

Extraction of Indium into Hydrophobic Amine-Based Mixtures from Dilute Hydrochloric Acid Medium

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Super Heavy Elements (SHEs)

- SHEs are elements with $Z \geq 112$
- The chemistry of SHEs is difficult to study
 - Short half-life
 - Low production rates
- Nihonium (113)
- Homolog experiments in group 13

atomic number atomic weight

symbol: black solid blue liquid red gas

name

alkali metals
alkaline earth metals
transitional metals
other metals
non metals
noble gases

1 H Hydrogen	2 He Helium
3 Li Lithium	4 Be Beryllium
5 B Boron	6 C Carbon
7 N Nitrogen	8 O Oxygen
9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium
13 Al Aluminum	14 Si Silicon
15 P Phosphorus	16 S Sulfur
17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium
21 Sc Scandium	22 Ti Titanium
23 V Vanadium	24 Cr Chromium
25 Mn Manganese	26 Fe Iron
27 Co Cobalt	28 Ni Nickel
29 Cu Copper	30 Zn Zinc
31 Ga Gallium	32 Ge Germanium
33 As Arsenic	34 Se Selenium
35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium
39 Y Yttrium	40 Zr Zirconium
41 Nb Niobium	42 Mo Molybdenum
43 Tc Technetium	44 Ru Ruthenium
45 Rh Rhodium	46 Pd Palladium
47 Ag Silver	48 Cd Cadmium
49 In Indium	50 Sn Tin
51 Sb Antimony	52 Te Tellurium
53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium
57 La Lanthanum	58 Ce Cerium
59 Pr Praseodymium	60 Nd Neodymium
61 Pm Promethium	62 Sm Samarium
63 Eu Europium	64 Gd Gadolinium
65 Tb Terbium	66 Dy Dysprosium
67 Ho Holmium	68 Er Erbium
69 Tm Thulium	70 Yb Ytterbium
71 Lu Lutetium	72 Hf Hafnium
73 Ta Tantalum	74 W Tungsten
75 Re Rhenium	76 Os Osmium
77 Ir Iridium	78 Pt Platinum
79 Au Gold	80 Hg Mercury
81 Tl Thallium	82 Pb Lead
83 Bi Bismuth	84 Po Polonium
85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium
89 Ac Actinium	90 Th Thorium
91 Pa Protactinium	92 U Uranium
93 Np Neptunium	94 Pu Plutonium
95 Am Americium	96 Cm Curium
97 Bk Berkelium	98 Cf Californium
99 Es Einsteinium	100 Fm Fermium
101 Md Mendelevium	102 No Nobelium
103 Lr Lawrencium	104 Rf Rutherfordium
105 Db Dubnium	106 Sg Seaborgium
107 Bh Bohrium	108 Hs Hassium
109 Mt Meitnerium	110 Ds Darmstadtium
111 Rg Roentgenium	112 Cn Copernicium
113 Nh Nihonium	114 Fl Flerovium
115 Mc Moscovium	116 Lv Livermorium
117 Ts Tennessine	118 Og Oganesson

