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8 Miles and a Couple of Antiparticles to Bridgewater State College

Edward Deveney
 Beetwater State College, edeveney@bridgew.edu

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Two years, ten days, three hours and twenty-four seconds. That's how long I lasted in industry as an engineer. While it wasn't 100% misery, my industry time certainly catalyzed my early mid-life crisis. The crisis was path dependent; one path was conventional and safe and the other was inherently risky but had the potential for infinite payoff. After six and a half years in a Ph.D. program at the University of Connecticut, two years in a post-doctoral fellowship at Oak Ridge National Laboratories and CERN (literally beneath Switzerland and France), and 3 years in various visiting professorship positions, the risky path has taken me to Bridgewater State College. The infinite payoffs have been, and continue to be, monetarily immeasurable. I've smashed atoms in a 18 mile long accelerator, learned to split and aim laser beams, and speculated about GUTs and TOEs (grand unification theories and theories of everything). Along the way I've made my share of quasimolecules and antiparticles, shmoozed with intellectual giants and Nobel prize winners, and I've pondered super-symmetric strings (superstrings), a strong TOE contender. Today I get to think about and research these deepest mysteries of the universe and share the rewards with the brightest and best students at Bridgewater State College in the classroom and through the research programs I am working to develop.

Blame my dad for the electron-atom smasher, the laser spectroscopy laboratory, the Maple software investigations, and the electronic circuit in a horse that I've brought to BSC and hope to describe a bit here. He was the one, after all, who planted the latent physics seeds in my head while I was growing up. "Imagine" my dad would say, "if you were one of the few capable of understanding the things that Einstein did". But Einstein didn't know everything. I believe that his chalkboard remains as it was at the time of his death; filled with questions he hoped to get the time to think about and answer. Something Linus Pauling said in an interview also stuck in my head - he recounted how he was able to come up with such brilliant ideas that ultimately led to two Nobel prizes (chemistry and peace). He simply stated that he had millions of ideas every day and that sometimes one or two panned out. As a scientist, there aren't enough hours in the day or days in the year to see all of your ideas through. That's cool.

To me it was physicists who were tackling the toughest questions and the ones that have always bugged me. With physics, I could not only know more everyday, I'd be swimming intellectually, way over my head. I wanted my brain to feel the soreness and fatigue from intense thinking workouts in the same way that my body did after tennis or basketball. I'd be exploring black holes, visiting atoms, probing the truly foreign cultures before the big bang, and be intellectually stimulated and challenged until the last gasp with physics.

The only problem was that I didn't have a degree in physics, I just wanted to be a physicist. Luckily as an undergraduate I caught the eye of a mathematics professor who managed to convince the physics department at the University of Connecticut that I had mathematical potential. This got my foot in the door but it wasn't fully opened yet. The recommendation was enough to allow me to take a tough graduate level course called Mathematical Methods for Physicists as a test of my ability to do the graduate work but probably more honestly to weed me out. So while working full time and competing with graduate students who already were accomplished undergraduate physics majors, I did well enough to convince the graduate physics faculty and even myself that I was a good candidate to earn a Ph.D. in the graduate physics program. This meant health and dental insurance, tuition, and a stipend of about $13,000 a year to work...
on getting a hold on the wonderful questions that intrigued me so much. When I did arrive on campus full time I still had to complete most of an entire undergraduate physics degree. Actually, as soon as I got accepted and while still working for a living, I bought all the undergraduate text books and mastered some of the undergraduate physics work on my own.

My head was plenty tired from doing physics all day so then all I needed to do was get my body exhausted so that I could sleep at night. I had used up my varsity eligibility in tennis as an undergraduate so I needed something else. Through a series of coincidences and wonderful friends I became the only graduate student on the crew team. Its funny how things work but the most beautiful crew coach in the world had just came face-to-face with her mid-life crisis as a Ph.D. candidate in history at Oxford University. Now at UConn and taking on essentially a new undergraduate degree like I was, the future veterinarian, of horses in particular, was yelling at me for catching a crab and throwing the boat off. Such distractions often lead to marriage as it did here and now my coach is yelling at students as a professor of Veterinary Medicine at Tufts University School of Veterinary Medicine. Incidentally, my coach's mom, Beverly Gouldrup Mazan, graduated from BSC in 1953.

