HWJS

HARVARD-WESTLAKE JOURNAL OF SCIENCE • ISSUE 1 • SPRING 2007

REVOLUTIONIZING AIR HOCKEY

FINDING A CURE FOR HPV

5 THINGS THAT WILL BOGGLE YOUR MIND

PLUS: Q & A WITH DR. NASSAR

HW Journal of Science

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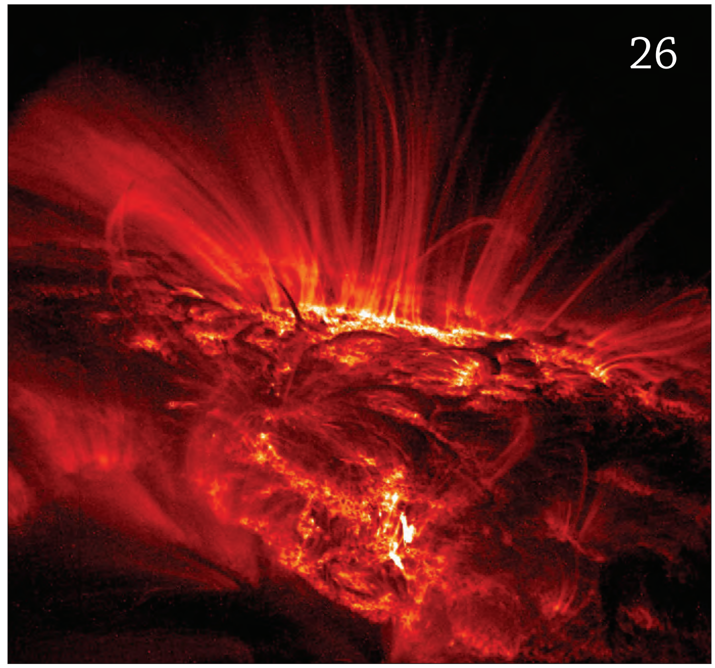

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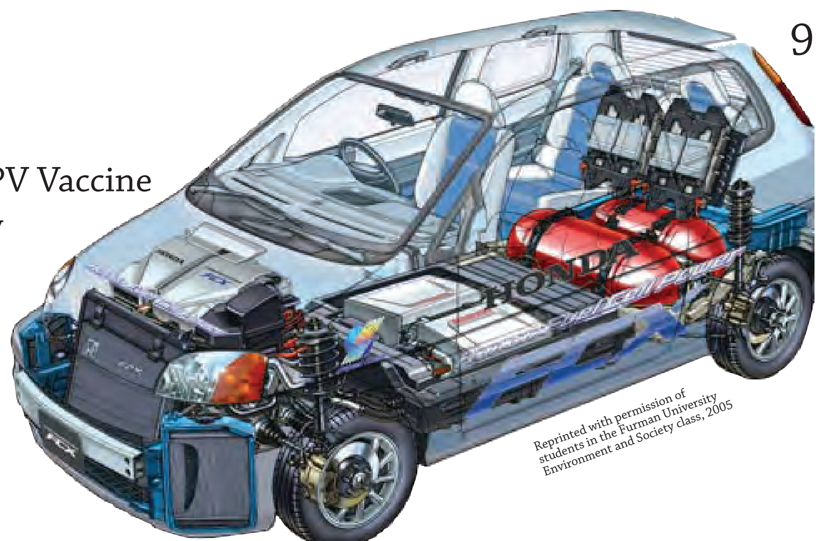

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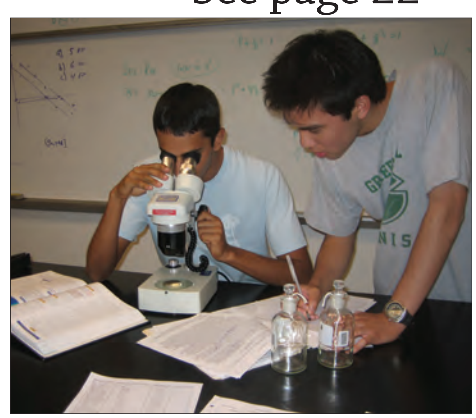

Allen Miller and Justin Chow

PHOTOGRAPHS BY Eliza Eddison, Allen Miller, and Emiliano Rios

From the Editors

Starting a Legacy

Allen Miller and Justin Chow

Since the merger in 1991, Harvard-Westlake has built one of the greatest high school level science programs in the nation. Our school offers 22 science courses—with everything from Astronomy to Geology to A.P. Physics C: Electricity and Magnetism. Our campus is home to the amazing physical resource of Munger Science Center—a building filled with state of the art equipment. We have talented and experienced teachers who annually help us top the nation in Advanced Placement exams while also cultivating imagination and discovery. At Harvard-Westlake we have a sense of pride towards our academic reputation and tradition of excellence. It is with this tradition of excellence in mind that we now cross a major milestone and proudly bring to you the first ever *Harvard-Westlake Journal of Science*.

When we first sat down to plan out the journal all we had was a faint idea of what we hoped to accomplish, wild imaginations and an empty folder we hoped to fill—nothing more. In fact, from that day forth, we believed that it was our imaginations coupled with the energy and dedication of each staff member that allowed us, more than anything else, to reach the point where you can now touch and read a tangible manuscript of what we had in mind all along. Nevertheless, our inexperience was an obstacle at times. On more than one occasion, one of us would comment to the other, "How are we going to pull this off?" The general response to such mutually felt moments of helplessness would be, "Well, I guess we'll just have to start with the basics." And so we did.

Early on, we both knew that we wanted the journal to appeal to the scientific community (i.e. students interested in science or research, faculty members in the science department and the administration). Yet, we wanted the journal to be broader in its appeal or more inclusive in its audience range. We wanted any person who happened to pick up a copy of the journal to be able to find something of interest in it. With this in mind, we began the long journey toward the production of the journal—a journey that would not be possible without the commitment of each staff member.

With this first issue, which was created, managed, and edited entirely by students at Harvard-Westlake, we hope to have accomplished these goals. In the journal you will find conventional academic-style research articles in the first section. However, if you seek humor, flip over to our cartoons page. For the scoop on new inventions and developing technology, have a look at our page on technological progress in 2006. These sections and many more are available for your enjoyment and intellectual fulfillment. We hope that this publication will generate within each of you an unquenchable curiosity in the physical and natural world. Yet, ultimately, we hope to inspire you to continue the Harvard-Westlake tradition of excellence!

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PHOTOGRAPHS BY Andrew Miller

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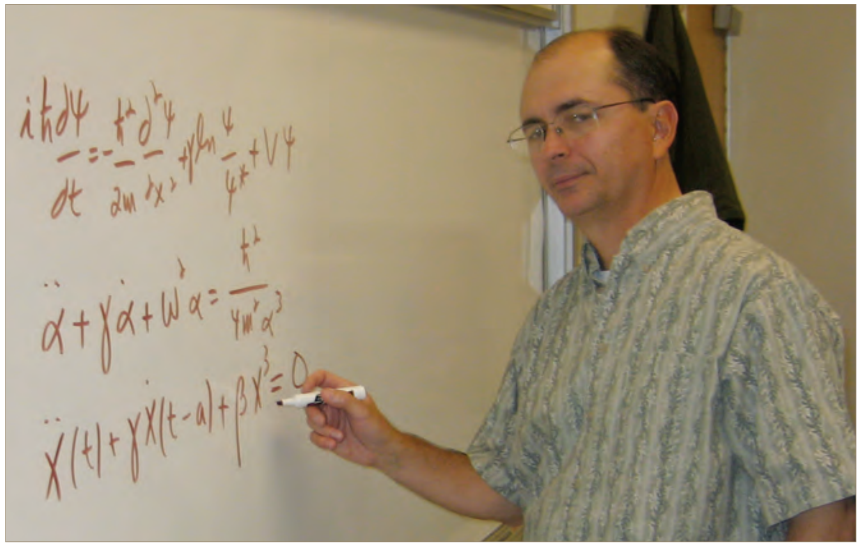
Meet the Doctor

Ten years ago, Dr. Antonio Nassar was mentoring a casual after-school scientific research activity for a few students when he realized the potential growth the genuine scientific interest exhibited by the small group could produce. Three years later, Nassar created what is now known as Directed Studies: Scientific Research (DSSR). Along with the scientific research club, DSSR encourages hands-on applications of scientific concepts spanning fields from astrophysics to game theory. We caught up with the mastermind of DSSR to find out more about him.



Dr. Antonio Nassar

In the Life of Dr. Nassar...