Lanthanides →

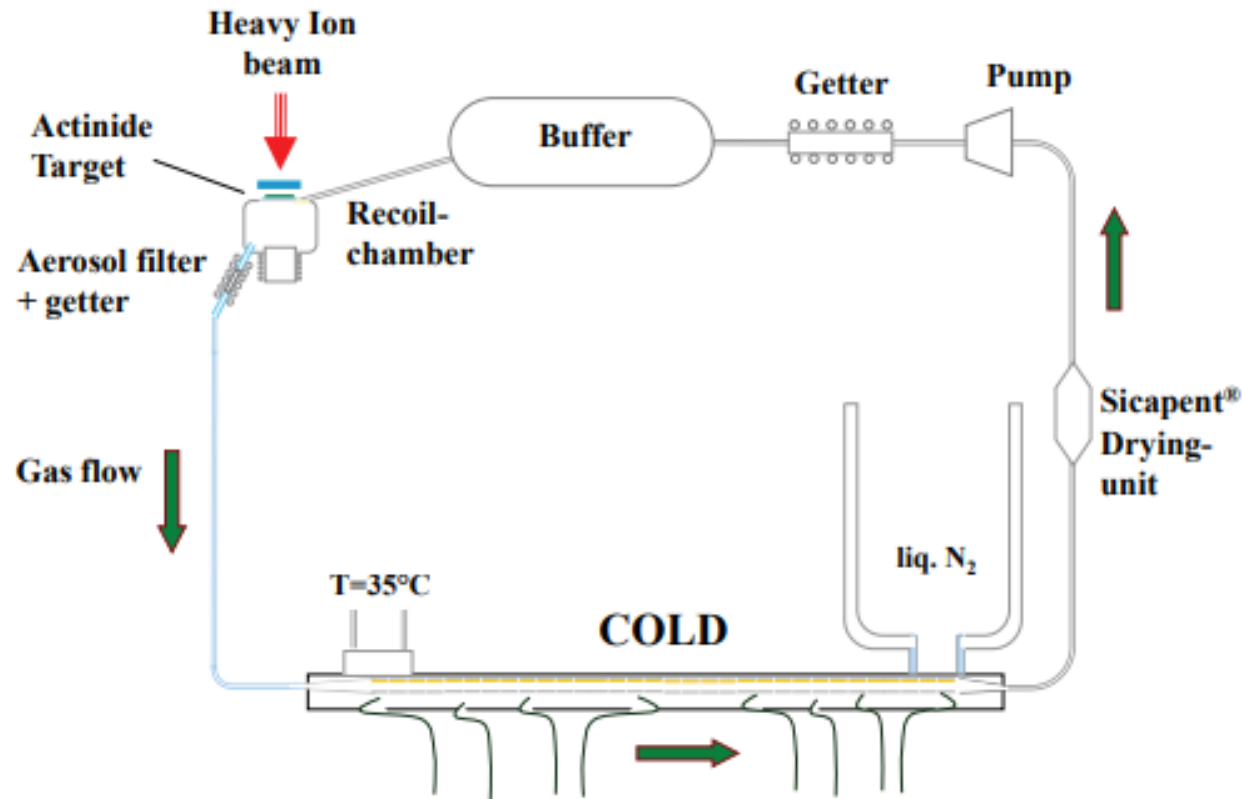
58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
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Actinides →

90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium
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Superactinides → (122-153)

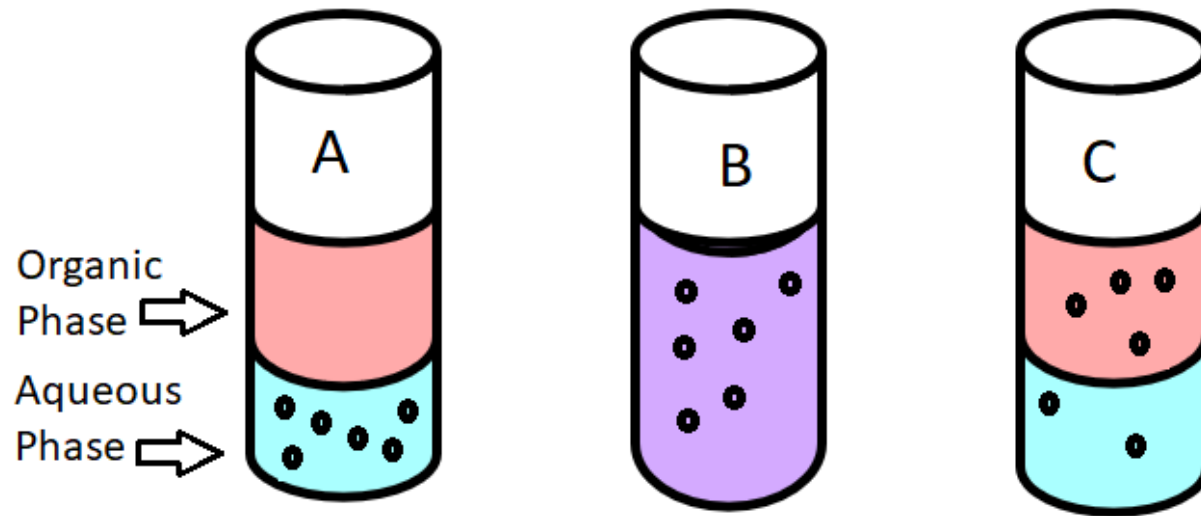
Gas Phase Chemistry



R. Eichler et. al., Chemical characterization of element 112, Nature, 447 (2007) 72-75.

Liquid-Liquid Extraction (LLE)

