

Solvent extraction of astatine with DIPE and attempt to identify the extracted species by thin layer chromatography[†]

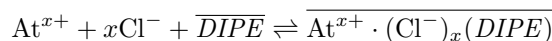
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Alpha particles with high linear energy transfer and short path length are key to targeted alpha therapy for cancer, with ²¹¹At as a promising nuclide owing to its 7.21-h half-life, suitable decay properties, and halogen-like chemistry.¹⁾ Although metallic properties of At and diverse species complicate its chemistry,²⁾ in this study we investigate its extraction into diisopropyl ether (DIPE). Using thin-layer chromatography (TLC) in argon, experiments aimed to elucidate the extraction mechanism in DIPE-hydrochloric acid systems, crucial for advancing At chemistry.

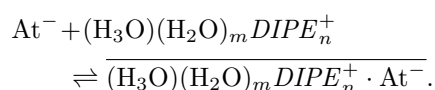
Astatine isotopes were produced via nuclear reactions involving ²⁰⁹Bi and either α or ⁷Li ions, with ²¹¹At extracted via dry distillation^{3,4)} and DIPE solvent extraction techniques.⁵⁾ Experiments explored the chemical forms of At and extraction mechanisms, analyzing dependencies on hydrochloric acid, chloride ions, and redox conditions. Radiometry and thin-layer chromatography confirmed distribution ratios and chemical species, advancing the understanding of astatine's behavior in DIPE-hydrochloric acid systems. This study investigated the solvent extraction behavior of astatine isotopes (²¹¹At and ²¹⁰At) in the DIPE-HCl system, focusing on the effects of HCl concentration, redox agents, and chloride ions. The results confirmed that at HCl concentrations ≥ 1 M, ²¹¹At and ²¹⁰At, despite their different production processes, showed consistent chemical behavior. However, at concentrations < 1 M, differences in behavior were observed, likely due to hydrolysis or other effects.

The addition of an oxidizing agent significantly improved the extraction efficiency, with the distribution ratio (D) showing dependence on HCl and chloride ion concentrations. By contrast, when a reducing agent was used, D increased with HCl concentration but showed minimal dependence on chloride ions. Thin-layer chromatography (TLC) analysis revealed stable chemical species such as AtO_4^- , AtO_3^- , and At^- under air,⁶⁻⁸⁾ while a new peak was identified under an argon atmosphere, potentially corresponding to cationic astatine species.

The findings suggest that the solvent extraction mechanism is governed by equilibrium reactions:⁹⁾



and



The addition of oxidizing agents promotes the formation of cationic species, while reducing agents enhance the formation of anionic species (At^-). Chloride ions play a significant role in extraction with oxidizing agents but slightly affect reducing agents. The extraction of cationic species depends on chloride ion concentration and offers a milder system than the anionic species extraction, making it potentially suitable for nuclear medicine applications.

In conclusion, for the extraction mechanism of astatine in DIPE-HCl solvent extraction, we proposed equations for the extraction of astatine in oxidized and reduced states, respectively. The equilibrium equations for the oxidized state are consistent with previous literature [13], while the equilibrium equations for the reduced state have not been reported previously.

Comparisons of the extraction behavior of astatine without redox, oxidized, and reduced states confirmed the differences in the extraction behavior of astatine in each case. These results indicate that the chemical form of astatine acquired without redox may not be consistent, which may pose a challenge in the labeling of drugs for use in isotope therapy.

A peak previously invisible owing to air oxidation was confirmed by TLC in an Ar atmosphere. Based on a previous study suggesting that cationic species of astatine is extracted in DIPE/HCl solvent extraction, this new peak was considered to be cationic species. This led to the successful identification of the astatine cation for the first time in TLC experiments.

References

- 1) F. Guérard *et al.*, *Cancer Biother. Radiopharm.* **28**, 1 (2013).
- 2) L. Liu *et al.*, *Inorg. Chem.* **61**, 13462 (2022).
- 3) I. Nishinaka *et al.*, *J. Radioanal. Nucl. Chem.* **304**, 1077 (2015).
- 4) I. Nishinaka *et al.*, *J. Radioanal. Nucl. Chem.* **326**, 743 (2020).
- 5) E. Maeda *et al.*, *J. Radioanal. Nucl. Chem.* **303**, 1465 (2015).

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- 6) I. Nishinaka *et al.*, J. Radioanal. Nucl. Chem. **318**, 897 (2018).
- 7) I. Nishinaka *et al.*, J. Radioanal. Nucl. Chem. **322**, 2003 (2019).
- 8) Y. Shin *et al.*, J. Radioanal. Nucl. Chem. **333**, 403 (2024).
- 9) C. Alliot *et al.*, J. Radiochim. Acta **97**, 161 (2009).