Education

- B.S. Electrical Engineering and Physics, Brazil
- M.A. Physics, UCLA
- Ph.D. Physics, UCLA (1992)

Teaching Experience

- 20 years of experience on General Physics (13 years teaching Physics 6A, B, and C at UCLA), Electronics, and Physics of Sound and Acoustics (17 years teaching at Harvard-Westlake School)

Publications

- American Journal of Physics, Journal of Optics B: Quantum and Semiclassical Optics, Nuovo Cimento, The Physics Teacher, Physical Review

Awards and Honors

- UCLA Physics Department Teaching Assistantship award (1981-1986; 1987- 1988)
- Letter of recognition for accomplishments in teaching and research from Governor Pete Wilson (January 31, 1991).
- Harvard-Westlake School Justin Rascoff Teaching Award
- MIT nomination and recognition for excellent teaching
- INTEL Science Talent Search - Teacher of Merit

Q+A: Dr. Antonio Nassar talks to the editors about his life, his work, science, and DSSR.

Q: What was it like growing up in Brazil?

A: I had a pretty good life, and from an early age I was very curious about science. I liked to put together plastic cars, ships and planes that my father bought for me.

Q: Did your family have a role in shaping your scientific life?

A: My father had a large building company that built, among other things, fifteen high-rise buildings (about sixteen stories each) in my hometown. Such influences as these fostered a great desire in me to become an engineer.

Q: What do you like to do for fun?

A: I have fun doing research on physics and staying home or going out with my wife and daughters.

Q: How successful do you think DSSR has become?

A: It has grown enormously. I started with four students the first year, six in the second and now we have eighteen students enrolled. We will have about twenty-eight students next year. The success can be measured by the interest and enthusiasm demonstrated by the students.

Q: What was your most recent accomplishment?

A: I just had my 42nd scientific article published in a major journal of physics. The article was entitled "Schrödinger Equation for an Extended Electron."

Q: Who do you consider to be your most prominent scientific hero?

A: I read many books written by Isaac Asimov and Arthur C. Clark, loved science fiction movies such as *2001: A Space Odyssey* and *Star Trek*. But the greatest scientific figure in my life was Richard Feynman.

Q: Current work?

A: I'm working on an application of the quantum theory I've developed for an extended electron. I hope to carry out quantum tunneling calculations using this new formalism.

Q: What is your take on the future of DSSR?

A: I'm sure DSSR will inspire a lot of students to become greater scientists. It will definitely leave a lasting impression on all the students who experience the course. Just ask any DSSR student for their perspective about the impact on their lives.

For more information, visit Dr. Nassar's website at www.physicsland.com.

Photograph by Justin Chow

RESEARCH ARTICLES

Bright ideas

The importance and implementation of photovoltaic cells

By Michael Casey, Sarah Park, Alfredo Ramirez and Maddy Young

PHOTOGRAPH BY Lars Sundström

USING THE SUN AS A SOURCE OF ENERGY has been tried by many different people. Both the ancient Greeks and Romans used it passively to light and heat indoor spaces. Many others have constructed machines that use solar energy. One of the earliest people to do so is Auguste Mouchout, a nineteenth-century inventor.

Concerned about France's dependence on coal and fossil fuels, Mouchout created a steam engine solely powered by the sun. His first experiment used a glass-enclosed iron cauldron that trapped the sun's rays as they passed through the glass cover. The heat from the rays caused the water in the cauldron to boil and form steam. Because the amount of steam was so little, Mouchout added a reflector to his setup that concentrated more radiation onto the cauldron, generating a greater amount of steam, enough to power a small steam engine.

Around the same time, William Adams created a setup of seventy-two flat mirrors arranged in a semicircle that would track the sun's movements. In testing this apparatus, he placed a piece of wood in the focus of the mirrors, causing the piece of wood to immediately ignite.

Beginning his work in refrigeration, which eventually led to the design of the first non-reflecting solar motor, Charles Tellier used an apparatus similar to the flat-plate collectors designed by William Adams to heat water. Using ammonia instead of water to power his apparatus, since ammonia's boiling point is significantly lower, Tellier was able to »

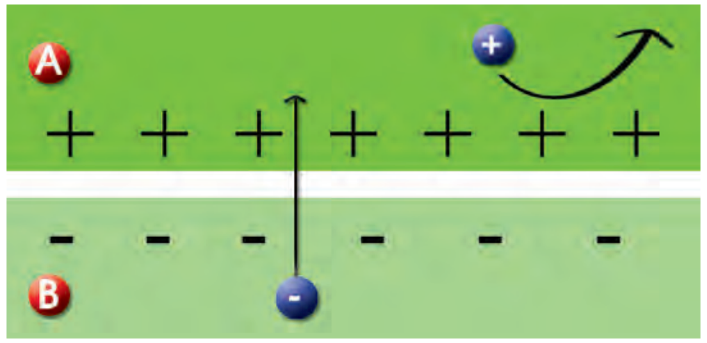


Figure 3

power a water pump in his well at a rate of about three hundred gallons per hour during daylight.

Swedish engineer John Ericsson invented an innovative method for collecting solar rays in the form of the parabolic trough. Unlike a real parabola that focuses radiation on a single focal point, the parabolic trough focused the sun's rays in a line across the open side of the reflector. Trying to solve problems in the telephone system of Bell Laboratories, scientists Gerald Pearson, Daryl Chapin, and Calvin Fuller developed the first silicon solar cell that could generate a measurable electric current. After building a solid-state rectifier of lithium-gallium silicon, an appliance that converts direct current to alternating current, Pearson, Chapin, and Fuller found, to their surprise, that the rectifier created a significant electrical flow.

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How a Solar Cell Works

A solar cell is generally made out of silicon. On the surface, an anti-reflective coating is used to block the reflection of light. Silicon is shiny, and therefore tends to reflect light easily. For the solar cell to be most efficient, it needs to capture the most sunlight. Thus this coating is used to attain maximum efficiency.

When sunlight strikes the cell, electrons are able to move freely about in the circuit. With the N-type and P-type semiconductors present, a current can be created and electricity can be generated.

The cell is composed of a semiconductor material (again, usually silicon) with impurities of other elements, such as boron and phosphorous. These impurities are integral to the function of the photovoltaic cell; without them, no current could exist and electricity would not be generated.

The silicon atom has four valence electrons—or electrons in the outermost orbital of the atom—whereas atoms of boron have three, and atoms of phosphorous have five. Each atom always wants to be stable– which generally requires a total of eight valence electrons. Therefore, silicon must find four more electrons with which it can bond.

Atoms of phosphorous have one more valence electron than atoms of silicon, so there will be one extra electron from the phosphorous with which no other electron will bond. When light strikes such an apparatus, the electron, because it repels the other electrons, leaves freely. The portion of the cell that has atoms of phosphorous, or other group V elements, is called N-type silicon.

P-type silicon, on the other hand, is the portion of the cell that has impurities such as atoms of boron, or other group three elements of the periodic table (those with three valence electrons). Because boron only has three electrons, there are "holes" where the electrons of silicon want to join with other electrons. These holes, because they represent an absence of an electron, make the "extra electrons" from the N-type silicon move towards this side of the apparatus.

By themselves, N-type and P-type silicon are electrically neutral. There is no large movement of electrons, and the number of protons in each atom matches the number of electrons for that atom. When the N-type and P-type silicon are placed in contact with one another, however, the free electrons move from the N- to the P-type silicon. The "holes" move from the P-type to N-type side. The place where this occurs is called the junction.

After a certain point, equilibrium is achieved and an electric field is formed. Because this equilibrium exists, it is harder for the electrons to move across from the N-type to the P-type side. Now electrons can only truly travel from the P-type to the N-type side. As a result, this junction acts as a diode.

When photons from the sun strike the cell, the electron flow is once more disrupted as electrons absorb energy from the photons. The electrons will now move from the P-type side to the N-type side. The "holes" will move to the P-type side from the N-type side. At this point, electrons will want to move to the P-type side, which is what happens before sunlight strikes the cell. Electrons will flow and generate a current. The electric field will be accountable for the voltage created by the cell.

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http://www.webelements.com

Current Research by Other Organizations

Inefficiency is a major problem in solar cells. Major electronics companies are continually doing research, trying to build newer ways to turn light into power and to improve the efficiency of existing solar technologies.

A new development in solar cell research is the triple junction solar cell. Traditional solar cells operate by absorbing light of a certain wavelength. This limits the amount of energy that can be absorbed by the cell. To make a triple junction solar cell, various semi-conducting materials are layered on top of each other. The result is a three-layer solar cell. The top layer absorbs one color of light, while the middle absorbs another color of light, and the bottom another color. This method allows for about 41% efficiency solar cells, doubling the efficiency of standard solar cells. Cells like these are predicted to be out on the market within twelve months. However, multi-junction cells are very expensive, at $40/cm^2.

A new coating has been produced that increases the efficiency of older solar cells by reducing the reflection of sunlight. By reducing the reflected sunlight, a higher concentration of sunlight is absorbed by the solar cell, increasing the power output of the cell. Layering various materials, gradually decreasing the index of refraction between each layer, produces the coating. This layering results in a reflection of as little as .01%, increasing solar cell output by 5% to 10%.