THE ELECTRON-ATOM SMASHER, 18-MILE LONG ACCELERATORS AND ANTIPARTICLES:

At the University of Connecticut I worked with a true physicist and good friend, Quentin Kessel. This friendship was strained only twice - both times on the tennis court on the annual physics department picnic day. My department head, witnessing one of the events, said it best: "if you are going to hit your thesis advisor, the single most important person involved in approving your Ph.D. work, you have to shoot to kill". Quentin recovered both times.

I always like to say that I smash atoms, and I do, but it is not entirely for the fun of it. I investigate atomic and molecular structure and electronic interactions using collisions, smashing atoms. This means I explore the ways in which bound and free electrons configure or develop about atoms and molecules in response to interactions initiated by a collision or some external field. The knowledge of collisions and how electrons behave themselves during collisions is integral to understanding parts of the universe made from atoms, ions and molecules - from chemical reactions here on earth to the spectroscopy of planetary atmospheres and astrophysical plasmas. Quentin and I did most of our work using a 2 million electron volt (2 MeV) Van de Graaff accelerator at the University of Connecticut. We also used the Van De Graaff to do material analysis for several companies doing semiconductor research. As Quentin's laboratory continues to be very productive I hope to have the opportunity to continue some of these investigations with my BSC students.

Almost immediately after writing and defending for my Ph.D., I had the good fortune to do a DOE post-doc with an absolutely brilliant thinker, Sheldon Datz, at Oak Ridge National Laboratory in Oak Ridge Tennessee. Even as a freshly ordained Ph.D. I had to struggle to keep pace with the high voltage, 70 year old, sharper than ever, Sheldon. While I was sitting in my office one tennis-playable late November day, Sheldon floated in on cloud nine. He had just determined that his latest idea for an experiment, one that could help to determine the amount of He atoms in the early universe, was indeed double. These ideas as well as many of the other good ones that he had "just came to him while in the shower", he explained. Sheldon's new experiment, which he later went on to complete with colleagues in Sweden, resulted in the creation of experimental numbers, called cross-sections. These cross-sections, when used in theoretical models of the cooling-condensing soup of electrons and nuclei after the Big Bang, could then be used to predict the relative abundances of the known elements we see today, some 15 billion-ish years later. Sheldon kept very clean and as a result the other post docs and I were all very fortunate to be the bouncing board for his wonderful ideas.

Sheldon and several of the senior scientists with whom I worked were actually chemists, so most of the time the problems we focused on in Oak Ridge (using a 6 MeV tandem Van de Graaff accelerator) continued to be concerned with the quasimolecular issues of electrons developing and decaying to and from atomic and molecular orbitals in collisions. Sheldon, Quentin and two other professors, Steve Shafroth at the University of North Carolina and Robert Fuller at the United States Coast Guard academy have since then graciously contributed electron-atom smashing equipment on permanent loan to me here at BSC.

Figure 1 is a picture of the apparatus that, as you might be able to see, was once mounted to the end of a big accelerator that supplied a steady stream of heavy atoms. An electron gun, a flash-light bulb filament, inside the chamber now provides accelerated electrons that are electrostatically guided into a target cell where they smash into individual atoms or molecules. The heart of the system, a high resolution position-sensitive, electron and ion spectrometer measures the numbers and energies of the electrons emerging from the collision event. The resulting spectra window the electronic energy-level structure of the target. It all boils down to a rather complicated game of bouncing, in effect, tennis balls from bowling balls in order to figure out the size and internal structure of the bowling ball. It is a useful technique that was in fact used on the first lunar probe in the 60's to measure the elemental composition of the lunar surface.
Before I left Oak Ridge, however, Sheldon asked me to take part in another of his projects at CERN in Geneva, Switzerland. CERN is the biggest particle physics accelerator facilities in the world. The SPS, the super-proton synchrotron, is a modest 7 miles in circumference while the LEP, large electron positron collider, is the largest particle accelerator in the world today stretching 18 miles in circumference. Particles accelerated to nearly the speed of light travel in these circular tunnels dug beneath the farms and hills straddling Switzerland and France before violently crashing to a halt in collisions with various targets.

