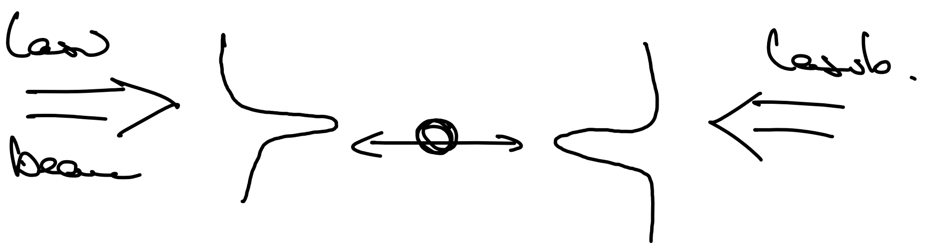
Experimental realization of optical traps



Gradient forces

Coaxial alignment

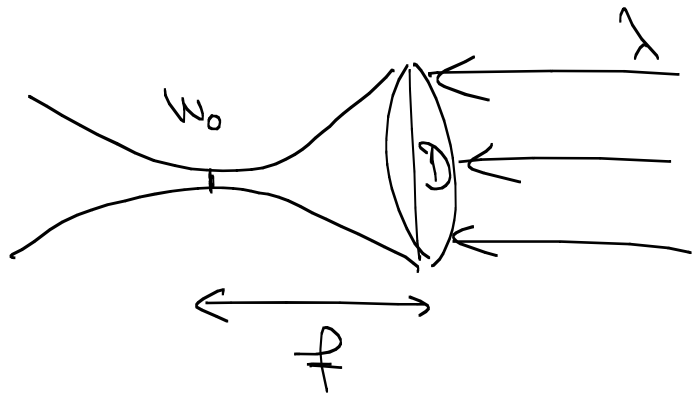
trap with a single laser beam

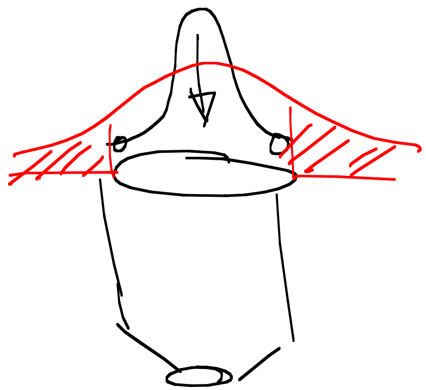
$$R = \frac{F_{grad}}{F_{rad}} = \frac{3\sqrt{3}\, n^2_{sol}}{64\pi^5 \left(\frac{n^2-1}{n^2+2}\right) a^3 \cdot w_0^2} \geq 1$$

↑ w_0: beam waist of gaussian beam

→ Small beam waist

$$w_0 = 1.22 \cdot \frac{\lambda \cdot f}{D}$$



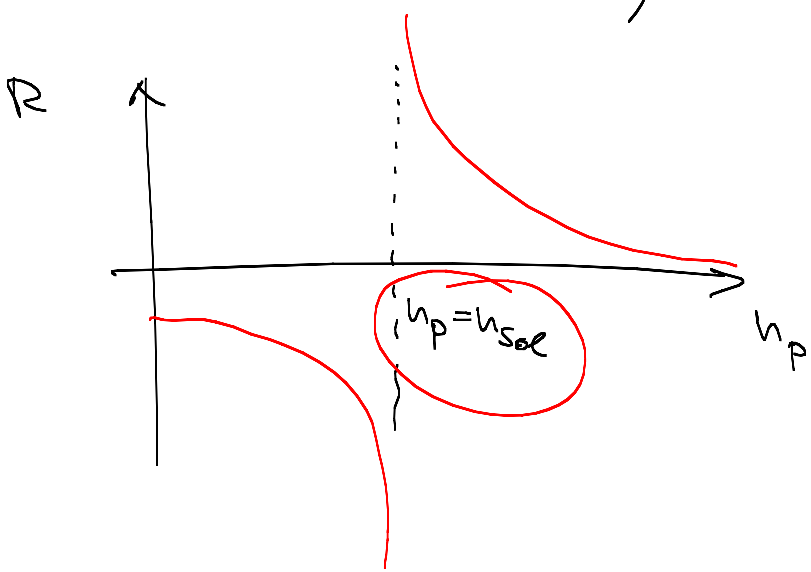


Overfilling of back aperture

in praxis $R \geq 3$

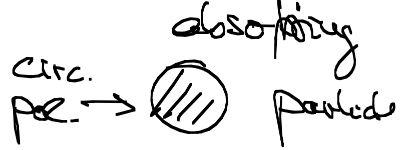
Dependence of R on indices of refraction

$$R \propto n_{sol}^2 \cdot \left(\frac{n^2+2}{n^2-1}\right) \quad ; \quad n^2 = \frac{\varepsilon_p}{\varepsilon_{sol}}$$



n_p close to n_{sol}

transfer angular momentum of photons to particles



birefringent particle

Multiple optical traps

i) Acousto-optical deflectors (AODs)

