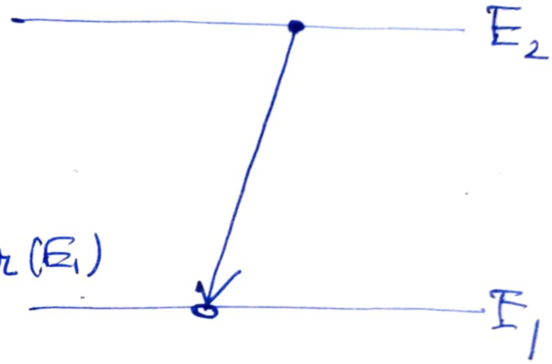
(a) Laser medium : Collection of atoms/ molecules / ions / crystals

⇒ Atomic energy levels & spontaneous emission

Quantum levels

⇒ Planck's Law



The frequency of emission due to electronic transition from upper (E_2) ~~and~~ to lower (E_1) energy level,

$$\omega_{21} = \frac{E_2 - E_1}{\hbar}$$

[Energy of emitted photon $E_{ph} = E_2 - E_1$]

$$\hbar = \frac{h}{2\pi}$$

h (Planck's constant)

$= 6.626 \times 10^{-34}$ Joule - second

$$\left[\omega = 2\pi\nu = 2\pi\frac{c}{\lambda}\right]$$

Using this formula you may findout the wavelenght of emitted light.

Often we use the energy unit electron volt (eV)

$1 \text{ eV} = 1.6 \times 10^{-19}$ Joule light has dual nature :

① particle $\Rightarrow$ photons with 'energy' (E_{ph}) and 'momentum' ($\vec{p}$)

② Wave $\Rightarrow$ Electromagnetic radiation with wavelength (λ), wave vector ($\vec{k}$)

The connection $E_{ph} = \hbar\omega = h\frac{c}{\lambda}$

$$\vec{p} = \vec{k}\hbar$$

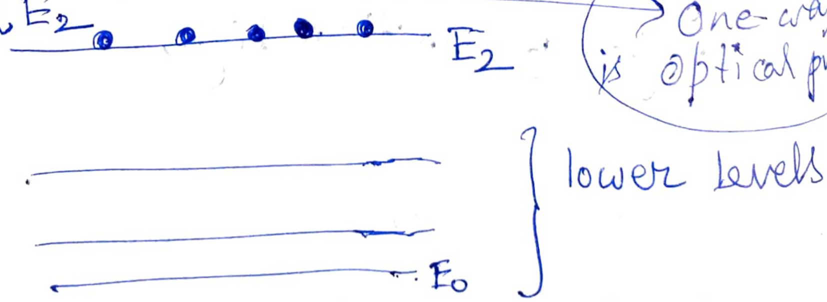
(Wave particle duality of light)

$\boxed{\text{Home work:}}$ Find out the wavelength of a light with photon energy 1·24 eV.

Spontaneous Energy Decay or Relaxation

N_2 number of atoms have been pumped into some upper energy level E_2

One-way is optical pump



These Atoms ~~electrons~~ then spontaneously drop down or relax to lower energy levels giving up the excess internal energy of the system.

Rate of spontaneous decay or relax downward

$$\left.\frac{dN_2}{dt}\right|_{spon} = -\gamma_2 N_2 \equiv -\frac{N_2}{\tau_2}$$

($\tau_2 = \frac{1}{\gamma_2}$ = lifetime of the upper level E_2 for energy decay to all lower levels)

Let say at $t = 0$, $N_2 = N_{20}$

From the rate equation above

$$N_2(t) = N_{20}\, e^{-\gamma_2 t} = N_{20}\, e^{-t/\tau_2}$$

"Spontaneous emission is ~~the~~ ultimately responsible for most of the light we see around".

(Different names are associated)

- Spontaneous emission is called luminescence if atoms/molecules are excited by means other than heating

example: fireflies

- Spontaneous emission is called fluorescence if the excitation happens via absorption of radiation (optical pumping)
- When fluorescence happens even long after the excitation is switched off from 'metastable' level

it is called <u>phosphorescent</u>.

☒ <u>Radiative and nonradiative decay/relaxation</u>

The spontaneous emission of radiation that we already discussed is actually nothing but "Radiative relaxation"

Another kind of relaxation is also possible
↓
"nonradiative relaxation"

In this case, the excess internal energy (due to the pumping or excitation) relaxes via the mechanical vibrations of the surrounding crystal lattice. ⟹ heating

<u>"Nonradiative relaxations are much faster than radiative ones."</u>

$$\boxed{\gamma_{total} = \gamma_{rad} + \gamma_{nr}}$$

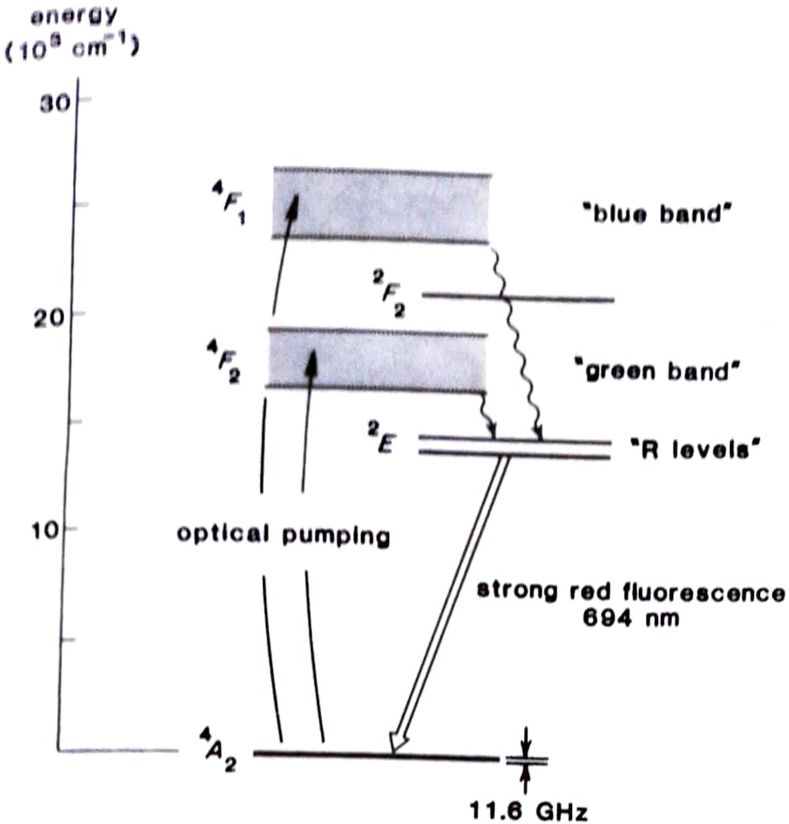


FIGURE 1.10
Quantum-mechanical energy levels of the Cr^{3+} ions in a ruby crystal.