General Course Information:

BIOL GU4075 BIOLOGY AT PHYSICAL EXTREMES (Spring 2023)

Instructor Information:

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Professor

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Textbooks for purchase:

None

Prerequisites

1 year each of biology and physics, or permission of the instructor.

Course Objectives

This is a combined lecture/seminar course designed for graduate students and advanced undergraduates. The course will cover a series of cases where biological systems take advantage of physical phenomena in counter intuitive and surprising ways to accomplish their functions. In each of these cases, we will discuss different physical mechanisms at work. We will limit our discussions to simple, qualitative arguments. We will also discuss experimental methods enabling the study of these biological systems. Overall, the course will expose students to a wide range of physical concepts involved in biological processes.

Method of Instruction

In each class, students will present and discuss selected papers for each topic. At the end of the discussions, the instructor will present a lecture to introduce the concepts of the following week's topic.

Method of Evaluation

Students must read assigned paper (2-3/week) prior to class and be prepared for discussions. Students will present papers assigned to them and lead discussions. Assessment will be based on class participation (40%) and two presentations (60%).

Students are expected to attend all classes. Inform the instructor in advance, if you are unable to attend a particular class.

Statement on Academic Integrity

Students are expected to meet academic integrity standards and practices outlined in Columbia University undergraduate guide in academic integrity (http://www.college.columbia.edu/academics/integrity):

"In practical terms, this means that, as students, you must be responsible for the full citations of others' ideas in all of your research papers and projects; you must be scrupulously honest when taking your examinations; you must always submit your own work and not that of another student, scholar, or internet agent.

Any breach of this intellectual responsibility is a breach of faith with the rest of our academic community. It undermines our shared intellectual culture, and it cannot be tolerated. Students failing to meet these responsibilities should anticipate being asked to leave Columbia."

Topics to be covered this semester:

Jan 19, 2023	Introduction to the course and a short lecture on mechanical measurements
Jan 26, 2023	Experimental methods for nanoscale and single-molecule mechanical measurements. Dufréne, Y.F. et al., "Imaging modes of atomic force microscopy for application in molecular and cell biology" Nature Nanotechnology **12**: 295-307. Neuman, K. C. and A. Nagy (2008). "Single-molecule force spectroscopy: optical tweezers, magnetic tweezers and atomic force microscopy." Nature Methods **5**(6): 491-505.
Feb 2, 2023	Force meets function: how can structural failure of molecules be useful? Ivanov, I. E. et al., (2020) "Cas9 interrogates DNA in discrete steps modulated by mismatches and supercoiling" Proc. Natl. Acad. Sci. **117**(11): 5853-5860. del Rio, A., R. Perez-Jimenez, et al. (2009). "Stretching single talin rod molecules activates vinculin binding." Science **323**(5914): 638-641. Buckley, C. et al., (2014) "The minimal cadherin-catenin complex binds to actin filaments under force" Science **346**: 1254211
Feb 9, 2023	Mechanical life of cells Moeendarbary, E., L. Valon, et al. (2013). "The cytoplasm of living cells behaves as a poroelastic material." Nature materials. Advance online publication doi:10.1038/nmat3517 Stewart, M. P., J. Helenius, et al. (2011). "Hydrostatic pressure and the actomyosin cortex drive mitotic cell rounding." Nature **469**(7329): 226-230. Ucar, H., Watanabe, S., Noguchi, J. *et al.* "Mechanical actions of dendritic-spine enlargement on presynaptic exocytosis." *Nature* **600**, 686–689 (2021).
Feb 16, 2023	Traction and contraction: force determines fate Du Roure, O., A. Saez, et al. (2005). "Force mapping in epithelial cell migration." Proc. Natl. Acad. Sci. **102**(7): 2390-2395. Lam, W. A., O. Chaudhuri, et al. (2010). "Mechanics and contraction dynamics of single platelets and implications for clot stiffening." Nature materials **10**(1): 61-66