- Homologue experiments in a radiochemistry lab
- Measure the distribution of Indium-111 in each phase



$$D = \frac{[c]_{org}}{[c]_{aq}} = \frac{[A]_{org}[V]_{aq}}{[A]_{aq}[V]_{org}}$$

In our case,

$$D = \frac{[A]_{org}}{[A]_{aq}}$$

Eutectic Solvents

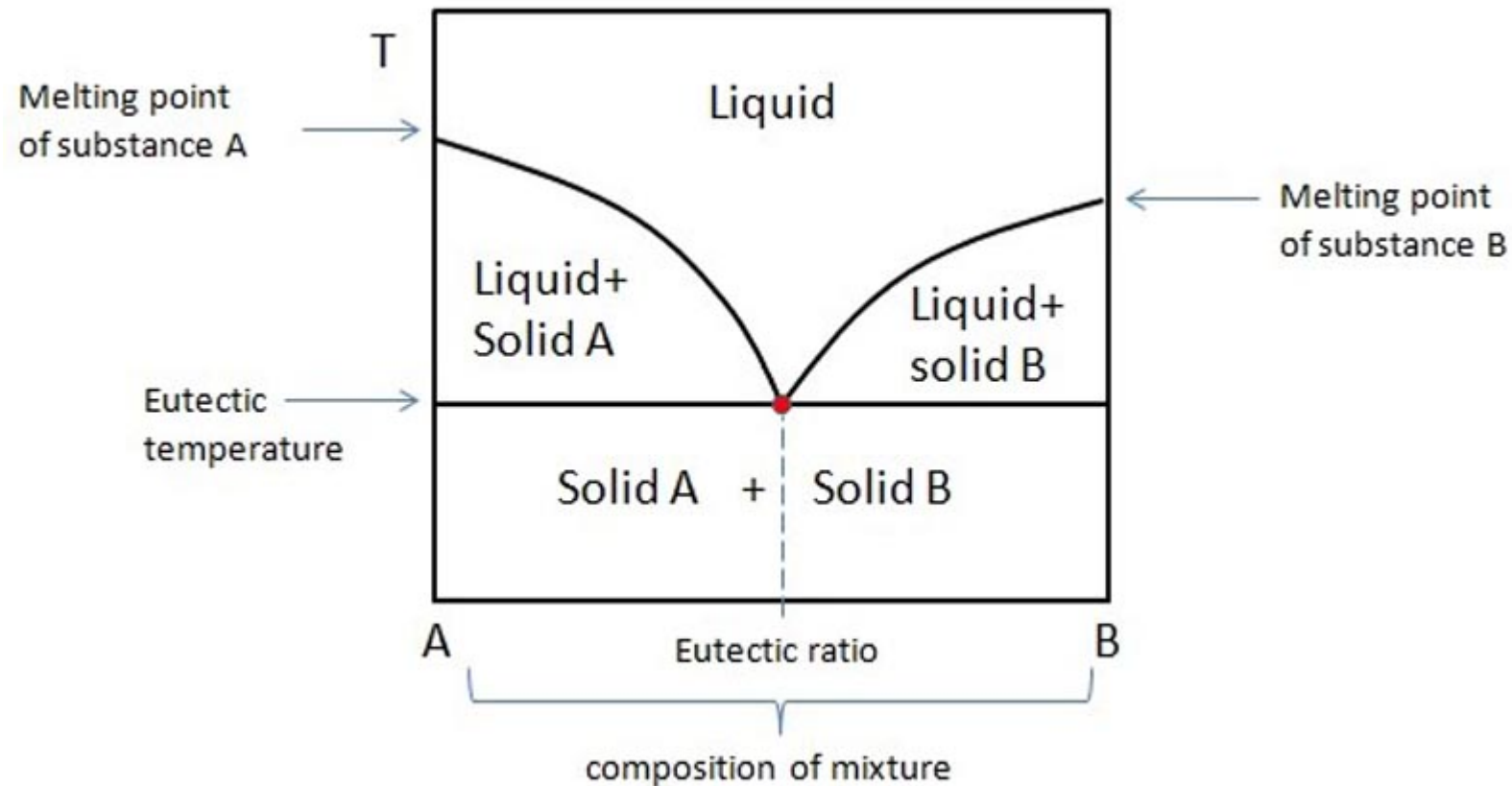


