

# American Physical Society New England Section Newsletter

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Fall 2013

## Co-editors

- Edward Deveney
- Peter K. LeMaire

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**FALL 2013 APS-NES MEETING**  
**Bridgewater State University, New Sciences and Mathematics**  
**Complex, Bridgewater MA**  
**Friday and Saturday, October 11 & 12, 2013**

## Theme: Biophysics and Optics

The plenary sessions will focus on Biophysics, in particular optical and nano techniques used in cutting-edge biology and chemistry research, as well as Optics; Optics in Industry and in the Advanced labs.

### Invited speakers include:

Ashley Carter (Amherst College)  
 Mark Williams (Northeastern Univ.)  
 Nate Derr (Harvard Medical School)  
 Wang Katherine Miao (Brown University)  
 David Weitz (Harvard Univ.)  
 Tom Kling (Bridgewater State Univ.)

For registration, travel and lodging information, and an up-to-date conference schedule, and workshop information, please visit the meeting website at <http://www1.bridgew.edu/NESAPS/>

For questions please send email to Edward Deveney ([edeveney@bridgew.edu](mailto:edeveney@bridgew.edu))

## From the organizers of the spring (cancelled) and fall 2013 NES APS meetings

We, the organizers of the canceled spring meeting and this fall's coming meeting, look forward to an exciting fall meeting at the very best time of the year in New England with all its sweater-time temperatures and wonderful fall colors. At the same time, we take this moment to reflect on the unfortunate events and timing that led to the cancellation of our April 19<sup>th</sup> and 20<sup>th</sup> meeting and thank everyone for their patience and understanding.

By week's end of the Monday 2013 Boston Marathon tragedy the situation nearby in Boston remained complicated, confusing and frightening. That Friday, April 19<sup>th</sup>, was also the 1<sup>st</sup> day of our NES APS meeting. Due to our proximity to Boston as well as events locally on our own campus and nearby related campuses, we made the difficult decision to cancel the meeting roughly two hours before doors opened for registration and welcoming.

We did not make this decision lightly. We had hoped to be able to carry on, but three of five of our afternoon and evening speakers were in the Boston area and the unfolding events made it difficult or impossible for them to travel to BSU. Similarly, vendors were unable to pick up equipment in Boston, and of course, APS and AAPT members look-

ing forward to the meeting faced uncertain travel issues out of the city and the immediate surrounding areas. This was bad enough, but events at other Massachusetts State Universities tied to the situation in Boston were also unfolding at the same time. To add to our difficulties, at approximately 9.30 AM on Friday morning, we had a serious situation right here on campus that required a bomb squad to come in. All the appropriate precautions were taken, resulting in bright police and fire department lights and concerned students standing outside of dorms and buildings. To our relief, this local situation turned out to be a false alarm but coupled with Boston events, the timing could not have been worse. As the host institution of the meeting the safety and wellbeing of our community and guests was of utmost concern and top priority. We received word from our President's Office shortly before 10 AM – they advised us to cancel the meeting and so we did.

We made our best attempts to update the conference web site and then make phone calls to all those who registered and whose phone contact numbers we had through the registration. We did not cross reference this list with presenters who did not regis-

ter. This process was handled by five people here in physics and we did the best we could given the truly unprecedented situation. We, even at the time just two hours before the start of the conference, understood and we appreciated any and all complications and hardships that the cancellation would likely cause, and perhaps ultimately did cause, and so we thank you for your understanding and patience.

But now as the fall BSU NES APS meeting now rapidly approaches and with spectacularly colorful leaves floating by and crunching under the feet of runners already in training for next April's Marathon, we look forward to seeing you here and having a great, and Boston Strong, Biophysics and Optics weekend here at Bridgewater.

**Author:**  
**Ed Deveney,**  
**on behalf of Organizing Committee**

**Do you have interesting Physics related articles, new programs, research report, physics talking points etc. that you will like to share with the New England Physics Community?**

**Send them to the co-editors:**

**Ed Deveney (edeveney@bridgew.edu), Peter LeMaire (lemaire@ccsu.edu)**

## BioPhysics at UConn: Protein-Based Biophotonic Devices

When I was asked to write an article about our research in bioelectronics for the Newsletter, I welcomed the opportunity. My research group makes three different types of protein-based devices: optical memories, photovoltaic solar energy converters, and artificial retinas. All of these devices are based on the light-activated protein, bacteriorhodopsin (BR). Although the native protein has excellent stability and photochemical efficiency, optimization of the photochemical properties of the protein is necessary for the successful implementation in devices. A majority of our research during the past decade has focused on optimization of the protein, rather than optimization of the design. We spent much of the 1980's and 1990's developing the device architectures to take advantage of the capabilities of this remarkable protein (for an overview, see Ref. (1)), however, optoelectronic design alone proved to be insufficient. What remained was to enhance the performance of the protein for use in these non-native environments. I will start this discussion with an overview of the protein, BR, and discuss optimization of the protein through techniques in genetic engineering. At the end, I will examine how these new mutants enhance our devices and open up new opportunities to explore.

**Bacteriorhodopsin (BR)** has been on the earth for roughly 3.5 billion years. It is isolated from an *archaeal* halophile called *Halobacterium salinarum*, an organism that populates salt flats throughout the world. Because of the extreme conditions and lack of oxygen in these salt flats, *H. salinarum* expresses the photosynthetic membrane protein, BR. Bacteriorhodopsin functions to pump protons from the intracellular to extracellular milieu of the protein upon the absorption of light. The proton gradient formed is used by ATPase as an alternative source of energy.

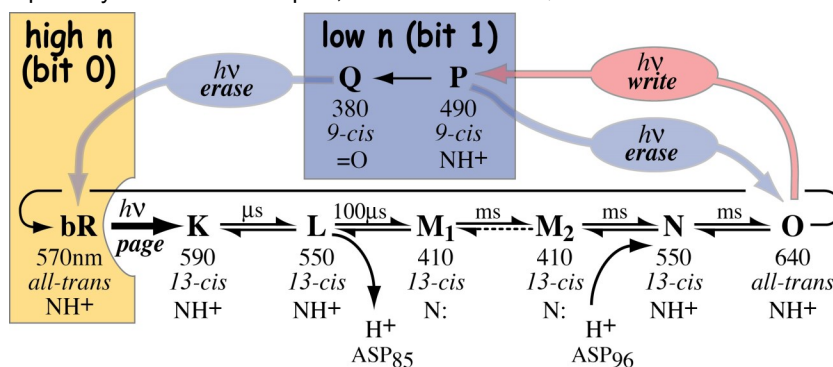
The fact that this organism can switch between energy sources as needed contributed to its long-term success in the biosphere. This capability also makes it possible to optimize the protein inside the native organism. Indeed, there are strains of *H. salinarum* that express the protein even under conditions when the protein is not needed as a source of energy. These strains are known as "overproducers", and they make prodigious amounts of the protein so long as there is oxygen, light and nutrients. We can mutate and express the protein in these overproducers even when the mutant protein does not pump protons. Because many devices rely on non-biologically relevant properties of the protein, this flexibility is critical.

