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Forces, Stresses and the (Thermo?) Dynamics of Active Matter

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Abstract

The statistical mechanics and microhydrodynamics of active matter systems have been studied intensively during the past several years, by various soft matter physicists, chemists, engineers, and biologists around the world. Recent attention has focused on the fascinating nonequilibrium behaviors of active matter that cannot be observed in equilibrium thermodynamic systems, such as spontaneous collective motion and swarming. Even minimal kinetic models of active Brownian particles exhibit self-assembly that resembles a gas-liquid phase separation from classical equilibrium systems. Self-propulsion allows active systems to generate internal stresses that enable them to control and direct their own behavior and that of their surroundings. In this Review we discuss the forces that govern the motion of active Brownian microswimmers, the stress (or pressure) they generate, and the implication of these concepts on their collective behavior. We focus on recent work involving the unique 'swim pressure' exerted by active systems, and discuss how this perspective may be the basic underlying physical mechanism responsible for self-assembly and pattern formation in all active matter. We discuss the utility of the swim pressure concept to quantify the forces, stresses, and the (thermo?) dynamics of active matter.

Keywords: active matter; swim pressure; nonequilibrium systems; collective behavior

1. Introduction

A distinguishing feature of many living organisms is their ability to move, to self-propel, to be active. Constituents of "active matter" systems are capable of independent self-propulsion by converting fuel into mechanical motion, and include both microscopic entities like microorganisms and motor proteins within our cells to large bodies like fishes and birds. Inanimate, nonliving bodies can also achieve self-propulsion using mechanisms that are different than living organisms, but the outcome of their collective behavior is not necessarily different between living and nonliving active systems. Indeed, active matter systems of all scales have the tendency to associate together and move collectively, from colonies of bacteria, swarms of insects, flocks of birds, schools of fish, and herds of cattle. A question arises as to the micromechanical origin for living organisms to exhibit collective and coherent motion, and whether it can be explained and expressed using basic physical quantities.

All active matter systems are intrinsically out of equilibrium, a trait which allows self-propelled entities