That physics describes the real world is a given for physicists. In spite of tireless efforts by instructors to connect physics to the real world, students walk away from physics courses believing physicists live in a world of their own. Are students clueless about the real world? Or are we perhaps deluding ourselves and misleading our students about the real world?
In recent years, in my group we have been working on various aspects of metamaterials and plasmonic nano-optics. We have introduced and been developing the concept of “metatronics”, i.e. metamaterial-inspired optical nanocircuitry, in which the three fields of “electronics”, “photonics” and “magnetics” can be brought together seamlessly under one umbrella – a paradigm which I call the “Unified Paradigm of Metatronics”. In this novel optical circuitry, the nanostructures with specific values of permittivity and permeability may act as the lumped circuit elements such as nanocapacitors, nanoinductors and nanoresistors. Nonlinearity in metatronics can also provide us with novel nonlinear lumped elements. We have investigated the concept of metatronics through extensive analytical and numerical studies, computer simulations, and recently in a set of experiments at the IR wavelengths. We have shown that nanorods made of low-stressed Si$_3$N$_4$ with properly designed cross sectional dimensions indeed function as lumped circuit elements at the IR wavelengths between 8 to 14 microns. We have been exploring how metamaterials can be exploited to control the flow of photons, analogous to what semiconductors do for electrons, providing the possibility of one-way flow of photons. We are now extending the concept of metatronics to other platforms such as graphene, which is a single atomically thin layer of carbon atoms, with unusual conductivity functions. We study the graphene as a new paradigm for metatronic circuitry and also as a “flatland” platform for IR metamaterials and transformation optics, leading to the concepts of one-atom-thick metamaterials, and one-atom-thick circuit elements and optical devices. I will give an overview of our most recent results in these fields.
Terahertz time-domain spectroscopy is a powerful tool to investigate complex materials broadly defined. This includes artificial electromagnetic composites such as metamaterials, and correlated electron materials where the interplay between microscopic degrees of freedom leads to phenomena such as superconductivity or metal-insulator transitions. I will discuss our recent results in these areas.

Metamaterials are a relatively new type of artificial composite with electromagnetic properties that derive from their sub-wavelength structure. The judicious combination of metamaterials with MEMS technology enables reconfigurable metamaterials where artificial “atoms” reorient within unit cells in response to an external stimulus. This is accomplished by fabricating planar arrays of split ring resonators on bimaterial cantilevers designed to bend out of plane in response to a thermal stimulus. In this way we can control the electric and magnetic response of these metamaterials.

Vanadium dioxide (VO$_2$) exhibits a metal-insulator transition (MIT) at a temperature (340K) that coincides with a structural phase transition. This leads to the “chicken and egg” problem. Is it the structural change or electron correlations that lead to the MIT transition? Uniaxially strained VO$_2$ films have been fabricated to help solve this problem. In unstrained VO$_2$ crystals the insulator to metal transition enables the electrons move freely in three dimensions. Non-contact THz-TDS conductivity measurements of strained samples reveal that the electrons prefer to move in one direction. That is, strain induces a quasi one-dimensional metallic conductivity.

These results reveal the utility of terahertz spectroscopy to investigate complex materials and point the way towards future studies of hybrid composites incorporating metamaterials with quantum-based complex matter. Such multi-scale structures may offer complementary benefits where quantum materials confer additional functionality to artificial electromagnetic composites or, conversely, metamaterials serve as a novel tool to facilitate fundamental studies of the electrodynamic response of complex quantum materials.
Materials Scientists more and more are looking to nature for clues on how to create highly functional surface coatings with exceptional properties. The fog harvesting capabilities of the Namib Desert beetle, the beautiful iridescent colors of the hummingbird, and the super water repellent abilities of the Lotus leaf are but a few examples of the amazing properties developed over many years in the natural world. Nature also makes extensive use of the pH-dependent behavior of weak functional groups such as carboxylic acid and amine functional groups. This presentation will explore synthetic mimics to the nano- and microstructures responsible for these fascinating properties. For example, we have demonstrated a pH-induced porosity transition that can be used to create porous films with pore sizes that are tunable from the nanometer scale to the multiple micron scale. The pores of these films, either nano- or micropores, can be reversibly opened and closed by changes in solution pH. The ability to engineer pH-gated porosity transitions in heterostructured thin films has led to the demonstration of broadband anti-reflection coatings that mimic the anti-reflection properties of the moth eye and pH-tunable Bragg reflectors with a structure and function similar to that found in hummingbird wings and the Longhorn beetle. In addition, the highly textured honeycomb-like surfaces created by the formation of micron-scale pores are ideally suited for the creation of superhydrophobic surfaces that mimic the behavior of the self-cleaning lotus leaf. The development of synthetic “backbacks” on immune system cells that may one day ferry drugs to disease sites will also be discussed.
Nanomaterials have many potential applications in energy conversion systems due to their special structural and physical properties. Such applications often require materials manufacturing at large scale and low cost. In the first part of this talk, I will discuss the manufacturing of nanostructured bulk thermoelectric materials at large scale with improved thermoelectric properties. The materials were produced by a low cost ball milling and hot pressing process. The ball milling makes nanopowders in the quantities of up to multiple tons. Such nanopowders were then hot pressed by a direct current induced hot pressing into dense bulk materials. In the second part of this talk, I will demonstrate the concept and realization of nano coax cables that can be used for sub-wavelength light transmission and efficient solar conversion into electricity. In the last part of this talk, I will show a highly sensitive biosensor using aligned carbon nanotubes and gas sensors using nano coaxial cables.