Image courtesy of Penn State University

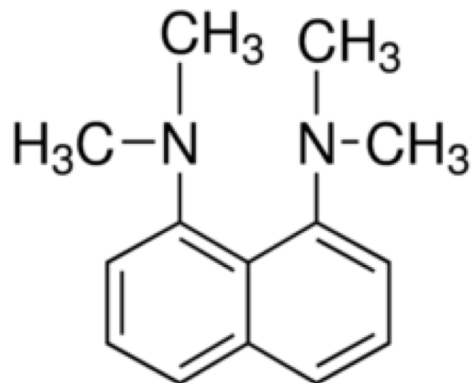


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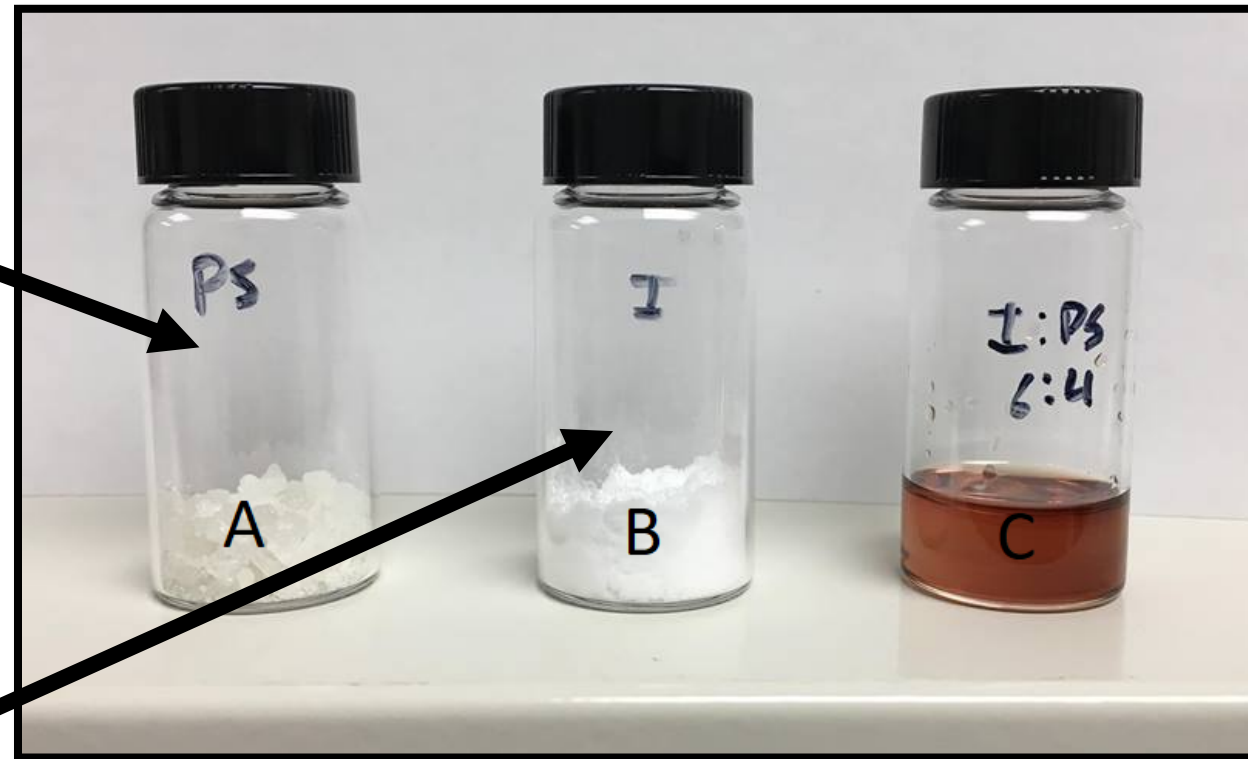
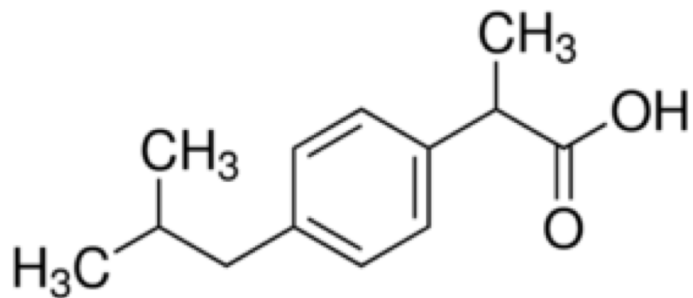
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Eutectic Solvents

