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Magnetic field control of active stress and flow in magnetotactic bacterial suspensions

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The hydrodynamics of active matter are largely governed by active stresses generated by the constituent elements. In particular, the self-propulsion of active elements such as bacteria produces force dipoles, which, after coarse graining, result in an active stress that depends on both the orientation and concentration of these elements. Additionally, torques arising from the rotation of bacterial flagella and bodies generate torque dipoles, contributing to what is known as couple stress. In this review, we focus on hydrodynamic phenomena that result from active stress, with a particular focus on suspensions of magnetotactic bacteria, where the active stress can be controlled by an external magnetic field. As a first example, we examine how an oblique magnetic field affects a concentration band of bacteria formed in an oxygen gradient [1]. Our results show that active stress induces a shear flow along the boundaries of the band. The second example explores the motion of swarms of magnetotactic bacteria that form near a confining wall as a result of hydrodynamic interactions [2]. Both theoretical analysis and experimental observations demonstrate that when a magnetic field is applied obliquely to the boundaries of the cell, a couple stress is induced, causing the swarms to move according to the left-hand rule: the normal component of the field enters the palm, the four fingers point along the tangential field, and the thumb indicates the direction of swarm motion. Finally, as a third example, we consider a model describing the vortical instability of a suspension of magnetotactic bacteria subjected to a rotating magnetic field [2]. This model incorporates active stresses arising from both the self-propulsion of the bacteria and their rotation in the field. To analyze the evolution of perturbations in the orientation and concentration fields, we derive a set of linear equations with time-dependent periodic coefficients. By calculating the monodromy matrix, we illustrate the instability with respect to both orientation and concentration perturbations.

References

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