NJAAP Spring Meeting - 2009
Focuses on Applications of Physics

Responding to the preferences of its membership, the New Jersey Section of the American Association of Physics Teachers (NJAAPT), meeting at Princeton University on 20-21 March 2009, devoted its annual spring meeting to applications of physics to other fields. Speakers covered such diverse areas of application as law enforcement, embryology, music, and medicine.

Leading off as the Friday night after-dinner speaker was William H. Pauli of the Collision Analysis Reconstruction Team in the Somerset County (NJ) Prosecutor's Office – a team formed as the result of two acquittals of people charged with vehicular homicide, presumably because less had been done to support the prosecution than the defense. A former police officer with a background in traffic safety, Pauli has sought to do outreach to students to prevent them from causing collisions themselves. He sought to do the same kind of outreach to NJAAPT – in a presentation called "Physics is Your Passenger."

Physical evidence, Pauli said, is the most important ingredient in reconstructing a collision. The intent is to determine the speeds of cars before they collided and how the collision occurred, matters that could be material to a subsequent court case. Evidence includes distribution of the severity of damage to vehicles and marks left on the road. The analyses Pauli showed focused on forces exerted between colliding vehicles at their point of maximum contact, and Pauli noted that forces striking far from the center of mass will cause a car to rotate about its center of mass, possibly including rotation about a horizontal axis to produce gouges in the road. But, in contrast to crime scenes that can be kept isolated for inspection as long as needed, Pauli noted that he needed to do his analysis quickly, because roads must be kept open.

Many of the examples of serious collisions shown by Pauli, most of them resulting in death, were caused by people under the influence of alcohol or drugs. In general, Pauli said, human factors are the major cause of accidents. But there are important physical factors too, principal among them the coefficient of friction between vehicle tires and the roadway. This coefficient, the ratio of the friction force to the vehicle's weight, is 0.8 for dry new pavement, but this reduces to 0.6 or 0.7 in time, is only 0.5 for wet gravel and 0.4 for a snow-covered road. Only 0.2 is needed for normal driving, but 0.5 is needed for casual braking and 0.7 for maximum braking. Moreover, sudden braking requires disproportionate stopping force applied by the front wheels. In this case the tire surface is found to buckle up in the middle.

The physics for calculating the speed of a vehicle prior to collision is very straightforward if the coefficient of friction and the distance traveled by the vehicle after collision are known. The vehicle is slowed by negative work done by the friction force, and this negative work equals the decrease in the vehicle's kinetic energy. Since the negative work is determined by multiplying the friction force by the distance through which it acts, one obtains

$$mg\mu d = \tfrac{1}{2} mv^2, \text{ where}$$

m = mass of car
g = acceleration due to gravity (32 ft/s^2 in the units used by Pauli)
μ = coefficient of friction
d = distance traveled by car (in ft)
v = speed of car (in ft/s).

This leads to

$$v = \sqrt{64\mu d}$$

for the speed in ft/s or

$$v = \sqrt{30\mu d}$$

for the speed in mi/hr, since 1 mi/hr = 1.466 ft/s.

Pauli stated that he measures the coefficient of friction on-site *three* ways and determines the distance traveled after collision by skid marks on the road. But, although this formula for measuring speed derives from energy transformation analysis, Pauli added that momentum analysis is far more useful a tool to analyze collisions.

Pauli also noted that the typical response time of drivers in accident situations, including the time to move their feet over to the brake pedal, is 1.6 seconds, more than the 0.7 seconds used in driver education manuals to calculate the distance traveled before braking when approaching a traffic light. He called the 1.6 seconds a *passive* response time and added that it is longer than 0.7 seconds for approaching a traffic light, because in the latter case the driver *expects* to have to take action. And even this 0.7 seconds is longer, Pauli said, than the 0.1 seconds needed to react after being hit in the head or blasted with a horn.

As an indication of the increased safety of automobiles, Pauli noted that vehicles must be subjected to barrier tests before they can be sold. Cars today, he said, are designed to bend, to lengthen the time of a collision impulse (and thereby reduce the force). Most of them also have black box recorders, to protect manufacturers in the case of product liability lawsuits. At the same time, Pauli expressed concern that drivers are lulled into the security of relaxing in their living rooms while driving. *Crashing at 40 miles per hour* (which is what some vehicles did in the accident scenes he showed us) *is equivalent to falling from a five-story building*, he observed. Pauli also pointed out that driver education cannot provide young drivers the experience that is ultimately the basis for safe driving. “Experience,” he said, “cannot be taught.”

Eighteen of New Jersey’s 21 counties now have units similar to the one in which Pauli works. The New Jersey Division of Highway Traffic Safety trains the personnel, using staged collisions with donated cars in a poor state of repair.

