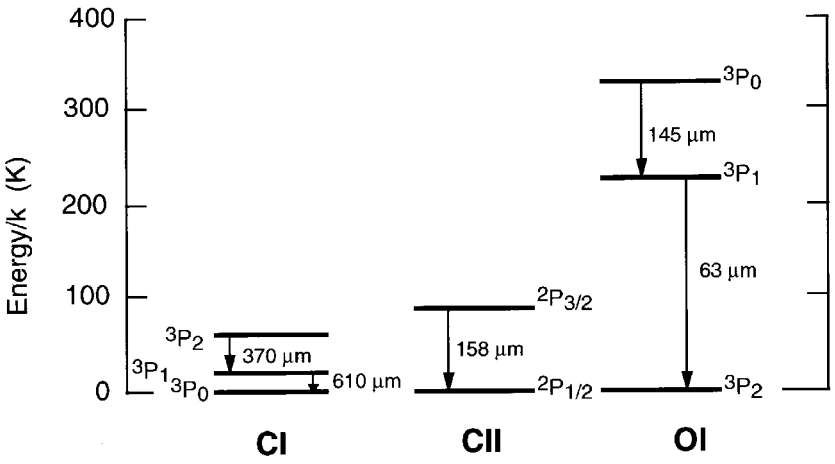



**Fig. 4.3.** Energy level diagram (Grotrian diagram) for C, $C^+$ et O, illustrating the fine-structure transitions. The wavelengths of the observable transitions are indicated.

J. Lequeux, 2004, *The Interstellar Medium*, p. 52

## Forbidden lines in the neutral medium

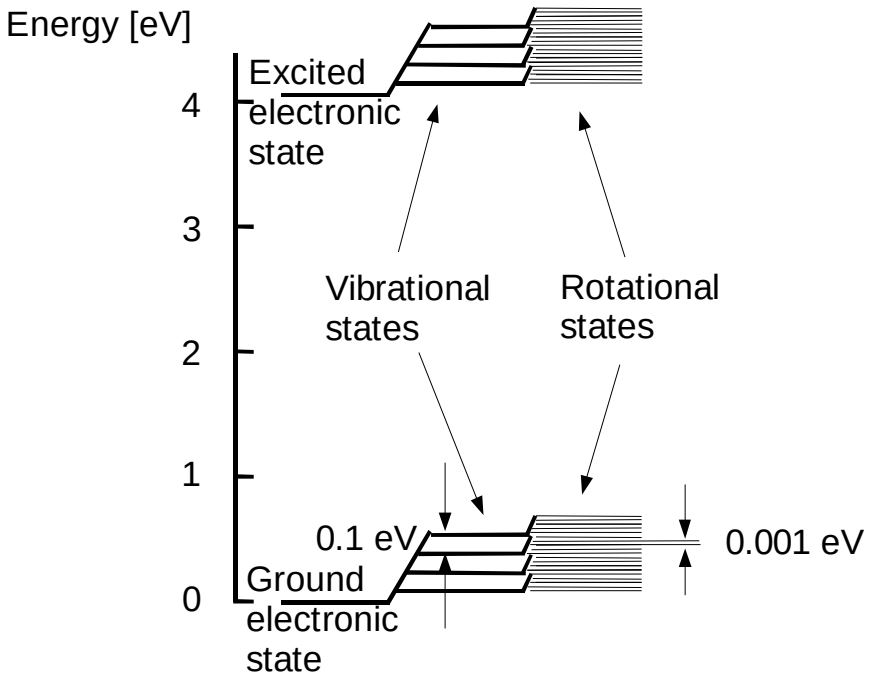
| Ion | Transition l–u | λ μm | $n_{crit}$ $cm^{-3}$ |
|---|---|---|---|
| C I | $^3P_0-^3P_1$ | 609.1354 | (500) |
| | $^3P_1-^3P_2$ | 370.4151 | (3000) |
| C II | $^2P_{1/2}-^2P_{3/2}$ | 157.741 | 47 (3000) |
| O I | $^3P_2-^3P_1$ | 63.184 | |
| | $^3P_1-^3P_0$ | 145.525 | $2.3 \times 10^4$ ($5 \times 10^5$) |
| | $^3P_2-^1D_2$ | 0.63003 | 3400 ($1 \times 10^5$) |
| Si II | $^2P_{1/2}-^2P_{3/2}$ | 34.8152 | ($3.4 \times 10^5$) |
| S II | $^4S_{3/2}-^2D_{5/2}$ | 0.67164 | 1240 |
| | $^4S_{3/2}-^2D_{3/2}$ | 0.67308 | 3270 |
| Fe II | $^6D_{7/2}-^6D_{5/2}$ | 35.3491 | ($3.3 \times 10^6$) |
| | $^6D_{9/2}-^6D_{7/2}$ | 25.9882 | ($2.2 \times 10^6$) |

