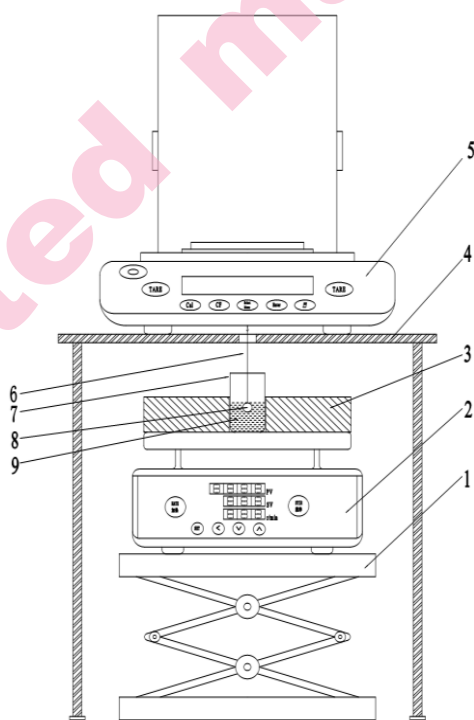


SUPPLEMENTARY MATERIAL TO  
**Systematic investigation into the physicochemical properties of deep eutectic AlCl<sub>3</sub>/amide electrolytes with additives**

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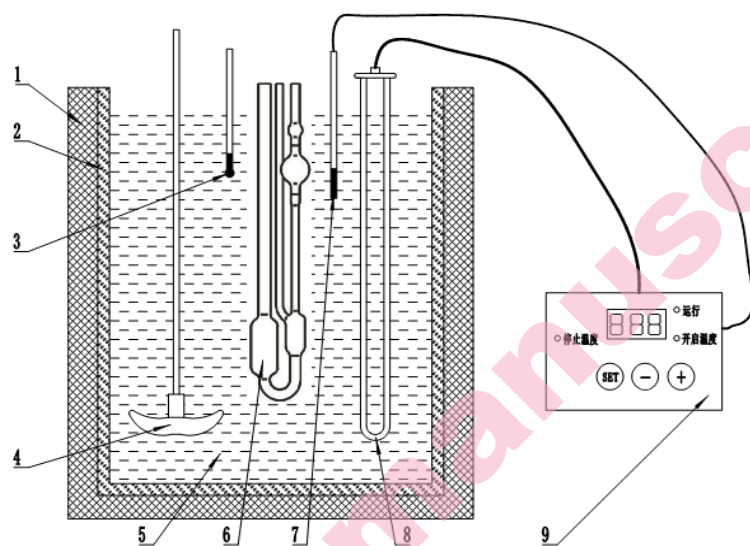
1- lifting table; 2- intelligent digital display magnetic heating plate; 3- insulation cotton; 4- trestle table; 5- electronic balance; 6- platinum wire; 7- beaker; 8- platinum ball; 9- electrolyte

Fig. S-1 Schematic diagram for the density measurement

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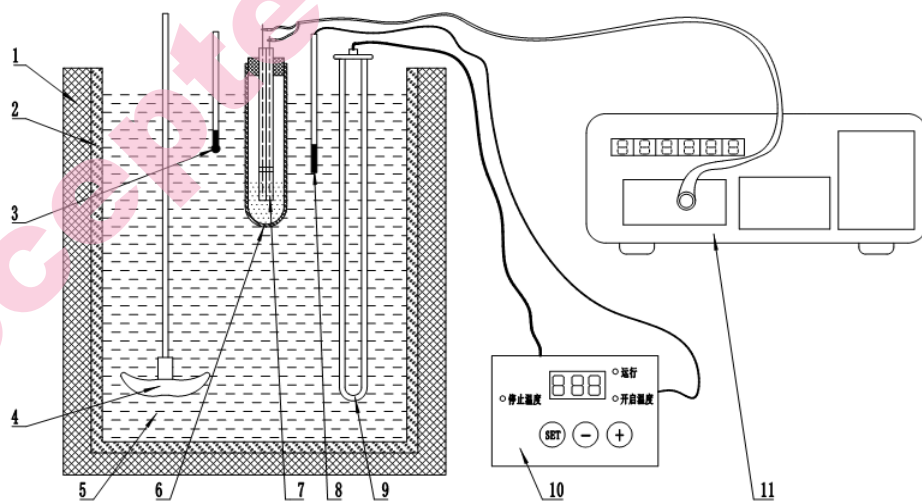
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1- insulation cotton; 2- quartz cell; 3- thermometer; 4- stirring paddle; 5- dimethicone; 6- Ubbelohde viscometer; 7- temperature sensor; 8- heating bar; 9- microcomputer intelligent temperature controller

