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Prof. Rob de Ruyter
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Dear Prof. de Ruyter,

Please consider the enclosed application for a School of Science faculty position in your new Biocomplexity Institute. I am a theoretical physicist, and currently an assistant professor of Physics at the Boston campus of the University of Massachusetts, and an adjunct assistant professor of Physics at the Amherst campus. (I should add that I am currently being considered for promotion to the position of associate professor here.) The enclosed materials should make it clear that my research and academic performance have been excellent, producing new and exciting results.

I am, however, actively seeking to move my research, grants, and patent application (one so far), to another school. Despite my successes here at UMass, there are a number of reasons prompting me to move. Some of the reasons are personal, some institutional, and some are systemic to this particular campus. One simple fact is that the teaching load here (2/2) is not readily negotiable, and it has begun to interfere with my research, and my ambitions for future research. Earlier this fall, I learned from Prof. Hofstadter about the Biocomplexity initiative at Indiana University, and then discussed it by phone with Prof. Glasier. Of all the job announcements that I've seen, it is yours that really excites me. I feel that the goals of the initiative fit me like a glove, and I am *extremely* eager to apply for one of the open positions.

I enjoy a good deal of support from the faculty at UMass, and I have *not* informed my colleagues here of my intention to leave. Therefore, I would appreciate your utmost discretion in this matter, at least at this time. I look forward to your response.

Yours sincerely,

Greg Huber

Research statement

To provide a focused account, I'll limit the discussion of my current and future research to only a few distinct projects, which is far from complete. To give a broader sense of my projects, I conclude with a listing of some other on-going collaborations.

Biofluiddynamics and cellular biomechanics

My collaborators and I have developed a number of projects that lie at the interface of biomechanics elasticity theory and fluid dynamics.

Bacterial propulsion. Understanding the mechanics and hydrodynamics of bacterial motility is an endlessly fascinating challenge. There are scores of unsolved problems in this general area, most of them fundamental. Even the obvious question "What are the mechanical details underlying how bacteria like *E.coli* swim?" is so far unanswered. How does the flagellar motor work? What are the hydrodynamic details of flagellar bundling? What is the effect of flagellar rotation on the polymorphic flagellar states? On the modes of flagellar propulsion? Over the last few years, I've worked on the theory of the elastic mechanics of the flagellar filament, on its interaction with flows, and on the flow-induced interaction of multiple flagella. About two years ago, I began discussions with Howard Berg of Harvard on how to directly apply this theoretical and numerical modeling to his experiments. In just the last year, we were fortunate to get joint support in the form of a large grant from the Defense Sciences Office of DARPA (my co-PIs at Harvard University, the Rowland Institute, and Brown University are Howard Berg, Kenneth Breuer and Thomas Powers). Our recent numerical simulations of the flagellar flow utilize what is called "slender body theory", an asymptotic technique for solving the Stokes equations of fluid motion around long, thin objects. These fundamental studies have led to models of the flow at the scale of many microns, and to addressing engineering concerns, such as the optimization and design of a prototype bacterial transportation system (see the next section on bacterial carpets). Other classes of bacteria present their own open problems, and I'll simply mention the gliding motility of *Mycoplasma*, and the *Synechococcus*-type motility, both completely unlike *E. coli*, and each other, in their propulsive mechanisms.

Bacterial carpets. Bacterial carpets are arrays of motile bacteria attached to two-dimensional surfaces. Improved understanding of carpet flows is important in the design of microfluidic devices and transport systems powered by bacterial flagellar motion. In recent experiments by the group of H. Berg, cells of swarming *S. marcescens* are stuck to the surface with most of their flagella free to rotate in the fluid. These studies show modified transport and greatly enhanced diffusion near the active carpet surface. Our theoretical work, both numerical and analytical, consists of nano- to macro-scale models of the flagella-driven flow. This, together with numerical simulations of the diffusion and advection of passive tracers, allows a comparison with the tracking data of Berg et al.

Mechanics of bilayer membranes. Thin cylindrical tethers are common phospholipids bilayer structures, arising in situations ranging from micromanipulation experiments on artificial vesicles to the dynamic structure of the Golgi apparatus. In previous work with Prof. Powers, we provided analytical and numerical solutions for the shape and formation of a single tether under simple forces, using ideas borrowed from the classical soap-film problem (coupled with ideas from boundary-layer analysis). It was found that a tether forms from the elastic boundary layer near the forcing, for sufficiently large displacements. I am currently extending this to the interaction of multiple tethers in more complicated geometries. Another extension that I am working on is the dynamics of coupled lipid and external flow, in tether geometries in particular. Finally, together with Tom Powers and Ranjan Mukhopadhyay, I am exploring model situations where the membrane Gaussian curvature plays a crucial energetic rôle. Another exciting direction, one where I am just starting out, is the study of membrane fusion.