J. Lequeux, 2004, *The Interstellar Medium*, p. 53, Table 4.1

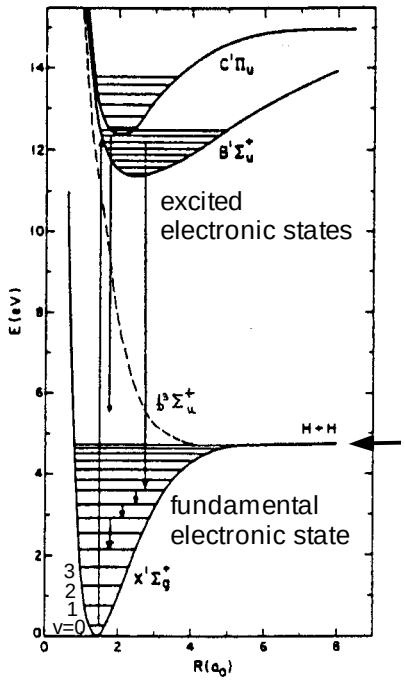
Most important interstellar absorption lines

- Sodium
  - Na I $D_1$ and $D_2$ at 5889 and 5895 Å
  - Na I at 3302 and 3303 Å
- Potassium
  - K I at 7699 Å
- Calcium
  - Ca II H and K at 3933 and 3968 Å
  - Ca I at 4266 Å
- Weaker lines of Li, $Ti^+$, ...

## Energy levels for diatomic molecules



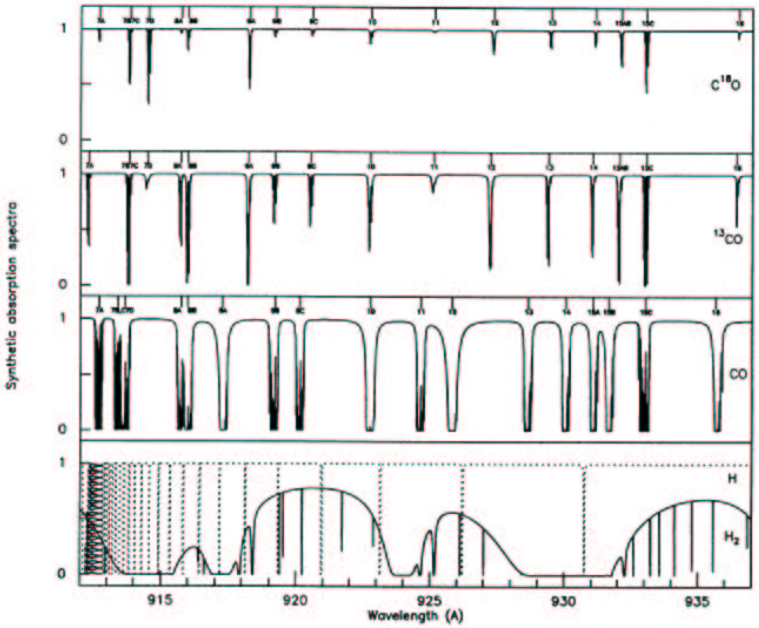
## Potential energy curves for $H_2$




J. Lequeux, 2004,
*The Interstellar Medium*,
p. 68, Fig. 4.8

## Cloud model

Intensity: $k_x(\lambda, \tau_v) = exp(-\sum_j N_j^X(\tau_v) \sum_i \sigma_{ji}(\lambda))$




$N_j^X(\tau_v)$
column density of level $J$ of species X
from the cloud surface
to the current point of depth $\tau_v$

$\sigma_{ji}(\lambda)$ absorption cross-sections

$n=10^3$ cm$^{-3}$
T= 25 K

**Fig. 2.** Absorbed intensity spectra of $C^{18}O$, $^{13}CO$, CO and $H_2$ in the center ($\tau_v$ = 2) of the translucent cloud model defined in Fig. 1. Labels of CO bands correspond to those listed in Table 1

Warin et al. (1996)