Create acoustic wave in crystal

~ MHz

→ density grating

→ index of refraction variation

$$n(z) = n + \Delta n \cos(\Omega t - Kz)$$

← phase grating

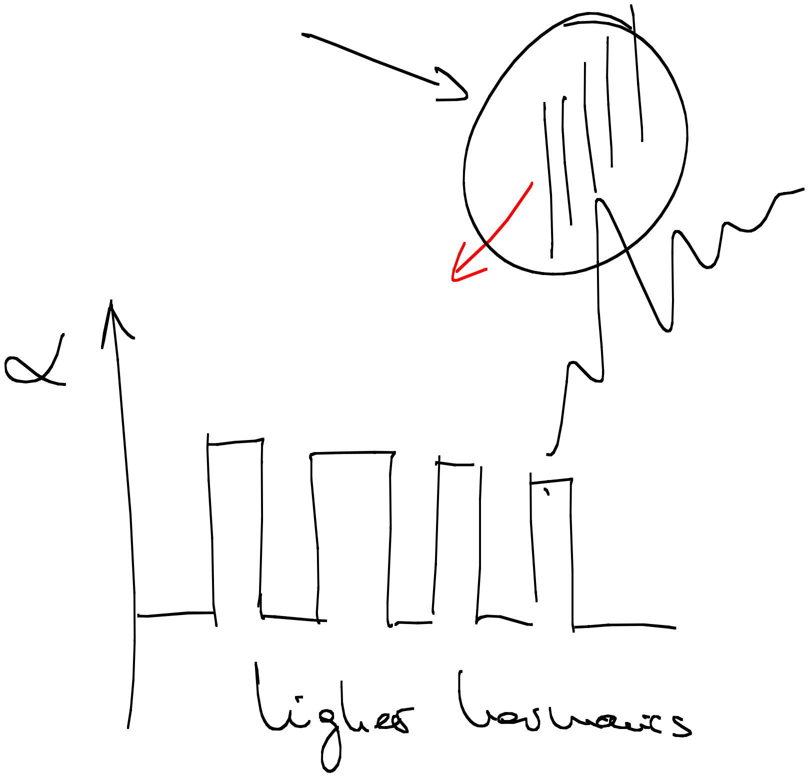
n : undistorted index o. r.

