" back across the bandgap they emit light of corresponding frequency

Why do we need a bandgap or clean difference b/w energy levels?

Compare to many other characteristic energies of electrons in solids, a visible light photon energy is very large. So if there are alternative relaxation opportunities, an electron is more likely to relax without emitting the photon.

To produce light one needs to use some sort of energy to promote electrons to excited state

1. Electrical energy — LED, discharge lamps, neon signs
2. Chemical energy — bio / chemi luminescence
3. Optical energy — phosphorescence, luminescence

How to build a laser

- <u>specific frequency</u> $\Rightarrow$ need energy levels

——— E_e (excited state energy)

——— E_g (ground state energy)

$$\hbar\omega = \frac{2\pi\hbar c}{\lambda} = E_e - E_g$$

- atomic population in the excited state

(all lasers need a pumping mechanism to ensure population in the excited state)

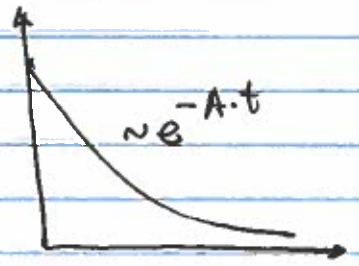
<u>• • •</u> N_e

<u>• • • • •</u> N_g

Spontaneous emission rate A_{eg}

$$\frac{dN_e}{dt} = -A \cdot N_e$$

Only spontaneous emission

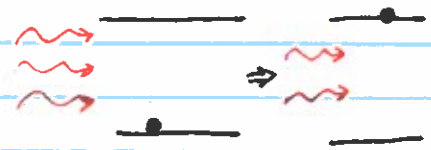


$$N_e = N_e(0)\, e^{-A\cdot t}$$

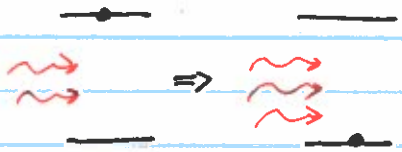
Problem: spontaneous emission goes in all directions, no coherence b/w photons

Stimulated emission and absorption

light excites a dipole $\Longleftrightarrow$ dipole oscillates and emits identical light



stimulated absorption



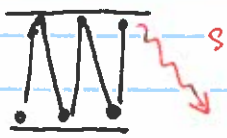
stimulated emission

produced photon is identical to the others

$$\frac{dN_e}{dt} = B_{ge} \cdot I^2 \cdot N_g \qquad \frac{dN_e}{dt} = -B_{eg} \cdot I^2 \cdot N_e$$

rate depends on B coefficients (depend on atomic structure) and light intensity

Strong light → mostly stimulated emission



weak light → more spontaneous emission

Change in light intensity

$$\frac{dI}{dt} = \frac{1}{c}\frac{dI}{dt} \cdot A \cdot c \cdot N \cdot dN$$

Number of absorbed photons $\propto N_g$

Number of emitted photons $\propto N_e$

A, B's – Einstein's coefficients establish relations b/w spontaneous and stimulated emission

$$B_{ge} = B_{eg}$$

$$A = \frac{4\pi\hbar\omega^3}{c^3} B_{eg}$$

The higher the frequency → the larger $\frac{A}{B}$

For the same amount of stimulated emission, the contribution of the spontaneous emission increases as ω^3

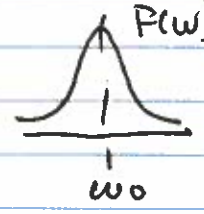
$$\frac{dI}{dt} = \text{stimulated emission} - \text{stimulated absorption} \left(- \text{loss due to spontaneous emission}\right)$$

$$\frac{dI(\omega)}{dt} = B_{ge}(N_e - N_g)\,\hbar\omega \cdot I(\omega)[F(\omega)]$$

$F(\omega)$ – spectral line, to take care of the resonant nature of interaction

in a wave $\frac{dz}{dt} = c \Rightarrow dz = c \cdot dt$

$$\frac{dI(\omega)}{dz} = B_{ge}\frac{\hbar\omega}{c} I(\omega) F(\omega)(N_e - N_g)$$



Solution $I(z) = I(0)\, e^{g(\omega)\cdot z}$

$$g(\omega) = A \cdot \left(\frac{c^2}{8\pi\omega^2}\right) F(\omega)(N_e - N_g)$$

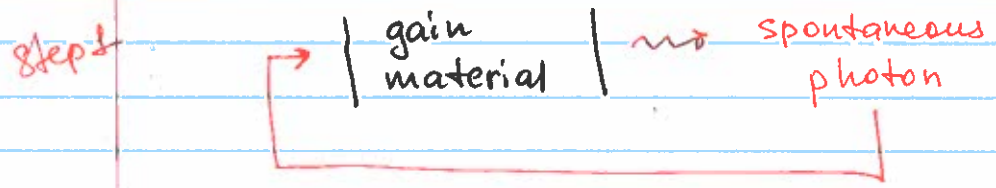
$g(\omega) < 0$ → exponential decay

$g(\omega) > 0$ → exponential growth, gain

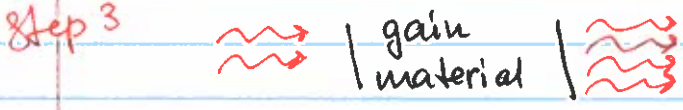
In order to produce more light than we started with, one needs to have more atoms in the excited state (emitting) than in the ground state (absorbing)

$N_e > N_g$ population inversion

- Feed back

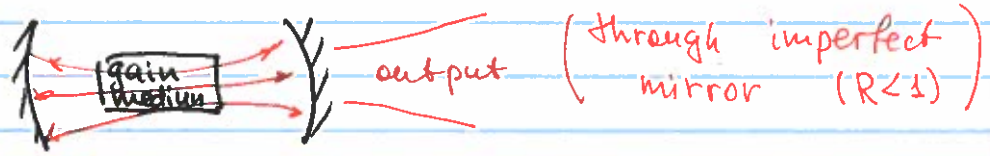






Optical feedback — cavity

Two mirrors (Fabri-Perot cavity)



Three mirror cavity (ring cavity)