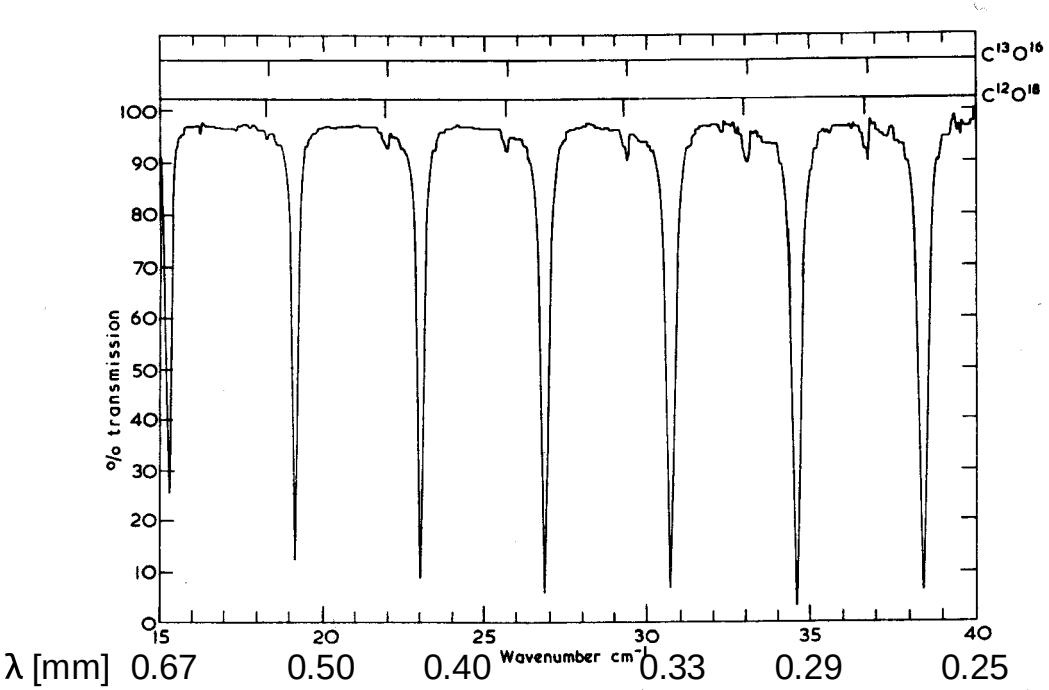
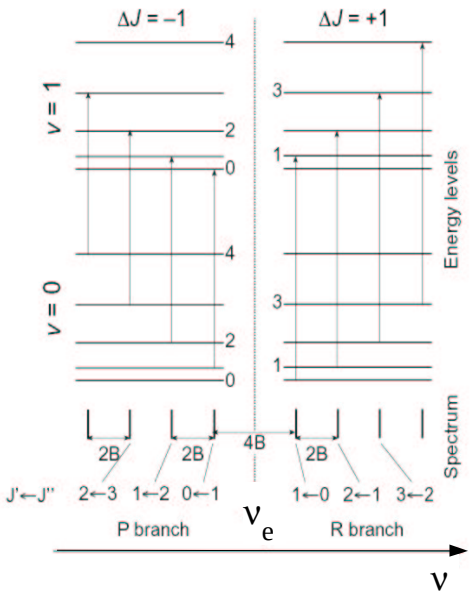


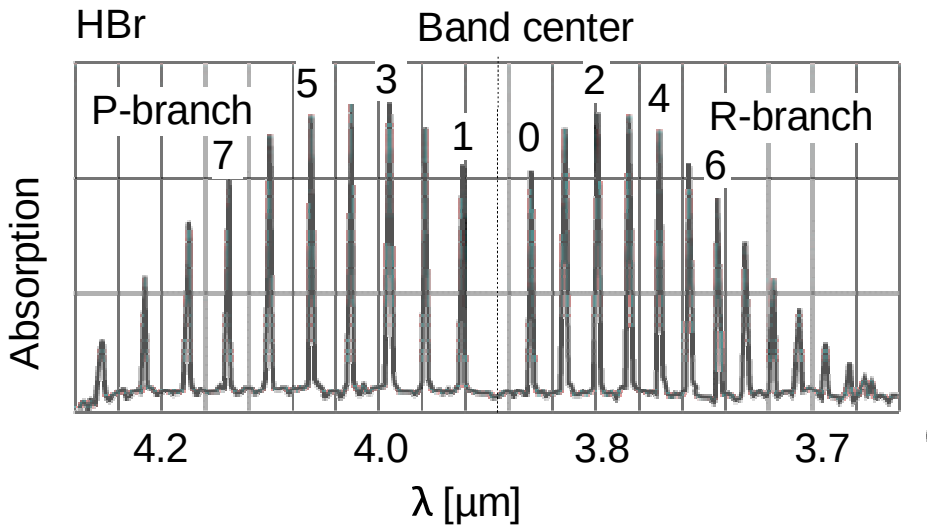

**Figure 6.15.** Far-infrared absorption spectrum of CO showing $J = 4 \leftarrow 3$ at 15.38 $cm^{-1}$ to $J = 10 \leftarrow 9$ at 38.41 $cm^{-1}$.

