1 The Photon

1.1 constants

$c\ \left[\frac{\mathrm{m}}{\mathrm{s}}\right]$	speed of light
$h\ \left[\frac{\mathrm{m}^2\,\mathrm{kg}}{\mathrm{s}}\right]$	planc's constant
$e\ [\mathrm{C}]$	electorn charge
$m_e\ [\mathrm{kg}]$	electron mass
$k_B\ \left[\frac{\mathrm{m}^2\,\mathrm{kg}}{\mathrm{s}^2\,\mathrm{K}}\right]$	bolzmann constant
$\lambda\ [\mathrm{m}]$	Wavelength
$\nu\ \left[\frac{1}{\mathrm{s}}\right]$	Frequency
$\omega\ \left[\frac{\mathrm{rad}}{\mathrm{s}}\right]$	Radial frequency
$E\ [\mathrm{J}]$	Energy

$$c = 2.998 \cdot 10^8\ \left[\frac{\mathrm{m}}{\mathrm{s}}\right]$$

$$h = 6.626 \cdot 10^{-34}\ \left[\frac{\mathrm{m}^2\,\mathrm{kg}}{\mathrm{s}}\right]$$

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

$$e = 1.602 \cdot 10^{-19}\ [\mathrm{C}]$$

$$m_e = 9.109 \cdot 10^{-31}\ [\mathrm{kg}]$$

$$k_B = 1.381 \cdot 10^{-23}\ \left[\frac{\mathrm{m}^2\,\mathrm{kg}}{\mathrm{s}^2\,\mathrm{K}}\right]$$

$$1\ [\mathrm{eV}] = 1.602 \cdot 10^{-19}\ [\mathrm{J}]$$

$$\lambda = \frac{c}{\nu} \qquad \nu = \frac{c}{\lambda} \qquad \omega = 2\pi\nu$$

$$E = h \cdot \nu$$

1.2 Photoelectric effect

$V\ [\mathrm{V}]$	Voltage
$\phi_0\ [\mathrm{eV}]$	Work function

$$h\nu - \phi_0 = \frac{1}{2}mv^2 = eV$$

$$V(\nu) = \frac{h}{e}\nu - \frac{\phi_0}{e}$$

1.3 Blackbody Radiation

$L\ [\mathrm{m}]$	length of blackbody cube	k_i	wave constants
E_x	Electric field in x-direction	$< E >$	Average Energy
N	Number of states	D	Density of states
u	Blackbody radiation	I	Power radiated

$$E_x(x,y,z) = E_{0x}\cos(k_x x) sin(k_y y) sin(k_z z)$$

$$k_x = n\frac{\pi}{L} \quad k_y = m\frac{\pi}{L} \quad k_z = l\frac{\pi}{L} \qquad k = \sqrt{k_x^2 + k_y^2 + k_z^2}$$

$$N(k) = \frac{1}{3\pi^2}k^3L^3 \qquad D(k) = \frac{k^2}{\pi^2}$$

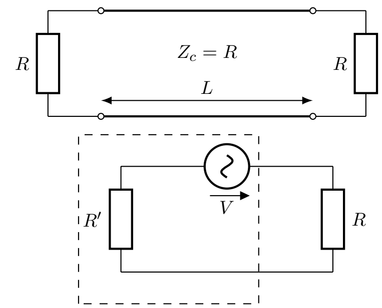
$$u(\omega) = \frac{\omega^2}{\pi^2c^3} \cdot \frac{\hbar\omega}{\exp\left(\frac{-\hbar\omega}{kT}\right) - 1}d\omega \qquad u(\nu) = \frac{8\pi h\nu^3}{c^3\left(\exp\left(\frac{h\nu}{kT}\right) - 1\right)}d\nu$$

$$I(\omega) = c \cdot u(\omega)$$

Equipartition-Theorem: Each degree of Freedom has an energy of kT

1.4 Johnson-Noise

This is the noise created in a one-dimensional circuit (like a coax-cable).

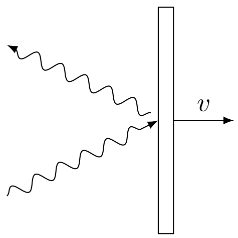


$\langle V^2 \rangle$	Noise Voltage
$\Delta\nu$	Bandwidth

$$E = E_0 \cdot \sin(k_x \cdot x)$$

$$\langle V^2 \rangle = 4R \cdot k_B T \cdot \Delta\nu$$

1.5 Momentum of a photon

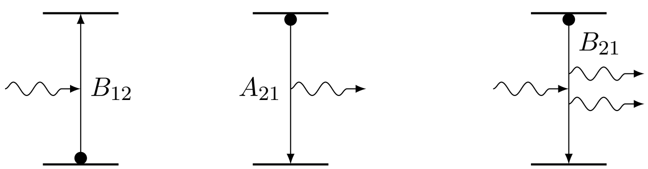


p momentum

$$p_{absorbing} = \frac{h\nu}{c}$$

$$p_{reflecting} = 2 \cdot \frac{h\nu}{c}$$

1.6 Absorption, spontaneous and stimulated emission



absorbtion spontaneous emission stimulated emission

n_1 Number of electrons in the lower energy state

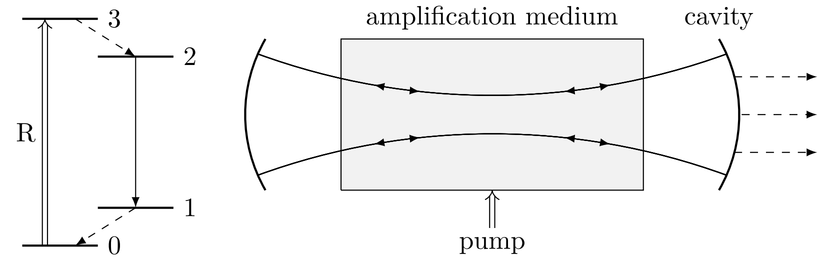
n_2 Number of electrons in the higher energy state

$$\frac{dn_2}{dt} = \underbrace{n_1 \cdot u(\nu) \cdot B_{12}}_{\text{absorbtion}} - \underbrace{n_2 \cdot u(\nu) \cdot B_{21}}_{\text{stimulated emission}} - \underbrace{n_2 \cdot A_{21}}_{\text{spontaneous emission}}$$

$$\frac{n_2}{n_1} = e^{-\frac{h\nu}{k_B T}} = \frac{u(\nu)B_{12}}{u(\nu)B_{21} + A_{21}}$$

$$B_{21} = B_{12} = B \qquad A_{21} = \frac{8\pi h\nu^3}{c^3}$$

1.7 Laser-optical amplification



Electrons are excited from the ground state “0” to the level “3” by pumping through incoherent radiation. The electrons then fall onto a long-lived state n_2 (State “2”) from level “3”. The pumping can be done either optically by shining a strong incoherent light or by passing a current. It is also assumed that the lower state is quickly emptied by a fast process with lifetime τ_1. As a result, the population in state “2” is:

$$n_2 = \frac{R}{A_{21}} \quad \text{whereas} \quad n_1 \approx 0 \quad \text{because} \quad A_{21} < \frac{1}{\tau_1}$$

We have rherefore a population inversion between the two states. The likelihood of a stimulated emission process is larger than the one of absorbtion. bIf we enclose the system in an optical cavity, we can achieve self-sustained oscillation at the frequency ν.