Fluid dynamics

Descriptions of turbulence, both weak and high-Re, have occupied me for many years. At UMass, I started a fluid dynamics lab, similar to that at MIT and the Courant Institute, to involve students in fluids research. A number of projects in elastohydrodynamics have been completed by students here. I'll discuss a recent direction that my interest in fluid dynamics has lead to.

From passive scalars to neutral models. A correct description of turbulence in fluid flows has been a thorny problem for many decades. Recently progress has been made on the more restrictive question of how a scalar field (like chemical or pollutant concentration, temperature, etc) is advected by a turbulent flow. With Prof. J. Kondev (Brandeis University), we've looked at novel geometrical measures for analyzing the complete spatial state of fluctuating scalar fields, particularly those dispersed by turbulence. Our initial motivation was to understand the experimental data coming out of Tabeling's lab in Paris, and that work has resulted in one prominent publication, with two others in preparation. Interest in this work has led to another collaboration with fluid dynamicists at Sandia National Lab. However, the methods are sufficiently general that they can be adapted to diverse disordered surfaces, including fitness landscapes in ecoloy and molecular biology. The statistical geometry of saddles and other level-set structures then constitutes a new quantitative tool for neutral theories of evolution. With this in mind, are working together on a major grant proposal to NSF which seeks to extend our methods to the analysis of rough energy surfaces and rough fitness landscapes, and thus provide new analytical tools in areas as diverse as molecular biology and population dynamics.

Flow of information across disparate scales and informatic turbulence

Q theory. Prof. D. R. Hofstadter (Cognitive Science and Computer Science, Indiana University) and I have been actively exploring a mathematical subject based on the idea of nested recursion. The "function" $Q(n) = Q(n-Q(n-1)) + Q(n-Q(n-2))$ was introduced by Hofstadter almost 25 years ago. Over those years, a number of mathematicians have studied this function, and though some statistical details about Q's type of chaos have been observed, no one has managed to prove a single fact about Q -- not even that it is a function! Hofstadter and I have taken a different, and mostly empirical, tack and have managed to discover a related, infinite family of functions, which can be seen as a well-defined arena for exploring the rôle of feedback and information flow in maintaining robust behavior. The Q family of functions, on the collective level, exhibits an amazing degree of regularity, and yet within the framework of that family-level regularity, there are very weird, irregular patterns unlike any seen before. Understanding when the deterministic flow of information makes a transition from order to disorder (turbulence) may have applications to fluctuations in the output of other recursive systems, such as large gene-expression networks, where deterministic and thermal disorder are entwined. I am preparing a grant application along these lines to the Research Corporation's Research Innovation and Opportunity Awards.

Other collaborations:

With A. M. Cazabat (College de France, Paris): Contact-line rings and interfacial motion.

With Prof. P. Cvitanovic (Georgia Tech): Spatiotemporal patterns in lattices of coupled rotors.

With Prof. V. Horváth (Eötvös Institute, Budapest): Theoretical issues in PIV analysis.

With Prof. P. Hosoi (MIT): Lubrication theory of gliding and slime-based motility.

With Prof. J. X. Tang (Brown University): Growth dynamics and elastic structure of of actin tails.

With Dr. S. Wunsch (Sandia National Lab): Loop analysis of passive and active scalars in two-dimensional turbulence.

With Prof. R. Ziff (University of Michigan): Percolation theory applied to the dynamics and structure of small-world and scale-free networks.

Teaching Philosophy

I am devoted to teaching. It is so obviously important and part of what we do -- creating information *and* transmitting it -- but I find myself drawn to it more for aesthetic and emotional reasons, than strictly logical ones. I like raising a student from one level of understanding to a higher level. I like seeing the satisfaction on the students' faces that comes from them finally having understood something profound. I like polishing the presentation of a concept until it shines with clarity and lights up the intuition. I enjoy the contact with young people, old people, students of all ages (I count myself among the latter). This past year, for instance, my best undergraduate student (Judith Freedman) turned 84!

Physics is a way of thinking, not a particular set of facts or formulae, or even methods. This is the emphasis in all of my physics teaching. I try to impart the manner of thinking that is the hallmark of physics, hoping that this leads to an appreciation and striving for depth. (Of course, to do this, I must use the methods, formulae and facts.) All told, I have been teaching physics at both undergraduate and graduate levels for about 6 years, first at the University of Arizona, and now in Boston. Before this, as a graduate student, of course, I TAed, and at the University of Chicago, Profs. Kadanoff and Sally gave me full responsibility for a series of wonderful summer mathematics courses. I have had many marvelous educational experiences with the undergraduate students at all of these schools, and have been gratified by their desire to learn and to raise themselves higher on the tree of knowledge.