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Wiring Solar Cells to Obtain Maximum Power Transfer

Below we present a method for wiring solar cells of a given internal resistance in a grid pattern so as to transfer maximum power to a load resistance. We also discuss further topics that we shall be researching in this field.

An important consideration that must be taken into account when using solar cells to power any device is that solar cells in a general sense act like real batteries. They can be modeled as consisting of a source of electromotive force and an internal resistance .

One can think of the electromotive force as a charge pump: as charges flow through the circuit, they are brought from a lower electric potential to a higher electric potential as they pass from the negative to the positive terminals of the battery. A charge carrier at a higher potential has the ability to do more work than a charge carrier at a lower potential. The electric potential is analogous to the height on a hill at which a tank of water is stored. The higher the potential, the greater the energy of the water when it reaches the bottom of the hill; the energy this water has can then be used to power a waterwheel for some application. A resistor having an internal resistance indicates that there is a resistance to the flow of charge in the circuit at the battery; the electrons cannot flow freely through the battery without exerting some energy to do so.

Because we are concerned with powering some device with solar cells, we define the load resistance R (Figure 3) as the resistance that the said device exerts in the circuit. As charges flow through the device, their electric potential decreases. Of concern is the wiring of the solar cells in a circuit to deliver the maximum amount of power to the load resistance, i.e. to match the power required for the given load resistance. We must not send an amount larger than required; e.g. if you send too much power to a light bulb, it will burn out. This task is roughly on the same level as optimization problems from algebra II or calculus: given a set of constraints, find a way to maximize a specified quantity. The quantity power P is given by the formula $P = \varepsilon^2R/(R+r)2$. When this curve is graphed, as P in terms of R, a curve arises similar with a definite maximum at the specific load resistance of R*. It can be shown using calculus that the value of R* that achieves this maximum power is when R* = R = r.

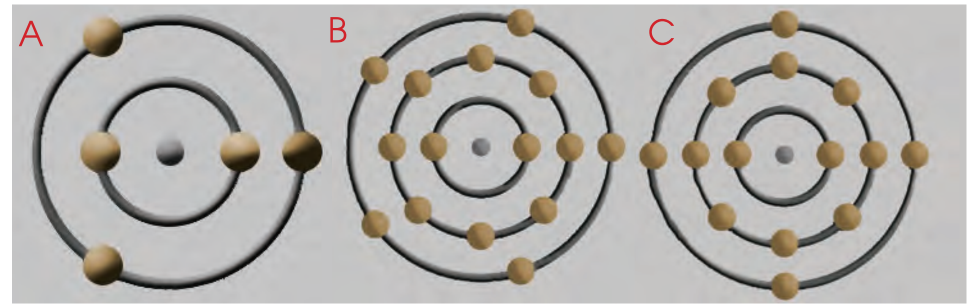

Figure 2: (A) Boron, (B) Phosphorus and (C) Silicon

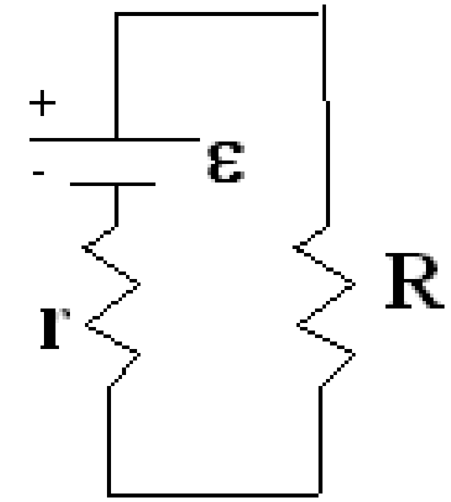

Figure 3

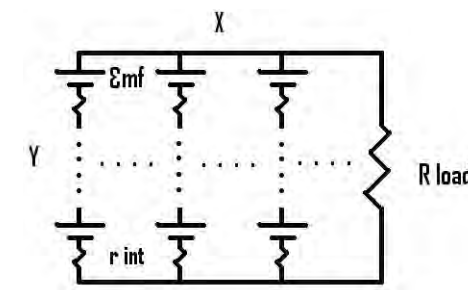

Figure 4

Finding the Setup for Maximum Power Transfer

We assume that we have no prior constraints on the number of solar cells we can use and that they all have the same electromotive force Emf and internal resistance rInt. We also take the power required by the load and the resistance of the load Rload as given. Our circuit is then set up as in Figure 4, with ySeries representing the number of solar cells in series per column and xParallel representing the number of columns in parallel.

We can make a grid of (ySeries)(xParallel) solar cells act as one large solar cell with an equivalent resistance Rload even if rInt does not equal Rload already. The solar cells put in series, the ones in each column i.e. one behind the other, essentially increase the equivalent resistance of that column from rInt. Putting the columns in parallel, i.e. side by side, essentially decreases the equivalent resistance of the equivalent large solar cell from the equivalent resistance of each column.

Through our calculations we showed that the optimum setup is defined by: Pdelivered = (Emf^{2}RloadxParallel^{2}ySeries^2) / (RloadxParallel + RIntySeries)^2 where Pdelivered is equal to the power required by the load.

Because the net internal resistance must equal the load resistance, (Rload)(xParallel) must equal (rInt)(ySeries), and we can say that: ySeries = 2√(Pdeli)√(Rload) / Emf; xParallel = 2√(Pdeli)rInt / Emf√(Rload).

Because the values of ySeries and xParallel may not necessarily be whole numbers as calculated, we considered several worst case scenario issues with rounding the values up or down by .5. Our analysis was made assuming an unlimited quantity of solar cells, but real world constraints may complicate this. We think that, for a given number of solar cells, we must configure the circuit to achieve as high a value on the original Pdelivered curve as possible, but further investigation is needed.

Because ySeries for the optimum setup depends inversely on the Emf of the solar cell, if the power delivered and load resistance values are rather large compared to the Emf, ySeries will be very large. We found that for our 1V solar cells and the goal of powering a normal household appliance, the setup would be impractical, requiring hundreds of solar cells.

Further Topics of Inquiry and Research

One problem is taking into account real world constraints such as the aforementioned maximum number of solar cells. We still have to investigate if this will affect our current approach significantly. Another real world issue would be if one or several of the solar cells or their connections shorted or broke; we could investigate if there are ways to mitigate the loss of the solar cell on the overall circuit because the broken solar cell will act as a higher resistance than rInt. There may be ways to make the circuit still work fairly well at this degraded level, such as bypassing that specific cell, etc.

An option that we have now is to construct a small electronics-scale type circuit using small light bulbs with the goal of showing that the brightness of the bulb does indeed depend on the arrangement of the grid of the small electromotive force solar cells we have. We have done some preliminary tests with various arrangements of ten solar cells and an LED and have verified that there is a noticeable difference. We now plan to quantify and document this data using more controlled conditions, because the intensity of the light and the temperature in the environment effect the operation of the solar cell. Also, given the large solar cell that powers the donated fan we received, we could find if the manufacturers matched the internal resistance of the solar panel to the load resistance of the motor. If they have not, we might be able to insert a grid of regular resistors between them to equate those resistances in the hopes of powering the motor better using the given solar panel.

We attempted to measure the internal resistance of one of our 1V solar cells for a given light source, but we kept finding rather high internal resistance values. We learned from article 2 given to us by Dr. J. Perreault that measuring the internal resistance is not a straightforward task; there is an actual maximum power point for the solar cell itself, and the internal resistance for a solar cell changes non-linearly depending on the light intensity. Two methods were presented to find this maximum power point, one using harmonics and one using a recursive method; we need to determine which we shall use for our measurements. We also would like to better quantify the performance of the solar cell, given the light intensity and temperature, so as to better calculate the internal resistance in terms of those quantities.

We would also like to define an efficiency regarding this problem; we would like to quantify how below the maximum power for the grid effects the performance of the load. This efficiency quantity could then help us determine how to operate under the constraints of a specified number of solar cells. How necessary is it for us to operate with matching resistances?