Bialek Discusses Embryological Problems

Although Bill Bialek spoke to NJAAPT about "Physics Problems in Early Embryonic Development," he holds an appointment in Princeton's Physics Department as part of an interdisciplinary program. Bialek chose as his subject the fruit fly, which starts life as a single-celled egg half a millimeter long, which becomes a maggot, sectioned like human vertebrae. Since this development happens within a shell, it happens at constant volume and mass and does so in the course of three hours. He observed that the type of a cell is determined by which protein is made from reading its DNA. This, in turn, is determined by "transcription factor" molecules which block certain genes in the DNA. The segmentation of maggots resulted from the alternating concentration of transcription factors in the egg.

Studies of all possible variations of segmentation of maggots shows that they are identified with only 100 of the fruit fly's 25,000 genes. Bialek said that the mother laying the eggs determines their segmentation by placing messenger-RNA for a particular protein at the head of the egg. This evolves into a decaying concentration from the head to the tail of the egg, which interacts with other proteins in the egg to produce the ultimate alternating concentration of transcription factors.

Bialek also observed that concentrations of proteins in cells are typically nanomolar and pointed out that a 1 nM solution would contain only 0.6 molecules per cubic micron (micrometer), typical size of a cell. For this reason, as little as 10% in the difference of a protein concentration would have a significant effect on the fate of a cell.

Aaronson Makes Us Aware of How We Hear

Using his background in psychoacoustics and a modification of his presentation on "Sounds, Hearing, and Music" to the American String Music Association, Neil Aaronson of Richard Stockton College of New Jersey, involved us in listening to a series of sounds to understand how they are perceived by the human ear. The vibrations of strings, with two fixed ends, are known for having harmonics with frequencies a whole number times the lowest, or fundamental, frequency, which corresponds to a wavelength twice the length of the string. Aaronson enabled us to hear that the apparent pitch of the sound of a vibrating string was that of the fundamental frequency, regardless of the distribution of harmonics. Moreover, the apparent pitch remained the same even when the fundamental frequency was deleted, because the synthesis of the harmonics had the same frequency as that of the missing fundamental.

By presenting only selected frequencies to us, Aaronson also enabled us to learn how information is transmitted in speech. Vowels, he pointed out, are characterized by formants, which are harmonics far above the fundamental frequency. When he transmitted a message of human speech with the formant frequencies deleted, we could barely understand what was being said. But when he transmitted the message with the fundamental frequency deleted, we could understand the message, although with poorer quality sound. Because this requires less energy, Aaronson said, telephones use this procedure, and this is why the voices of mothers and their daughters can be confused on the telephone.

Aaronson took us on a “tour” of the human ear, noting that we can hear sounds produced when the amplitude of the vibration of the eardrum is as low as a tenth of a nanometer. Our hearing system, he pointed out, uses analog signals until they reach the organ of Corti, which converts them to digital input to our brain. Aaronson demonstrated cross-linking between our visual and auditory systems by playing what was ostensibly an audiovisual of a person saying “da.” But when he replayed it and asked us to close our eyes, we heard “ba” – our lip reading of the visual signal overrode what our ears had been hearing (the separately-recorded soundtrack had been synchronized with the visual “da”).

Lastly, Aaronson showed, by playing a repetition of a phrase, that although different parts of our brain handle speech and music, there is a musical quality of speech. The more we heard the repeated phrase, the more it sounded as if it were being sung – and Aaronson even showed the notes he had written to represent the music.

Dougherty Speaks About Physics in Medicine

Larry Dougherty, from the University of Pennsylvania, speaking about “Physics Research and Clinical Medicine,” observed that 76% of all physicists in medicine were involved with therapeutic radiology and another 15% with diagnostic imaging. He focused his presentation on these two aspects of physics in medicine.

Dougherty cited six types of diagnostic imaging – X-rays, nuclear radiation, CT (computerized tomography), ultrasound, MRI (magnetic resonance imaging), and optical (diffuse optical tomography). MRI, he said, images local body chemistry and shows up the contrast between healthy and diseased tissue, primarily by imaging protons from their magnetic properties as a spinning charge. A strong magnetic field aligns them, but even with a field as strong as 1.5 tesla, the ratio of “spin up” to “spin down” is only a thousandth of a percent greater than 1. Applying a resonant oscillating magnetic field causes the aligned protons to flip, and MRI looks for an echo that indicates the presence of disease. The first commercial MRI scanner was developed by General Electric in 1982, Dougherty said, and in 1985 Medicare started paying for MRI scans. MRI can produce images at various depths, he added, noting that it can detect breast cancers more reliably than mammograms, which give 20% false negatives. On the other hand, MRI is much more expensive and has been accused of detecting too much. Dougherty noted an emerging school of thought that the body can heal many cancers, that lung and breast cancers below a certain size should be left alone except for further monitoring. “Overtreatment,” Dougherty observed, can escalate the already exploding cost of medicine even more.

