Supporting Information

"Axial" Magnetic Levitation Using Ring Magnets Enables Simple Density-Based Analysis, Separation, and Manipulation

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Materials and the associated densities

Polyamide-imides (Torlon®) and polytetrafluoroethylene (Teflon®) were obtained from McMaster-Carr. Aluminum foil was obtained from Sigma-Aldrich. Zirconium silicate was obtained from Cospheric LLC. The density of air was obtained from the CRC Handbook of Chemistry and Physics, 98th Edition.

Correlation of swelling ratio and densities

Eq S1 gives the density of a crosslinked polymeric sample in the dry state, eq S2 gives the density in the swollen state, and eq S3 gives the swelling ratio of the sample.

$$\rho_p = \frac{m_p}{V_p} \qquad (S1)$$

$$\rho_{sp} = \frac{m_p + m_s}{V_{sp}} \qquad (S2)$$

$$f = \frac{V_{sp}}{V_p} \qquad (S3)$$

In eqs S1-3, m_p is the mass of the sample, m_s is the mass of the solvent present in the swollen sample, V_{sp} is the volume of the swollen sample, V_p is the volume of the dry sample, ρ_p is the density of the sample, ρ_{sp} is the volume of the swollen sample, and ρ_{sol} is the density of the solvent.

In a swollen sample, the mass of the solvent is described by eq S4.

$$m_s = \rho_{sol}\left(V_{sp} - V_p\right) \qquad (S4)$$

Solve eqs S1-4 to give eq S5, which describes the relationship between the swelling ratio and the densities.