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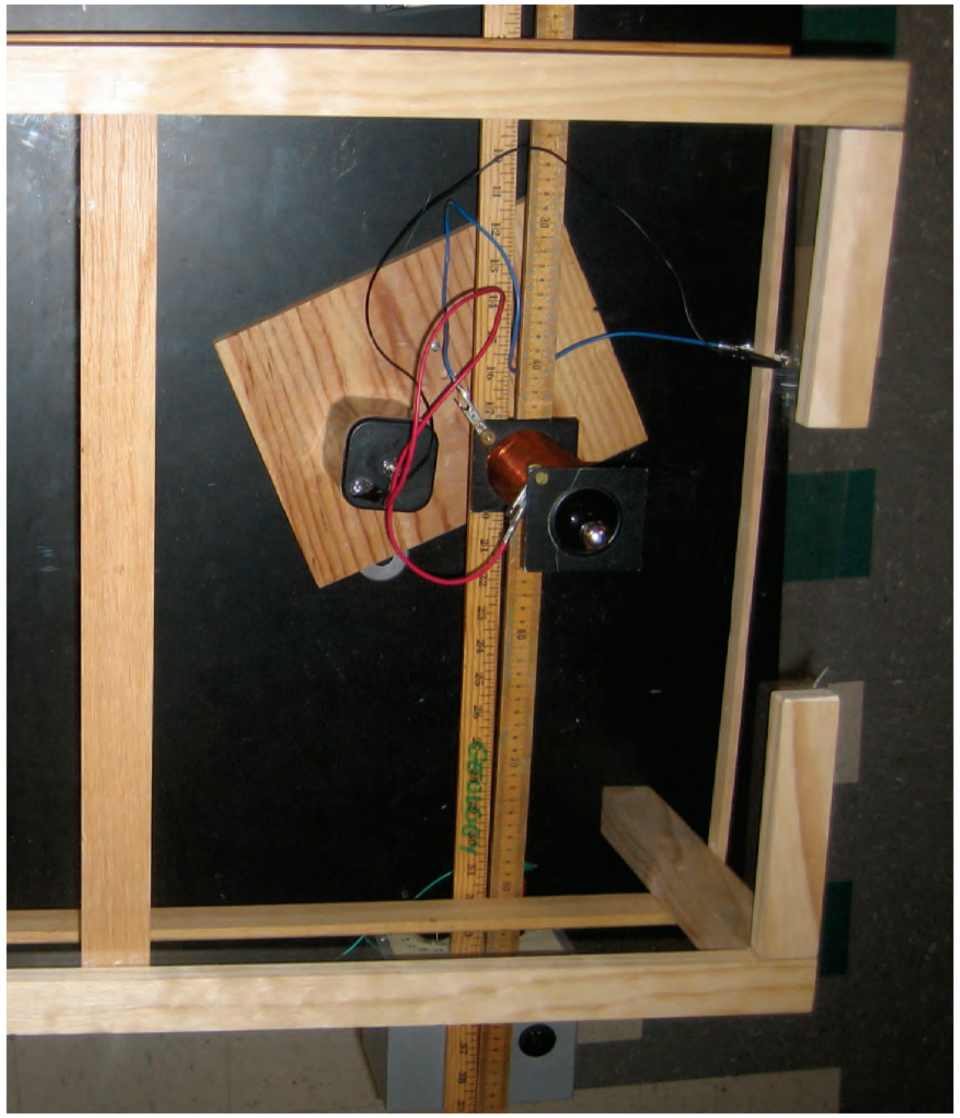


Game time

Taking air hockey to a new level

By Marc Firestein, Matt Kremer and Jerry Porter

ELECTROMAGNETIC "AIR HOCKEY" consists of an acrylic table, electromagnets, and a metallic sphere. Utilizing the ability to switch circuits on and off at will and the properties of electromagnetic induction, we can create and control magnetic fields. We can thus move a sphere in a game that also resembles foosball.

Introduction

We were intrigued by the possibilities that switches in circuits present. The application of switches is quite powerful; the ability to control current opens up a world of possibilities.

We considered combining circuits and electromagnetism when we began a side investigation experimenting with solenoids and the lowest energy potentials of combinations of magnets in them. This enlightened us to the power of creating magnetic fields with switches. Being big players of table sports games, we came up with our game: Electromagnetic "Air Hockey."

The Physics

This project, more than anything, tested our ability to engineer the model. The physics is fairly simple, but applying it to achieve our goal was a little bit more complicated.

A solenoid is a tube of material with a large number of tightly wound coils of wire around it, with two ends through which to run direct current. There exists a known relationship between electric current and the magnetic field a solenoid creates: $B=\mu_0 nI$, where μ_0 is the permittivity of free space constant, n is the number of turns per unit length, and I is the current. However, there was a major issue with our plan: solenoids create this field primarily inside of the tube, and the field outside diminishes rapidly with respect to distance.

There was a solution, however. By placing a ferromagnetic bar (a bar that can be magnetized) inside the solenoid, the magnetic field inside the solenoid magnetizes the bar. The bar, then, acts as a standard magnet, thus extending the field beyond the solenoid. Since a switch can stop and start the current at will, we can also stop and start the magnetic field when desired.

One problem not yet encountered that is possible occurs from the fact that ferromagnetic materials will eventually maintain some magnetism. However, fixing this problem would simply require replacing the bars.

The Design

The table on which the game is played, built with the help of Max Gindi, is a combination of acrylic and wood. A 24" by 36" plate of 0.25" thick acrylic rests upon a wooden frame. The frame, supporting the perimeter of the plate, is raised by four 12" high legs. A wooden perimeter also exists on the top of the plate to keep the ball in play, with two 7" wide holes in this perimeter serving as goals.

In our plan, the solenoids rest just underneath the table; however, this poses two questions: how do we move the solenoids naturally, and how do we make a system that allows for free flowing play? After trial and error, we found with solutions for both issues. By using mechanical joysticks that attach to the electromagnets and run through a ball joint, and on which the entire circuit is contained, the electromagnets can move in two dimensions smoothly. These joysticks are PVC pipe that extend as far as one needs to move the electromagnet. Then, by using momentary push button switches, the current can be turned on and off by holding down the switch. Imagine a joystick with a trigger; if the trigger is held down, the current runs, but once the trigger is released, the current stops.

Our current design gives each player one electromagnet joystick, which is constrained to movement on that player's half of the table to prevent collisions. However, changes in the number, strength, and configuration of the electromagnets could improve gameplay. Our table is a prototype, but improvements are definitely possible. Maybe a project for a 2008 DSSR student? ■

PHOTOGRAPH BY Matt Kremer

Fuel for thought

Understanding hydrogen vehicles

By Matt Kremer and Marc Firestein

HYDROGEN VEHICLES run on hydrogen fuel cells, the concept of which was first discovered by Christian Friedrich Schonbien in 1838. Five years later, the first rudimentary fuel cell was made by Sir William Robert Grove. However, fuel cells were not put to important use until the space age, when they were used to produce both electricity and water on space shuttles. It was not until very recently that fuel cells were first produced commercially by United Technologies.

There are four major components to the basic hydrogen vehicle (Fig. 1). First is the fuel tank (1), which holds compressed pure hydrogen, either in liquid or gaseous form. Second is the fuel cell stack (2), which is equivalent to the internal combustion engine in a gasoline vehicle. There are anywhere between 150 and 200 fuel cells stacked together in order to obtain enough power to make the vehicle run. The electricity travels to the third component, an electric motor (3), which converts the electricity to the mechanical energy that propels the vehicle. The final component is a battery pack (4), which acts similarly in some ways to the engine in a hybrid vehicle. Part of the electricity from the fuel cell stack is stored in the battery to be released when rapid acceleration and extra power are desired.

Hydrogen cells create electricity by capturing the energy released in the exothermic chemical reaction: 2H2 + O2 => 2H2O

Hydrogen atoms consist of one electron and one proton. The fuel cell splits these at the anode. The protons are then able to pass through a polymer membrane to the cathode. The electrons cannot pass through and travel through a wire to the cathode, creating an electrical current.

Hydrogen vehicles have many positive attributes which make them appealing to society, which is why so much research is being done in an attempt to make them affordable to consumers. First, hydrogen power is completely clean; its only emission is pure water, so it does not harm the environment at all. Also, hydrogen cars are more practical than other alternative energy vehicles being researched or already on the market.

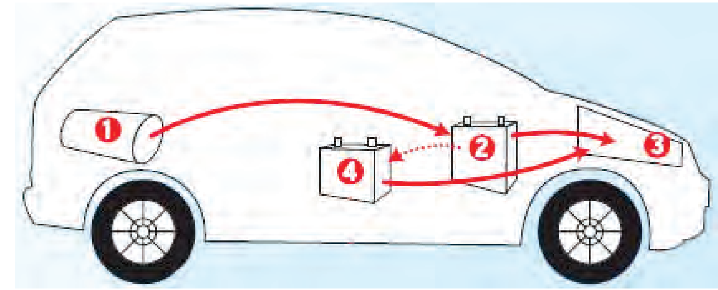


Figure 1

For example, a tank of hydrogen will last for a distance comparable to a tank of gasoline, whereas pure electric vehicles have a much shorter range before they need to be recharged.

With such positive attributes helping to fix critical global problems, one might ask why hydrogen vehicles are not being commercially produced. The answer is that hydrogen vehicles cannot yet be produced cost efficiently; for example, the Honda FCX, which has minimal features beyond those of a basic car, has a production cost of over $100,000. Hydrogen vehicles are expensive because hydrogen cells are expensive, for two main reasons. First, hydrogen cell materials, especially the polymer membrane, and production processes are expensive because of the complicated nature of fuel cells. Single fuel cells are not cheap as is, and a single vehicle needs 150 to 200 medium size cells to have enough power to run. Further, the fuel efficiency of hydrogen cells decreases as power increases. Thus the cost of increasing the potential power output of the fuel cell stack, and therefore increasing the horsepower of the vehicle, becomes increasingly multiplied with each additional desired horsepower. In addition, hydrogen cells are extremely fragile, and, if hit in an accident, would be easily destroyed; thus necessary protection compounds the issue of expense.