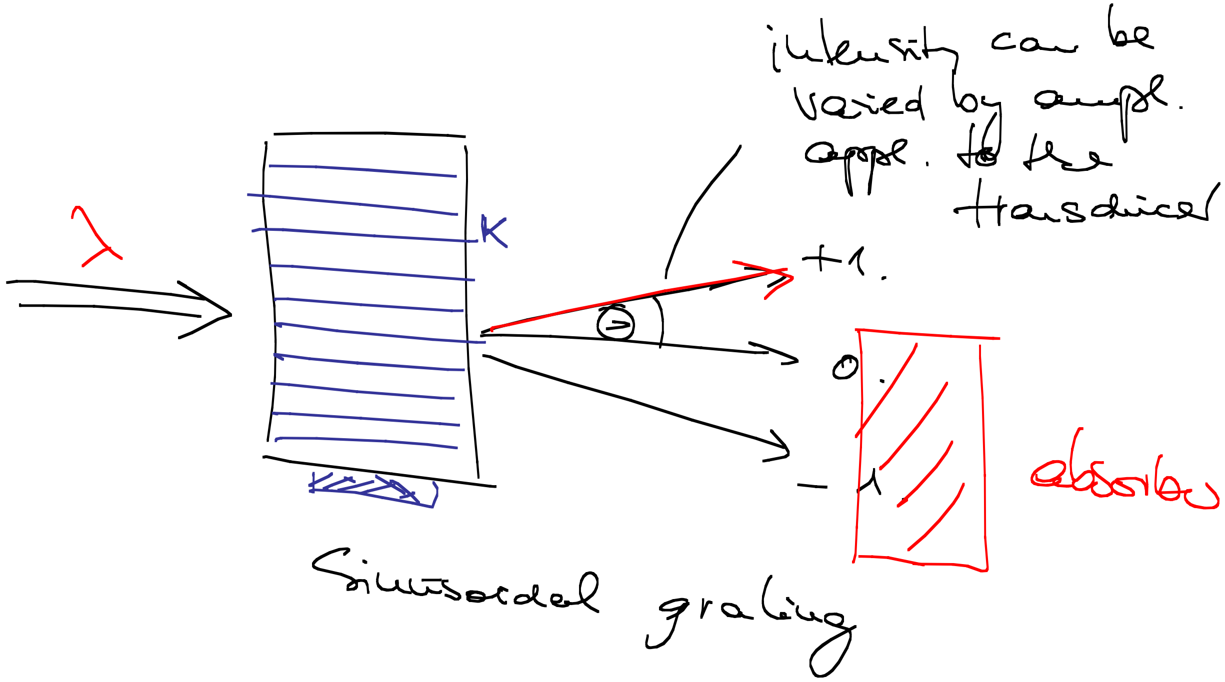
Ω : Frequency } of acoustic wave

K : Wave vector } of acoustic wave

$\Delta n \propto p \cdot \alpha$ ← mech. distortion

(p ← photo-elast. const.)

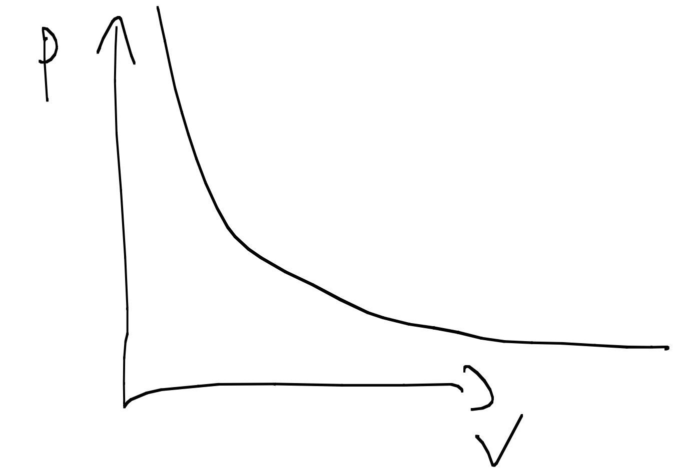




$$2d \cdot \sin\Theta = n \cdot \lambda$$

Phase transition

Ideal gas , isotherm (P-V const T)



$$P = \frac{N}{V} k_B T \qquad (N, V, T) \text{ ensemble}$$

Real gas : Van-der Waals gas

$$\left(P + \frac{N^2 a}{V^2}\right)(V - Nb) = N k_B T \quad (\text{EOS})$$

a : attraction between gas particles

excluded volume (b)

$$c = \frac{N}{V}$$

$$\hookrightarrow \left(p + ac^2\right)\left(\frac{1}{c} - b\right) = k_B T$$

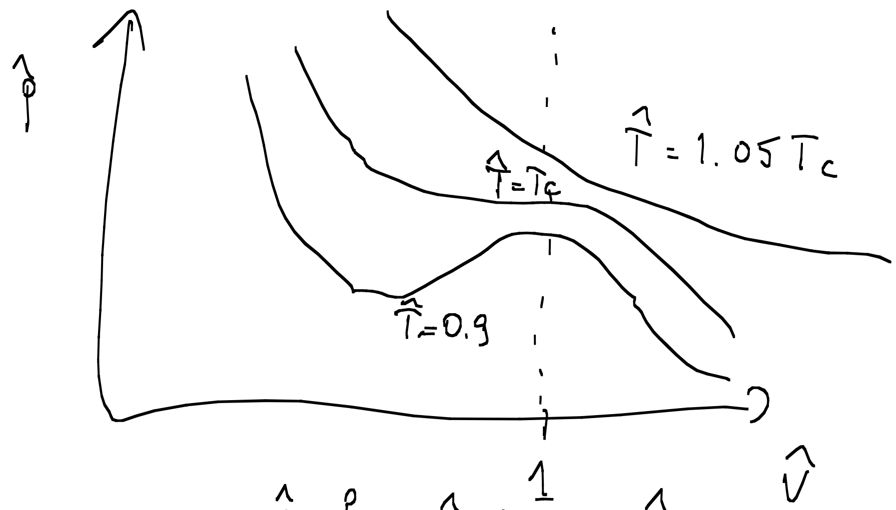
$$\left(p + ac^2\right) = k_B T c \Big/ (1 - cb)$$

$$p = \frac{k_B T c}{1 - cb} - ac^2 \quad \Big| \text{ exp in powers of density}$$

$$p = k_B T c \left(1 + cb + (cb)^2 \dots\right) - ac^2$$

$$= k_B T c + \underbrace{\left(k_B T b - a\right)}_{\text{second virial coeff.}} c^2 + \underbrace{k_B T b^3}_{3^{rd} \text{ virial coeff.}} c^3 \dots\dots$$