After the chromophore, all-*trans* retinal, absorbs light, the protein undergoes a photocycle that will pump a proton from the intracellular to extracellular milieu. The photocycle is rather complex, and is



Dr. Nicole Wagner in front of the automated irradiation system that is used to photochemically convert the protein from the resting state (bR) to the Q state and measure the efficiency of the process.

it is the only photochemical event and a proton is pumped during the L to M<sub>1</sub> transition. The protein cycles back to the resting state in about 10 ms and is ready to pump another proton. In the optical memories, data are written when the



**Figure 1.** The photocycle of BR is shown along with the branched photocycle that generates the P and Q intermediates. The protein can be used for both volumetric and holographic memory. In either case, bit 1 is represented by the Q state, a long-lived intermediate that lasts for about 7 years at ambient temperature (see Ref. (2) for details).

shown schematically in Figure 1.

The photocycle is shown in Figure 1 using labels primarily intended for device application. Initiating the primary event is called *paging*. In the native organism,

longest lived intermediate, the O state, absorbs a red photon of light to transfer the protein into the branched photocycle. This event forms the P state, which spontaneously decays to form the Q state. The Q state is a unique photo-

## BioPhysics at UConn: Protein-Based Biophotonic Devices

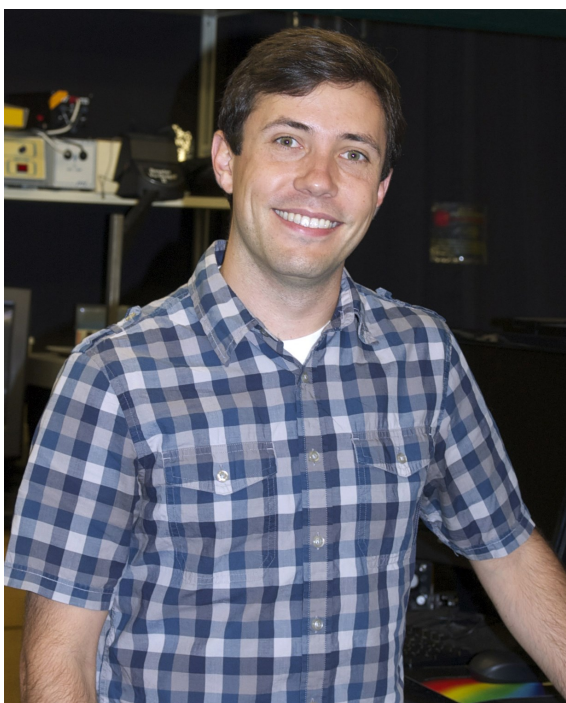
intermediate because it lasts for approximately seven years at room temperature. It is the branching photocycle capability that makes BR so useful for protein-based memories.

It should be noted that there are other significant advantages of using this protein for device applications. First, the protein is extremely stable and can withstand high fluctuations of light and temperature. Nature designed BR to operate in a salt marsh organism that must survive in these extremes, and nature solved the problem by creating a protein with high thermal and photochemical stability. The protein is grown in a semicrystalline lattice of trimers known as the purple membrane. All of our devices use the purple membrane, rather than protein monomers, because the lattice and native lipid environment provides stability. Thin films of the purple membrane can withstand temperatures as high as 180°C and intense laser pulses without denaturation. Hence, it is important that any optimization of the protein be carried out inside the native organism (or inside a genetically modified overproducer) so that the purple membrane is formed.

**Protein optimization** is necessary because the native organism does not gain comparative advantages from making a protein that is suited for devices. Only some of the characteristics of BR that are important to devices were promoted through natural selection. The branched photocycle that we use to store data is minimized in the native organism because formation of the **Q** state stops the pumping of protons. Thus, the protein is no longer biologically useful to provide energy for the native organism. Many of our volumetric and holographic memories and devices make use of the **Q** state, and thus we needed to find a chemical or genetic method of in-

creasing the yield of this photoproduct. Although Russian scientists had early success with chemical modifications of BR for holographic applications, we decided that a mutational strategy was the best approach based on the success of German researchers in optimizing BR (3).

**Directed Evolution** has long been known as a powerful method for optimizing proteins. In Type II directed evolution, the properties of the protein can be measured inside the organism.



**Jordan Greco in the laser lab where the protein memories are tested. He is a graduate student in physical chemistry at UConn.**

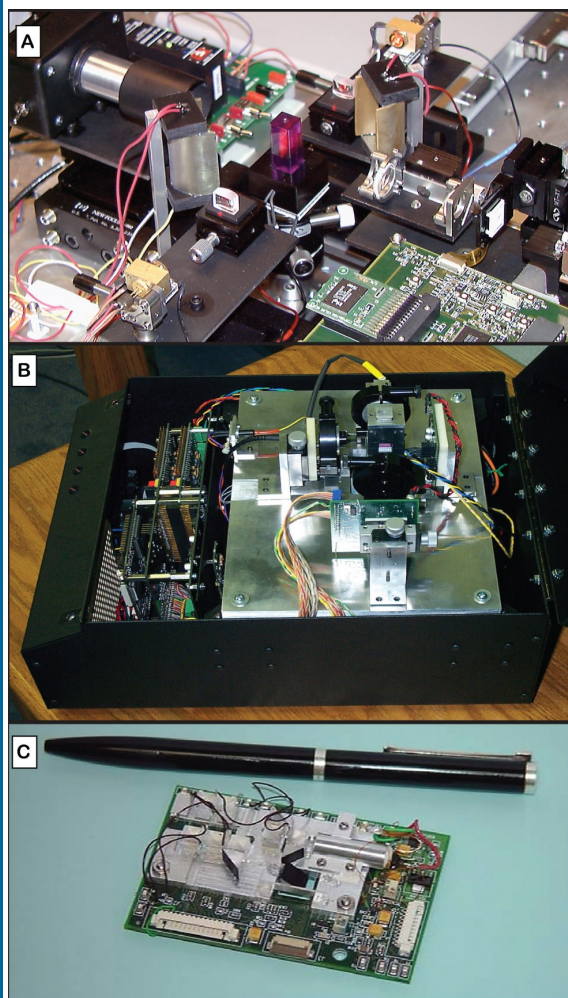
This requirement could not be met in our studies because we needed to optimize the protein for a photochemical process that could only be monitored with isolated protein. Furthermore, pH was an important variable, and the organism was quite unresponsive to internal pH manipulation. Thus, we had to isolate the protein to fully characterize it. Our mutational approach, called Type I directed evolution, is less efficient than Type II directed evolution, but we circumvented

the time and cost associated with the process by developing screening tools and automating as much of the process as possible. This effort was led by Nicole Wagner, a postdoctoral fellow in molecular and cell biology. Her recent paper in *Royal Society Interface* (4) provides the details of our methods and procedures.

The goal of the optimization process was to improve the efficiency of the branching reaction, as well as the back reaction that converts the **Q** state to the resting state (**bR**). We optimized these reactions via six stages of directed evolution. After six stages of directed evolution we yielded a quadruple mutation, V49A/I119T/T121S/A126T, which has outstanding characteristics. This protein operates with an efficiency between 62 and 3800 greater than the native protein depending upon applications. We are currently studying this mutation in more detail to understand the structure-function relationships that yield the excellent performance. With this protein, we can write data into protein cuvettes using 3 mW lasers instead of the 100 mW lasers that were used previously. We can also explore new architectures for associative holographic memories that mimic the way the human brain stores information (2).