Another major engineering issue that is critical to the hydrogen car is safety. Hydrogen cars presently run on highly pressurized hydrogen gas mounted in canisters. If the canisters crack in an accident, or through ordinary wear and tear, the ensuing combustion from the dispersed hydrogen could cause a large, invisible fire, a property of hydrogen-heavy combustion. In addition, the rush of hydrogen from a tank with a pressure of 5000 psi could push a car far off of the road, leading to other obviously negative outcomes.

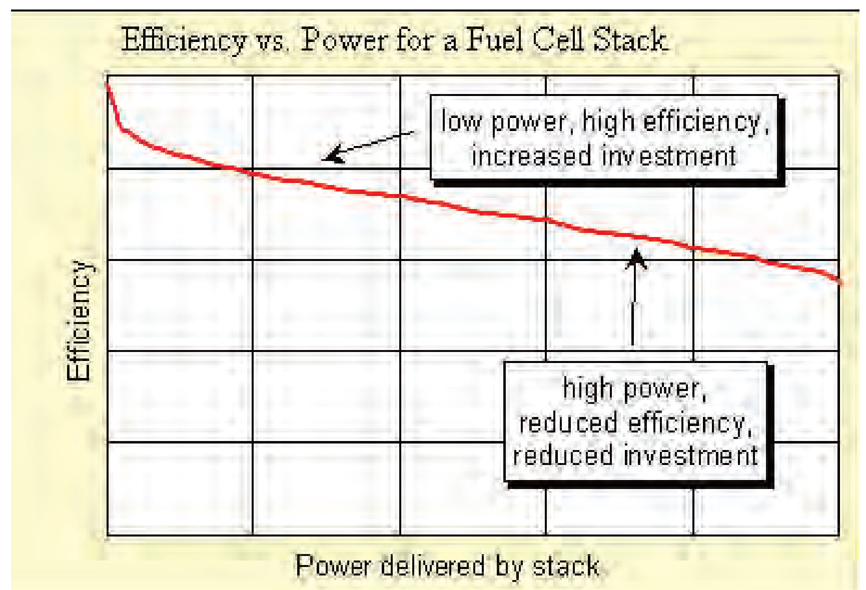


Figure 2

One potential solution could improve the existing model: electrolysis. This process utilizes electricity to split water into hydrogen and oxygen, which would be stored in somewhat smaller, safer tanks. The hydrogen cell stack would recombine the two and convert the chemical energy to mechanical energy. Refueling would be similar to that of an electric vehicle. The vehicle would be plugged in to an electric source to perform the refueling process of electrolysis; however, certain drawbacks of the electric vehicle, such as necessity for frequent charging and reduced power, would be eliminated. Furthermore, using pure oxygen instead of air would increase the efficiency of the cell.

While the hydrogen car seems to have quite a few positive values, its drawbacks seem to make it a dangerous, inefficient model. Nevertheless, possibilities like electrolysis and advances made in the last generation point to this style of power being the future of vehicular movement. ■

Zeroes and ones

Frequency distributions and ciphers

By Carlee Joe-Wong

MONOALPHABETIC SUBSTITUTION CIPHERS are predecessors of enciphering messages by replacing each letter with another, often using some kind of algorithm. This turns a coherent message, called the plaintext, into the ciphertext, which means nothing unless the reader converts the ciphertext back to the plaintext. Ideally, only the intended recipient can perform this conversion; however, almost all monoalphabetic ciphers can be solved without knowledge of the enciphering algorithm.

Over the years, cryptanalysts have established a fairly systematic method of decipherment that relies on frequency analysis. After computing the frequency of each letter in the ciphertext, the cryptanalyst compares these frequencies to the known average frequencies of letters in English writing and thus identifies, at least tentatively, the plaintext letters that correspond to the ciphertext ones. While this method is extremely useful in starting to guess letter identities, letter frequencies vary, and the degree of their variation is obviously relevant to a cryptanalyst using frequency analysis. In this paper, I examine the degree of frequency distribution variation between different samples of text, and conclude from my analysis that monoalphabetic frequency distributions are in general quite uniform. However, individual frequecies and the letters corresponding to the relative frequencies (most frequent, second most frequent, etc.) can vary a good deal.

General Method

Before any analysis could be performed, samples of text had to be gathered from a variety of sources to generate twenty-five unique text samples, which were then numbered from 1 to 25, with at least three-hundred and fifty characters. The occurrences of all twenty-six letters in each sample were found using a program in Maple and divided by the number of characters in each sample after discarding numerals, spaces, and punctuation, to get each letter's percent frequency. The matrices in Figures 1-3 show the resulting data up to sample 10 (see "Explanation of Figures.")

Percent Frequency Analysis

To investigate the overall difference in total frequency distribution between samples, percent frequencies of each sample are compared to every other sample's by subtracting the relative percent frequencies (the greatest percent frequencies from each other, the second greatest percent frequencies from each other, etc.) to find the frequency distribution, or FD. The absolute values of these differences were then added to obtain the total frequency difference (total FD), a number representing the variation in overall frequency distribution between the two samples of text.

This analysis yielded a set of three hundred total FDs, whose values are plotted on the three-dimensional plot shown in Figure 4. The numbers of the two texts are the x- and y-values and the total frequency difference is the z-value, ranging from approximately 0.0651 to about 0.255 with a mean value of 0.128. Thus, the average FD per letter between two samples of text, calculated between letters of the same relative frequencies, is only 0.128/26, or 0.00491. Because the relative frequencies are being subtracted from each other to obtain the total FD, varying frequencies can be ignored in calculating the average FD; the difference between the largest frequencies and between smallest frequencies should be of the same general magnitude. Admittedly, the greatest total FD, produced by samples 14 and 19, is more than twice the mean total FD at 0.255, which yields a relatively high 0.00981 average FD per letter. However, this is a fairly isolated value, and irregularities should be expected from a sample of only twenty-five texts. 0.00981 is also significantly less than $(1-{}^{1}/_{26} + {}^{25}/_{26})/26 = 0.0740$, the maximum possible average FD per letter; in fact, 0.00981 is 86.7% of 0.740 and 0.00491, the average FD per letter, is 93.3% of 0.740. Thus, most samples of text appear to have fairly uniform frequency distributions overall.

The general uniformity of frequency distributions partially carries over to individual frequencies; the FD between two letters of the same relative frequency is generally similar to the average FD, especially in letters of lower frequency. The maximum FD between the letters of any two samples is 0.049, between the most frequent letters in samples 7 and 14. The FDs between letters of the thirteen lowest frequencies, however, are more reasonable; the maximum is 0.0144. However, these large FDs were clearly moderated by the other letters in the text samples, since the maximum average FD per letter found between two samples was only 0.0098. The average maximum FD between letters of the thirteen greatest frequencies is 0.280; it is 0.00946. Thus, though frequencies vary widely among individual letters, especially among the letters of greater frequency, the overall frequency distributions between two samples of text are in general relatively consistent.

Because of the relatively large range of total FDs, I then analyzed the ten pairs of texts with the greatest and the ten pairs of texts with the least total FDs to determine whether specific samples of text caused the abnormal results. Text samples 2, 14, 19, and 24 occurred at least twice in the pairs of text with the greatest total FDs, with 19 by far the most common, occurring 35% of the time. Since sample 19 therefore caused 70% of the abnormally high total FDs, one can probably assume that, in general, total FDs are not as pronounced as, for instance, 0.255, from samples 19 and 14. The ten least total FDs were produced by fourteen samples in all, indicating that these lesser total FDs are not caused by texts with abnormal frequency distributions. Thus, frequency distributions may well be more uniform than indicated in the previous paragraph.

There are clearly too many letter possibilities for a cryptanalyst to rely completely on frequency analysis.

The graph in Figure 4 clearly shows the wide range of total FDs in my data, with "peaks" and "valleys" representing extremely high and low total FDs respectively. One can see that several of the "peaks" occur in a straight line, when the y-value is held constant. This value is 19, and the occurrence of so many peaks at y=19 visually demonstrates that sample 19 is responsible for several of the largest total FDs. Most of the "valleys," however, or the lowest total FDs, seem to be spread throughout the graph, just as the lowest total FDs come from a wide range of samples. The graph also supports my conclusion that frequency distributions are relatively uniform, since most of the z-values, or total FDs, appear to be around 0.15 or less.

