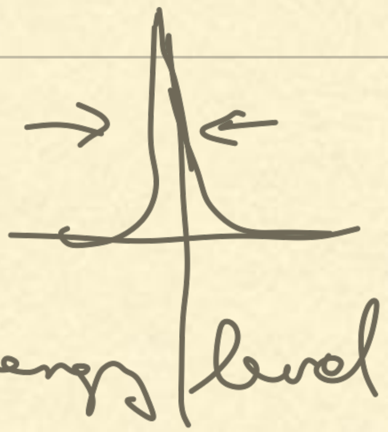
9.3. Line Broadening

Every line will have a natural line width ∝ time spent in upper energy level



line Lorentzian

Observed line width > natural line width

ie other broadening mechanisms happen.

1 Doppler broadening ← most common

2 Pressure broadening

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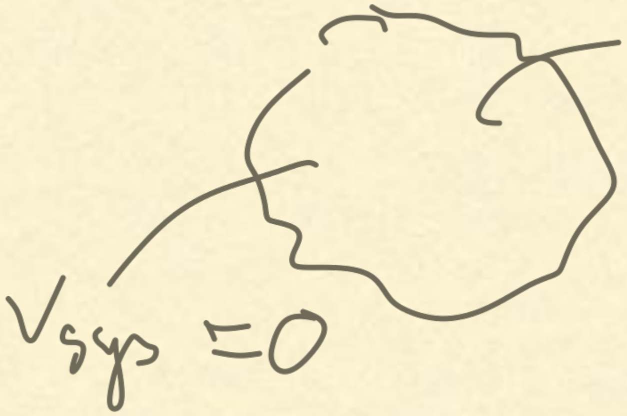
1) Doppler broadening



particles moving around emitting a spectral line

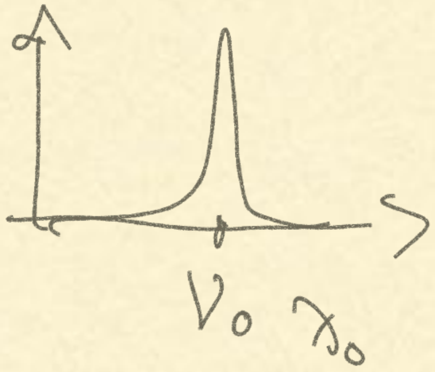
individual motions

– thermal, turbulence rotation, expansion contraction, shock waves

⇒ lots of radial velocity components, lots of doppler shifts

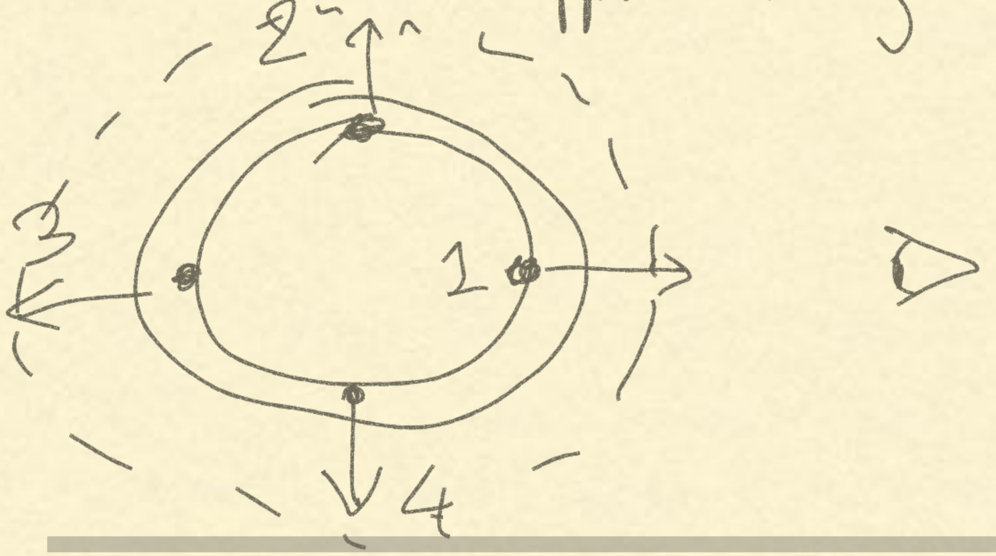
superposition of all ⇒ broadening of line