The holographic memories use Fourier optical association to match an input image (or redundant binary representation) to a series of pages that contain possible matching data. The page providing the best match is returned, and because the process is optical, large databases can be searched quickly. The associative process is important to the development of artificial intelligence because an important component of human intelligence is creative association. By manipulating thresholding, creativity versus rigor can be explored. These memories can be made using photochromic polymers or genetically optimized BR. The recent mutants that we have developed provide comparative advantages in terms of writing speed, which is the bottleneck limiting the utilization of these memories.

## BioPhysics at UConn: Protein-Based Biophotonic Devices

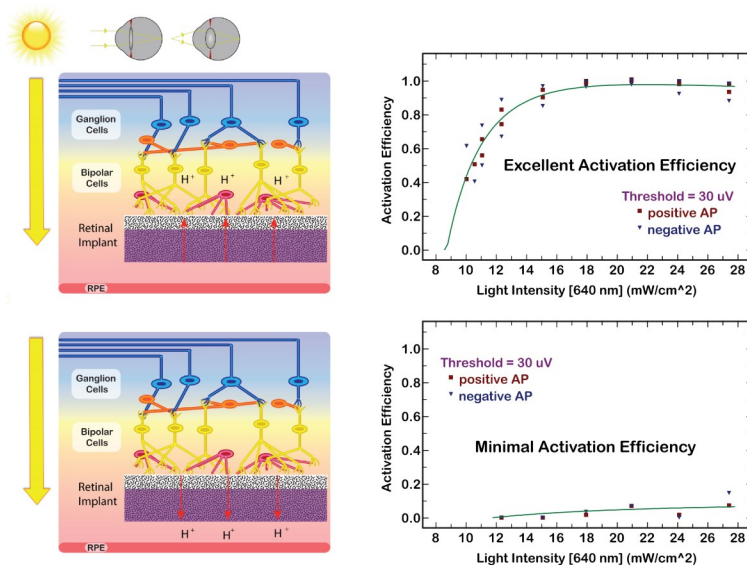


**Figure 2.** Three versions of the sequential two-photon volumetric memory in the form of the original prototype, based on WT BR (A), as built for the Air Force (B), and a miniature prototype made by Starzent Corporation (C). The memory shown in B won the Connecticut Innovations Award for 2009, and uses an early mutant, F208N. The Starzent memory has no moving parts and can use either V49A/I119T/T121S/A126T for read/write versions or commercial photochromic polymers for write once/read many applications.

The volumetric memories use 3 cm<sup>3</sup> plastic cuvettes containing the protein held in a clear, rigid polymer matrix. During the writing process a paging beam is used to activate the photocycle in a thin slice of the memory medium, and after 2 ms, data are written orthogonal to the page beam by using a red laser to photochemically convert the O state into the P state, which then spontaneously relaxes to form the Q state. Because the P to Q transition takes a few seconds, the memories are

designed to treat both the P and Q states as bit 1. The entire page is read by paging and imaging the page onto a charge-coupled device (CCD) detector using a weak red laser beam. More light passes through written data because the P and Q states do not absorb red light, while the O state (formed during the photocycle of the un-switched protein) strongly absorbs red light. Protein that is not probed within the paged region does not photocycle and does not participate in the reading or writing processes. Low read beam intensities minimize damage to the data, however, some damage does occur during a read cycle and after 20 or so reads, the page must be rewritten to enhance reliability (1). Figure 2 shows the evolution of protein volumetric memories that were made possible through protein optimization. We do not have enough space to describe these memories in detail, but all of the designs have been published (Refs. (1), (2) and references therein).

**An artificial retina** based on BR is also under development. The high-resolution, subretinal implant under development uses the retinal-containing protein, bacteriorhodopsin (BR), to convert light into a pH gradient. This gradient is capable of activating the neural circuitry of the retina, specifically the bipolar and ganglion cells. Bacteriorhodopsin has a quantum efficiency nearly identical to rhodopsin, the protein in the rod outer segments of the eye. The high thermal and photochemical stability of BR make it an excellent candidate for use as the photoactive medium in a protein-based retinal implant. The subretinal implant will operate by using a local pH gradient to activate the neural circuitry of the retina by decreasing the pH in the milieu surrounding the remaining neural cells. Preliminary *ex vivo* extracellular recording



**Figure 3.** Performance of our multilayered BR-based implant with respect to the activation of the bipolar and ganglion cells of a rat model of retinitis pigmentosa (P23H line 1 homozygous rat retina). When the implant lowers the pH of the milieu around the neural cells, signals are observed. When the retinal implant is oriented so that it makes the region more basic, virtually no signals are observed.

## BioPhysics at UConn: Protein-Based Biophotonic Devices

experiments have demonstrated that the retinal implant is capable of reproducibly stimulating the neural circuitry of a diseased model of RP using light intensities comparable to indoor ambient light. Because the implant can be activated by incident light it does not require any external apparatus or wires, an advantage over competing electrode-based technologies. Additionally, because of the unique photocycle of BR, the retinal implant under development has the ability to mediate pixels using the **Q** state of the protein. By manipulating the photochemistry of the protein, we have developed an implant which can the pixel density can be calibrated based on the **Q** state of the protein.

**Acknowledgements.** We thank Dr. Tim Harvey for providing us with a picture of the Starzent memory (Figure 2), and Drs. Ralph Jensen, Matthew Ranaghan, Megan Sandberg and Daniel Sandberg for contributions to the artificial retina project. The recent work in the Birge laboratory was funded in part by the NIH (GM-34548), NSF (EMT-0829916, EIA-0129731) and the Harold S. Schwenk Sr. Distinguished Chair in chemistry at the University of Connecticut.

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### Author:

Robert R. Birge,  
Departments of Chemistry, Physics and  
Molecular and Cell Biology, University  
of Connecticut

## NES APS special topics section: Advanced Lab Spot Light.

Welcome to the 1<sup>st</sup> special topics section, the Advanced Lab Spot Light (ALSL – why not?). In this section of the Newsletter an advanced lab (sometimes loosely defined as upper-division labs or labs that are ‘Beyond First Year, BFY’) will be given the spot light. In subsequent issues, we hope to have NES APS and NES AAPT contributors join in the action by sending their own advanced/BFY lab ideas and we will highlight one of those in each NES APS Newsletter. If these ideas do not come in on their own, the editors will find you and your labs and bother you for a contribution! The idea for the ALSL section is to give faculty/staff and students who build new or recreate already established advanced labs a forum to share their experiences, note resources and establish local contacts with the chance of running into each other, or maybe even seeing the actual lab in action, at a NES meeting. All this adds up to the healthy practice of dissemination of successful labs, practices, resources and ideas and to fortify

social and professional ties between those working on advanced labs. The ultimate goal just described is in fact the central theme of at least two well-known and established organizations who take on this mission at the National Level; AAPT’s Advanced Labs Archive as well as the ALPhA organization. As part of our inaugural ALSL we’ll take a moment to identify and cite web resources for the AAPT Advanced Lab and ALPhA organizations - we’ll also acknowledge a fantastic ALPhA Immersions Lab program that I took part in this past summer at Cal-Tech - before moving on the 1<sup>st</sup> ALSL which is an Optical Trap that was built at Bridgewater State University based on a design in an *American Journal of Physics* (AJP) paper.