Figure 1: 13 Greatest Percent Frequencies in Descending Order

Sample 1	0.114	0.0677	0.0609	0.0609	0.0582	0.0582	0.0568	0.0528	0.0487	0.0419	0.0352	0.0284	0.0244
Sample 2	0.135	0.0805	0.0725	0.0725	0.0692	0.0692	0.0676	0.0628	0.0580	0.0499	0.0419	0.0338	0.0290
Sample 3	0.111	0.0705	0.0690	0.0564	0.0549	0.0533	0.0533	0.0439	0.0360	0.0329	0.0282	0.0266	0.0266
Sample 4	0.120	0.0957	0.0855	0.0841	0.0812	0.0797	0.0638	0.0565	0.0522	0.0435	0.0333	0.0333	0.0275
Sample 5	0.133	0.0844	0.0793	0.0793	0.0793	0.0639	0.0614	0.0512	0.0460	0.0409	0.0332	0.0332	0.0332
Sample 6	0.139	0.0854	0.0784	0.0756	0.0728	0.0672	0.0658	0.0616	0.0602	0.0462	0.0420	0.0294	0.0252
Sample 7	0.100	0.0952	0.0940	0.0879	0.0842	0.0781	0.0635	0.0501	0.0464	0.0440	0.0403	0.0317	0.0317
Sample 8	0.119	0.0883	0.0834	0.0761	0.0736	0.0699	0.0650	0.0650	0.0552	0.0540	0.0344	0.0307	0.0307
Sample 9	0.137	0.0953	0.0913	0.0819	0.0725	0.0685	0.0617	0.0523	0.0456	0.0430	0.0403	0.0349	0.0349
Sample 10	0.104	0.100	0.0905	0.0865	0.0689	0.0676	0.0608	0.0541	0.0514	0.0473	0.0324	0.0324	0.0284

Figure 2: 13 Lowest Percent Frequencies in Descending Order

Sample 1	0.0203	0.0176	0.0176	0.0162	0.0162	0.0135	0.0135	0.0108	0.00541	0.00135	0	0	0
Sample 2	0.0242	0.0209	0.0209	0.0193	0.0193	0.0161	0.0161	0.0129	0.00644	0.00161	0	0	0
Sample 3	0.0251	0.0219	0.0219	0.0157	0.0141	0.0141	0.0125	0.0094	0.00627	0.00470	0	0	0
Sample 4	0.0261	0.0217	0.0188	0.0188	0.0159	0.0159	0.0101	0.0101	0.00435	0.00145	0	0	0
Sample 5	0.0307	0.0281	0.0281	0.0205	0.0153	0.0153	0.0128	0.0128	0.0102	0.00512	0.00256	0	0
Sample 6	0.0252	0.0238	0.0224	0.0182	0.0154	0.0140	0.0126	0.0084	0.00420	0.00420	0.00140	0.00140	0
Sample 7	0.0305	0.0220	0.0183	0.0159	0.0159	0.0122	0.0122	0.0122	0.00855	0.00244	0.00122	0.00122	0
Sample 8	0.0270	0.0221	0.0209	0.0196	0.0172	0.0135	0.0123	0.0110	0.00736	0.00245	0.00123	0	0
Sample 9	0.0268	0.0228	0.0161	0.0161	0.0134	0.0121	0.0107	0.0094	0.00805	0.00134	0.00134	0.00134	0.00134
Sample 10	0.0257	0.0243	0.0230	0.0216	0.0203	0.0149	0.0135	0.0122	0.0108	0.00405	0.00270	0.00135	0.00135

Figure 3: Letters in Descending Order of Frequency

Sample 1	E	N	I	O	A	L	S	T	H	D	R	U	G	C	F	Y	B	P	K	M	W	V	Q	J	X	Z
Sample 2	E	N	I	O	A	L	S	T	H	D	R	U	G	C	F	Y	B	P	K	M	W	V	Q	J	X	Z
Sample 3	E	S	A	T	N	I	O	H	R	L	C	M	U	D	G	P	V	B	Y	F	W	K	X	J	Q	Z
Sample 4	E	T	N	I	S	O	H	A	R	L	C	F	D	U	P	M	Y	G	W	B	V	K	J	Q	X	Z
Sample 5	E	A	I	N	T	O	S	L	R	P	F	H	U	C	B	D	M	G	W	V	Y	K	X	Z	J	Q
Sample 6	E	O	A	I	S	N	T	R	L	H	D	C	P	W	M	U	V	B	F	Y	G	K	X	J	Q	Z
Sample 7	E	N	A	S	I	T	O	R	D	H	L	C	G	U	M	P	W	Y	B	K	V	F	Q	J	X	Z
Sample 8	E	T	A	O	H	S	I	N	R	D	M	L	U	C	Y	P	F	W	G	V	B	K	X	J	Q	Z
Sample 9	E	T	I	N	A	S	O	H	R	C	L	D	U	G	F	B	M	V	Y	W	P	Z	J	K	Q	X
Sample 10	E	T	A	I	O	N	H	L	R	S	D	W	U	C	M	G	F	Y	B	P	V	K	J	Q	X	Z

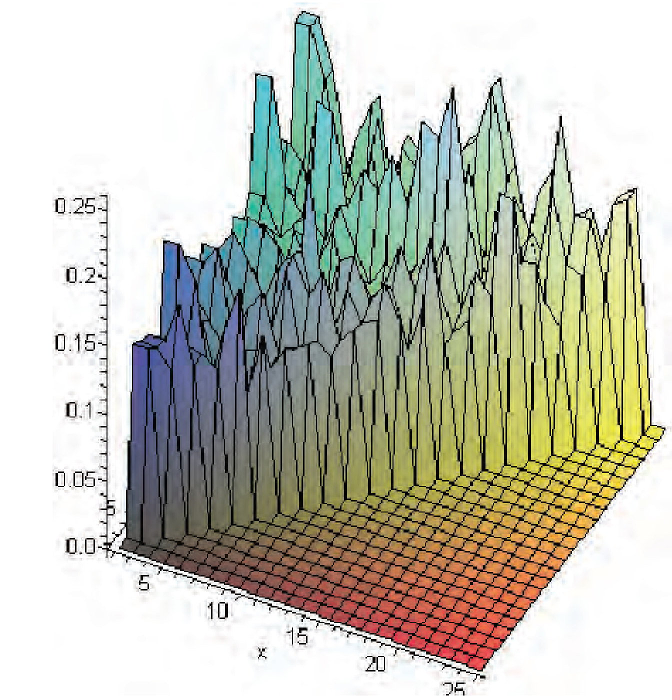


Figure 4: Total Frequency Difference Between Samples (z) as a Function of Sample Number (x, y)

Direct Application to Cryptanalysis: Letter Analysis

Although a study of the variation in total frequency distribution between samples of text is interesting to a cryptanalyst, it becomes useful only when frequencies of individual letters are analyzed. Comparison of the letters in each column of Figure 3 should give a good indication of frequency analysis' accuracy; for example, if one letter is almost always the most frequent, a cryptanalyst could reasonably assume that the most frequent letter in a given ciphertext represents that letter. This is in fact the case; in 24 samples of text, "E" is the most frequent letter.

The results become somewhat more varied in the next columns; while "T" is generally the 2nd most frequent letter, "A" and "O" combined make up 28% of the elements in the second column of Figure 3. This increased diversity of letters continues and increases slightly throughout the other columns. For example, in the 13th column of Figure 3, the two most common letters, "U" and "F," occur almost the same number of times, and "G" and "P" combined make up 24% of the elements in the column. In some columns five or even six letters appear more than twice and up to seven letters more than once. While even seven is significantly less than the twenty-six letters of the alphabet, showing that there are definite trends for a certain letter's relative frequency, there are clearly too many letter possibilities for a cryptanalyst to rely completely on frequency analysis in deciphering a message.

