

Electronic Supplementary Material

Rare-earth separation based on the differences of ionic magnetic moment via quasi-liquid strategy

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1 Calculation Methods

Distribution ratio D and separation factor β were defined as follows:

$$D = \frac{M_p}{M_d}$$

$$\beta = \frac{D_2}{D_1}$$

Where M_p and M_d represent proximal and distal concentrations of Er(III), Ho(III) and Y(III) ends of the magnet; D_1 and D_2 were the distribution ratios of rare earths 1 and 2, respectively.

2 Characterization Methods

2.1 TGA analysis

Thermal gravimetric analysis (TGA) was conducted by the instrument (LABSYS EVO, French) from 303 K to 873 K at a heating rate of 10 °C·min⁻¹ in nitrogen atmosphere.

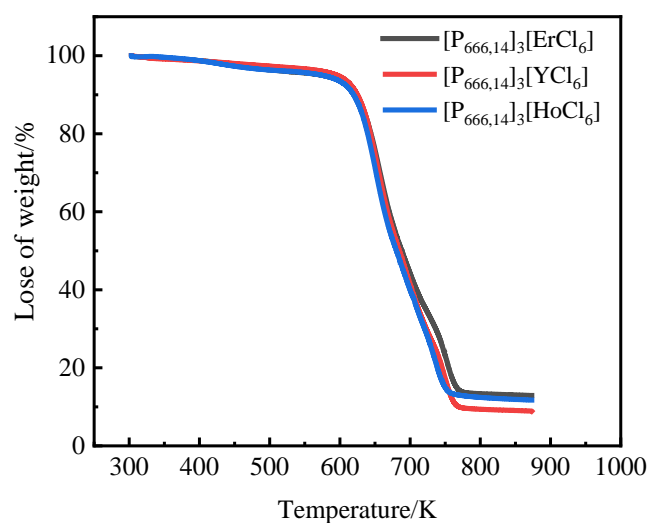


Fig S1. Thermogravimetric analysis diagram of $[P_{666,14}]_3[ErCl_6]$, $[P_{666,14}]_3[YCl_6]$ and $[P_{666,14}]_3[HoCl_6]$

2.2 Density and viscosity

The density was measured at 293 K to 363 K using a density meter (DMA5000M-Lovis2000ME, Austria). The viscosity was determined at 298 K to 431 K using the Discovery Hybrid Rheometer (DHR-2, America). The density and viscosity of each sample were measured three times and the average was reported.

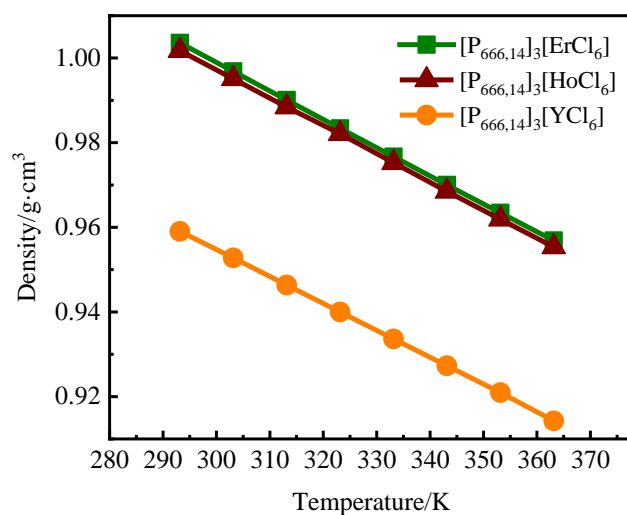


Fig S2. Density of $[P_{666,14}]_3[ErCl_6]$, $[P_{666,14}]_3[HoCl_6]$ and $[P_{666,14}]_3[YCl_6]$ at 293 K to 363 K.

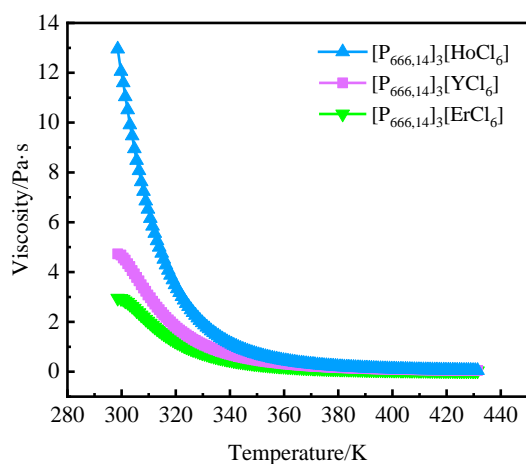


Fig S3. Viscosity of $[P_{666,14}]_3[HoCl_6]$, $[P_{666,14}]_3[YCl_6]$ and $[P_{666,14}]_3[ErCl_6]$ at 298 K to 431 K.