$$f = \frac{\rho_p - \rho_{sol}}{\rho_{sp} - \rho_{sol}} \qquad (S5)$$

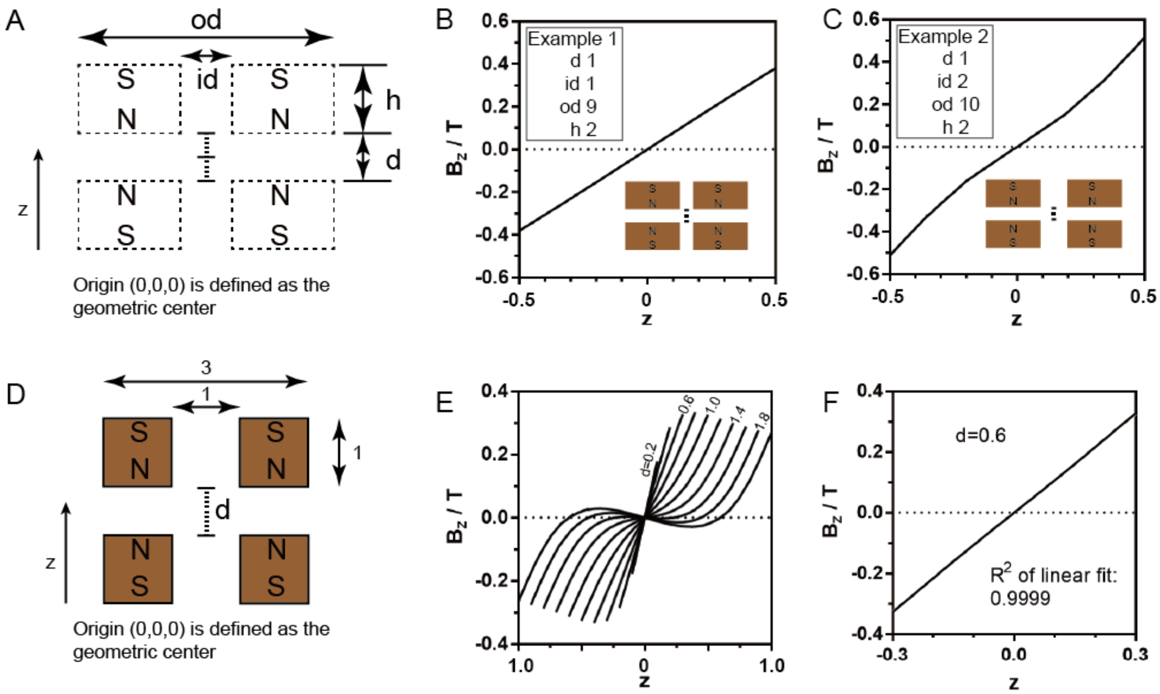


Figure S1 Selection of the geometry and the distance of separation between the ring magnets using Comsol® simulation (A) A schematic shows the four independent physical parameters to define its configuration of the setup (od: out diameter, id: inner diameter, h: height of the magnet, d: distance of separation). All combinations of the parameters explored using Comsol® simulation in this study are given in Table S1. (B) A specific example shows a linear gradient with a max field strength of ~0.4 T along the central axis between the magnets (dotted line in the inset). (C) A specific example shows a non-linear gradient with a max field strength of ~0.5 T along the central axis between the magnets (dotted line in the inset). (D) Fine-tuning of the separation distance between the two magnets (od: 3, id: 1, h: 1) used in this study. (E) The field strength B_z along the central axis between the two magnets as the distance of separation varied from 0.2 to 2 at a step of 0.2. (F) Replot of the curve at d=0.6 in (E). We focused on the aspect ratios of the these parameters (d is set to be 1) to optimize the magnetic field profile, and thus, the parameters are all unitless.

Table S1 All combinations of the parameters were examined using Comsol® simulations

parameter	range	description
d	1	Distance of separation of the two magnets
id	¼, ½, 1, 2, 4	Inner diameter of the ring magnet
k_{od}	½, 1, 2, 4, 8, 16	A parameter to define the outer diameter of the ring magnet, od=id×(1+k_{od}).
height	¼, ½,1, 2, 4	height of the ring magnet