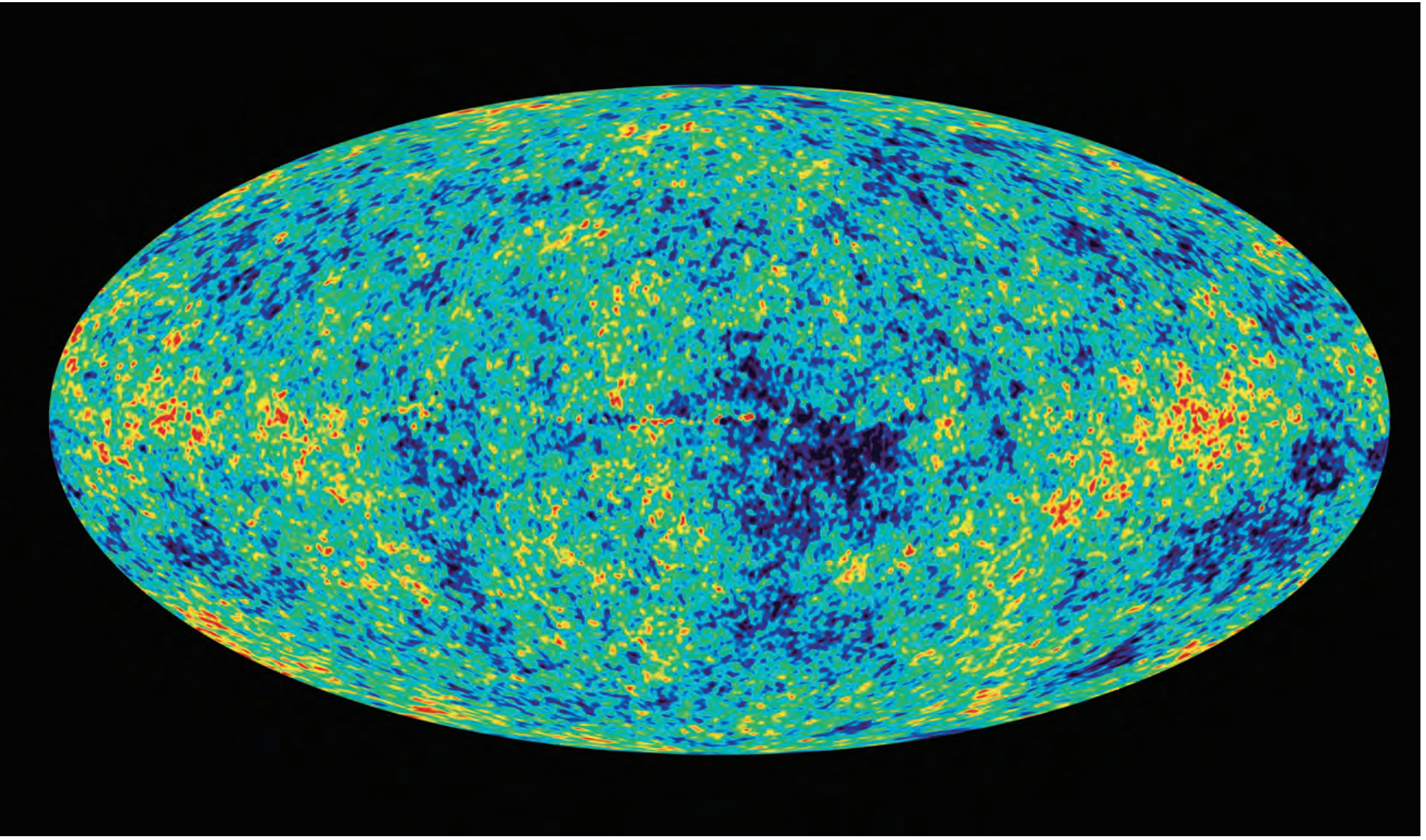
Conclusion: Other Applications

As stated above, overall frequency distributions, provided letter identities are not considered, are fairly uniform in two given samples of plaintext or monoalphabetic ciphertexts (if they are sufficiently long). This principle is particularly useful in another area of cryptanalysis, solving polyalphabetic Vigenère ciphers. The general method of Vigenère encipherment is to encipher every nth letter with a different sequence of letters, where n = 1,2,3...x and x is the length of a chosen keyword. Thus, the frequency distribution of a Vigenère ciphertext, or in fact any polyalphabetic ciphertext, would look very different from one generated by a monoalphabetic cipher, since one cipher letter would represent n plain letters instead of just one plain letter. The general uniformity of monoalphabetic frequency distributions would thus allow a cryptanalyst to determine whether a ciphertext is poly- or monoalphabetic, a very useful distinction since deciphering polyalphabetic ciphertexts is very different from deciphering monoalphabetic ciphertexts. The uniformity of monoalphabetic ciphers also suggests that ciphertexts using a given number of alphabets have fairly uniform frequency distributions, which is in fact the case. This principle is extremely useful in deciphering polyalphabetic ciphertexts; it allows the use of frequency distributions to determine the number of alphabets used in polyalphabetic encipherment.

Explanation of Figures

Figures 1 and 2 represent the 13 greatest and least percent frequencies yielded by all twenty-five samples respectively, sorted in descending order from left to right. Each row represents a different sample. Thus, the number in [8,9] of Figure 1 represents the ninth-greatest percent frequency of any letter in sample 8. In Figure 2, the number in [8,9] represents the twenty-second greatest percent frequency in sample 8. The zeros at the end of Figure 2 represent all letters that do not occur in a given sample. Figure 3 contains the letters corresponding to Figures 1 and 2. For example, the H in [3,8] of Figure 3 means that H's percent frequency in sample 3 is given by the number in [3,8] of Figure 1. All letters with a 0% frequency are listed in alphabetical order from left to right at the end of the row in Figure 3.

Figure 4 is a three-dimensional graph shown at an angle. The total FD is the z-value and the samples that yielded a particular total FD are the x- and y-values. For example, the z-value at x=3, y=4 is the total FD from the comparison of samples 3 and 4. Since comparing two identical text samples yields a total FD of 0, the z-values along the line x=y are all zero. In addition, the graph on one side of x=y is a reflection of itself on the other side. Therefore, I have only shown the z-values on one side of x=y to provide greater visual clarity. On the other side of the line x=y, the z-values are shown as 0. ■



A brief history of space

Finding answers in the cosmic microwave background radiation

***Adapted from a lecture given February 2007**

By Adam Gold

GERMAN ASTRONOMER HEINRICH WILHELM OLBERS formulated a paradox in 1823 that followed a long line of astronomical thought. If the universe is infinite, as we assume it to be, then why is the sky dark? If the universe is truly infinite, than every possible line of sight in the night sky should end on the surface of a star. It can be shown that if we were to draw a series of spheres around the earth, each sphere, containing a certain number of stars on it, would add the same amount of light to our sky. An infinite sum of spheres would mean a sky that was not only bright but infinitely so. Yet the night sky, even when there are no clouds, is mostly dark. Another explanation might involve cosmic dust or other particles (non-stars) that exist in the universe and block out the light, explaining why most of what we see is darkness. But thermodynamics states that nothing can continue to absorb radiation without eventually having to re-emit it. So this cosmic dust could only act as an intermediary between the stars and our eyeballs. Clearly this was not the answer.

Kepler believed the paradox was the foundation of an argument for a finite universe, or at least a finite observable universe, and he was only partly right. One of the most basic concepts in Cosmology is universal expansion. That is, about 13.7 billion years ago, the universe was extremely dense and hot and has been expanding and cooling ever since. Why do we think this is true?

It is a very radical idea, to think the universe expands. Students today learn it in elementary school, but for most of human history, nearly all scientists have believed the universe, at least once it was created, was static. The Greek scientist Aristotle, to whom we owe the scientific method, viewed heavenly bodies as perfect substances made of imperishable aether. Stars and planets were neither created nor destroyed, moving according to well-defined principles. Newton, too, believed that on a large scale, the universe must be static, and he also believed it was largely the same everywhere, irregardless of direction. The word scientists use for such independence of direction is "isotropic."

Even Einstein, the greatest physicist of the 20th century, was unsettled by the concept of a universe that was not static. In his theory of general relativity, was unhappy with his field equations because they would not lead to a static universe. So, he added a cosmological constant (literally the energy density of a vacuum) to the equations in order to force the universe to be static. Of course, he later called it the "biggest blunder" of his life. His equations had been right all along, and he didn't need the cosmological constant.

But even around the time of Einstein's greatest discoveries, there was growing evidence that the universe did indeed change over time. Some of the first observational evidence to support expansion came from Edwin Hubble, working at the Mount Wilson Observatory in Pasadena. His work involved the concept of redshift.

Redshift is quite literally, the shifting of electromagnetic radiation, typically visible light, toward the red end of the spectrum as it travels from the source to the observer. This will occur when an object is moving away from the observer as it emits light, similar to the Doppler effect, because the waves of light get lengthened and thus appear redder. (However, if the wavelength is already longer than red, redshifting will actually move it further away from red.) A redshift can also occur because the space itself through which the light travels is expanding, which has a similar lengthening effect.

Hubble noticed that spectra of light coming from galaxies and other distant astronomical objects appeared to be redshifted from what would be expected in laboratory conditions. This led him to conclude that there is a force moving galaxies (and by extension all objects) away from us. Since there was a direct correlation between the galaxy's distance and its redshift, data suggested an isotropic, (remember, the same in all directions) metric expansion. That is, the speed at which distant galaxies were moving away from us was proportional to their distance, otherwise known as Hubble's Law.

Hubble explained that the reason objects within our galaxy are not themselves expanding (in fact, the stars in the galaxy are not even moving apart from each other, which is why they are not really redshifted) is because objects within a galaxy are gravitationally bound—for them, the strength of gravity overpowers the strength of expansion. Thus, expansion can be though of simply as an increase in the space between galaxies.

Hubble's findings gave weight to the burgeoning Big Bang Theory, first proposed by a number of physicists during the twenties. If the universe is currently expanding, and there is no evidence of it having ever contracted, then we can follow that expansion backwards in time to an early universe that must have once been at an extremely high temperature, density and pressure.