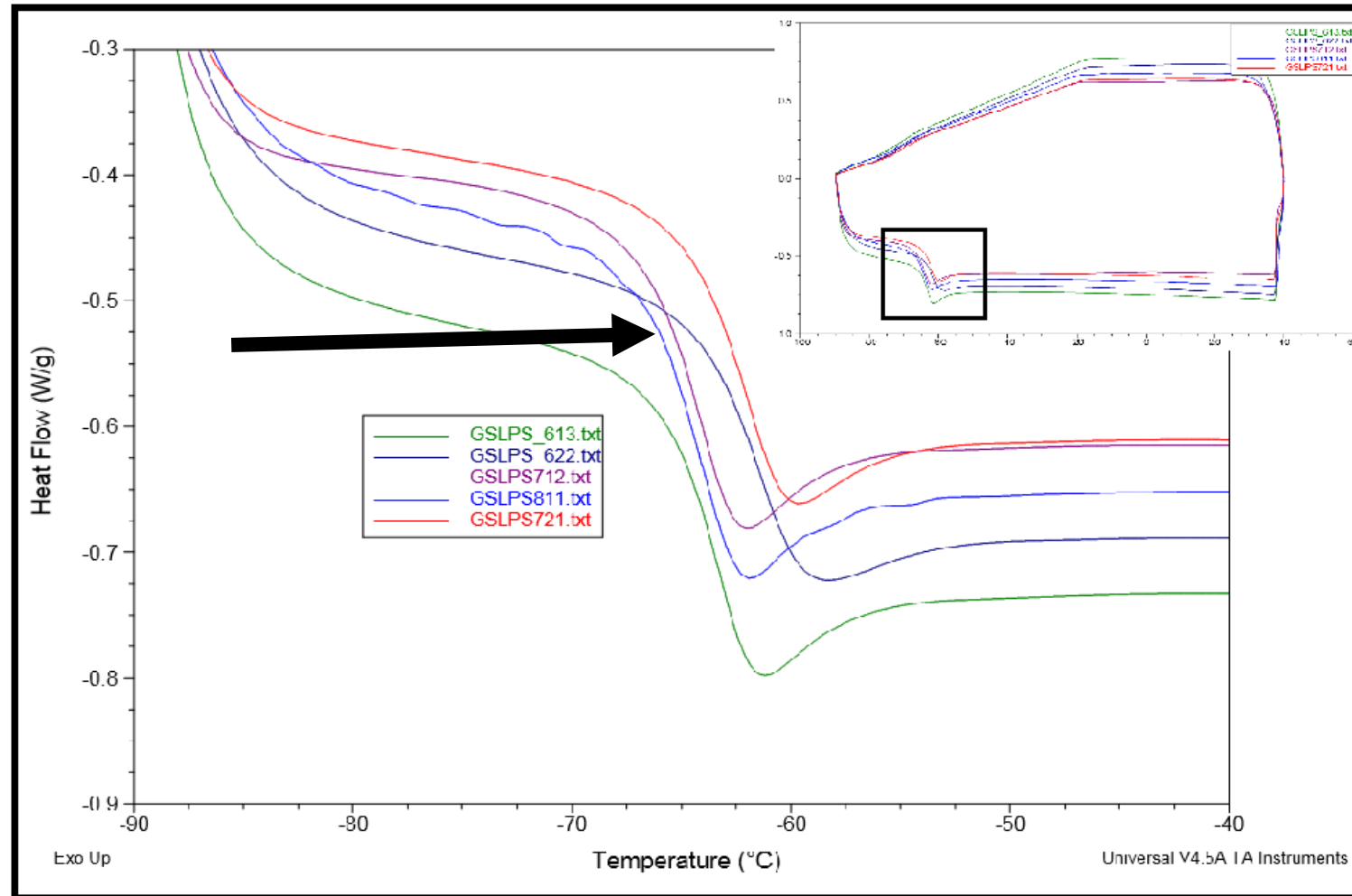
Proton Sponge™



Ibuprofen