Let’s start with the Advanced Labs Archive which is produced by the American Association of Physics Teachers and part of ComPADRE. Here is the web site and a brief description for the site:

AAPT Advanced Labs: <http://advlabs.aapt.org/>

“Advanced Labs intends to provide a central, comprehensive information base for college/university faculty who teach upper-level

undergraduate laboratories. These include, but are not limited to, labs in electronics, condensed matter, optics, atomic physics, mechanics, and the like -- and also researched-based, independent-study labs. Accepted resources will be available by browsing or searching the collection by content topic or resource type. “Further, “Advanced Labs is produced by the American Association of Physics Teachers (AAPT). It is a part of ComPADRE, the online collection of resources in physics and astronomy education, which itself is a part of the National Science Foundation-funded National Science Digital Library (NSDL).”

So let’s introduce ComPADRE, which is a digital library with tons of resources for us:

<http://www.compadre.org/>

Here is how ComPADRE is described on its web site:

“ComPADRE is filling a stewardship role within the National Science Digital Library for the educational resources used by broad communities in physics

## NES APS special topics section: Advanced Lab Spot Light.

and astronomy. This partnership of the American Association of Physics Teachers (AAPT), the American Astronomical Society (AAS), the American Institute of Physics/Society of Physics Students (AIP/SPS), and the American Physical Society (APS) helps teachers and learners find, and use, high quality resources through collections and services tailored to their specific needs. Many authors and organizations are creating this rich educational content and faculty training opportunities, but wider accessibility and dissemination are needed. Authors are developing simulations, curricula, and multimedia for a wide range of topics and all education levels; science education researchers are developing research-based models of effective teaching and learning; organizations are providing workshops for teachers to improve their knowledge and skills; and students are communicating about learning physics. ComPADRE is supporting these author/user communities through discovery, organization, description, and sharing of their resources to achieve greater effectiveness for physics and astronomy education.”

Now we'll introduce an independent organization that's tremendously active in advanced labs, ALPhA.

ALPhA: <http://www.advlab.org/>  
From ALPhA's web site: “The Advanced Laboratory Physics Association (ALPhA), founded in 2007, is an association of college and university faculty and staff dedicated to advanced experimental physics instruction. ALPhA is independent and separate from the American Association of Physics Teachers (AAPT), the American Physical Society (APS), and the Optical Society of America (OSA), but works with these organizations to advance instruction”

And now I can not only introduce ALPhA's Laboratory Immersion Program but I can also speak from first-hand experience of how truly exceptional and worthwhile this program is.  
ALPhA Immersions: [www.advlab.org/immersions.html](http://www.advlab.org/immersions.html) .  
Citing their web page: “ALPhA's Laboratory Immersion experiences provide participants with two to three days of intensive hands-on work with a single advanced la-

boratory experiment. Enrollment is limited to two to three participants per experimental setup to ensure a confidence-building experience. The Immersion program has been running since 2010 and over that time, 152 participants have learned a wide variety of new experiments to take back to their own institutions. A number of those faculty and instructional staff have taken part in multiple Immersions. Currently, the Immersions program is supported by a grant from the NSF.”

As I mention I took part in an ALPhA immersions program at CalTech this summer and can report back that it was one of the most productive advanced-lab experiences I have ever had. My CalTech hosts were as top-notch as they get and the material that I brought back to me to home place (Bridgewater) was overflowing. My original intentions were to have working experience with a lock-in and bring home lock-in labs that matched 'what they do at CalTech', which I did and we now have at BSU, but I also had the chance to interact with a larger group of exceptional advanced lab people from around the country and learn from them and my Caltech hosts, again, so much more and about so many more experiments and possibilities. I recommend the immersions highly, and note there are many focused topics for you to choose from. They are a very efficient use of your time!

Finally I'd like to note friends who seem to be likewise friends to just about everyone involved in the advanced labs community, and that's Jonathan and Barbara Reichert plus all others in the TeachSpin group. They all champion, promote and bring to action all that 'is advanced labs' and are always at the heart of all that is good and progressive with the advanced labs, such as ALPhA and related activities of the APS FED and AAPT.

TeachSpin: <http://www.teachspin.com/index.html>

Here is how teachSpin describes itself: “**TEACHSPIN is dedicated to the design, development, manufacture, and marketing of apparatus** appropriate for laboratory instruction in physics and engineering. Our goal is to become the

world's premier designer, manufacturer and marketer of **high quality, rugged, reliable, hands-on instruments** that allow any school, no matter what the size or individual expertise of its faculty, to teach a wide variety of classic and modern experiments. All of our apparatus is designed and built by university physicists who have taught in the undergraduate lab and are well aware of the constraints of both student use and student laboratory budgets. Many of the advanced instruments give **research quality data** and lend themselves to **open-ended upper level projects**. Several of our instruments have been built in collaboration with faculty who have used our apparatus and then worked with us to make experiments they had built for their own students available to colleagues world wide.

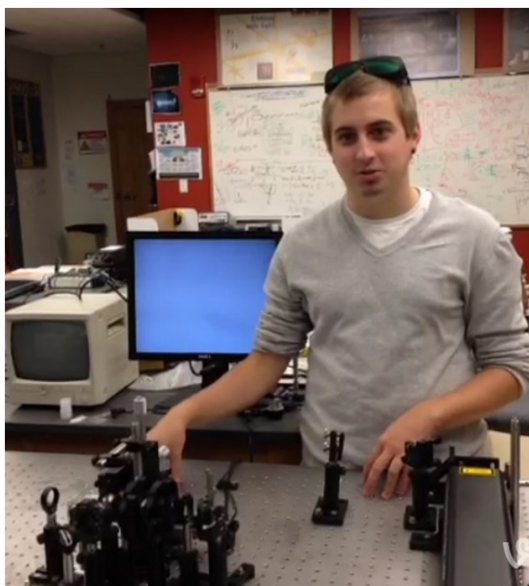
Because they were specifically designed for teaching, these instruments promote conceptual understanding while providing quantitative data that is often of research quality. Although there is “**No Resident Expert Required**,” the experiments are challenging and satisfying for faculty as well as students. We in the physics community are not in the business of training technicians to manipulate equipment. Our mission is to educate physicists so that they will be able to create new instruments to explore new physics. No matter what you call it, **Advanced Physics Lab, Upper Division Lab, Junior/Senior Lab, Modern Lab, Optics Lab or even Great Experiments in Physics**, TeachSpin apparatus offers your faculty and students a wide array of exciting and challenging hands-on physics experiments. “

Having made this introduction to the advanced labs let's move on to the NES APS Newsletter Advanced Lab in the Spot Light (ALSL) with full appreciation of the significant place that the advanced labs and with appreciation for those who keep the experiments working and advancing forward.

<sup>3</sup>AAPT Advanced Labs and ALPhA both are co-sponsors of the BFY Labs Conferences which is, in fact, where the acronym 'BFY' was first introduced. (It is pronounced as “Buffy.”)

