Reply to "Comment on 'Structure of ferrofluid dynamics' "

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Derived from general principles, the recently introduced ferrofluid dynamics is structurally identical to Shliomis' theory for incompressional flows, yet distinctly different for compressional ones. It provides a complementary point of view for the first case, but also shows that the standard theory partially violates general principles. Overemphasizing the competition between both theories while ignoring their factual differences could hinder progress in ferrofluid physics.

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In a recent paper titled "Structure of ferrofluid dynamics" [1], we introduced the general framework for the hydrodynamics of magnetizable fluids. Unlike Shliomis' earlier works on ferrofluid, which relies on microscopic details such as the form, size, size distribution of the particles and the lack of their interaction, ferrofluid-dynamics is a general, strictly macroscopic approach relying solely on symmetry considerations, conservation laws, and thermodynamics. The derivation is done in close analogy to that of hydrodynamic theories for ordinary liquids or nematic liquid crystals.

In his comment, Shliomis compares both approaches, touting his as state of the art, while denouncing ours as "*unsatisfactory . . . purely formal*," and lacking a "*steering physical idea*." As discussed at length in Ref. [1], we do not see this as a competitive case between Shliomis' standard theory and our macroscopic results. First of all, there is no doubt that Shliomis' theory has mostly served the community well in accounting for ferrofluid behavior. And second, our results shed additional light, which helps to understand the system yet better.

There are two versions of the Shliomis theory, with magnetization equations that (as Shliomis himself admits) "*undergo revisions from time to time.*" When we take our equations and specify incompressible flows, we can reproduce them all, if appropriate values for the transport coefficients are prescribed [2]. This shows that in spite of the rather specific microscopic inputs, the Shliomis theory is structurally sound—a fact that certainly helps to explain why the theory works so well even for those ferrofluids, in which these inputs are only approximately, even partially, valid.

Moreover, given the knowledge of the general structure, we know which coefficients may be altered from the Shliomis values to better accommodate experimental data. In fact, there is experimental evidence [3] that this is necessary for λ_2, for which the Shliomis value is zero, while it has been measured as 0.2, comparable in size to other coefficients.

For compressional flows, the difference between our equations and all versions of the Shliomis theory is structural and cannot be bridged by a choice of transport coefficients. The Shliomis stress contains the magnetodissipative term $\delta\mathbf{M}\times\mathbf{H}$, which contributes only if the off-equilibrium magnetization $\delta\mathbf{M}$ and the field $\mathbf{H}$ point in different directions. However, as shown in Ref. [1], energy and momentum conservation cogently require a stress contribution $\sim\delta\mathbf{M}\cdot\mathbf{H}$, producing magnetodissipation even when $\delta\mathbf{M}$ and $\mathbf{H}$ are parallel. As a result, sound waves will suffer additional energy loss if the medium is magnetized. Now, this is a discrepancy that needs to be settled yet seems to have been completely overlooked. Since we have no reasons to expect reaching an agreement on theoretical grounds, experiments must decide. Appropriate suggestions may be found in Ref. [4].

[1] H.W. Müller and M. Liu, Phys. Rev. E **64**, 061405 (2001).

[2] This is not true for the third, rather younger version, specifically constructed, again in a comment [M. Shliomis, Phys. Rev. E **64**, 063501 (2001)] on the work of B.U. Felderhof and H.J. Kroh, *ibid.* **62**, 3848 (2000).

[3] S. Odenbach and H.W. Müller, Phys. Rev. Lett. **89**, 037202 (2002).

[4] H.W. Müller and M. Liu, Phys. Rev. E **67**, 031201 (2003); see also H.W. Müller and M. Liu, Phys. Rev. Lett. **89**, 067201 (2002). We have no doubt that our theory displays the proper structure to ensure conservation laws under all circumstances, as this is the point we focused on. So we expect experiments to prove us right. But we are even surer that this would not in any way diminish Shliomis' outstanding and enduring contributions.

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