Fiscal Year:	FY 2022	**Task Last Updated:**	FY 12/02/2021
PI Name:	Clark, Noel A. Ph.D.		
Project Title:	Ferromagnetic Liquid Crystal Colloids in Microgravity		
Division Name:	Physical Sciences		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	COMPLEX FLUIDS/SOFT MATTER--Complex Fluids		
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	None		
Human Research Program Risks:	None		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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Zip Code:	80309-0001	**Congressional District:**	2
Comments:			
Project Type:	FLIGHT	**Solicitation / Funding Source:**	2015 NNH15ZTT002N MaterialsLab Open Science Campaigns for Experiments on the International Space Station
Start Date:	12/02/2016	**End Date:**	12/01/2022
No. of Post Docs:	2	**No. of PhD Degrees:**	2
No. of PhD Candidates:	2	**No. of Master' Degrees:**	
No. of Master's Candidates:		**No. of Bachelor's Degrees:**	6
No. of Bachelor's Candidates:	8	**Monitoring Center:**	NASA GRC
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Flight Program:	ISS		
Flight Assignment:	Liquid Crystal Facility NOTE: End date changed to 12/01/2022 per NSSC information. Previous end date was 12/01/2021. (Ed., 12/2/21)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Glaser, Matthew Ph.D. (University of Colorado, Boulder) Maclennan, Joseph Ph.D. (University of Colorado, Boulder) Park, Cheol M.S. (University of Colorado, Boulder) Shuai, Min Ph.D. (University of Colorado, Boulder)		
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Task Description:

Paramagnetic ferrofluids are familiar as suspensions of magnetic particles in solvents that become strongly magnetized in applied fields. A longstanding challenge has been to make such fluids ferromagnetic, so that they exhibit spontaneous macroscopic ferromagnetic ordering even in the absence of an applied field. Recently, ferromagnetic fluid phases have been achieved by the ferromagnetic orientation of magnetic nanoplates in colloidal suspensions, either by dispersion in a thermotropic nematic liquid crystal (LC) host or by spontaneous nematic ordering in an isotropic solvent. These novel materials are optically birefringent, dichroic, and translucent, so that structures and textures can easily be visualized in polarized light. They manifest a variety of interesting and distinctive magnetic interaction effects and, because of the static magnetization, display ultrahigh sensitivity to externally applied magnetic fields. Field-induced changes in the shape of fluid drops, such as interfacial magnetic spike instabilities, occur even in the Earth's magnetic field, and readily achievable benchtop magnetic fields are expected to induce spectacular magnetofluidic responses. Ferromagnetic nematics also exhibit distinctive magnetic self-interactions, including liquid crystal textures of fluid magnetic domains arranged in closed flux loops that in microgravity should strongly affect the shape of free-floating drops. Freely suspended smectic LC films in the form of bubbles, the LC geometry currently studied in OASIS (Observation and Analysis of Smectic Islands in Space), will be rendered ferromagnetic by doping with magnetic nanoplates and manipulated magnetically. In suspensions studied on Earth, the typically more dense liquid crystal phase sediments to the lower parts of test cells, leaving a sharp interface with the co-existing isotropic phase. Microgravity offers the opportunity to perform critical experiments that are not possible on Earth, such as the observation of ferromagnetic droplets and other fluid interface shapes as a function of an applied magnetic field, investigations of magnetic convective instabilities and thermocapillary effects resulting from temperature gradients, studies of liquid crystal ordering kinetics in the absence of gravity, and magnetic islands on smectic bubbles.

The proposed research has both fundamental and applied aspects. One of the most interesting scientific subthemes of ferromagnetism is ferrofluidics, the study and application of paramagnetic, colloidal suspensions of sub-micron size ferromagnetic particles dispersed in solvents with random orientation of the magnetic dipoles. In ferrofluids, originally developed by NASA for enabling transport of rocket propellant in space vehicles, these nano-magnets orient in applied fields, producing a bulk magnetization that in turn generates forces and torques on the host fluid. This results in a variety of exotic and useful magneto-mechanical effects, including field-induced transport and radical changes of shape, which have led to a wide variety of technical and biomedical applications. Ferromagnetic nematics combine the traditional advantages of liquid crystal ordering with permanent magnetization, leading to delicate temperature control of the intrinsic magnetic order and a facile response to applied magnetic fields that suggests a range of enhanced applications analogous to those of conventional ferrofluids. Experiments in microgravity will enable the investigation of the fundamental properties of this new family of colloidal materials and of physical phenomena that cannot easily be probed on Earth. Microgravity investigations will be carried out using the OASIS hardware in the Materials Science Glovebox on the International Space Station (ISS), with various modifications. The experiments will use the OASIS high and low resolution video cameras in their orthogonal view geometry. Magnetic freely suspended smectic bubble experiments will employ a slightly modified OASIS sample chamber. The other experiments will require new sample box designs.