Diffraction strongly affects our everyday life as well as our future progress. It provides the resolution limit for microscopy, photography, and other imaging techniques; it determines the scattering and emission properties of small objects; it affects the propagation of telecom signals in bent fibers. The diffraction can be understood as the ability of the relatively small, wavelength-scale, structures to change the direction of the beam of light propagating in the surrounding medium. The resulting change in the propagation of the beam is determined by the complex interplay between the shape and size of the structures and of the beam, and, to the large degree, by the properties of the material surrounding the obstacles. Here we show that a subclass of metamaterials, nanostructured composites with strong anisotropy of their optical response, known as hyperbolic media, are capable of providing unique modifications to the well-known
diffraction laws. In particular, hyperbolic media open the door for negative refraction, sub-wavelength focusing, super-resolution imaging, and introduce new mechanisms for nonlinear interaction of optical beams. In the talk we will discuss theoretical foundations of optics of hyperbolic metamaterials and will also present the results of recent experimental studies of these unique systems.

A Series of Fortunate Events: Serendipitous Encounters with Remarkable Materials

Mark Silverman
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Chance involvement in bizarrely controversial issues relating to the unexpected behaviour of more or less ordinary materials led to many of the projects I have undertaken as a physicist. Some of these unusual undertakings included (a) organic dyes and the amplification of light that does not pass through them, (b) left-right asymmetric materials and the resolution of conflicting claims over the validity of Maxwell’s equations, (c) opaquely turbid media and the surprising capacity to see through them with polarised light, (d) radioactive materials and the radical proposition that nuclear decays are correlated by an unknown universal force, (e) hot metal and the non-Newtonian behaviour of their cooling curves, (f) exploding glass and the thorny question of how solids fragment, and (g) quantum condensates and the unresolved fundamental problem of matter distribution in the universe. To the extent that time permits, I will discuss salient features of these diverse physical systems and the materials that contributed to, or helped resolve, the associated controversies.
AAPT Talks

The Student-Centered Active Learning Environment for Undergraduate Programs (SCALE-UP) Project

Robert J. Beichner
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How do you keep a classroom of 100 undergraduates actively learning? Can students practice communication and teamwork skills in a large class? How do you boost the performance of underrepresented groups? The Student-Centered Active Learning Environment for Undergraduate Programs (SCALE-UP) Project has addressed these concerns. Because of their inclusion in a leading introductory physics textbook, project materials are used by more than 1/3 of all science, math, and engineering majors nationwide. The room design and pedagogy have been adopted at more than 100 leading institutions across the country. Physics, chemistry, math, astronomy, biology, engineering, earth sciences, and even literature classes are currently being taught this way.

Educational research indicates that students should collaborate on interesting tasks and be deeply involved with the material they are studying. We promote active learning in a redesigned classroom for 100 students or more. (Of course, smaller classes can also benefit.) Class time is spent primarily on “tangibles” and “ponderables”—hands-on activities, simulations, and interesting questions. Nine students sit in three teams at round tables. Instructors circulate and engage in Socratic dialogues. The setting looks like a banquet hall, with lively interactions nearly all the time.

Hundreds of hours of classroom video and audio recordings, transcripts of numerous interviews and focus groups, data from conceptual learning assessments (using widely-recognized instruments in a pretest/posttest protocol), and collected portfolios of student work are part of our rigorous assessment effort. Our findings (based on data from over 16,000 students collected over five years as well as replications at adopting sites) can be summarized as the following:

- Female failure rate is 1/5 of previous levels, even though more is demanded of students
- Minority failure rate is 1/4 that seen in traditionally taught courses
- At-risk students are more successful in later engineering courses.
- Top students gain the most, although students at all levels benefit.
- Conceptual learning and problem solving are significantly improved, with same content coverage

In this talk I will discuss the need for reform, the SCALE-UP classroom environment, and examine the findings of studies of learning.
Physics With Robotics – A decade with our little electro-mechanical friends

William Church

Physics and Robotics Teacher
Littleton High School
Littleton, MA

Robotics tools for secondary classrooms have developed greatly in the past ten years. Currently available robotics resources offer a physics student many opportunities to explore the concepts and skills of physics. Opportunities range from 15-minute prediction testing exercises to multi-week engineering projects and multi-grade outreach projects. Physics skills developed through robotics exercises range from graph interpretation to experimental design. Topics to explore with robotics include kinematics, dynamics, thermodynamics, electricity and magnetism, vibrations, and wave phenomena. This session will provide many specific examples from the authors past decade’s work with robotics as a highly engaging student centered physics learning tool.

Exceptional Science Teaching

David Lustick

Graduate School of Education
UMass Lowell
Lowell, MA

What kind of teaching is indicative of an exceptional practice? In this secondary science teacher workshop, participants will explore and consider an array of standards based instructional strategies designed to foster specific types of student learning outcomes. Using a backward design approach, first the goals of science learning will be identified and then the best strategies for achieving those goals will be described. Finally, policies and practices that promote (or stifle) exceptional science teaching will be discussed. Specific examples of classroom teaching will be shared throughout to illustrate the concepts addressed.
Effective instructional strategies in physics classrooms

Sachiko Tosa

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Instructional strategies such as Think-Pair-Share and Socratic questioning are powerful ways to get students engaged in thinking processes. In this talk, tips and techniques that help students make sense of physics concepts in lecture-based classes are presented with specific examples. The participants will see the effectiveness of the instructional strategies by actually experiencing the process as learners with the use of clickers.