	Yang, B., Wolfenson, H., Chung, V.Y. et al. “Stopping transformed cancer cell growth by rigidity sensing.” Nat. Mater. **19**, 239–250 (2020).
Feb 23, 2023	Electro-mechanical and opto-mechanical coupling in living cells Zhang, P. C., A. M. Keleshian, et al. (2001). "Voltage-induced membrane movement." Nature **413**(6854): 428-432. Breneman, K. D., W. E. Brownell, et al. (2009). "Hair cell bundles: flexoelectric motors of the inner ear." PLoS One **4**(4): e5201. Hardie, R. C. and K. Franze (2012). "Photomechanical Responses in Drosophila Photoreceptors." Science **338**(6104): 260-263.
Mar 2, 2023	Mysterious mechanics of cell membranes Houk, A. R. et al., (2012) “Membrane Tension Maintains Cell Polarity by Confining Signals to the Leading Edge during Neutrophil Migration” Cell **148**, 175–188 Shi Z. et al., (2018) “Cell Membranes Resist Flow” Cell **175**, 1–11
Mar 9, 2023	Physics of viruses Alsteens *et al*., “Nanomechanical mapping of first binding steps of a virus to animal cells” *Nature Nanotechnology* **12**, 177-183 (2017) Liu et al., “A Viral Packaging Motor Varies Its DNA Rotation and Step Size to Preserve Subunit Coordination as the Capsid Fills” Cell **157**, 702-713, (2014)
Mar 16, 2023	More than a fluid: how water animates living matter Hacke, U. G., J. S. Sperry, et al. (2001). "Trends in wood density and structure are linked to prevention of xylem implosion by negative pressure." Oecologia **126**(4): 457-461. Elbaum, R. et al., “The Role of Wheat Awns in the Seed Dispersal Unit” Science **316**, 884-886 (2007) Harrington, M.J., et al. (2011). “Origami-like unfolding of hydro-actuated ice plant seed capsules” Nature Communications 2:337
Mar 23, 2023	Spring recess
Mar 30, 2021	Extreme biomaterials Buehler, M. J. and Y. C. Yung (2009). "Deformation and failure of protein materials in physiologically extreme conditions and disease." Nature materials **8**(3): 175-188. Agnarsson, I., A. Dhinojwala, et al. (2009). "Spider silk as a novel high-performance biomimetic muscle driven by humidity." Journal of Experimental Biology **212**(13): 1990-1994. Zheng, Y., H. Bai, et al. (2010). "Directional water collection on wetted spider silk." Nature **463**(7281): 640-643.
Apr 6, 2023	To adhere or not to adhere: How geometry and physics help Geckos? Geim, A., S. V. D. I. V. Grigorieva, et al. (2003). "Microfabricated adhesive mimicking gecko foot-hair." Nature materials **2**(7): 461-463.

	Bhushan, B. (2012). "Bioinspired structured surfaces." Langmuir **28**(3): 1698-1714. Bixler, G. D. and B. Bhushan (2012). "Bioinspired rice leaf and butterfly wing surface structures combining shark skin and lotus effects." Soft Matter. **8**, 11271-11284
Apr 13, 2023	Watching dynamic biomolecular processes Shibata, M., H. Yamashita, et al. (2010). "High-speed atomic force microscopy shows dynamic molecular processes in photoactivated bacteriorhodopsin." Nature nanotechnology **5**(3): 208-212. Uchihashi, T., R. Iino, et al. (2011). "High-speed atomic force microscopy reveals rotary catalysis of rotorless F1-ATPase." Science **333**(6043): 755-758. Kodera, N., D. Yamamoto, et al. (2010). "Video imaging of walking myosin V by high-speed atomic force microscopy." Nature **468**(7320): 72-76. Igarashi, K., T. Uchihashi, et al. (2011). "Traffic jams reduce hydrolytic efficiency of cellulase on cellulose surface." Science **333**(6047): 1279-1282.
Apr 20, 2023	Technology: Folding DNA into complex shapes Rothemund, P. W. K. (2006). "Folding DNA to create nanoscale shapes and patterns." Nature **440**(7082): 297-302. Andersen, E. S., M. Dong, et al. (2009). "Self-assembly of a nanoscale DNA box with a controllable lid." Nature **459**(7243): 73-76. Wei, B., M. Dai, et al. (2012). "Complex shapes self-assembled from single-stranded DNA tiles." Nature **485**(7400): 623-626.
Apr 27 2023	Phase separation in biology C. P. Brangwynne et al., Germline P granules are liquid droplets that localize by controlled dissolution/condensation. Science **324**, 1729–1732 (2009).