Fig. S-2 Schematic diagram for the viscosity measurement



1- insulation cotton; 2- quartz cell; 3- thermometer; 4- stirring paddle; 5- dimethicone; 6- quartz tube; 7- conductance cell; 8- temperature sensor; 9- heating bar; 10- microcomputer intelligent temperature controller; 11- agilent impedance meter

Fig. S-3 Schematic diagram for the electrical conductivity measurement

TABLE S-I. Density of  $\text{AlCl}_3\text{-AcA}$  and  $\text{AlCl}_3\text{-Ur}$  electrolytes with various additives at different temperatures

| $T$ (K)                    | $\rho$ ( $\text{g}\cdot\text{cm}^{-3}$ ) |       |       |       |       |       |       |       |       |
|----------------------------|------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|                            | blank                                    | LiCl  | LiBr  | NaCl  | NaBr  | DCE   | EC    | THF   | EMIC  |
| $\text{AlCl}_3\text{-AcA}$ |                                          |       |       |       |       |       |       |       |       |
| 313                        | 1.456                                    | 1.460 | 1.469 | 1.456 | 1.474 | 1.450 | 1.455 | 1.444 | 1.437 |
| 323                        | 1.447                                    | 1.452 | 1.461 | 1.449 | 1.466 | 1.443 | 1.448 | 1.436 | 1.430 |
| 333                        | 1.439                                    | 1.443 | 1.454 | 1.442 | 1.458 | 1.435 | 1.440 | 1.428 | 1.422 |
| 343                        | 1.430                                    | 1.435 | 1.446 | 1.434 | 1.450 | 1.427 | 1.431 | 1.420 | 1.415 |
| 353                        | 1.421                                    | 1.428 | 1.437 | 1.427 | 1.442 | 1.419 | 1.423 | 1.413 | 1.407 |
| 363                        | 1.414                                    | 1.421 | 1.430 | 1.420 | 1.435 | 1.413 | 1.416 | 1.404 | 1.399 |
| 373                        | 1.406                                    | 1.413 | 1.423 | 1.413 | 1.426 | 1.407 | 1.409 | 1.397 | 1.392 |
| $\text{AlCl}_3\text{-Ur}$  |                                          |       |       |       |       |       |       |       |       |
| 313                        | 1.542                                    | 1.547 | 1.564 | 1.553 | 1.567 | 1.546 | 1.548 | 1.520 | 1.523 |
| 323                        | 1.535                                    | 1.539 | 1.556 | 1.546 | 1.560 | 1.539 | 1.541 | 1.513 | 1.515 |
| 333                        | 1.527                                    | 1.532 | 1.548 | 1.537 | 1.552 | 1.532 | 1.534 | 1.506 | 1.508 |
| 343                        | 1.519                                    | 1.524 | 1.540 | 1.529 | 1.544 | 1.524 | 1.526 | 1.498 | 1.501 |
| 353                        | 1.511                                    | 1.516 | 1.532 | 1.521 | 1.536 | 1.516 | 1.519 | 1.491 | 1.493 |
| 363                        | 1.503                                    | 1.509 | 1.525 | 1.513 | 1.529 | 1.509 | 1.511 | 1.483 | 1.485 |
| 373                        | 1.496                                    | 1.502 | 1.517 | 1.507 | 1.522 | 1.501 | 1.504 | 1.476 | 1.478 |

TABLE S-II. Least-squares fitted parameters of density equation for  $\text{AlCl}_3\text{-AcA}$  and  $\text{AlCl}_3\text{-Ur}$  electrolytes with various additives

| Additives                  | $\rho = a + bT$ ( $\text{g}\cdot\text{cm}^{-3}$ ) |                     |        |
|----------------------------|---------------------------------------------------|---------------------|--------|
|                            | $a$                                               | $-b \times 10^{-4}$ | $R^2$  |
| $\text{AlCl}_3\text{-AcA}$ |                                                   |                     |        |
| blank                      | 1.7144                                            | 8.2786              | 0.9987 |
| LiCl                       | 1.7015                                            | 7.7429              | 0.9981 |
| LiBr                       | 1.7106                                            | 7.7214              | 0.9988 |
| NaCl                       | 1.6795                                            | 7.1500              | 0.9997 |
| NaBr                       | 1.7221                                            | 7.9286              | 0.9995 |
| DCE                        | 1.6789                                            | 7.3214              | 0.9964 |
| EC                         | 1.6986                                            | 7.7857              | 0.9983 |
| THF                        | 1.6898                                            | 7.8571              | 0.9994 |
| EMIC                       | 1.6743                                            | 7.5714              | 0.9996 |
| $\text{AlCl}_3\text{-Ur}$  |                                                   |                     |        |
| blank                      | 1.7866                                            | 7.8000              | 0.9991 |
| LiCl                       | 1.7814                                            | 7.5000              | 0.9983 |
| LiBr                       | 1.8086                                            | 7.8214              | 0.9996 |
| NaCl                       | 1.7990                                            | 7.8571              | 0.9978 |
| NaBr                       | 1.8052                                            | 7.6074              | 0.9992 |
| DCE                        | 1.7810                                            | 7.5000              | 0.9997 |
| EC                         | 1.7797                                            | 7.3929              | 0.9996 |
| THF                        | 1.7517                                            | 7.3929              | 0.9996 |
| EMIC                       | 1.7577                                            | 7.5000              | 0.9995 |