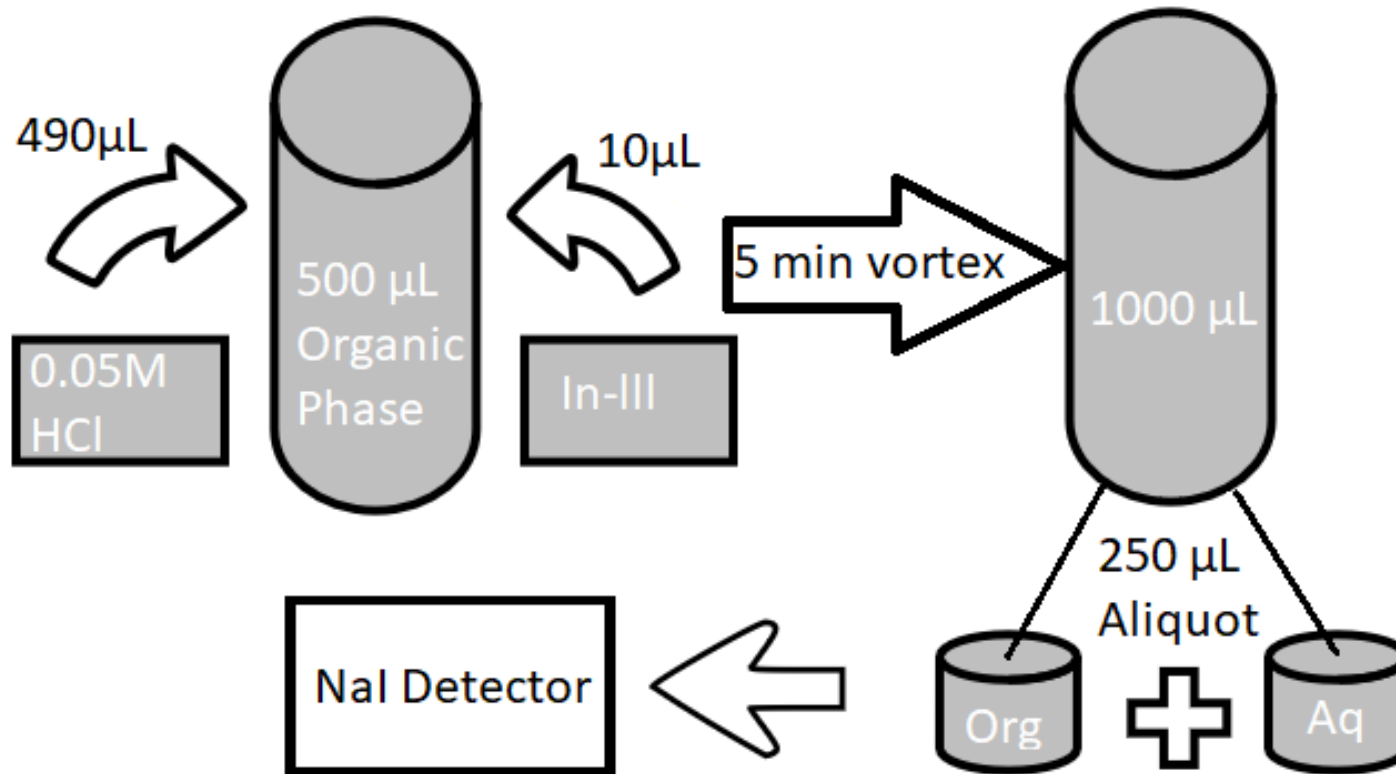
Differential Scanning Calorimetry (DSC)