**Author:** Edward Deveney, BSU  
Thanks to Gabe Spalding, Illinois Wesleyan Univ. for insightful suggestions

## Advanced Lab in the Spot Light: Bridgewater State University Optical Trap



focused polarized laser to trap, control, and measure the forces on micrometer sized plastic dielectric beads. These plastic beads can then be bonded to biological samples such as DNA and molecular motors, allowing the operator to control the sample's position and to measure the small forces they experience in, for example, a cellular environment. This ability to manipulate and measure molecular-magnitude forces of biological samples has made optical traps an integral part of many advanced biological and biochemical research. Our trap was based entirely on the design of Bechhoefer and Wilson 'Faster, cheaper, safer optical tweezers for the undergraduate laboratory' published in the *American Journal of Physics* (AJP) 2002<sup>1</sup>.

Over the 2013 summer Tyler Holloway (above) with the help of Mark Berube, Sean Costello, and Jared Buckley successfully built an optical trap (laser tweezers) under the supervision of Prof. Ed Deveney in his Laser Lab at Bridgewater State Univ. (BSU). Funding for the project came through a competitive summer research program at BSU called the Adrian Tinsley Summer research program. Professor Deveney's interest in the project also included its potential use as a cross-disciplinary Advanced Lab. As a result of our work, we did come to definitive conclusions on how well and for what types of advanced labs this optical trap would be well suited.

### Introduction

Optical traps use the field gradient of a

The first single-beam optical gradient trap was built by Ashkin in 1986<sup>2</sup>. Since then there have been great advances in designs of optical traps as well as their applications.

The theory behind optical traps has been discussed extensively and in different levels of detail and can be found elsewhere<sup>3-5</sup>. The general working idea of how it all happens is that the trap is formed when the dielectric beads experience an attractive force due to the spatially varying electric field directed toward the area of greatest change (field gradient). A dielectric in a spatially varying electric field of an optical trap feels a force much as magnetic dipoles experiences forces in spatially varying magnetic fields of a Stern-Gerlach device. The spatially changing electric field is supplied by focusing linearly polarized laser light to a small beam waist using a microscope objective.

### Construction and Optical Trap Design and Setup

Construction of the trap was based on the paper 'Faster, cheaper, safer optical tweezers for the undergraduate laboratory' by Bechhoefer and Wilson 2002<sup>1</sup>, the reason obvious in the article's title, with novel modifications we will note. The trap is formed when polarizer laser

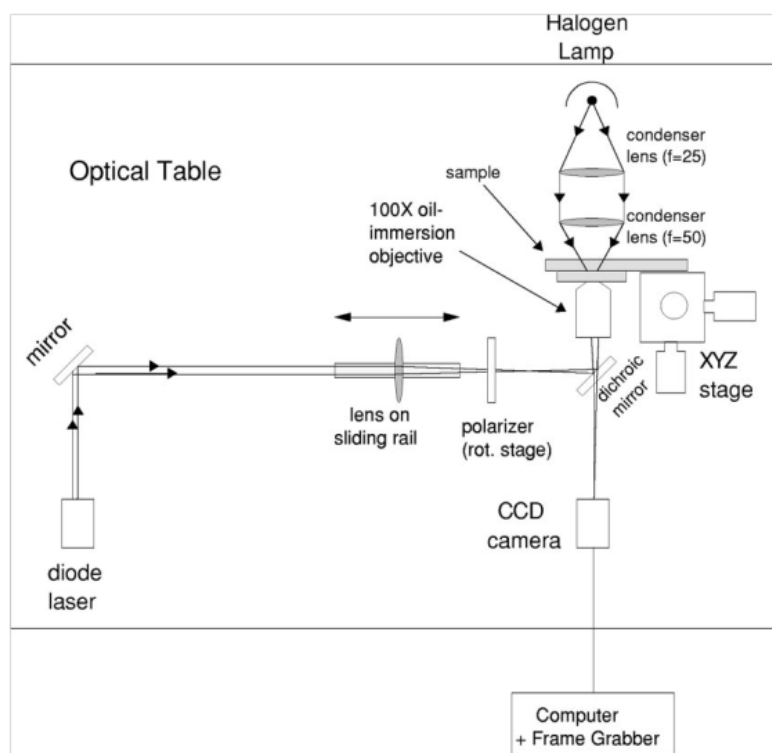


Figure 1. Optical trap and design taken from Bechhoefer and Wilson<sup>1</sup>



## Advanced Lab in the Spot Light: Bridgewater State University Optical Trap

light is tightly focused at an adjustable depth and plane, using translation plates, within the sample and slide. Beads in the sample are pulled into the trap and can be observed using white light that counter propagates the direction of the laser all the way back into a CCD camera and seen on a PC monitor. Construction took about three months due in part to our own learning curve (so perhaps a more experienced optics person might do this far more quickly and efficiently) with a total cost of approximately \$1500 which does not include the cost of the laser, laser table and some optics pieces that were all already in the laser lab (see appendix at end for full costs). Figure 1 is taken from Bechhoefer and Wilson<sup>1</sup> and is the design we followed.

### Microscope

The microscope was of an 'open' design<sup>1</sup>. Specifically we used a 100x DIN Achromatic from Edmund Optics (#43-905, NA=1.25) as our main objective lens which is one of the crucial pieces of the entire optical trap; a high NA is important for establishing the strong gradient in the optical fields that is necessary for optical tweezers. Trapping laser light traveled 'downstream' through the set up while the imaging white light traveled back and 'upstream'.

### Laser

We used a 35mW class 3b, 633 nm, HeNe which was chosen for its ample power and random polarization properties (over diode lasers) and because we had it on the shelf (this would have been significant cost expenditure had we not had it). Great attention was paid to aligning the laser beam using irises separated by 10's of cm, expand by a single lens with a 100mm focal length and through a ThorLabs polarizer placed in a rotational stage. After the polarizer, the laser is reflected off the 1/2" long-pass 638 nm dichroic mirror from Thor Labs which we elected to keep stationary and two mirrors before the beam expander were used to steer the beam. Moving the dichroic mirror, which is at a 45 degree angle, caused part of the image from the objective to get cut off by the mirror mount and meant the CCD would need to be constantly adjusted, so instead it we elected to leave the

mirror fixed. The back aperture of the objective should be slightly over filled to keep the trap strong but not so over filled as to cause a loss of power, this can be controlled by changing the distance to the beam expander. A decent amount of laser light seen making its way through the lens of the microscope objective is a good sign of the back aperture being filled.

### White Light Source

A 35 mW halogen bulb was our white light source. It was placed in a standard aluminum lamp shade with an aluminum cover fashioned over the top. This aluminum cover had a two inch hole cut in the middle to give a more collimated light source and reduce stray light on the CCD. While this modification was very effective, large amounts of heat built up and caused our first halogen lamp to burn out. A pair of two inch 'vent' holes was cut in the top and bottom of the shade and a standard computer fan was powered and placed underneath to keep air flowing over the lamp and successfully increase the lifetime of the bulb. The collimator consisted of a 25mm and 50mm plano convex lenses; alignment of this collimator with the microscope objective is crucial to getting crisp images. The white light cone on the back side of our objective rapidly diverged so a 50mm convex lens was used to focus the light through a 633nm filter (this filtered our 633 nm laser light) in a filter wheel and finally onto a raw CCD (web cam we took apart and removed it's filters) which was then connected to our monitor. We found the addition of the filter was quite useful: With the filter 'in' we had crisp imaging of the trap because laser light reflected back into the CCD was blocked but then when out the reflected laser light was useful for alignment purposes.