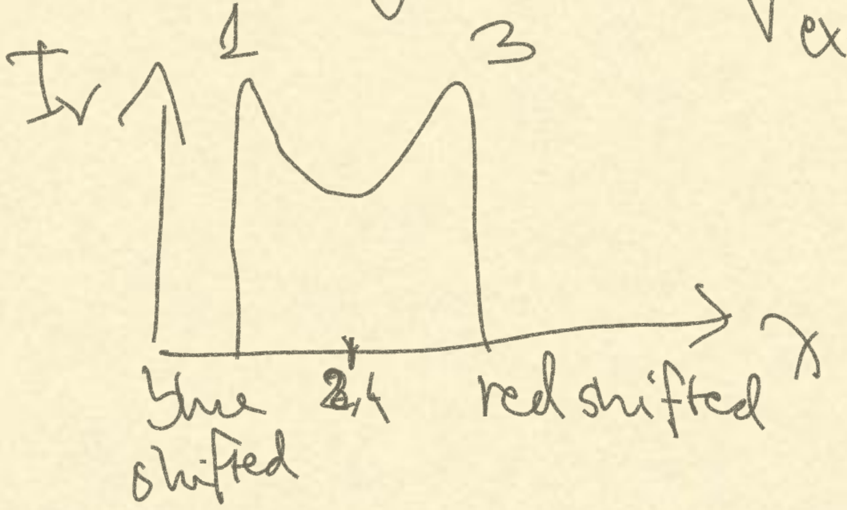
if $v_{sys} = 0$



if $v_{sys} \neq 0$ centre at λ corresponding to v_{sys}

eg. SNR width of the line shows max velocity of both the approaching and receding sides





$V_{expansion} = \frac{1}{2}$ linewidth

problem (9.4)

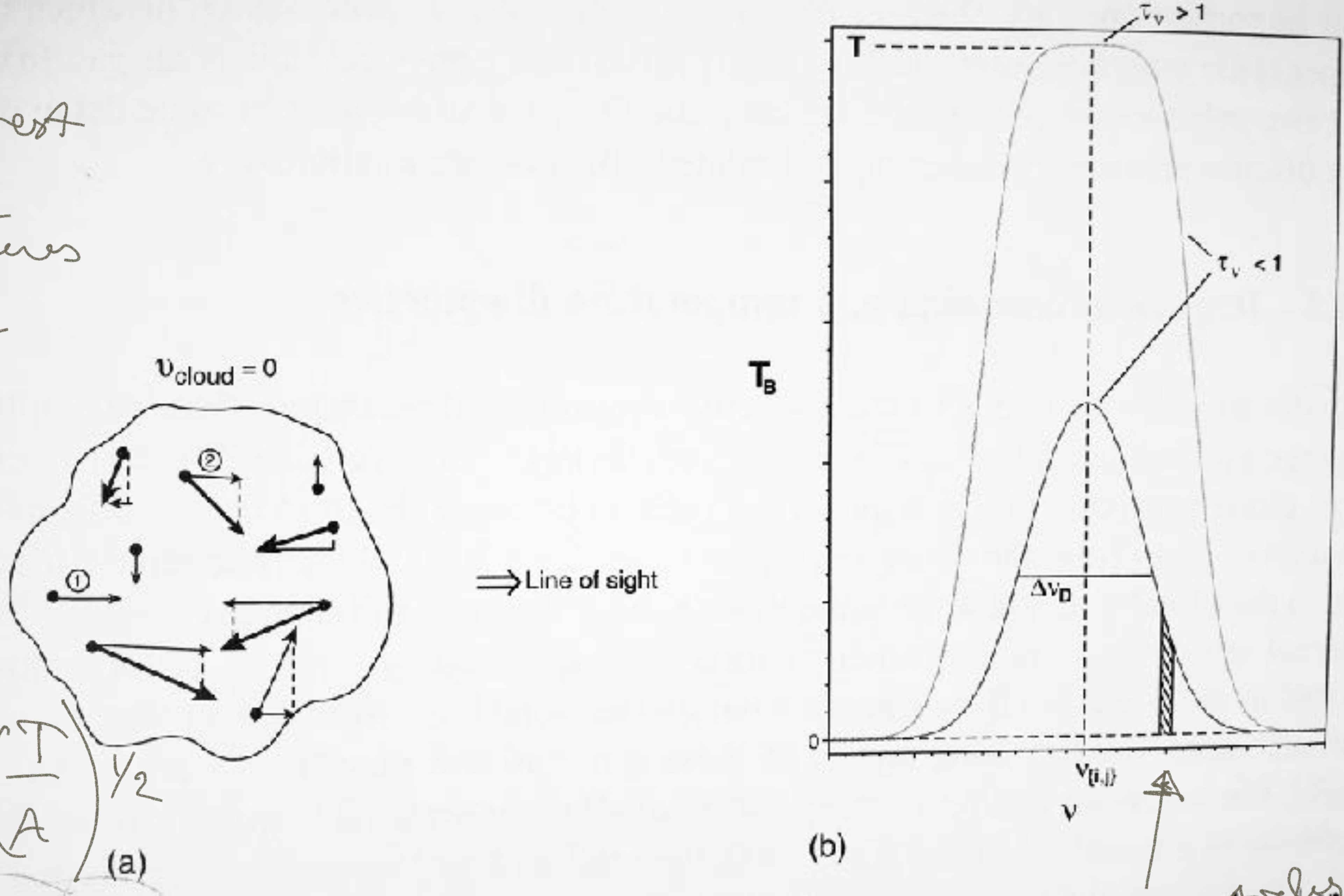
even if cloud is very calm (no special peculiar motions)
just having a temperature T