Occasionally new, massive, short-lived particles are created as the kinetic energy of the collision is converted into mass energy according to that famous equation having something to do with $E$, $m$, and $c$. You might remember the United States started to build what was to be called the SSC, superconductor super collider, in Texas but the money and support has sadly gone by and what we have left is a tunnel 53 miles in circumference that would have housed the largest accelerator in the world. There we might have found the highly sought after Higgs particle which has been called by some the 'God particle'.

At CERN, we were involved in the first ever ultra-relativistic experiments with lead atoms (Pb) traveling at 0.99996 times the speed of light at CERN. What we measured experimentally was this: we used the intense electromagnetic fields generated from the relativistic Coulomb interactions between the speeding Pb projectiles and the target gold atoms to excite and then capture the electron of an electron-positron pair sparked from the vacuum. Let me try again... at these energies, we were able to make, yes out of nothing, an electron and its antiparticle the positron, and then measure how often the very electron we made stuck to (electron capture) the very Pb projectile going nearly the speed of light that started the whole process. For me, that's as good as it gets.

To appreciate why we, or anyone else for that matter, cares about antiparticles and Pb ions traveling at nearly the speed of light, I am going to have to talk about the scientific method and the nature of fundamental, or basic, research. The scientific method is like the world ladder ranking of tennis players. The best player emerges eventually at the top of the ladder, but can never rest, and must always accept the challenge of the players below continually defending his title. The same is true of theories that emerge from the scientific method with one major exception. In science, the number one theory got to be number one by being tested against, every other theory and experimental piece of evidence ever accumulated or measured! Today's theories are the accumulation and strength, or evolution, of every bit of knowledge ever gained. Now that's a tough ranking system. Hopefully critical thinkers remember to apply this system to things like astrology, magnetic therapy, and chi. We can now wing big heavy atoms like lead near the speed of light, cool things to almost absolute zero, and measure the velocities and luminosities of supernovas throughout the cosmos. If our theories are going to finally crack, they ought to start cracking soon as we are pushing them to explain more and more.

Our experiment at CERN pushed the predictive ability of quantum mechanics to an extreme never before possible. The good and the bad news is that the theories appear to be holding. It is good that the theories work at these extremes but bad because it would have been fun to help turn the physics community absolutely upside down. Additionally, our experimental numbers are being used for another accelerator in Long Island New York called RHIC for relativistic heavy ion collider, where we might get a glimpse of another big prize in physics called a quark gluon plasma—but that's another story.

**THE LASER SPECTROMETRY LABORATORY AND SUPER SYMMETRIC THEORIES:**

With my post-doc winding down and Melissa in Florida the only happy people were the ones at AT&T and USAir. We decided it would be nice to live together under the same roof and Massachusetts was the place to be. We would be central to our families in
To top it off, he is the most natural and wonderful teacher of physics I have ever been. David DeMille is now at Yale University. David is beyond the standard model with students here at BSC.

The Standard Model (SM) is the third of the three most influential physicists in my career, David DeMille, who is now at Yale University. David is the ultimate physicist, combining mathematical rigor with keen insight. To top it off, he is the most natural and wonderful teacher of physics I have ever known, and he stinks at golf just like me. It is thanks to Dave that I am able to think about and share physics beyond the standard model with students here at BSC.

The ambition of the SM is to understand the known diversity of the universe, four fundamental forces (gravitational, electromagnetic, strong nuclear and weak nuclear) and lots of different subatomic particles, in terms of common first principles or mechanisms. The underlying idea of the SM is that perhaps everything is explainable as an inevitable consequence of understandable principles or laws of physics. The list of characters in the SM include fermions (things we recognize or think of as particles such as electrons) and bosons (particles or fields that mediate or carry the four known forces). The SM's greatest achievement is that it houses under one theoretical roof the mechanisms and reason for three of the four known forces. Gravity is the odd ball out. GUTs (grand unification theories) are a higher order of unifications of three of the fundamental forces under one guise and a TOE (theories of everything) would finally show gravity in the same vein as the other three forces. GUTs and TOEs have yet to be fully developed. Crazy as it seems, a happy dog - its biology, its chemistry, the cosmos that he chases cats in for all of eternity - is consistent with the standard model.