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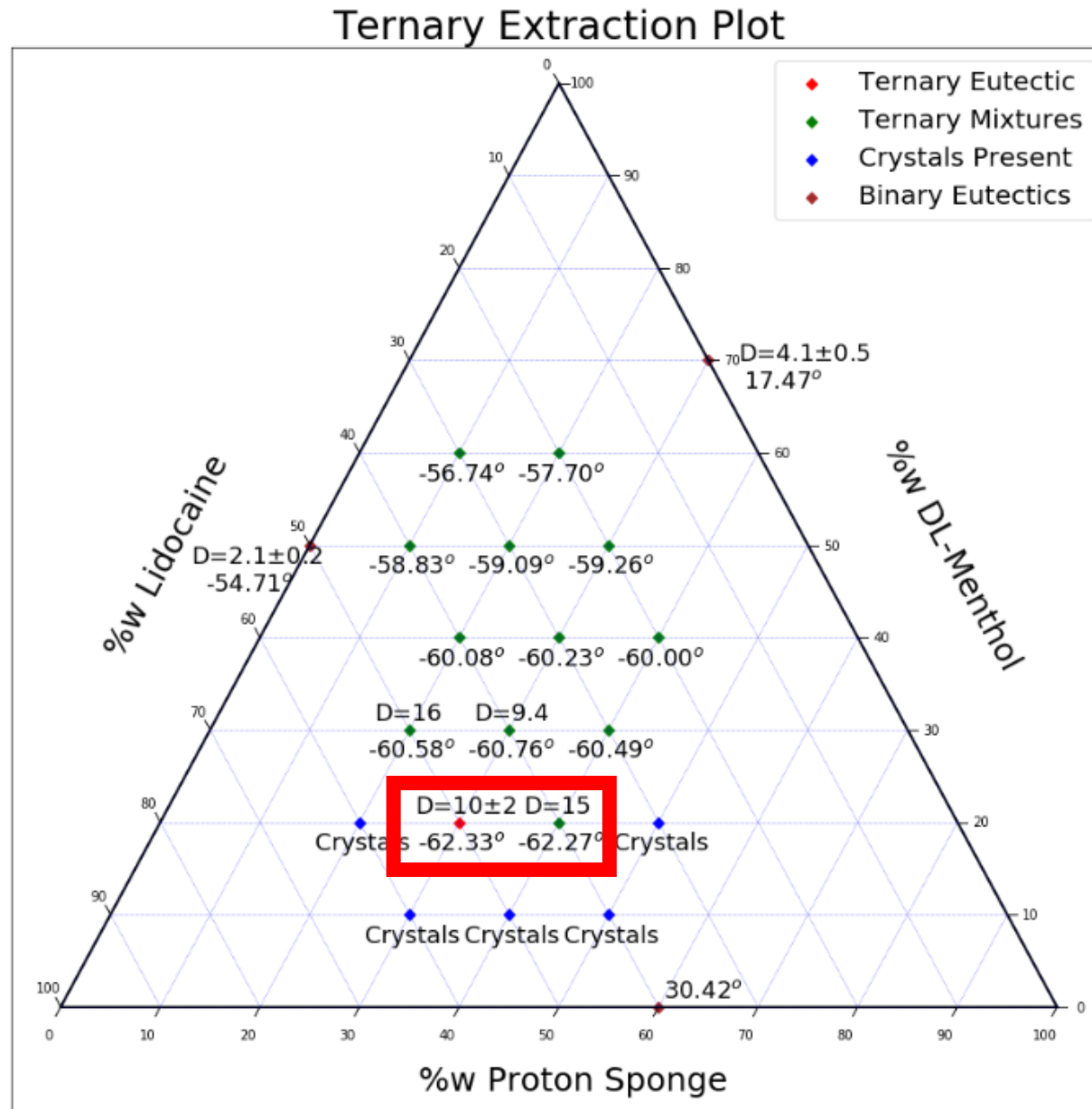
Experimental Design



In-111, medical isotope
($t_{1/2}$ =2.80 days)
 $E_{\gamma}=171.3, 245.5 \text{ keV}$

E. E. Tereshatov *et al.*, J. Phys. Chem. B, **120**(9), 2311 (2016).

Results



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Mechanism of Extraction

- $[C^+]_{org} + [A^-]_{org} \rightarrow [C^+]_{aq} + [A^-]_{aq}$
- $K_{sp} = [C^+][A^-]$
- $[C^+]_{eq} = [A^-]_{aq} - z \cdot \Delta[S^{z-}]_{aq}$
- $K_{sp} = ([A^-]_{aq} - z \cdot \Delta[S^{z-}]_{aq}) \cdot [A^-]_{aq}$
- $[A^-] = \frac{z \cdot \Delta[S^{z-}]_{aq} + \sqrt{(z \cdot \Delta[S^{z-}]_{aq})^2 + 4 \cdot K_{sp}}}{2}$
- $\lim_{\Delta[S^{z-}]_{aq} \rightarrow \infty} [A^-] = z \cdot \Delta[S^{z-}]_{aq}$

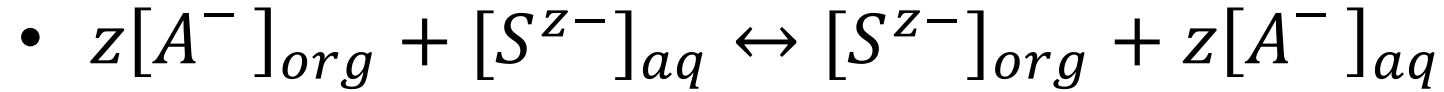
E. E. Tereshatov *et al.*, Green Chem. **17**, 4616 (2016).



