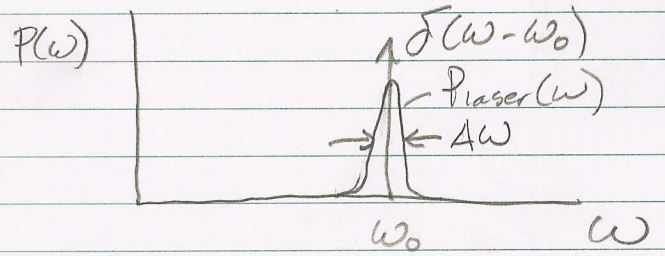
Special properties of laser light

1. Monochromaticity. Ultra-narrow spectral bandwidth



"power spectral density plot"

For pure single frequency: [redacted] light field

$$P(\omega) \sim P_0 \delta(\omega - \omega_0)$$

laser light has very narrow bandwidth - close to delta function. For visible light - $\lambda = 500$ nm. $\nu_0 = 6 \times 10^{14}$ Hz
Typical laser bandwidth ~ 10 MHz ~ 10^7 Hz :- [redacted]

Specially engineered lasers for ultra precision measurements can have $\Delta\nu$ below 0.01 Hz

Stimulated emission is coherent

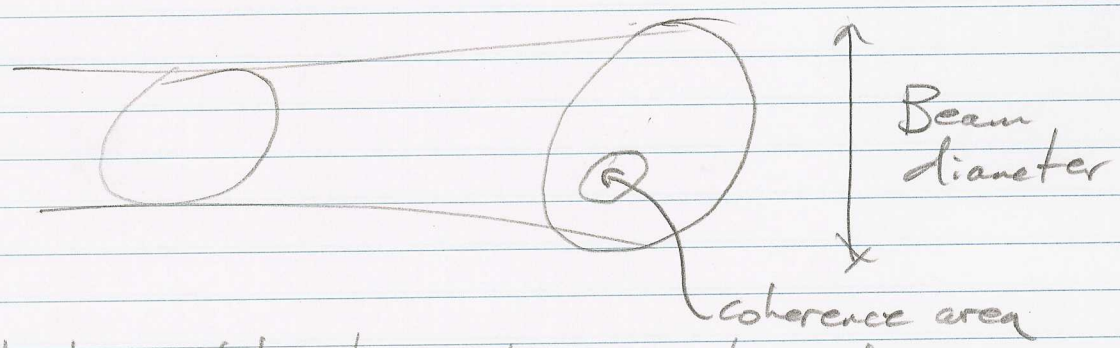
Why? - Atomic transition provides gain only near ν_0.
Also (usually more important) - laser cavity provides feedback only at resonant frequencies. These come from discrete frequencies of standing-wave cavity modes.

2. Coherence

a) temporal coherence. Ultra-narrow bandwidth is synonomous with temporal coherence. Any wave with bandwidth $\Delta\nu$ can be modelled as a nearly perfect, constant amplitude sinewave for a period of time $\tau_c \sim 1/\Delta\nu$. Amplitude and/or phase variations occur on the timescale of τ_c - the coherence time.

random

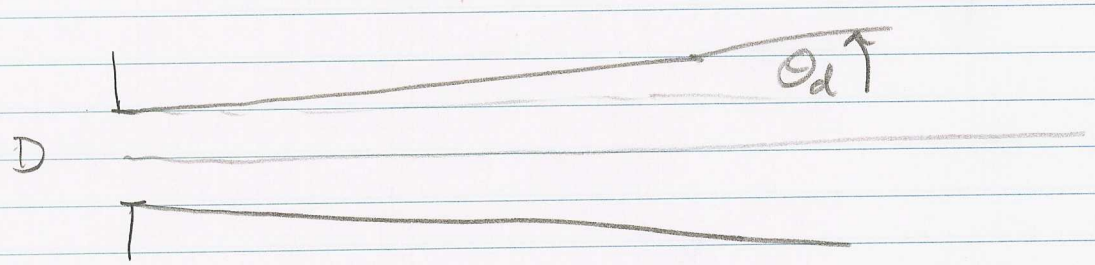
b) <u>Spatial coherence</u>. This relates to how the field at different points separated in space are correlated. Since the amplitude/phase is fluctuating, different points may be totally independent, or fluctuate together (coherently). In a light beam, spatial points that are close together are usually correlated strongly (mutually coherent). The area over which this correlation extends is called the coherence area, S_c.



For high quality laser beams, the coherence area is the <u>entire</u> beam area. (as in a plane wave). This is one of the most unique qualities of laser light. All other sources have much smaller coherence area.

High spatial coherence is synonomous with low beam divergence (beam divergence is related to <u>spatial bandwidth</u> in Fourier Optics).

For a <u>coherent</u> beam with diameter D, the divergence due to diffraction is



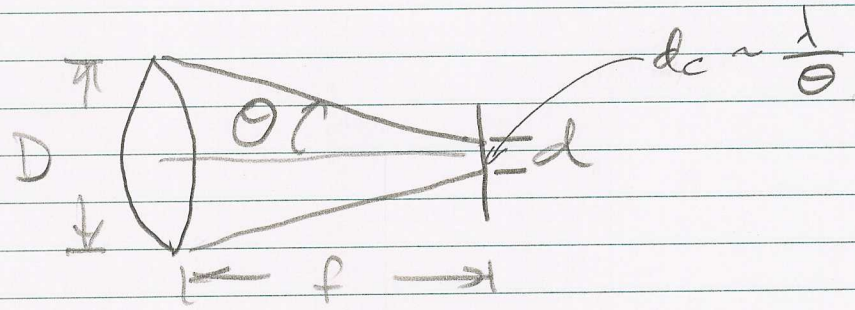
diameter D

For a partially coherent beam the divergence is always larger than Θ_d. In fact the actual divergence is related to the coherence area

d_c: coherence diameter

Minimum value of S_c is $\sim \lambda^2$. This corresponds to an isotropic light source with $\Theta \sim \pi$

Also true in reverse – for a converging beam (i.e. from a lens), same relation holds for convergence angle and coherence area at minimum spot



For partial spatial coherence, $d > d_c$. For laser light, we get smallest possible spot $d = d_c$