A well-known experimental measurement for physics beyond the standard model is called the electron electric dipole moment (eEDM). The SM is relatively silent about what the eEDM should be; it could even be exactly zero. But some of the new theories currently challenging the SM do say something about the eEDM. Supersymmetric theories, for example superstrings, do say something about the eEDM and that it is non zero. Thus experiments that we foresee being able to do shortly that the SM cannot answer adequately or simply has no answer for at all. These questions and experiments constitute physics beyond the SM.

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Dave's unique idea is to take high precision measurements of an induced Stark shift in a paramagnetic metastable excited state of PbO molecule to make an experimental measurement of the EDM that can made with a sensitivity $10^{-10}$ times better than any existing experiment. This definitive experimental evidence on the validity of the SM, physics 'beyond the SM' will be achieved.

I have been trying to enter BSC into this exciting game by proposing to build what I have called the Large Spectral Range Laser Laboratory (LSRLL). Simply stated, Dave needs to know everything about this molecule, PbO, in order to do his eEDM experiment. This means the electronic molecular structure of the molecule has to be identified, mapped and understood. Laser spectroscopy provides the tool to do this. However, traditionally the lasers that are needed to do this have been costly and space consuming two-laser (pump and dye) systems. With the advent of inexpensive, extremely stable, narrow bandwidth, and large spectral range diode laser systems it has become possible to do this type of research program at BSC.

Our first effort in the proposed LSRLL will be to study the PbO molecule needed for Dave's e-EDM measurement. Professor Noda in the chemistry department has teamed up with me on this proposal so that in addition to physics experiments that include Doppler and Doppler-free saturated absorption spectroscopy, nonlinear optics and magneto optics, and laser cooling and trapping, we will also be able to do chemistry studies including overtone spectroscopy, Curricular development, research and educational programs from biology, environmental studies and earth sciences at BSC as...
well as ‘reach out’ programs to local colleges, community colleges and high schools targeting underprivileged and minority groups will also be developed thus making the LSRLL a fundamental tool for all of the science programs at BSC and the community at large.

In the mean time, I have secured funding to construct a research-grade tunable diode laser here on campus to begin some of the research and curriculum development. One of our current physics majors and promising experimentalist, Petr Liska, has experience building a similar laser. Petr won a prestigious NSF sponsored REU (research experience for undergraduates) fellowship to study atomic-molecular and optical physics and to build this laser at Stony Brook University in New York this past summer. Figure 2 on page 22 shows Petr’s hand holding the nifty, research grade and revolutionary diode laser we will soon be working with at BSC.

MAPLE:

As a physicist today, you must be very computer literate, using computers for everything from data acquisition, to data analysis, and theoretical simulations. I have spearheaded a physics curriculum development to teach some of these skills in the undergraduate physics curriculum using a powerful, but not easy, symbolic mathematics computer code called Maple. Maple understands more than just numbers, it understands (at some level) the symbols, logic and concepts of mathematics.

The ability to communicate with a software package like Maple that recognizes symbolic mathematics affords the user the power and versatility of the computer along with a full programming language that can be used for theoretical as well as numerical calculations. Philosophically this is much different from the number-crunching routines your calculator uses or that computer code is typically written to do. Even when you do have to crunch numbers, symbolic codes are inherently more precise and accurate.

My goals for the implementation of Maple cover pedagogy and research. Teachers, students and researchers will be able to effortlessly incorporate mathematical modeling and computing into all aspects of their work. For pedagogy, symbolic algebraic software allows the teacher and the student the ability to ‘see’ beyond the mathematics with state of the art numerical, symbolic, statistical, graphical and animation capabilities. I am fortunate to have won a BSC CART award to pursue these goals. With this award, I created ‘A Maple Symbolic Algebra Software Primer for BSC Scientists’ this past summer (2000). I have made this manual available to my PH438 class, Electrodynamics, and plan on making it available on the web for all. I have asked students to use Maple in their homework and on exams to help facilitate the visualization of vector fields and the three dimensional vector calculus operations that they perform mathematically on these fields. For example, Figure 3 on page 24 is the graphical representation of how the Pauli Exclusion Principle is manifested for the complex quantum mechanical solution for 2 electrons in a box. The reviews have so far been very positive. One of our physics majors, Lisa DeFalco, who is a promising theorist, and I are currently studying several published papers on Maple.