### Sample Holder and Sample

For our sample we purchased an optical trap supply kit from Thor Labs which contained: 1 micrometer fused silica beads in deionized water, micropipette, slides with channels, and immersion oil. While we found all of these supplies useful; part way through the project we made our own slides to make more permanent samples. These slides were made by taking plastic microscope slides and cutting a 1/2

inch square out of the middle and gluing a glass cover slip to the underside. The solution with the beads was then added to the chamber and a second glass cover slip was put on top to seal it and make a more permanent sample for testing of the trap itself. The slides are placed in the sample holder, attached to the translation stage, very close to the objective (figure 1). The standard procedure of using a thin film of immersion oil (dripped) maintained between the objective and sample when using the optical trap. The immersion oil has a tendency to slip off due to the vertical setup of this trap therefore a small amount oil should be placed on the sample and the objective moved in to seal the oil in place. The sample holder is connected to a XYZ translational stage constructed from two ThorLabs imperial translational stages and one old translation stage that we had in the lab. The Z component responsible for the distance from the objective (this acts as your focus) to the sample should be able to make very fine adjustments with little slop or the user will likely find the entire process very difficult.

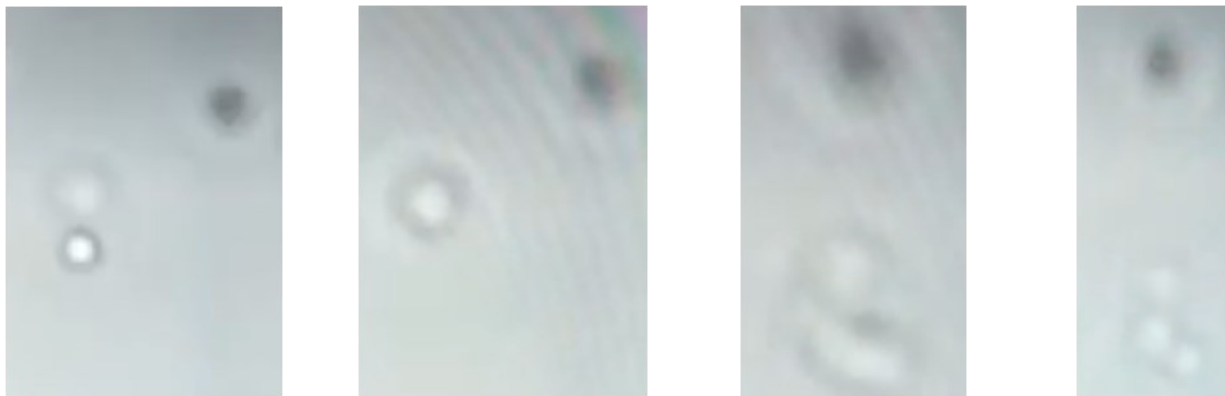
### The optical trap in action

Next page, figure 2, we attempt to show the trap in action: In (a) the trap (slightly blurred circle which is actually already trapped beads slightly defocused as they are pushed slightly deeper into the sample by the radiation pressure of the laser) is seen pulling in its victim dielectric bead (well focused circle in the focus plane). In (b) the bead has been sucked into the trap and pushed like the other trapped beads slightly downstream due to the radiation pressure. In (c) the trap has been turned off: simply block the trapping laser light upstream and all of the trapped beads begin to fall out. In (d) sometime later the beads have fallen downward (again, this is a vertical trap design so the beads experience gravitational acceleration) a bit more.

### Conclusion for the Optical Trap as Advanced Lab in the Spot Light

Our project to build and work an optical trap was clearly a huge success for us and with it we opened the door for lots of potential cross-disciplinary advance lab work with students from chemistry, biolo-

## Advanced Lab in the Spot Light: Bridgewater State University Optical Trap



**Figure 2:** (a) (b) (c) (d)

gy and physics. As far as building a trap like this from scratch as an Advanced Lab we would have to draw two scenario-based conclusions: If the advanced lab course is set up so that students build one or maybe two at the most labs per semester, then then construction from scratch seems reasonable (though maybe difficult). If, however, the course is set up so that in one semester several labs, say three or more are expected to be completed, building this from scratch does not seem realistic. However it would still easily be useful – and a great cross disciplinary lab for sure – if the majority of the apparatus is already set up and students then work to figure out what is going on ‘optically’ and ultimately have to do the alignment, sample preparation and quantify trap parameters (though we have yet to make it to this point) by performing calculations based on actual trap measurements then this

would be a do-able (still tough) advanced lab and worthy of the spot light.

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### Optical Trap Parts List if starting from zero.

633nm 35mW He-Ne- \$7,000 (we did not investigate trapping with cheaper and/or less powerful lasers and different wavelengths—we ‘had’ this laser—potentially then there is chance for cost savings with a more detailed study of laser choice)  
 100x Achromatic Objective- \$100  
 Linear Polarizer+Mount- \$600  
 3-axis micrometer translation stage- \$800  
 1/2" 638nm longpass dichroic mirror- \$120  
 ccd camera- \$100 (web camera we took apart).  
 25mm plano-convex- \$20  
 (2) 50mm plano-convex- \$40  
 100mm plano-convex-\$20  
 (2) Broadband dielectric mirrors + kinematic mounts- \$300  
 780nm longpass colored glass filter-\$55  
 Mounting post + post holders- \$100  
 Halogen bulb + aluminum hood+ cooling fan- \$30  
 Total= \$9300 (not including optics table—we used half of an 4' by 8' active isolation table, \$7500)

**Authors:** Tyler Holloway (BSU '014) and Mentor: Ed Deveney, BSU.  
 Thanks to Gabe Spalding, Illinois Wesleyan Univ. for insightful suggestions

## 15th annual Greater Boston Area Statistical Mechanics meeting

About 70 people are expected to attend the 15th annual Greater Boston Area Statistical Mechanics meeting on Saturday, October 12, 2013 at Brandeis University. The main goal of these meetings is to offer an informal and supportive environment where people from a variety of departments and institutions can meet and exchange ideas. In addition, our goal is to give students and post-docs a venue where they can discuss their work with more senior scientists. The tradition of the meeting is to invite speakers who have recently em-

barked on their independent research careers, speakers who are new to the Boston area, or more senior people whose research deserves greater recognition among people working in statistical mechanics. The invited speakers for this year's meeting:

- Benjamin Davidovitch, UMass Amherst, "Morphological transitions in confined sheets and shells."

- Kirill Korolev, Boston University, "Dynamics of evolutionary innovation in cancer."
- M. Cristina Marchetti, Syracuse University, "Active nematic liquid crystals."
- Shmuel Rubinstein, Harvard University, "Furrows in the wake of propagating d-cones."

Usually there are about 30 contributed talks on topics ranging from molecular motors, clathrate formation, spin glass-

## Science Foundation \$1.45 Million Noyce grant to support future science teachers in the region at Bridgewater State Univ.