Rationale for HRP Directed Research:

Research Impact/Earth Benefits:

Paramagnetic ferrofluids are familiar as suspensions of magnetic particles in solvents that become strongly magnetized in an applied field. A longstanding challenge has been to make such fluids ferromagnetic, so that they exhibit spontaneous macroscopic ferromagnetic ordering even in the absence of an applied field. Recently, ferromagnetic fluid phases have been achieved by the ferromagnetic orientation of magnetic nanoplates in colloidal suspensions, either by dispersion in a thermotropic nematic liquid crystal host or by spontaneous nematic ordering in an isotropic solvent. These novel materials are optically birefringent, dichroic, and translucent, so that structures and textures can easily be visualized in polarized light.

Task Progress:

Dynamic process of phase separation between isotropic and ferromagnetic nematic and ferromagnetic droplets in isotropic fluids We have shown previously that suspensions of disk-shaped, ferromagnetic barium hexaferrite nanoplates in isotropic solvent spontaneously form a ferromagnetic nematic phase at nanoplate concentrations higher than the Onsager isotropic-nematic phase transition point for hard disks. At an overall nanoplate concentration below this value and within the coexistence region, such suspensions phase-separate into ferromagnetic nematic and isotropic domains. Under these conditions, the suspension can be driven into a uniform state by mechanical or magnetic stirring, and undergoes a dynamic process of phase separation immediately after the removal of stirring forces, which we have investigated by polarized optical microscopy under Earth's gravity. Liquid crystal droplets have attracted intense study, focused on understanding their topological structures and their potential optical applications. With coupled spontaneous ferromagnetic and liquid crystal order, ferromagnetic nematics exhibit novel magnetic domain structures. The structures of these magnetic liquid crystal domains are controlled by the shape of the container, i.e., the boundary conditions, and are very sensitive to external magnetic fields. Previously, we studied the deformation of ferromagnetic droplets suspended in fluorinated oil. We quantitatively characterized the shape changes of the magnetic droplets with the application of a magnetic field. More recently, we have investigated ferromagnetic nematic droplets in isotropic media consisting of the same magnetic nanoplate suspension. With the nanoplate density only slightly higher in the droplets than that of the surrounding isotropic suspension, the surface tension at the interface is negligible. This provides a convenient way of studying the effects of forces on domain shape other than surface tension, such as the magnetic self-interactions of the nanoplates.

Field Induced Interactions of Isotropic Oil and Ferromagnetic Droplets on Smectic Films

Small droplets of paraffin oil, both neat and doped with colloidal particles of barium hexaferrite (BF), have been deposited on the surface of ultra-thin, freely suspended smectic liquid crystal films, allowing the equilibrium structures and hydrodynamics to be studied in a quasi-two-dimensional geometry. Paraffin oil droplets are observed to have both attractive forces, leading to close-packed hexagonal aggregates, as well as repulsive forces, leading to linear aggregates with well-spaced droplets. Droplet chains are observed both on uniformly thick films and along layer steps, with a droplet spacing that can be controlled, in general, with an applied electric field. Droplets doped with BF colloidal particles respond both to electric and applied magnetic fields, which induce translational motion, island formation, and changes in the droplet size.

The aggregation and chaining behavior induced by electric fields alone are significantly altered in the presence of magnetic fields. The dependence of the observed structures on electric and magnetic fields is suggestive of dipolar

	interactions between the droplets, while the droplet dynamics are mediated by hydrodynamic interactions with the smectic film.
Bibliography Type:	Description: (Last Updated: 08/07/2023)
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