TABLE S-III. Viscosity of  $\text{AlCl}_3$ -AcA and  $\text{AlCl}_3$ -Ur electrolytes with various additives at different temperatures

| $T$<br>(K)           | $\eta$ (mPa·s) |        |        |        |        |        |        |        |        |
|----------------------|----------------|--------|--------|--------|--------|--------|--------|--------|--------|
|                      | blank          | LiCl   | LiBr   | NaCl   | NaBr   | DCE    | EC     | THF    | EMIC   |
| $\text{AlCl}_3$ -AcA |                |        |        |        |        |        |        |        |        |
| 313                  | 46.144         | 45.960 | 46.537 | 44.799 | 47.528 | 40.904 | 46.478 | 41.364 | 38.372 |
| 323                  | 30.017         | 30.033 | 32.387 | 31.880 | 33.112 | 28.952 | 32.121 | 28.995 | 27.301 |
| 333                  | 22.060         | 21.998 | 23.613 | 22.857 | 24.040 | 20.635 | 23.769 | 21.271 | 20.154 |
| 343                  | 16.709         | 16.524 | 17.783 | 17.092 | 18.033 | 16.339 | 18.007 | 16.301 | 14.858 |
| 353                  | 13.132         | 12.831 | 14.039 | 13.630 | 13.809 | 12.625 | 14.216 | 12.705 | 11.829 |
| 363                  | 10.587         | 10.222 | 11.185 | 10.769 | 11.351 | 10.348 | 11.157 | 10.257 | 9.686  |
| 373                  | 8.745          | 8.445  | 9.156  | 9.108  | 9.247  | 8.533  | 8.862  | 8.548  | 8.084  |
| $\text{AlCl}_3$ -Ur  |                |        |        |        |        |        |        |        |        |
| 313                  | 48.967         | 44.455 | 47.483 | 49.627 | 50.558 | 40.782 | 71.298 | 45.531 | 39.131 |
| 323                  | 33.931         | 31.711 | 32.741 | 33.741 | 35.061 | 28.449 | 46.736 | 31.366 | 27.327 |
| 333                  | 24.575         | 22.377 | 24.378 | 24.587 | 25.318 | 21.097 | 31.016 | 23.798 | 20.446 |
| 343                  | 18.760         | 17.137 | 18.274 | 18.013 | 18.618 | 16.421 | 21.638 | 17.526 | 15.716 |
| 353                  | 14.716         | 13.264 | 14.483 | 14.662 | 14.885 | 13.303 | 16.710 | 13.698 | 12.671 |
| 363                  | 11.844         | 10.591 | 11.572 | 11.698 | 11.760 | 10.946 | 12.992 | 11.144 | 10.169 |
| 373                  | 9.307          | 8.945  | 9.618  | 9.699  | 9.748  | 9.336  | 11.133 | 9.356  | 8.538  |

TABLE S-IV. Conductivity of  $\text{AlCl}_3$ -AcA and  $\text{AlCl}_3$ -Ur electrolytes with various additives at different temperatures