**Drs. Nicole Glen and Jeff Williams, Co-PIs for the Noyce grant**

Over the next five years, forty Bridgewater State University (BSU) science majors will be supported by a \$1.45 million National Science Foundation grant received by BSU. Through its Robert Noyce Teacher Scholarship Program, NSF provides funding to institutions for scholarships and programmatic support to recruit and prepare science majors to become K-12 teachers. The Science Teacher Scholars program seeks to increase the number of K-12 teachers with

science content knowledge to teach in high-need school districts. The five-year grant was obtained by Bridgewater in partnership with Massachusetts Community College and four public school districts – Brockton, Fall River, Randolph and Freetown-Lakeville. Scholarships will be awarded to support the final two years of 40 BSU science majors who decide to enroll in an education licensure program. The scholarships

are valued at \$10,000 for each year, fully covering tuition, fees and books for the academic year. Twelve of the scholarships will be specifically for science majors seeking to become elementary education teachers and 28 for secondary education. The program will also fund eight paid summer internships at either BSU or Massachusetts for first and second-year science majors. “As an institution, we are proud to receive another significant grant from the National Science Foundation,” said Dr. Dana Mohler-Faria, president of BSU, “As the largest educator of science and mathematics teachers in the commonwealth, the Science Teacher Scholars program will continue to support a core mission of the university since its founding – to expertly prepare those aspiring to become educators.”

Dr. Jeffrey Williams, professor of physics, and Dr. Nicole Glen, assistant professor of elementary and early childhood education, are the co-principal investigators of the grant.

## 15th annual Greater Boston Area Statistical Mechanics meeting, cont'd

es, to granular matter. This year we plan to try a new format. Instead of three minute talks with a limited time for questions, contributors will give a short announcement of their work. We will then move from the lecture hall to the adjacent room for an extended discussion during which each contributor will sit at a separate table with their laptop or tablet and discuss their work with interested meeting participants. We expect that the “table talks” will remove most of the work and expense associated with posters and provide greater feedback to speakers than is usually obtained by a short talk. The new format will take advantage of the fact that almost all contributors have access to a laptop or tablet and

that the time preparing for a table talk will be about the same as preparing for a short talk.

The meeting is subsidized by the APS Topical Group on Statistical & Nonlinear Physics and by the Department of Physics, Boston University; Materials Research Science and Engineering Center, Brandeis University; Materials Research Science and Engineering Center, Harvard University; Center for Complex Network Research, Northeastern University; and Department of Physics, UMass, Amherst.

The organizers of this fall's meeting are Bulbul Chakraborty, Claudio

Chamon, Harvey Gould, Michael Hagan, Greg Huber, Bill Klein, and Sidney Redner, and David Weitz.

The meeting is open to anyone, including non-members of the APS and undergraduate students. More information about the meeting, including a registration form and titles of the table talks, can be found at [physics.clarku.edu/gbasmm/](http://physics.clarku.edu/gbasmm/). The deadline for registering is Tuesday, October 8. If you miss the deadline, you may still attend the meeting, but the cost will be \$10, and we cannot guarantee that food will be available.

## HUMANITY'S PREDICAMENT: CAN NEW TECHNOLOGIES SAVE US?



**Paul H. Carr**

The burning of fossil fuels has increased the standard of living in developed countries like the US and Europe at the expense of increased global warming. Growing carbon dioxide levels are now 31 per cent higher than in the last million years. Rising temperatures and weather extremes are accompanying them (1). Humanity must limit these increases. Our predicament is that developing countries like China and India are also increasing their fossil fuel burning to enhance their standard of living.

Could the Arab Spring be a precursor to the 2030-crash in the world's food production per capita predicted in MIT's "Limits to Growth?" Published in 1972, its dire predictions from the population explosion, and climate change, and resource depletion have been accurate to date. Can new technologies save us in time?

Syria's 2006 to 2011 drought caused 800,000 farmers to leave their land and move to crowded urban areas. They and the unemployed youth from the population explosion, which started in 1980, are manning the present revolution.

Record-high food prices helped spark the Arab Spring. Egypt must

import grain to feed its exploding population. The severe drought in the summer of 2010 caused Russia, a major grain exporter, to stop shipping grain outside its borders, driving up food prices.

The 2012 drought in the US Midwest was the worst since the Dust Bowl. Half the corn crop was lost resulting in a \$ 20 -\$25 billion loss in crop insurance. Corn-futures prices were the highest in history.

Can new technologies save us? For example, the article "Wild Plants to the Rescue" published in the "American Scientist," May-June 2013 describes research underway to develop perennial wheat. Its deeper roots could withstand severe draught from increased global warming and stabilize the soil erosion that was the source of the Dust Bowl.

The Gates Foundation is investing in birth-control technology. Melinda Gates plans to use the foundation's billions to revolutionize contraception worldwide. The Roman Catholic right is pushing back. Is she ready for the political firestorm ahead? Her Catholic faith, has always informed her work. She has said from the very beginning that we, as a foundation, we will not support abortion.

The Gates Foundation is serving the other piece of the Roman Catholic mission, which is social justice. The Depo-Provera contraceptive is popular in many poor countries because women need to inject it only 4 times a year.

The June 21, 2008 cover article in "The Economist" envisioned an oil-free, non- carbon-emitting transportation sector with electric vehicles charged by wind, solar, and nuclear power plants. Today, electric cars like the Nissan Leaf, Mitsubishi-i, Tesla Model S, and the plug-in hybrid Chevy Volt now get the equivalent of 100 miles per gallon. Hybrids like the Toyota Prius typically get 50 mpg. If Jesus were to return to earth, what car would he drive?

The cost of solar photovoltaic cells has in the last year come down to 10 cents per kWhr, less than what most people can buy from the grid. Companies will install roof-top solar cells at a nominal cost to the homeowner in return for a 20-year contract.

Conservation and efficiency can reduce our use of fossil fuels. Steven Chu, President Obama's former Secretary of Energy, has said that conservation is "sexy" and it can be high tech. The nation's energy secretary has pushed for the next breakthroughs, along with energy efficiency.

The US energy use and per capita carbon emissions are the highest in the world. Our emissions are twice those of Europe and the former Soviet Union. The US energy use is four times that of China and the rest of the world. With 5 per cent of the world's population, the US is using 20% of its oil.

Nature is the capital on which capitalism is based. In the long-term, our world's economy will be constrained by ecology. The world's exponential population explosion cannot continue indefinitely. There are indeed limits to growth.

The environmental challenge is to balance the beauty of nature with its utility. Is beauty "in the eye of the beholder" or an encounter with the Divine? Without divinely created beauty, nature becomes an object that may be ravaged. For example, the tar sands oil fields can be beautiful in the eye of its owner because they are source of black gold. Can we re-envision beauty to transform our relationship with nature in time?