$\Rightarrow$ thermal line broadening due to doppler shifts of particles in a maxwellian vel distr.

ex $v_{sys} = 0$ $\tau_\nu \ll 1$ spectral line will have a Gaussian shape, centred @ rest freq.

a) gas cloud@ rest

b) 2 spectral lines (from different clouds, different dens i.e diff τ_ν)



all particles with same radial vel.

$\Delta\nu_D$ = FWHM

$$= [9.3] = \frac{2.14 \cdot 10^4}{\lambda_{ij}} \left(\frac{T}{A}\right)^{1/2}$$

A = atomic weight (=1 for H, 4 for He)

T = kinetic temp of the gas.

Relationship b/w line width & temp_

eq 9.6 shows same but in velocity:

$$\overset{\overset{\text{vel}}{\downarrow}}{\Delta V_D} = 2.14 \cdot 10^4 \left(\frac{T}{A}\right)^{1/2}$$

Can have contributions to line width from several effects — so T won't be true temp but an <u>upper limit</u>

Observed FWHM of a line ≥ thermal line width

$$\Delta \nu_{FWHM} \geq \Delta \nu_D \quad \text{or} \quad \Delta V_{FWHM} \geq \Delta V_D \qquad (9.7)$$

Useful – only need observe & plot spectral line, measure width $\rightarrow$ upper limit to T

in 6.4.1 can use peak of spectral line in LTE for a <u>lower limit</u> of gas temp

Ex 9.1 ISM cloud with 21 cm HI line

line peak at $I_\nu = 4.63 \cdot 10^{-17}$ erg/s/cm²/Hz/sr

21 cm HI

$I_\nu = 4.03 \cdot 10^{-17}$ cgs

$\Delta\nu_{FWHM} = 15\,\text{kHz}$

} Find the temp range!

HI line collisions $\Longrightarrow$ LTE (always)

1) Lower limit

$T_B \le T$

$h\nu \ll kT$ can use R-J (eq 4.6)

21 cm = 1420.4 MHz = line centre ν_{ij}

$\uparrow$ 21.106

$$\underset{\substack{\uparrow \\ I_\nu}}{B_\nu(T)} = \frac{2\nu^2 kT}{c^2} \Longrightarrow T = 65K \text{ @ peak}$$

$I_\nu = B_\nu(T)(1-e^{-\tau_\nu})$

(no BG)

$T_{B\nu} = T(1-e^{-\tau_\nu})$ eq 6.31

for $\tau_\nu \ll 1$

$T_{B\nu} = T\tau_\nu$

$T_{B\nu} \le T$ eq 6.33

2 Upper limit

$$\Delta\nu_{FWHM} = 15\ \mathrm{kHz}$$

use eq 9.3 $\Delta\nu_D = \dfrac{2.14\cdot 10^4}{\lambda_{ij}}\left(\dfrac{T}{A}\right)^{1/2}$

$\uparrow$ 21,106 (table C.1)

$\Rightarrow T = 219\ K$ $65 \le T \le 219\ K$

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line width determined by vel distr

transition type doesn't matter

So upper limit of T valid for any optically thin line (transition physics doesn't matter)

(has to be LTE)

