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STATISTICAL MECHANICS OF GEOMAGNETIC ORIENTATION IN SEDIMENT BACTERIA

by

Michael K. Gilson
and
Ad. J. Kalmijn

April 1981

TECHNICAL REPORT

Prepared for the Office of Naval Research under Contract N00014-79-C-0071.

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Department of Biology

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Statistical mechanics of geomagnetic orientation in sediment bacteria. MICHAEL K. GILSON AND AD. J. KALMIJN.

Last year we reported on time-of-transit experiments in which magnetically orienting bacteria crossed a 1-mm stretch in the direction of a uniform magnetic field. The bacteria were found to behave as tiny self-propelled compass needles subject both to magnetic field alignment and to the randomizing effect of thermal agitation. In strong fields, magnetic bacteria are held in tight alignment; in weaker fields, their swimming paths meander more and transit times are greater. Paul Langevin derived an expression for the distribution of orientation in an ensemble of free-moving dipole particles as a function of ambient field strength. His theory becomes applicable to our experiments when bacterial migration is analyzed as a sequence of short steps during each of which the cell swims in a direction randomly selected from the Langevin distribution. The duration of each step, Δt, is actually a time constant of the cell's loss of directionality due to thermal agitation. By thus treating the migration as a process of random walk with drift, we are able to predict the mean and variance of the time of transit across a 1-mm stretch. The behavior of the model depends on three parameters: the randomization time Δt, the cell's intrinsic dipole moment m, and the speed of propulsion V_0. We use nonlinear regression analysis to estimate these parameters and to fit the behavior of the model to that of the bacteria. We also determine the goodness of fit of the model in its entirety, and the approximate confidence limits of the parameter estimates. The estimated randomization times are in accord with preliminary calculations of rotational diffusion rates. The dipole strengths agree well with those expected on the basis of the number and size range of the bacteria's intracellular magnetite crystals. Our values are slightly lower due to the inevitable impurities and imperfections in alignment of the crystals, and to additional agitation resulting from swimming movements. In short, the dipole moments direct the bacteria magnetically despite thermal agitation and swimming noise. As statistical mechanics suffice to explain the orientation of magnetic bacteria, there is no need to invoke an active orientation mechanism.

(Kalmijn's project on electric and magnetic detection operates under the auspices of the Office of Naval Research, Oceanic Biology Program, N00014-79-C-0071.)

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Last year we reported on time-of-transit experiments in which magnetically orienting bacteria crossed a 1-mm stretch in the direction of a uniform magnetic field. The bacteria were found to behave as tiny self-propelled compass needles subject both to magnetic field alignment and to the randomizing effect of thermal agitation. In strong fields, magnetic bacteria are held in tight aligment; in weaker fields, their swimming paths meander more and transit times are greater.

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Paul Langevin derived an expression for the distribution of orientation in an ensemble of free-moving dipole particles as a function of ambient field strength. His theory becomes applicable to our experiments when bacterial migration is analyzed as a sequence of short steps during each of which the cell swims in a direction randomly selected from the Langevin distribution. The duration of each step, Δt, is actually a time constant of the cell's loss of directionality due to thermal agitation. By thus treating the migration as a process of random walk with drift, we are able to predict the mean and variance of the time of transit across a 1-mm stretch.

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