| $T$ (K)              | $\sigma$ (mS·cm <sup>-1</sup> ) |       |       |       |       |       |      |      |       |
|----------------------|---------------------------------|-------|-------|-------|-------|-------|------|------|-------|
|                      | blank                           | LiCl  | LiBr  | NaCl  | NaBr  | DCE   | EC   | THF  | EMIC  |
| $\text{AlCl}_3$ -AcA |                                 |       |       |       |       |       |      |      |       |
| 313                  | 2.35                            | 2.70  | 2.58  | 2.52  | 2.50  | 2.45  | 2.19 | 2.46 | 2.99  |
| 323                  | 3.16                            | 3.73  | 3.41  | 3.28  | 3.33  | 3.26  | 2.92 | 3.27 | 4.03  |
| 333                  | 4.21                            | 4.81  | 4.55  | 4.27  | 4.37  | 4.30  | 3.77 | 4.21 | 5.09  |
| 343                  | 5.34                            | 6.21  | 5.73  | 5.58  | 5.68  | 5.45  | 4.76 | 5.40 | 6.37  |
| 353                  | 6.77                            | 7.64  | 7.32  | 7.04  | 6.96  | 6.87  | 5.98 | 6.87 | 7.85  |
| 363                  | 8.08                            | 9.40  | 8.62  | 8.41  | 8.36  | 8.39  | 7.17 | 8.21 | 9.21  |
| 373                  | 9.46                            | 11.06 | 10.39 | 10.30 | 9.64  | 10.38 | 8.41 | 9.98 | 10.96 |
| $\text{AlCl}_3$ -Ur  |                                 |       |       |       |       |       |      |      |       |
| 313                  | 2.34                            | 2.66  | 2.73  | 2.60  | 2.61  | 2.34  | 1.97 | 2.42 | 3.04  |
| 323                  | 3.19                            | 3.60  | 3.69  | 3.52  | 3.57  | 3.57  | 2.70 | 3.27 | 4.02  |
| 333                  | 4.18                            | 4.73  | 4.82  | 4.63  | 4.72  | 4.22  | 3.57 | 4.22 | 5.21  |
| 343                  | 5.22                            | 5.97  | 6.05  | 5.85  | 6.00  | 5.24  | 4.61 | 5.31 | 6.46  |
| 353                  | 6.50                            | 7.57  | 7.48  | 7.36  | 7.24  | 6.76  | 5.80 | 6.60 | 7.94  |
| 363                  | 7.81                            | 9.20  | 9.14  | 9.07  | 8.79  | 7.96  | 6.95 | 7.95 | 9.37  |
| 373                  | 9.31                            | 11.04 | 10.95 | 10.67 | 10.57 | 9.41  | 8.30 | 9.42 | 11.04 |

TABLE S-V. Molar conductivity of  $\text{AlCl}_3\text{-AcA}$  and  $\text{AlCl}_3\text{-Ur}$  electrolytes with various additives at different temperatures

| $T$<br>(K)                 | $\sigma_m$ ( $\text{mS}\cdot\text{cm}^2\cdot\text{mol}^{-1}$ ) |        |        |        |        |        |        |        |
|----------------------------|----------------------------------------------------------------|--------|--------|--------|--------|--------|--------|--------|
|                            | blank                                                          | LiCl   | LiBr   | NaCl   | NaBr   | DCE    | EC     | THF    |
| $\text{AlCl}_3\text{-AcA}$ |                                                                |        |        |        |        |        |        |        |
| 313                        | 163.19                                                         | 184.50 | 176.98 | 173.30 | 171.52 | 170.72 | 151.71 | 171.10 |
| 323                        | 220.80                                                         | 256.28 | 235.19 | 226.65 | 229.71 | 228.27 | 203.26 | 228.71 |
| 333                        | 295.80                                                         | 332.55 | 315.33 | 296.49 | 303.10 | 302.76 | 263.88 | 296.10 |
| 343                        | 377.56                                                         | 431.74 | 399.30 | 389.62 | 396.14 | 385.89 | 335.28 | 381.94 |
| 353                        | 481.70                                                         | 533.76 | 513.30 | 493.97 | 488.10 | 489.17 | 423.58 | 488.31 |
| 363                        | 577.75                                                         | 659.96 | 607.42 | 593.01 | 589.15 | 599.94 | 510.37 | 587.30 |
| 373                        | 680.28                                                         | 780.90 | 735.75 | 729.87 | 683.64 | 745.41 | 601.62 | 717.49 |
| $\text{AlCl}_3\text{-Ur}$  |                                                                |        |        |        |        |        |        |        |
| 313                        | 153.87                                                         | 172.13 | 176.52 | 168.21 | 169.05 | 153.49 | 128.73 | 160.47 |
| 323                        | 210.86                                                         | 234.01 | 239.82 | 228.76 | 232.27 | 208.87 | 177.23 | 217.83 |
| 333                        | 277.74                                                         | 309.07 | 314.88 | 302.66 | 308.67 | 272.71 | 235.41 | 282.42 |
| 343                        | 348.68                                                         | 392.14 | 397.29 | 384.42 | 394.42 | 348.66 | 305.58 | 357.27 |
| 353                        | 436.48                                                         | 499.86 | 493.75 | 486.18 | 478.40 | 425.42 | 386.24 | 446.14 |
| 363                        | 527.23                                                         | 610.31 | 606.10 | 602.31 | 583.48 | 514.75 | 465.27 | 540.30 |
| 373                        | 631.43                                                         | 735.78 | 729.95 | 711.38 | 704.87 | 608.70 | 558.23 | 643.24 |