Astrochemistry: Recent Successes and Current Challenges
Poster Book IAU Symposium No. 231, 2005
A. J. Markwick-Kemper, ed.

DOI: 00.0000/X000000000000000X

Turbulent diffusion and chemistry in the outer protoplanetary disk

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Abstract. The chemistry in protoplanetary disks plays an important role in understanding the formation and evolution of planets. The variation in the physical and chemical state of a protoplanetary disk is a balance of dynamics, mass transport and radiation effects. The net effect of these processes is expressed in the distribution of the chemical constituents of the disk.

Protoplanetary disks are thought to be highly turbulent. Turbulence is important as it is linked to the physical properties of the disk, such as its vertical structure, magnetization, temperature and angular momentum dispersion. Turbulence will also cause the mixing of disk material and will affect the chemical composition of the disk and therefore the material out of which planets can form. We have adapted a diffusive mixing model previously used to model the chemistry in planetary atmospheres (Allen et al. 1980, Shia et al. 1990) to model the turbulent driven mixing in a disk.

We use the disk model of Bryden et al. (2005) to provide the physical parameters of the disk. This model calculated the structure of the disk by solving the hydrodynamical equations in a self-consistent structure. The density and temperature distributions are similar to those determined by the model of d'Alessio et al. (2001) We estimate the diffusion coefficient, K from the turbulent viscosity ($K = \nu = \alpha\ c_s\ h$, where c_s is the sound speed, h is the pressure scale height and α is a dimensionless parameter used to describe the turbulence (Shakura & Sunyaev). At 100 AU and for $\alpha = 10^{-2}$ we find $K = 9.9 \times 10^{16}$ cm^{2}s^{-1}. Because of the uncertainty in K we consider values of K between 10^{16} and 10^{18} cm^{2}s^{-1} to test the effects of different mixing rates on the results. Freezeout onto dust grains is included, as is thermal desorption.

We present the results of the disk models after a time of 1 Myrs. We find that vertical mixing in disks can have a considerable effect on the predicted molecular column densities and abundances. The effects of mixing are molecule dependent and cannot be predicted without detailed modeling. Diffusion increases both the thickness of the molecular layer and the fractional abundances of many species e.g. CO (Figure 1). Other molecules, notably NH_3 and N_2H^+ show a decrease in abundance (Figure 2) at $R > 200$ AU. Not all nitrogen-bearing molecules show this behavior - for example the column density of HCN is increased at all radii with the inclusion of mixing. The chemical origin of this difference in behavior is explored. This may have an impact on the interpretation of observational data, and may lead to the possibility of using chemistry to trace the transport processes in disks.

Keywords. Stars: formation – protoplanetary disks, ISM: general – molecular processes, astrochemistry

Acknowledgements

This research was conducted at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration. Partial support was provided by the NASA Origins Program.

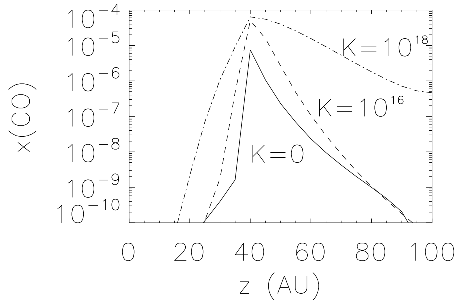

Figure 1. Vertical fractional abundance distribution of CO at 100 AU for t = 1 Myrs. The inclusion of diffusion increases the thickness of the molecular layer and the peak fractional abundance.

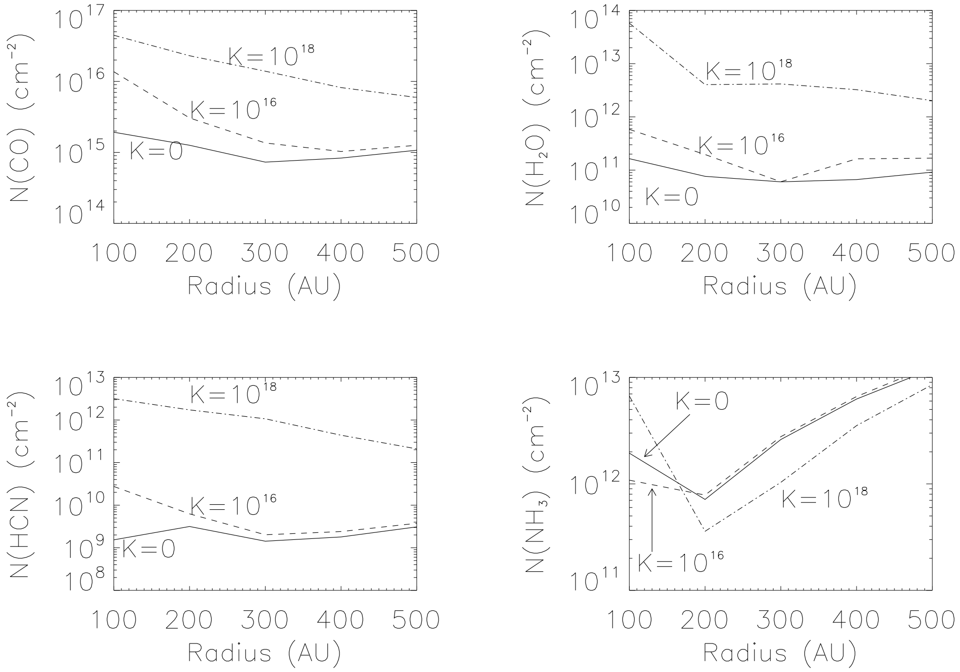

Figure 2. Radial column density distributions for CO, H_2O, HCN and NH_3 showing how diffusion affects different molecules.

References

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