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Mechanism of Extraction



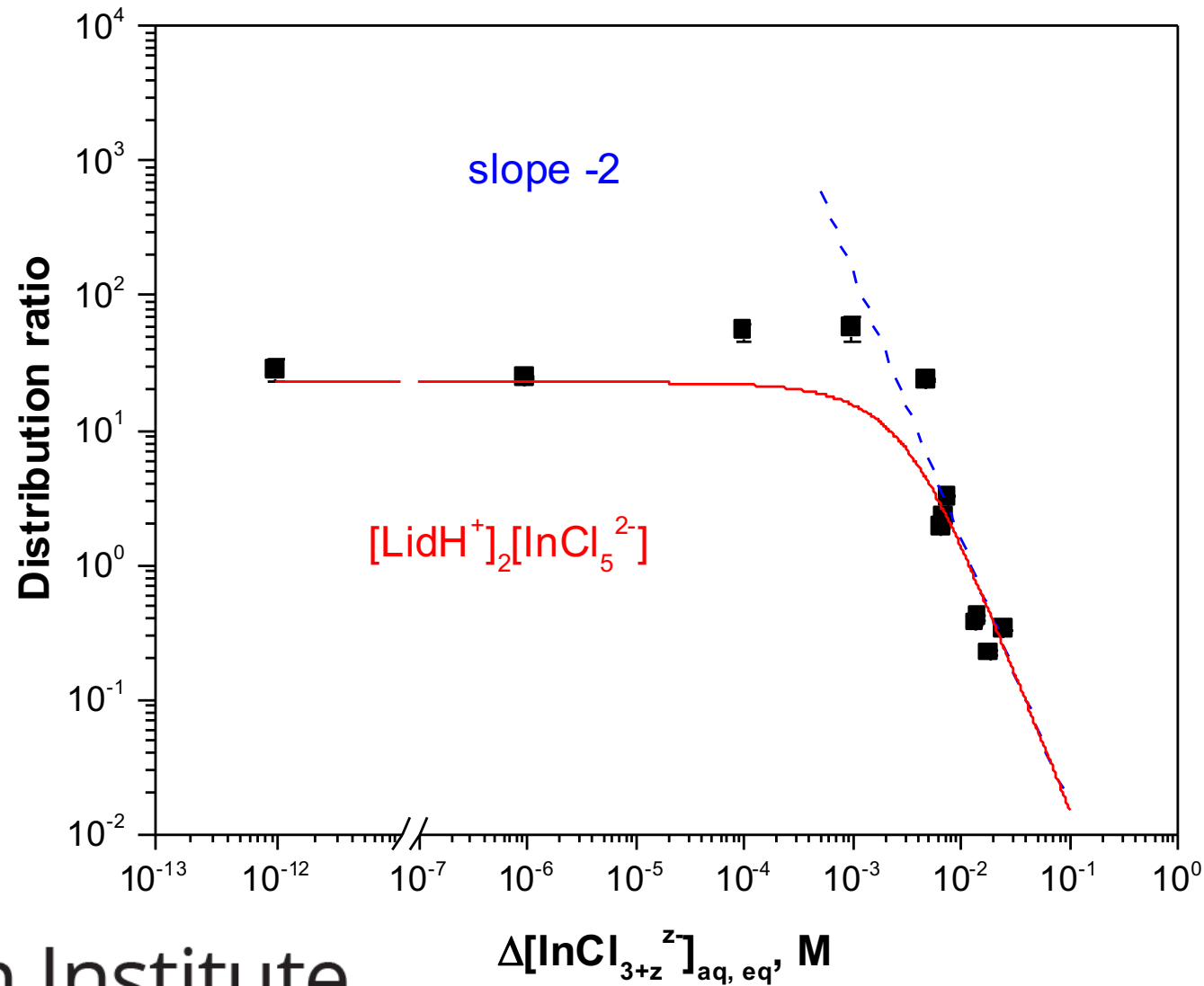
- $K = \frac{[S^{z-}]_{org} \cdot [A^-]_{aq}^z}{[S^{z-}]_{aq} \cdot [A^-]_{org}^z} = D \cdot [A^-]_{aq}^z$

- $D = \frac{K}{[A^-]_{aq}^z}$, so...

- $\log(D) = \log(K) - \log\left(\frac{z \cdot \Delta[S^{z-}]_{aq} + \sqrt{(z \cdot \Delta[S^{z-}]_{aq})^2 + 4 \cdot K_{sp}}}{2}\right)^z$



Mechanism of Extraction



Conclusions

- Determine eutectic composition for various systems
- Measured D-value for those systems
- Report on the mechanism of extraction



Future Work

- Run extractions with more non-eutectic mixtures
- Study the mechanism of ternary systems
- Apply to gas phase online experiments
- Time dependency of extraction efficiency of certain mixtures



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Question?