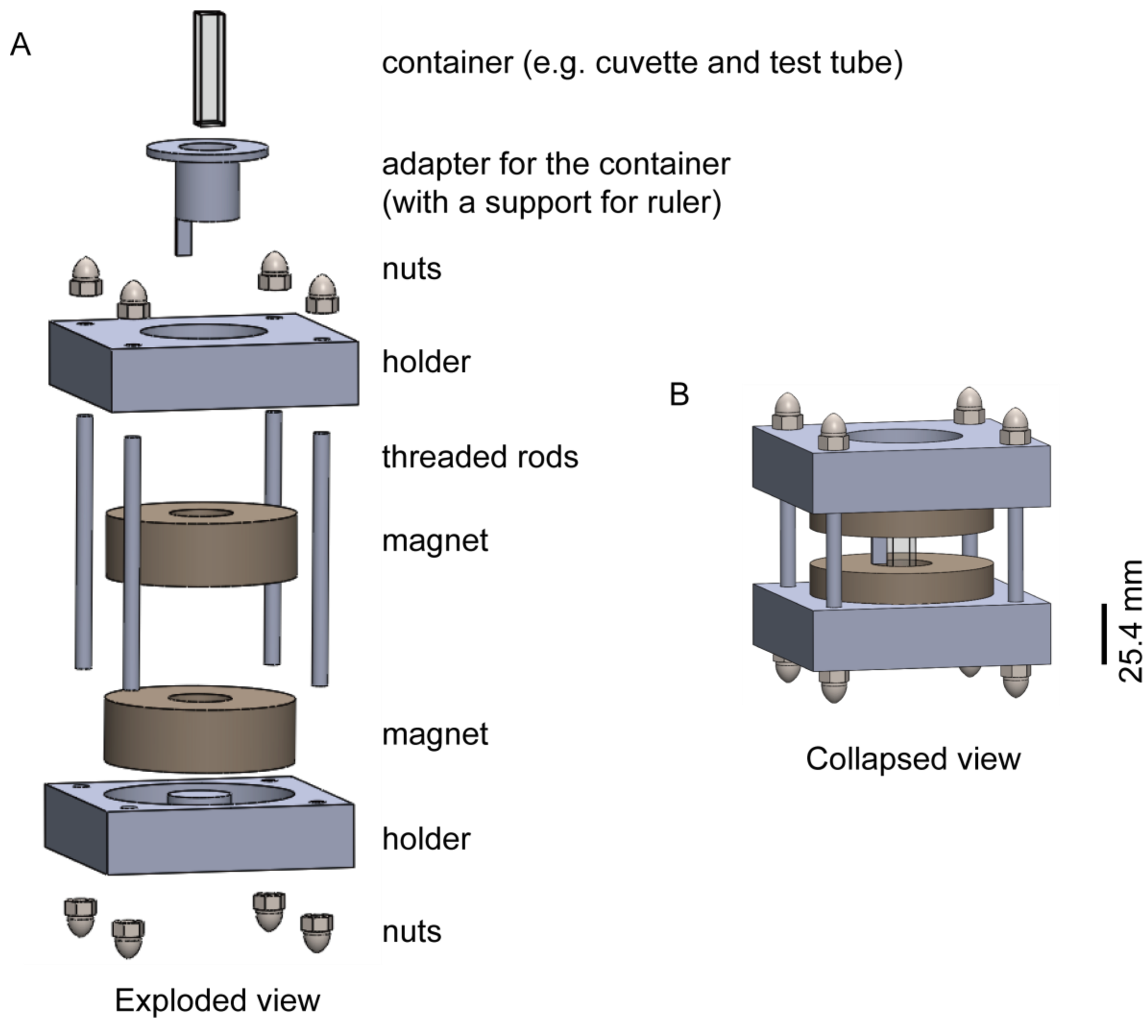


Figure S2 Assembly of the device

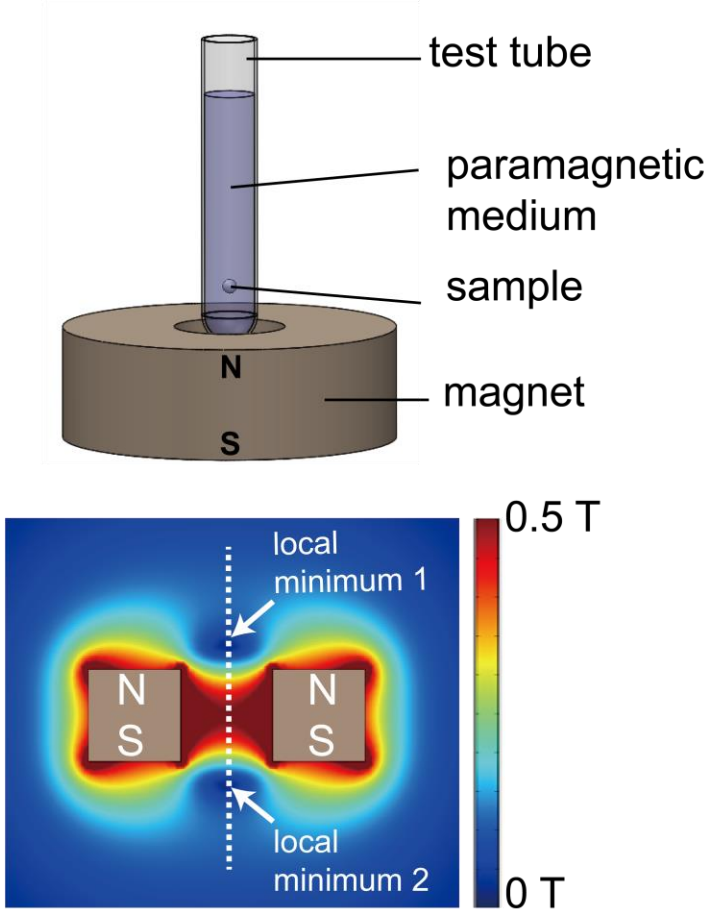
A


Figure S3 Magnetic levitation using a single ring magnet.

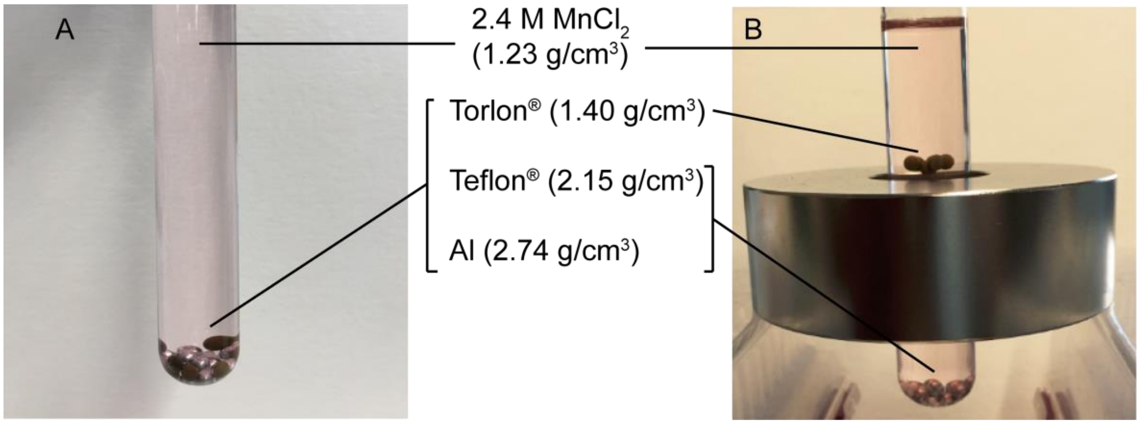


Figure S4 Separation of beads having different densities (A) In the absence of an applied magnetic field, all three types of beads sunk to the bottom of the test tube containing an aqueous solution of 2.4 M $MnCl_2$. (B) Only Torlon® beads levitated in the $MnCl_2$ solution above the ring magnet when the test tube was inserted slowly into the cavity of the ring magnet.