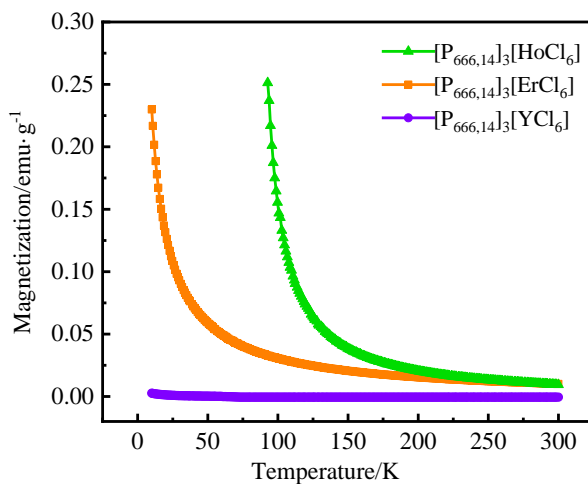


Fig S4. Relationship between magnetization and temperature of $[P_{666,14}]_3[ErCl_6]$, $[P_{666,14}]_3[HoCl_6]$ and $[P_{666,14}]_3[YCl_6]$.

3 Mixed separation experiments

Isadorar [1] found that concentration gradient had a great influence on trivalent rare earth ions, and concentration gradient could be realized through solvent evaporation. When there was a concentration gradient, the paramagnetic rare earth ions would move towards the magnetic field. However, rare earth chloride could not form clusters in the solution due to the high charge radius ratio of rare earth ions and relatively strong ion-water interaction. In the magnetic field gradient, paramagnetic ions tend to move in the form of ion clusters [2]. Hence, Er(III) and Y(III) chloride were dissolved in $[P_{666,14}][Cl]$ to form ionic quasi-liquid cluster of $[P_{666,14}]_3[ErCl_6]$ and

[P_{666,14}]₃[YCl₆]. Separation experiments of Er/Y mixed ionic liquids were performed. Firstly, Er/Y mixed ionic liquids in 1:1 mole ratio were prepared. Then, the 1.0 mL mixed ionic liquids and 5.0 mL ethanol solvent were added to the petri dish under a maximum surface magnetic field intensity of 4200 Oe. The separation experiments under different intensity of applied magnetic field were tested. At room temperature, with the volatilization of ethanol, the paramagnetic rare earth Er(III) formed a concentration gradient and migrated towards the magnetic field. Lastly, obvious aggregation was observed near the magnetic field. In the magnetic field gradient and concentration gradient, Er/Y mixed ionic liquids were separated. The results showed that the separation coefficient was increased by 12 % under the condition of magnetic field and separation effect was obviously enhanced with the increasing of magnetic field intensity.

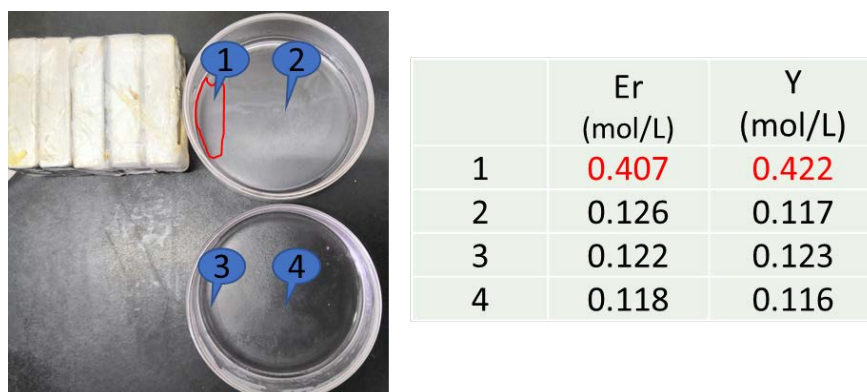


Fig S5. Experimental results of separation of Er/Y mixed ionic liquids.

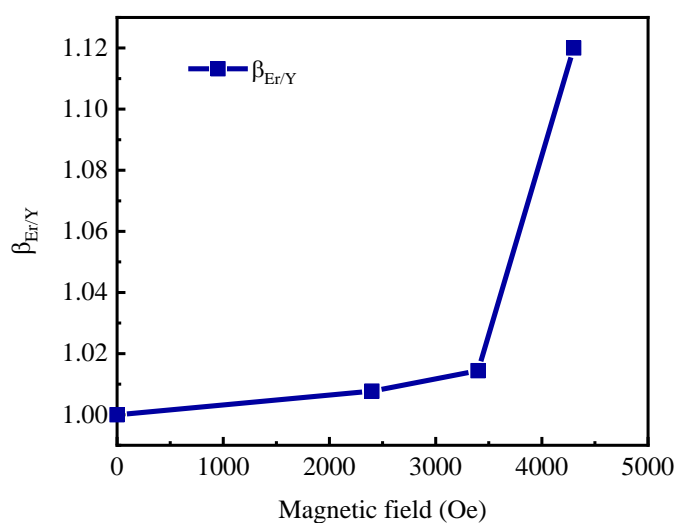


Fig S6. The relationship between the $\beta_{Er/Y}$ and magnetic field intensity.

Supplementary References

1. Rodrigues I R, Lukina L, Dehaeck S, Colinet P, Binnemans K, Fransaer J. Magnetophoretic sprinting: a study on the magnetic properties of aqueous lanthanide solutions. *The Journal of Physical Chemistry C*, 2018, 122(41): 23675-23682
2. Lin H, Zhang R R, Chen Q W. Synthesis and assembly of nanomaterials under magnetic fields. *Nanoscale*, 2014, 6:14064-14105.