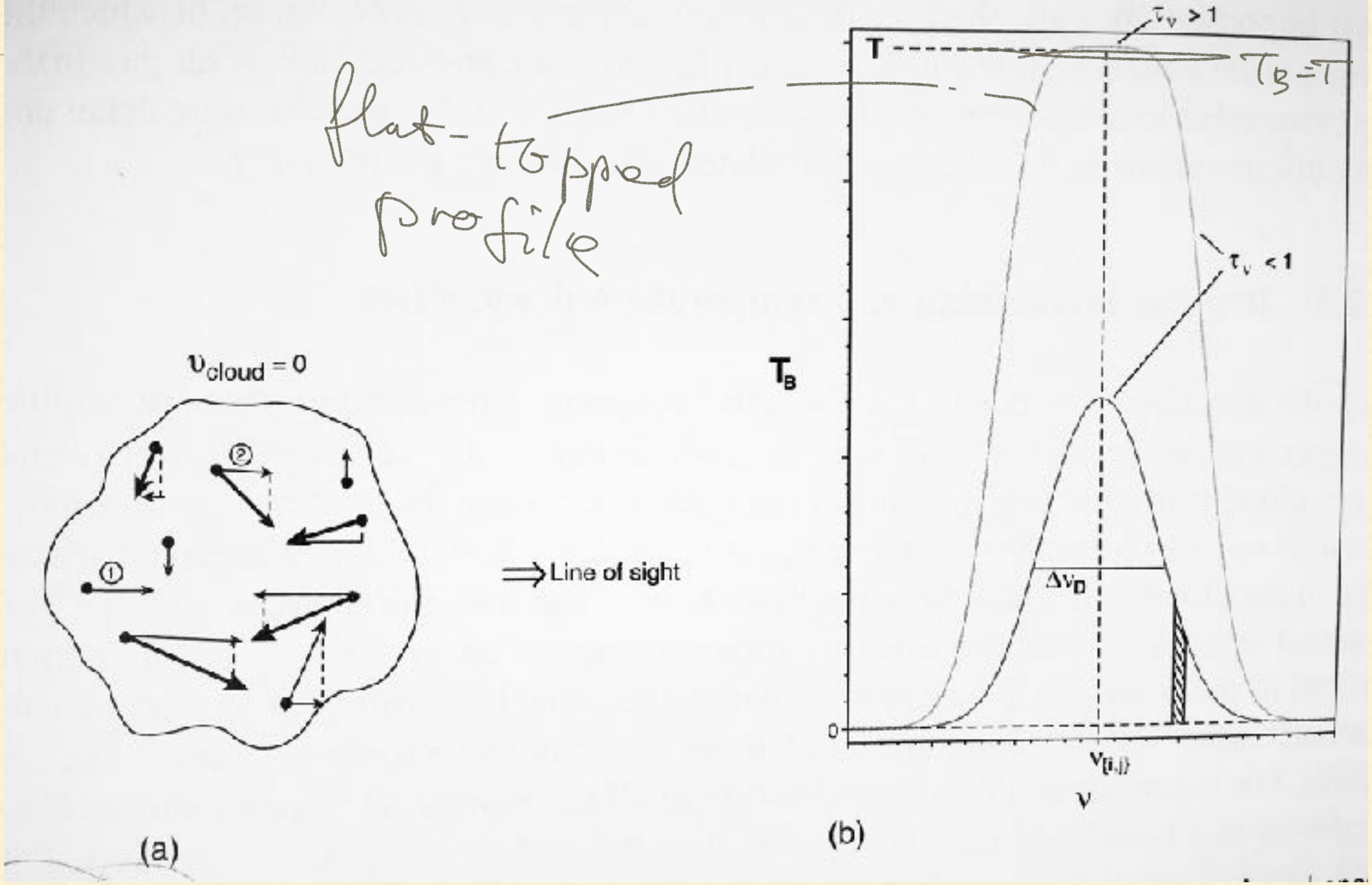
optically thick line?

Look at LTE-solution to ERT (eq 6.20)

$\Rightarrow$ $I_\nu = B_\nu(T)$ $(\tau_\nu >> 1)$ at ν where $\tau_\nu >> 1$

$\Leftrightarrow$ $T_B = T$ for these ν

So, if we have a flat-topped profile ⇒ optically thick, in LTE = "thermalized" T_{gas} is given by peak T_B of that line.



2. Pressure broadening

higher densities ~ stellar atmosphere

several effects

interactions b/w emitting atom and other particles due to higher density.

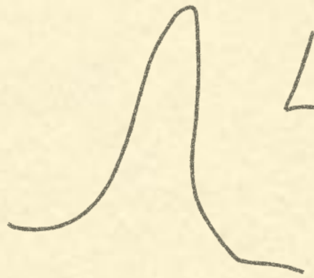
⇒ perturbs radiating atom transition (don't cause transitions)

⇒ causes small shifts in ν

lots of particles ⇒ lots of small shifts

⇒ widened line.

if both ⇒ Gaussian + Lorentzian profiles
= Voigt profile.



Lorentzian profile

Emission coefficient for line emission

Einstein coefficient (orpc)

eq 9.8:

$$j_\nu = \frac{n_j A_{ji} h\nu}{4\pi}\,\phi(\nu)$$

density of atoms w/ e^- in level j

e.g Gaussian

eg eq 9.1