

## Methane, Carbon Monoxide, and Ammonia in Brown Dwarfs and Self-Luminous Giant Planets

### Abstract

We address disequilibrium abundances of some simple molecules in the atmospheres of solar composition brown dwarfs and self-luminous extrasolar giant planets using a kinetics-based 1D atmospheric chemistry model. Our approach is to use the full kinetics model to survey the parameter space with effective temperatures between 500 K and 1100 K. In all of these worlds equilibrium chemistry favors CH<sub>4</sub> over CO in the parts of the atmosphere that can be seen from Earth, but in most disequilibrium favors CO. The small surface gravity of a planet strongly discriminates against CH<sub>4</sub> when compared to an otherwise comparable brown dwarf. If vertical mixing is like Jupiter's, the transition from methane to CO occurs at 500 K in a planet. Sluggish vertical mixing can raise this to 600 K; clouds or more vigorous vertical mixing could lower this to 400 K. The comparable thresholds in brown dwarfs are 1100±100 K. Ammonia is also sensitive to gravity, but unlike CH<sub>4</sub>/CO, the NH<sub>3</sub>/N<sub>2</sub> ratio is insensitive to mixing, which makes NH<sub>3</sub> a potential proxy for gravity. HCN may become interesting in high gravity brown dwarfs with very strong vertical mixing. Detailed analysis of the CO-CH<sub>4</sub> reaction network reveals that the bottleneck to CO hydrogenation goes through methanol, in partial agreement with previous work. Simple, easy to use quenching relations are derived by fitting to the complete chemistry of the full ensemble of models. These relations are valid for determining CO, CH<sub>4</sub>, NH<sub>3</sub>, HCN, and CO<sub>2</sub> abundances in the range of self-luminous worlds we have studied but may not apply if atmospheres are strongly heated at high altitudes by processes not considered here (e.g., wave breaking).