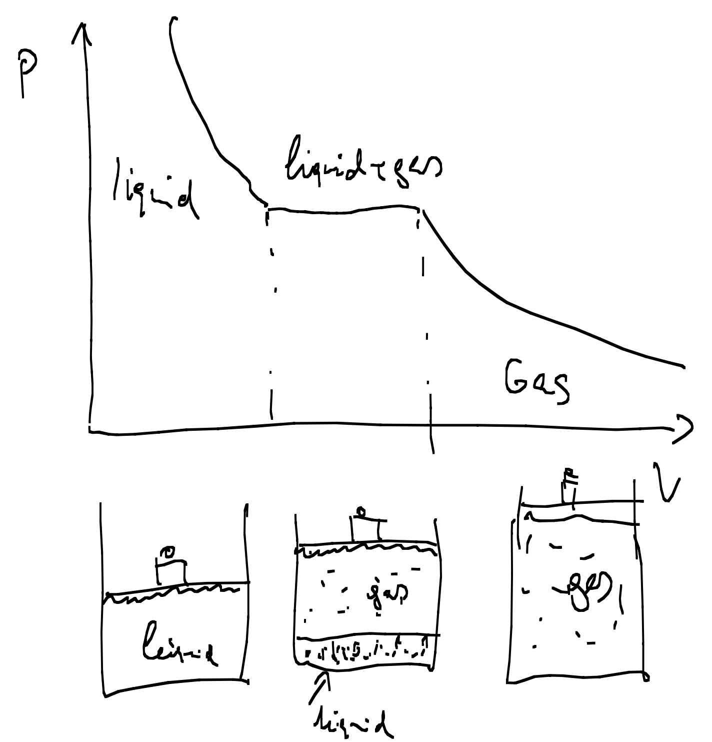
↑ ideal gas



$\hat{p} = \frac{p}{p_c}$, $\hat{V} = \frac{V}{V_c}$ – $\hat{T} = \frac{T}{T_c}$

$p_c = \frac{a}{27 b^2}$

Virial expansion



coexistence only if $T < T_c$ ← critical temperature

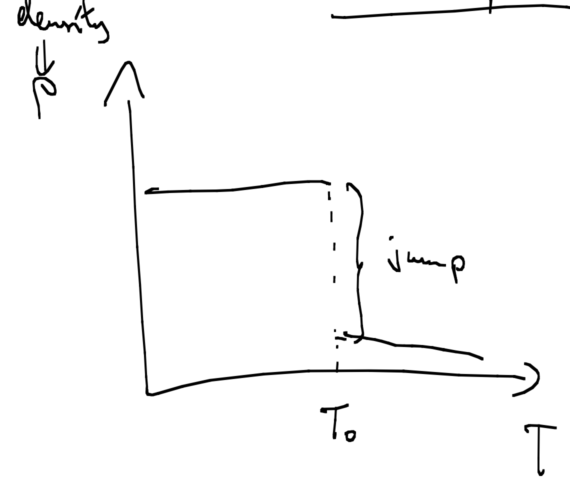
for $T > T_c$ only one single phase (fluid phase) no matter how high the pressure

Thermodynamic condition for coexistence of two phases

$$P_\ell = P_g \,, \quad T_\ell = T_g \,, \quad \mu_\ell = \mu_g$$

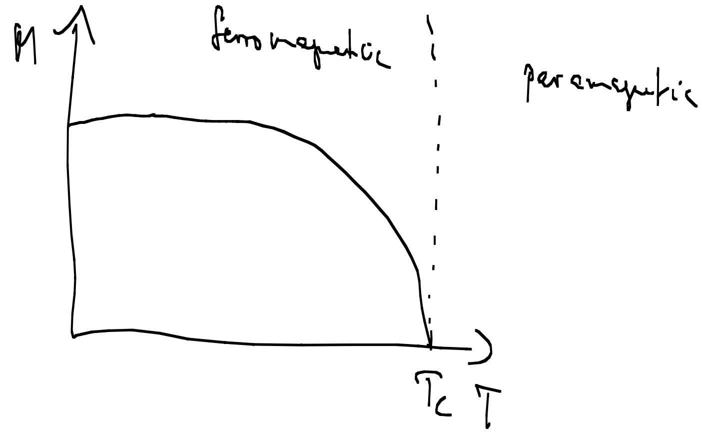
$$\mu_g(P,T) = \mu_\ell(P,T)$$ condition of coexistence

Examples:



discontinuous
"first order"

Spontaneous magnetization



continuous
"2nd order"

Phase transitions can also be visible as peaks (divergencies) in appropriate response function.

Let's look at it next time!
next year!