Dougherty spoke about two other techniques of diagnostic imaging – PET (positron emission tomography) scans and optical tomography. PET uses positrons from radioactive beta decay, by the gamma rays emitted from positron-electron annihilation, to produce images, but it requires a nearby cyclotron to make the required short-lived radioactive isotopes. Optical tomography uses near-infrared radiation, which is scattered multiply as it passes through tissues. It does no damage and *can* detect cancer, Dougherty said.

Once cancer is detected, Dougherty went on, there are three radiation options: 1) X-rays, which penetrate too much to concentrate energy onto a target; 2) electrons, which don’t penetrate much and are therefore useful for treating only surface cancers; and 3) protons, the most versatile option. Proton dosage is maximized at a "Bragg peak," whose depth is determined by the proton energy.

Treatment consists of determining the total does needed and the number of installments needed to deliver it. Multiple beams will insure delivery of maximum dose to the target while afflicting neighboring areas with lower doses. Although proton treatment was pioneered by Bragg and Wilson, little was done on a widespread basis until Loma Linda made it available in 1990. In addition to Loma Linda, there are now four other proton treatment centers in the U.S. It is very expensive, and Dougherty felt it might be most efficacious in children, who are more radiosensitive than adults.

Bilash Presents Physics Demonstrations

The classic end to NJAAPT meetings at Princeton University is the presentation of physics demonstrations, usually by the Princeton University staff, drawing from their huge emporium of lecture demonstrations. But this time the demonstrations were scheduled for presentation by the team of Borislaw Bilash II of Pascack Valley High School and Dave Maiullo of Rutgers University – this team has recently published a book, *A Demo a Day – A Year of Physics Demonstrations*, available through Flinn Scientific. However, because Flinn had called Maiullo to present demonstrations to the National Science Teachers Association's Annual Conference in New Orleans, his participation at the NJAAPT meeting was limited to a call to Bilash on his cell phone.

This couldn't have been timed better. Bilash had just made a splashy entrance with a fire extinguisher backpack that had ripped the slats out of the side of the stage left entrance, when the phone rang to have Maiullo ask him how things were going. After we shouted our greetings to Maiullo, Bilash picked up where things had left off before the phone call and posed a very legitimate question: is a teacher entering his classroom with a fire extinguisher backpack teaching or showing off? Would a balloon or fan cart be more effective to teach Newton's Laws of Motion? Demonstrations should be followed by questions to engage students in inquiry, he said. The fan cart allows more variations to lead to a lot more discussion than a backpack fire extinguisher, and Bilash demonstrated several of these. Learning through demonstrations without subsequent engagement, Bilash went on, shows only a 30% retention rate. On the other hand, practice by doing gives 75% retention, and teaching others 90%. In teaching students how to learn, we should build upon what they *already have learned*, Bilash said. If you want only to entertain, you should join a circus.

Bilash demonstrated some interesting kinematics with dart guns, which he observed have become hard to find and have been totally banned in Australia. Two darts, one weighted, will hit the ground simultaneously when dropped at the same height from rest. But when fired downward, the lighter dart had a greater initial velocity and it the floor before the weighted one.

Bilash also demonstrated a tug-of-war between two evenly-matched constant velocity buggies. He showed that adding mass to one increases its friction with the ground and allows it to win. So does allowing a cart to move onto sandpaper (another way to increase friction between it and the ground).

Among the other things Bilash demonstrated: eggs dropped from the same height onto a plain and cushioned bucket to show the effect of lengthening the time for the impulse to stop them; beats from the sounds generated by rubbing two aluminum rods differing in length by a centimeter when held at their center; electric field lines emanating from a charged object, represented by tinsel taped to the charged object.

Hein Presents AAPT Vision

Warren Hein, Executive Officer of the national American Association of Physics Teachers, was also on hand to tell members of the New Jersey Section what the national organization offers. An incentive to get more section members to join the national organization, which will be available the next three years on a trial basis, is a reduced-price Associate Membership. Costing only $36, it offers first-time members hard copy of *Physics Today* and the *AAPT Annual Report* plus 42 articles on-line from the two AAPT journals, the *American Journal of Physics* and *The Physics Teacher*. There is also a financial incentive of $9 to each section for each new AAPT member they produce. AAPT's goal for 2009 is to increase its membership by 2000 in this way, Hein said, and he is counting on the sections to help achieve it.