Modeling Nitrogen Isotope Chemistry in the Solar Nebula. J. Garani$^1$ and J. R. Lyons$^1$, $^1$School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85281; jgarani@asu.edu, jimlyons@asu.edu

**Introduction:** In the early 2000s the Genesis mission was sent to the Sun to collect solar wind particles. From analyses of the returned samples, we know that there is a 400‰ difference in the $^{15}\text{N}/^{14}\text{N}$ ratio between bulk Earth and the Sun [1]. The range of nitrogen isotope ratios in the solar system and is shown in Figure 1.

![Image](https://example.com/image.png)

**Figure 1.** Nitrogen isotope ratios in solar system materials, which show the 400‰ difference between $\delta^{15}\text{N}$ (relative to Earth atmosphere) on the Earth and the Sun from solar wind measurements [1].

Self-shielding of CO has been demonstrated to be able to account for the distribution of oxygen isotopes throughout the solar system [2],[3],[4]. $\text{N}_2$ photodissociation and the process of self-shielding in the solar nebula may account for this drastic difference seen in N isotope ratios [5],[6],[7],[8]. Here, we start the analysis of $\text{N}_2$ isotopes based on $\text{N}_2$ self-shielding and explore speciation and different parameters of the disk model.

$\text{N}_2$ Photodissociation and Self-Shielding: In H-rich environments, $\text{N}_2$ is photodissociation from 91-100nm. We consider two isotopologues of nitrogen, $^{28}\text{N}_2$ and $^{29}\text{N}_2$. With the substitution of the heavier isotope, the absorption spectrum of the isotopologue changes. This means that in order to photodissociate, $^{28}\text{N}_2$ and $^{29}\text{N}_2$ absorb photons of slightly different wavelengths, leading to the self-shielding isotope effects. As the photons penetrate into columns of gas in the solar nebula, the $^{28}\text{N}_2$ become optically thick and dissociates very slowly. Beyond this point, no photons of wavelengths that dissociate this isotopologue make it through. However, since $^{29}\text{N}_2$ dissociates at different wavelengths, those photons still make it past this point. This results in an accumulation of $^{15}\text{N}$ because only $^{29}\text{N}_2$ is dissociating.

**Methods:** Using a 2-D solar nebula disk model, 717 chemical reactions are modeled through simulated turbulent mixing in a vertical column with 1-D diffusion from the mid-plane to the upper UV surface of the disk. 323 new reactions have been added to the original model in order to account for the nitrogen chemistry. The UV radiation is assumed to be perpendicular to the disk, allowing the radiative transfer to be one-dimensional, and simulating FUV radiation from a nearby OB star.

Three important parameters for the model are $\alpha$, $\varepsilon$, and initial molecular cloud value (MCV) of key N-bearing species. $\alpha$ characterizes the strength of turbulent mixing in the disk. Here we explore values from $10^{-4}$ to $10^{-2}$. $\varepsilon$ is the parameter which scales the UV flux incident on the disk. The product of $\varepsilon$ and the photodissociation rate coefficient due to the local ISM radiation field, $J_{\text{ISM}}$, is given the $\text{N}_2$ photodissociation rate coefficient at the top of the disk model. The initial MCV is the abundance of a species in the molecular cloud that contributes to the initial mixing ratios in the solar nebula model.

**Results:** With our updated model including the new nitrogen chemistry, we explore possible solutions, (e.g., Figure 2), to the nitrogen isotope distribution in the solar system.

![Image](https://example.com/image.png)

**Figure 2.** $\delta$-values of $\text{HCN}_{gr}$, $\text{NH}_3_{gr}$, and $\text{N}_2$ at the midplane of the disk. Values are compared to air on Earth. $\text{N}_2$ shows the starting value of -400‰ relative to Earth atmosphere with initial molecular values of 0 for HCN and NH$_3$.

Figure 2 shows total $\delta$-values for two key dust grain-bound species, NH$_{3gr}$ and HCN$_{gr}$, compared to Earth atmosphere. It can be seen that the values for NH$_{3gr}$ are above zero after $10^3$ years, which is required to explain...
solar system nitrogen isotopes. We then explored the parameter space by varying $\alpha$, $\varepsilon$, and MCV. The first trial we performed, shown in Figure 3 was with $\varepsilon=10$, MCV values of NH$_3$ and HCN of 0, and varying alphas of $10^{-2}$, $10^{-3}$, and $10^{-4}$.

![Figure 3. $\delta$-values of HCN$_{gr}$ and NH$_3gr$ at $\varepsilon=10$ for different alphas at the midplane, and assuming initial molecular cloud values (MCV) of zero for HCN$_{gr}$ and NH$_3gr$.](image)

The second trial was conducted was with alpha set at 0.01 and epsilon values of 1, 10, and 100. The results are shown in Figure 4.

![Figure 4. $\delta$-values for HCN$_{gr}$ and NH$_3gr$ at $\alpha=0.01$ for different epsilons at the midplane. Initial MCV's are again set to zero.](image)

The final trial we performed was with the initial molecular cloud values of HCN and NH$_3$. Until now, we have assumed that the initial values of these species were zero. Figure 5 shows the results for difference molecular cloud values for the model with $\alpha=0.01$ and $\varepsilon=10$. We have assumed that initial molecular cloud HCN$_{gr}$ and NH$_3gr$ have solar N isotope ratios, so for the moment we are neglecting N$_2$ self-shielding in the molecular cloud.

![Figure 5. $\delta$-values for HCN$_{gr}$ and NH$_3gr$ at $\alpha=0.01$ and $\varepsilon=10$ at the midplane.](image)

**Conclusion:** Given our baseline model of $\alpha=0.01$, $\varepsilon=10$, and zero contribution of HCN and NH$_3$ from the molecular cloud, we find a possible solution for NH$_3gr$ for explaining the nitrogen isotope differences seen in the solar system. Comparing our model in Figure 2 to the data shown in Figure 1, our results show $\delta$-values in excess of measurements from inner solar system objects. Our parameter testing reveals a strong dependence of delta-values on $\alpha$ and the initial MCVs of HCN and NH$_3$. From Figure 5, it can be argued that a fraction of up to $10^{-6}$ of HCN and NH$_3$ in the molecular cloud, and with solar N isotopes, that was inherited by the solar nebular. If we allow for N$_2$ self-shielding in the parent molecular cloud, then these constraints on initial cloud HCN$_{gr}$ and NH$_3gr$ are likely to be relaxed. We can also see from Figures 3 and 4 that an alpha value of 0.01 is produces results most consistent with observations and an epsilon value of either 1 or 10 may also produce the most plausible solution.

Our new model, with updated nitrogen chemistry, demonstrates that self-shielding of N$_2$ can explain the $400 \%$ enrichment of inner solar system N isotope ratios. We are currently exploring simultaneous solution for both nitrogen and oxygen isotopes.

**References:**