I like to solve problems in my classes, and I approach the business of teaching as a problem solver. I am not afraid to try new approaches, even in the most traditional courses, but I've found, mostly through trial and error (mostly error) that my most effective teaching episodes followed neither a new paradigm, nor a purely traditional lecture format, but rather an approach where something novel was added to a well-established foundation. A recurring problem that I encounter among under-graduates, both majors and non-majors, is that their level of preparation, i.e. what they bring to the first day of class, is shockingly low. Correcting this, or, in many cases, working with it, has been a major concern in my problem-solving view of teaching. To deal with this problem at UMass, I have tried new strategies that I'd not had the opportunity to fully explore in my previous teaching at the University of Chicago, and the University of Arizona. For example, in introductory astronomy and planetary astronomy, which are large, general-education courses, I implemented group projects that require, in addition to out-of-class research and reading, significant web-based and presentation skills. I also try to bring cutting-edge research to the classroom, as I feel it is essential for the students' education. In these astronomy courses, I invited guest lecturers, who I knew to be good expositors, speak about their current research. And I changed the curriculum to add a large unit on Astrobiology. This latter was a great hit with the students, and has inspired me to design an entire general education course (so far, untaught) called "Life in the Universe". I have also designed (and will teach next semester) a course called "Intro to Computational Science" which is a MATLAB-based introduction to scientific computing and simulation, accessible to all sophomore-level science majors who have had two semesters of calculus and introductory physics. In my junior-level E&M course, I incorporated the study of some original papers of Maxwell, as a way to see how physicists used analogy (and still do), and to see beyond the sanitization that many physics textbooks have performed on physics. The remarkable flipside of all this, is that the challenge of explaining deep and hard concepts at the undergraduate level can lead to different perspectives on classical subjects, and often getting a new view on an old problem is the hardest single thing in research.

In some freshman-level introductory physics courses, I have implemented the peer instruction ideas promoted by P. Mazur (Harvard). These stress conceptual questions and concept tests -- specially designed questions with peer-interactive periods that cut to the core of students' understanding of physics at the deep level of concepts. I don't see these methods as panaceas, but the experience has been valuable for me, and the evaluations indicate that the peer methods are appealing to the students as well. Two other features that I have tried in my undergraduate classes are "quizwork" and "course corrections".

Quizwork -- In addition to required readings, and homework problems that arose naturally from the lectures, I set aside many class hours for miniquizzes. I would sometimes give multiple quizzes a week and at unannounced times, averaging more than 10 per semester, typically. I know from my evaluations that some of the students dreaded this for the first few weeks. One even said that, until my course, he thought the pop quiz was a urban legend -- a story to frighten freshmen. But by being so relentless in my onslaught of quizzes, they came to expect a miniquiz in every class, and this led to a higher level of preparation and facility on their part. Although the time spent on miniquizzes *per class* was not much, the net effect over an entire semester meant leaving out some material. Hence, this led to covering less material, but covering it in greater depth.

Course corrections -- Some level of frustration is part of learning, but I've tried to eliminate some of the anxiety from test-taking. I offer a sort of voucher system: during the test, a student may use the voucher to consult with me about one of the problems, and I will frankly evaluate their path, and, if appropriate, offer a course correction on that particular problem. The course correction extends to some degree the concept of the open atmosphere of exchange that I expect in the classroom, and it reinforces my role as a partner in their education, not just their taskmaster.

In addition to traditional graduate courses, I have taught some graduate courses (particularly at the University of Arizona) that were elaborations of my research, and I developed two new courses at this level, ``Nonlinear methods for dynamics and flow" and ``Scaling and renormalization", in that area. One goal that I have *not* been able to fulfil presently is to teach an undergraduate biological physics course from Phil Nelson's excellent new text. In my department, we are simply too short-staffed, and such a course is considered a luxury. This is unfortunate, as my own research problems are often simple enough to explain to undergraduate students, even high-school students, yet intriguing enough to capture their interest. Here, oddly, all of my best students here have been undergraduates, and I am excited by the prospect of involving more undergraduates in my research program.

Of course, I am still learning how to teach. I think that I'm a very good teacher, and that I have the potential to be much better still. And I certainly consider myself fortunate, in that I have been given the opportunity, many times over, to teach serious students.