Peter F. Bernath, 1995, *Spectra of Atoms and Molecules*, p. 172

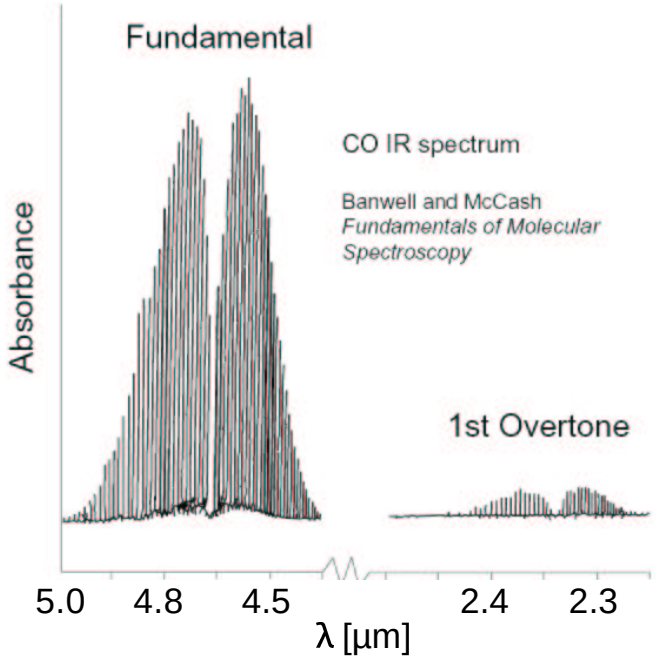
## Vibration-rotation transitions of diatomic molecules



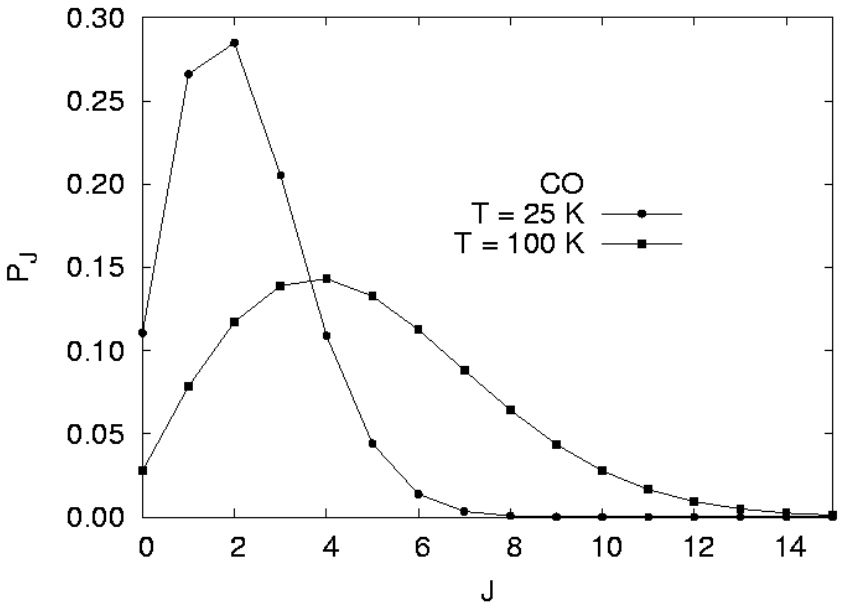

From lecture notes by G.R. Darling, University of Liverpool

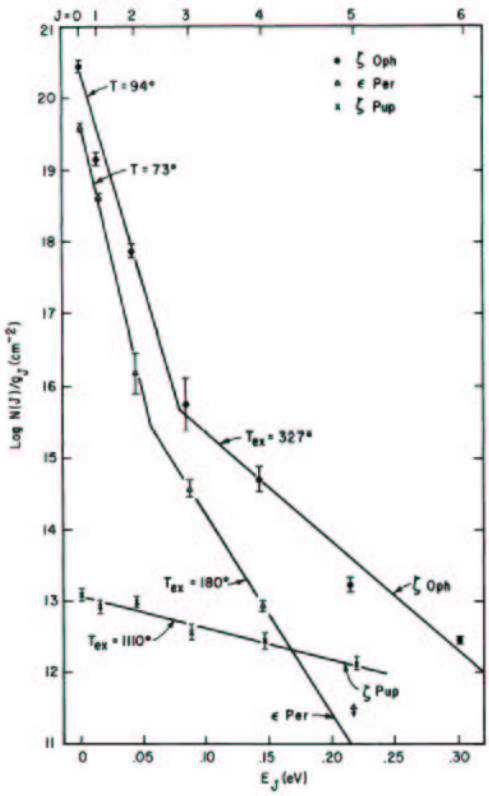



http://hyperphysics.phy-astr.gsu.edu/hbase/molecule/vibrot3.html



## Populations of rotational levels




Determination of cloud temperatures from relative intensities of rotational lines

(Spitzer & Cochran 1973)