RLC CIRCUITS IN A HORSE:

Last but not least, is one of my pet research projects called an RLC electronic circuit in a horse. For physicists, this is a huge step, but my wife, who knows what she is doing, uses this technique at the Tufts University School of Veterinary Medicine Lung Function Laboratory. Melissa’s goal is to help diagnose, test, and fix the lungs of sick horses and to improve the function of the equine (horse) athlete using a non-invasive technique called forced oscillatory mechanics (FOM) which is based on the resistor inductor capacitor (RLC) electronic model.

Where is the RLC circuit in a horse? To see, you must start what I call the art of the approximation, which is a technique employed when faced with needed insight into a tough problem. The complete physical and mathematical description of a horse’s pulmonary system certainly meets this criteria. I like to tell students that an approximation isn’t necessarily right or wrong but often good or bad. So the idea is to recognize the similarities between a pulmonary system and what is called a Helmholtz oscillator which consists of a small tube or neck attached to a larger volume. When air is pushed from the neck into the volume, the number of particles inside the volume is increased and subsequently the pressure inside increases pushing air back into the neck. As an excess of particles begins to be pushed out of the volume, negative pressure or a vacuum is created within the volume and air from the neck is now pulled back. Eventually an oscillation is set up with a quantifiable and measurable frequency that depends on the physical parameters of the oscillator including the size and restrictions of the neck, the mass of the fluid, and the size and elasticity of the larger volume. Approximating the biological pulmonary system as a Helmholtz oscillator is now not much of a stretch; the lung is equivalent to the larger volume, the neck is, well the neck and the fluid is air. Oscillation are set up in the horse’s airways by using small pressure waves, which set up inaudible sound waves of known frequencies, inside a mask that the horse wears very comfortably and while he gets the royal head scratching treatment. The measurable characteristics of the oscillations set up in the mask and the horse’s airways then yield specific physical information on the horse’s biology and well being.

The final piece of the puzzle is that the physics and mathematics of the Helmholtz oscillator, and now our
horse, is exactly the same as the mathematics used to analyze an RLC electrical system. Historically, these systems have been studied to the greatest extent so analogies are made directly from the horse to the Helmholtz oscillator to the electrical components. The medical and biological communities are actually quite familiar with this idea and the field is mature and covered in many texts and journals. My goal is to make physicists aware of this work and to bridge the gap between medicine, biology and physics and of course to make new contributions in collaboration with Melissa and students from both Tufts and BSC.

To wrap it all up, I hope that it is now clear to see that in both my classroom and in my laboratory I strive with my students for clarity and understanding of physical concepts, always stressing critical thinking using the scientific method and having fun. With each new problem, we question whether the theories, ideas and laws we examine make sense and if they are consistent with experiment and reality. In learning to do physics, I believe that my students take away useful problem-solving skills that they will use in critical thinking and solution-finding in realms far separated from classroom physics. It is clear that the trends and advances in medicine-related fields have been and will be done by those with strong physics backgrounds as evidenced by the recent Nobel Prizes in medicine and in chemistry which were both shared by physicists. I also believe my responsibilities as a physics professor extend into many of the social and economic issues and questions leaders of today and tomorrow face that increasingly require a solid knowledge of physics.

I haven’t mentioned it yet, but on my path from high school, to undergraduate, to Ph.D., to post-doc and CERN, to the speed of light and to supersymmetric theories beyond the Standard model, and finally here to BSC, my net displacement has only been about 8 miles. I grew up with the best parents, family and friends, and was educated in sports and academics in Brockton. Some of my most influential teachers at Brockton High were BSC graduates such as Antonio Cabral, Carol Vecchi and Doug Mildram. I haven’t changed much. I still play basketball and tennis as often as possible; I get a huge kick from teaching and learning; my mom still makes me brownies (to the delight of my colleagues in the department), and I always hope I don’t have to mow the lawn tomorrow so that I can think about physics for a while, and maybe talk to my daughter Rae about fermions and bosons.

Edward Deveney is Assistant Professor of Physics.