Sedimentation of Chiral Particles in Shear Flow

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This experiment will attempt to separate chiral particles via shear flow. We will place 3-D printed chiral particles in a high viscosity fluid and use a Taylor-Couette apparatus to generate a shear flow. The results of this experiment should help to verify research by M. Makino and M. Doi [6][4][5]. Additionally, our observations should give us a degree of insight into naturally occurring chiral behavior.

A. Motivation

The behavior of chiral particles is of interest due to their prevalence in biology. Examples include amino acids and the locomotion of many flagellate-driven microorganisms. Observations of chiral objects in shear flow may help us understand how such biological systems behave in certain environments.

Additionally, chirality can be important in the development of drugs, as enantiomers often have differing chemical properties. Finding efficient ways of separating enantiomers is thus a matter of great interest. Shear flow is of particular note as it may provide a mechanical separation method whereas most current methods are chemical[7]. While our experiment will not determine if chiral separation is possible on a chemical scale, it should demonstrate much of the physics that would be involved in such separation.

B. Goals

The primary purpose of this project is to experimentally verify the paper by Makino, where chiral separation of ribbon shaped particles is investigated using computer simulations [4]. The first goal will be to verify the separation effect. We have only found one paper proving this effect [6], so by doing another experiment we can improve its scientific credibility. Additionally, we will be using another apparatus to generate shear flow, and different shapes of the chiral particles. When this is done, we will move into specifics of the theoretical paper [4] if time allows. Finally, we might be able to go beyond the aforementioned paper and learn something entirely new about separation of chiral particles.

C. Experimental Design

To reach our goals for this experiment we need a highly viscous fluid in shear flow and particles that are significantly chiral.

The centerpiece of the experiment will be a Taylor-Couette device, pictured in figure A.2. This device creates a reliable shear flow that should be optimal to generate the separation effect. The device will be constructed using a 3–D printer and a piece of transparent PVC tubing. The dimension of the central dowel will be maximized to generate a strong flow profile, while leaving enough clearance for the particles to rotate freely. Our Taylor–Couette device will be powered by either a stepping motor or a handheld drill. The effect we are demonstrating has only been experimentally examined using rotating parallel plates, so this should be the first time the effect is demonstrated in Taylor–Couette flow.

Since the separation effect depends on a high Peclet number, we will be using a highly viscous fluid. Our fluid of choice will be transparent corn syrup, with a viscosity of 1450–2170 cSt. [2]. This should be sufficiently viscous, easy to see though, and readily available at any grocery store. Another reason to use a highly viscous fluid is that it dampens the effect of diffusion, that would otherwise overshadow the separation effect were measuring. A high viscosity also gives a greater margin of error for buoyancy. With a density of about $1380 kg/m^3$ [3] the 3–D printed particles (with a density of $1210 - 1430 kg/m^3$ [1]) will be close to neutral buoyancy, and the viscosity will be great enough to hold the particles at the same level.

Finally, we will put chiral particles into the apparatus. Since one of the goals of this project is to verify the paper by M. Makino and M. Doi [4] we will be using ribbon shaped particles, see figure A.1. By 3–D printing the particles we can experiment with different lengths and properties of the ribbons and compare these to the predictions made by Makino [4]. The ribbons will have a radii of about 5 mm and a length of about 10 mm. These sizes are large enough to guarantee a high Peclet number, so we will be able to see the effect quite clearly. As mentioned above, the density of the 3–D printing filament is close to the density of corn syrup.

The first step of the experiment will be to verify the existence of the effect, using a primitive version of the Taylor–Couette apparatus. When this is done, the apparatus will be improved using 3–D printing technology for a better, more consistent shear flow. This will allow us to quantify the effect, by measuring Z–displacement over time for known shear flows. The measurements of the particles positions will be made using a video camera. By placing four tilted mirrors around Taylor–Couette apparatus, we can capture all four sides using only one camera at a birds eye perspective. By marking the dowel, the rate of the rotation can be measured from the video. Finally, some post processing will need to be done to translate the video files into useful data. This will be done using MATLAB. We will either do the tracking manually, or use an available package.

[1] Matbase: Pla monomere. http://www.matbase.com/material-categories/natural-and-synthetic-polymers/agro-based-polymers/material-properties-of-polylactic-acid-monomere-pla-m.html.
[2] Viscosity chart. http://www.research-equipment.com/viscosity
[3] Glen Elert.
[4] Masao Doi Masato Makino. Migration of twisted ribbon-like particles in simple shear flow.
[5] Masao Doi Masato Makino. Motion of micro-particles of complex shape.
[6] Masao Doi Masato Makino, Leo Arai. Shear migration of chiral particle in parallel-disk.
[7] Ralf Eichhorn Friedrike Schmid Sebastian Meinhardt, Jens Smiatek. Separation of chiral particles in micro- or nanofluidic channels.

APPENDIX A: IMAGES

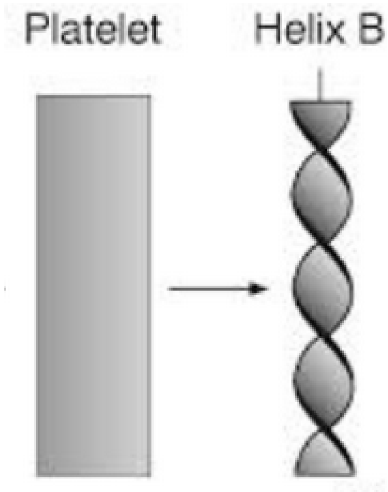

FIG. A.1: The shapes of the flat ribbon particles (control case) and twisted ribbon particles (test case). Courtsey of Nature.com

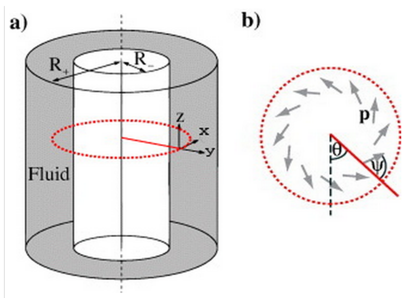

FIG. A.2: Basic design of a Taylor-Couette cylinder. Courtesy of IOP Science

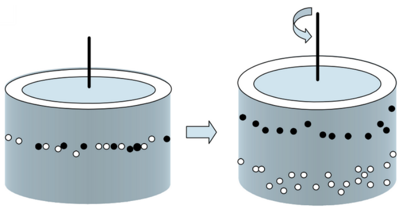

FIG. A.3: A conceptual sketch of chiral separation in a Taylor–Couette cylinder [6].