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**Author:**  
**Paul H. Carr, Hanscom MA**

## TRIBUTE TO PROFESSOR EMERITUS WESLEY NYBORG



**Professor Emeritus Wesley Nyborg**

*(Photo courtesy of the National Academy of Engineering (NAE))*

Wesley Nyborg, Physics Professor Emeritus at the University of Vermont, passed away on September 24, 2011 after a full and wonderful life of 94 years. Wesley was born in Ruthven, Iowa in 1917 as the youngest of Isaac Nyborg and Leva Larson's 6 children. Wesley's childhood was spent on a rural farm in a time and place before electricity and cars were widely available. In his youth, he attended a one-room schoolhouse, and greatly enjoyed family sing-a-longs at the piano. After high school, he studied at Luther College where he was introduced to physics, which became his lifelong intellectual pursuit. He earned his Ph.D. from Pennsylvania State University in 1947, and served as an Assistant and Associate Professor of Physics at Brown University prior to joining the UVM Physics Department in 1960.

He loved physics passionately and authored numerous peer reviewed articles and book chapters with a focus on ultra-

sound, particularly its clinical application and biophysical effects. He developed fundamental theories on microstreaming, acoustic radiation pressure and thermal effects of ultrasound, and he was considered as one of most influential pioneers by the international biomedical ultrasound community.

He was of the Acoustical Society of America, the American Institute of Ultrasound in Medicine (AIUM), and the American Association for the Advancement of Sciences. He was also an honorary member of National Council on Radiation Protection and Measurements and served as a consultant to the WHO and FDA. He was presented with many honors and awards including the prestigious Silver Medal of Acoustic Society of America, the Joseph H. Homes Pioneer Award, the W. J. Fry Memorial Lecture Award, and the Lauriston S. Taylor Lecture Award.

He was a venerable, gentle man with a fine sweetness of character and humility. He loved the UVM Physics Department, and worked there more than 50 years. He donated generously to the department, making possible the establishment of a physics colloquium, a new faculty startup fund and a students' summer research scholarship. Wes was also a deeply religious man. He was active in his local Community Lutheran church and the community, and gave freely and generously to many charities. He loved to sing, and was in a barbershop quartet as a young man and in church choirs for many years thereafter.

Wes deeply loved and cherished his wife Beth who died in 1989 after 44 years of marriage. He is survived by his daughter, Elsa Mondou, of Raleigh, North Carolina, four grandchildren, Christine, Michael, Julie, and Martin, and additional family and friends. He was an exceptional man with a profoundly good temperament, whose gift of unconditional love, and qualities of determination and independent spirit will provide inspiration for young scientists for a long time to come.

You may visit the following url for Hal Frost's more complete memorial: [http://www.nap.edu/openbook.php?record\\_id=13338&page=196](http://www.nap.edu/openbook.php?record_id=13338&page=196)

**By**

By Junru Wu and Elsa Mondou

(Submitted by Paul H. Carr)

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Department of Physics  
Univ. of Connecticut Storrs, CT  
winthrop.smith@uconn.edu

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Lowell MA  
partha\_chowdhury@uml.edu

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Department of Physics  
Amherst College  
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Dept of Physics  
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rb@bu.edu

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james\_egan@uml.edu

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Dept. of Physics & Earth Sc.  
Central Connecticut State Uni.  
sharmanim@mail.ccsu.edu

B. Lee Roberts (2012-14)  
Dept. of Physics  
Boston University  
roberts@bu.edu

Shubha Tewari (2012-14)  
Western New England Univ  
shubha.tewari@wne.edu

Mark Peterson (2013-15)  
Mt. Holyoke College  
mpeterso@mtholyoke.edu

Travis Norsen (2013-15)  
Smith College  
tnorsen@smith.edu

### Newsletter Co-editors (2013-16)

(Non-voting members)  
Edward F. Deveney  
Physics Department  
Bridgewater State University  
eeveney@bridgew.edu

Peter K. LeMaire  
Department of Physics & Earth Sc.  
Central Connecticut State Univ.  
lemaire@ccsu.edu

## COMMUNICATING PHYSICS

In recent years, much has been said, analyzed, and discussed about the need to increase the number of students pursuing physics in schools to provide well trained physicists to address current and future economic needs. Much effort is being made by various groups led by the APS, AAPT, and related societies to encourage more students to consider majoring in physics. Over the years, Physics has continued to be the critical piece needed for the growth and development of economies all over the world. In the last several years, due in great part to the economic downturn and other related issues, there has been an increased interest in and emphasis on what is now generally known as STEM (Science, Technology, Engineering and Mathematics) education to restore innovation and development to help stir up economic development. The Federal government and its agencies, State governments, academic institutions, industries, non-profits have all been working toward improvement in STEM education. At the core of these developments is the indispensable role of Physics education.

In addition to technology, the rigorous analytical, thinking and reasoning skills that are acquired through its study, Physics has found application in a host of other non-traditional physics disciplines. The world of finance<sup>1</sup>, from Wall Street to Insurance companies, has sought physicists and others with such analytical skills, known as *quants*, to fill their need for quantitative analysis. The power and role of these physicists and their compatriots has been discussed and written about in books<sup>2</sup>, and in a New York Times article titled *Quants*<sup>3</sup> which describes them as “experts in mathematics, physics and computer science who brought sophisticated quantitative approaches to the world of Wall Street” and defines

a quant as “The nerdy epithet for Wall Street’s analytical alpha dogs”. In medical education and in the study of law, physics majors have consistently outperformed other majors in the medical school entry test, the MCAT, as well as in the law school entrance exams, the LSAT.<sup>4</sup>

Considering the above and the widespread view that physics is a difficult discipline, the physics community has placed quite a bit of emphasis and resources in working to improve the teaching of physics at all levels<sup>5</sup> leading to very respectable growth in students opting to major in physics. At my institution for example, the number of physics majors has grown by 46% over the last five years.

In spite of the widespread role of physicists, and efforts by many physics groups in raising awareness about the role of physics in society, there seems to be a nagging perception of physics as simply an academic pursuit with little practical use. A common question often posed is “what do you do with a physics degree?” Ask an average non-physicist, and indeed a good number of non-physicist scientists about physics and they are much more likely to start referring to space travel, galaxies, black holes and the big bang theory, than the role of physics in technology and the large number of other everyday applications.

For all the initiatives on growing physics to continue to be successful, there is a need to also win the hearts and minds of the large number of students who Earl Barrett<sup>6</sup>, a 40 plus year veteran science teacher, in an opinion piece describes as students who “don’t want easy courses” but “want a relevant, enjoyable experience where good grades and useable future technological skills are attainable”, by communicating a whole lot more about the role physicists in our daily lives. There

is the need, then, to aggressively modify the narrative about physics education to purposefully include the critical role of physicists in medicine<sup>7,8</sup> – MRI, X-rays – robotics, renewable energy<sup>9</sup>, communication technologies such as smart phones, nanotechnology, satellite technology, display technologies, GPS systems, Finance, etc and research and development in general. AIP, APS and AAPT continue their efforts in this area but there is the need for a more concerted effort by physics instructors and guidance counselors at all levels to promote the numerous roles of physicists in our everyday lives.

This emphasis will also bring the well kept secret of the role of physicists to parents, politicians and the general public, leading to more resource support and encouragement of students to study physics. The current economic state and the need for STEM education have created a unique opportunity for physics and we must strike the proverbial iron while it is still hot.

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### Author

Peter K. LeMaire  
Central Connecticut State Univ.