Of course, the Big Bang theory does not explain what happened before this. Many scientists have given their opinions, ranging from a gravitational singularity to God. Furthermore, the idea of a Big Bang was hard for some people to swallow. If the universe had a beginning, it likely also had an end. The most common theory today about the ultimate fate of the universe is called the "Big Freeze," in which the universe keeps expanding, cooling all the while, until it is too cold to support life. Other theories have equally unsavory names such as the "Big Rip" or the "Big Crunch."

One way of getting rid of that pesky end that no one wanted to really think about was the Steady State Theory. Proposed in 1948 by Hermann Bondi, Thomas Gold, and Sir Fred Hoyle, it accepted universal expansion but found a way to keep the universe static. Although the universe clearly was expanding, the theory suggested that perhaps small quantities of matter would also be continually formed, so the overall density of the universe would remain constant. In so doing, they could happily conclude that the universe has always looked the same as it does today, and it will always look that way. Due to the rate of expansion, the amount of matter that would have to be constantly created would be small enough that we would not have to detect it.

Though they were proven wrong, the Steady State theorists actually helped another branch of astronomy. With only Hydrogen, Deuterium, Helium and lithium they needed a source for heavier elements, as fusion in normal stars can only create elements as heavy as Oxygen. They helped show that supernovae could a source for heavy elements, which eventually became an aspect of the Big Bang theory as well.

While the Steady State theory showed promise at the time of its inception, it didn't last very long. Quasars were first discovered in the late 1950s and had been conclusively shown by the 1960s to only be found at extreme redshift. This suggested, along with other evidence, that there was such thing as an "early" universe, one which looked very different from how it does today.

> *Even Einstein, the greatest physicist of the 20th century, was unsettled by the concept of a universe that wasn't static.*

But the best evidence in favor of the big bang theory was about to arrive. In 1948, the same years the steady state theory was proposed, a group of physicists had predicted that the base temperature of vacuum in the universe was above absolute zero, due to energy left over from the big bang. The proposal was largely ignored until the 1960s, when it was rediscovered by Robert Dickie and Yakov Zel'Dovich. In 1964, several of Dickie's colleagues at Princeton, David Todd Wilkinson and Peter Roll, decided to try to build a very powerful microwave detector (they called it a Dickie radiometer) to see if the universe really was filled with radiation just above absolute zero. If there was this remnant of the big bang that filled all of space, there was not any reason that they would not be able to detect it.

Before the Princeton experiment yielded results, Dickie received a phone call from Crawford Hill in nearby Holmdel Township, New Jersey. Arno Penzias and Robert Woodrow Wilson, working with Bell Labs, had also built a powerful radiometer, though they wanted to use it to conduct satellite communication experiments. However, their instrument had a small hiss in all directions that made it impossible for them to conduct their experiments, an excess 3.5 K antenna temperature that would not go away. Penzias and Wilson thought it was perhaps due to pigeons trying to roost in the antenna, and they went to great lengths to remove them. But the pigeons weren't the answer. They had discovered the Cosmic Microwave Background, as they and Dickie began to realize over the phone. Penzias and Wilson won the Nobel Prize in 1978.

The proponents of the steady-state model countered that the radiation might be coming from modern day sources, but, as repeated measurements of the CMBR showed it to be extremely uniform, these arguments were proven false. Universal expansion soon became the most widely accepted theory in cosmology.

So where exactly does the radiation come from? Remember that as we look out into the night sky, it is as though we are looking back in time. Since light only travels at 3 x 10^8 meters per second, the farther the light has to travel to reach our eyes, the longer ago it started its journey. We can only see back so far into the universe, up to a finite distance called the horizon length—past the horizon length it would take light from those objects more time to travel to our eyes than the history of the universe.

The farthest we can see back into the universe is called the surface of last scattering, and it is also the starting point of all CMB radiation we observe. Before about 380,000 after the start of the universe, everything was hot plasma, a nearly uniform cosmic soup of charged particles and photons. Radiation pressure kept mass from coalescing into denser chunks due to gravity, as it does today. Temperatures were so great, in fact, that electrons did not bind to atoms, and energy was not absorbed by matter as it is today but scattered, or re-emitted in a random direction, bouncing around the clumps of plasma. But when the temperature of the universe cooled enough that atoms were formed, a process called recombination, the energy was no longer scattered and continued to travel in the same direction as when it was last scattered, cooling with the expansion of the universe. »

Images from NASA and the WMAP Science Team

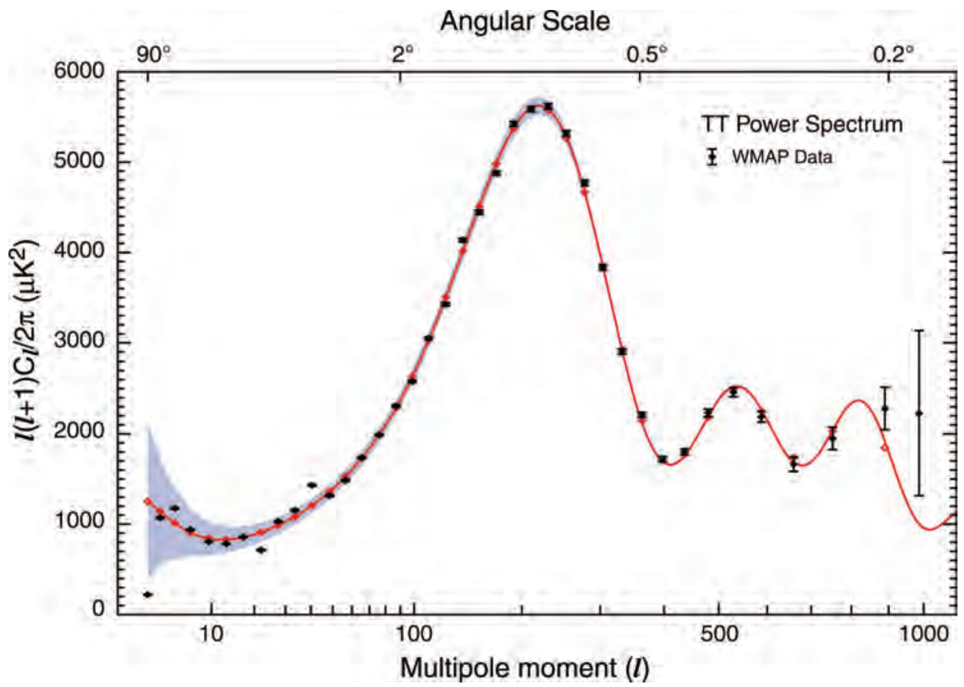
From the point of view of an observer, the surface of last scattering can be thought of as a sphere encircling that position at horizon length. We cannot see past the surface of last scattering the same way that we can't see sky through the clouds—because past the surface of last scattering (and therefore before the surface of last scattering) the universe was opaque to radiation.

Of course, to answer the question of when the photons of the CMB themselves were originally formed, you have to go even earlier back in time. In the first few seconds, temperatures were so extreme that particles and anti-particles were constantly being created and annihilated, with each annihilation creating lots of energy. However, once the temperature cooled enough so that the particles and anti-particles could not be created again from the energy, the energy was "stuck" in the universe, and it has been traveling and through it ever since, cooling with the expansion of the universe.

We know today that the Cosmic Microwave Background Radiation is uniform to 1 part in 100,000 and is extremely cold, comparable to the radiation emitted by a body at about 2.73 degrees Kelvin. Why so cold? As the universe has expanded and the radiation has been redshifted, it gets cooler and cooler, and will continue to do so as the universe continues to expand. When it was first released, 380,000 years after the big bang, it was at a temperature of about 3,000 K, which at about 4,090 degrees F, is pretty toasty. The CMBR is so uniform, in fact, that temperature differences in it can only be detected outside our atmosphere.

Even if the planet was not encased in atmosphere, it would be impossible to "see" the CMBR on the planets surface. The photons have been redshifted to the point that they are below the visible spectrum of light and are microwaves, around the same length as radio and TV waves. In fact, about 1% of the static you used to be able to see between TV channels before the age of cable was from the CMBR. If humans could see light in the microwave range, the night sky would appear to be bathed in a faint but extremely uniform glow in every direction. The photons are arriving at a rate of 10 trillion photons per second per square centimeter.

So what does the CMBR get us? Well, one application is to help discover the curvature of the universe. What does it mean for space-time to be curved? Well, here is an example. Two people living at the equator decide that they are tired of the heat and the rain and want to move somewhere cooler and drier. Not having traveled much, they both immediately decide on the North Pole. They start off 100 feet apart from each other and walk north, traveling in perfectly straight lines. They are quite surprised to find that they migrate closer and closer to each other as they approach the pole, and they collide just as they reach it, even though both were walking completely straight. What



This graph is a measure of the angular power spectrum as measured by WMAP from l = 2 to l = 1000. The measured data is shown in black.

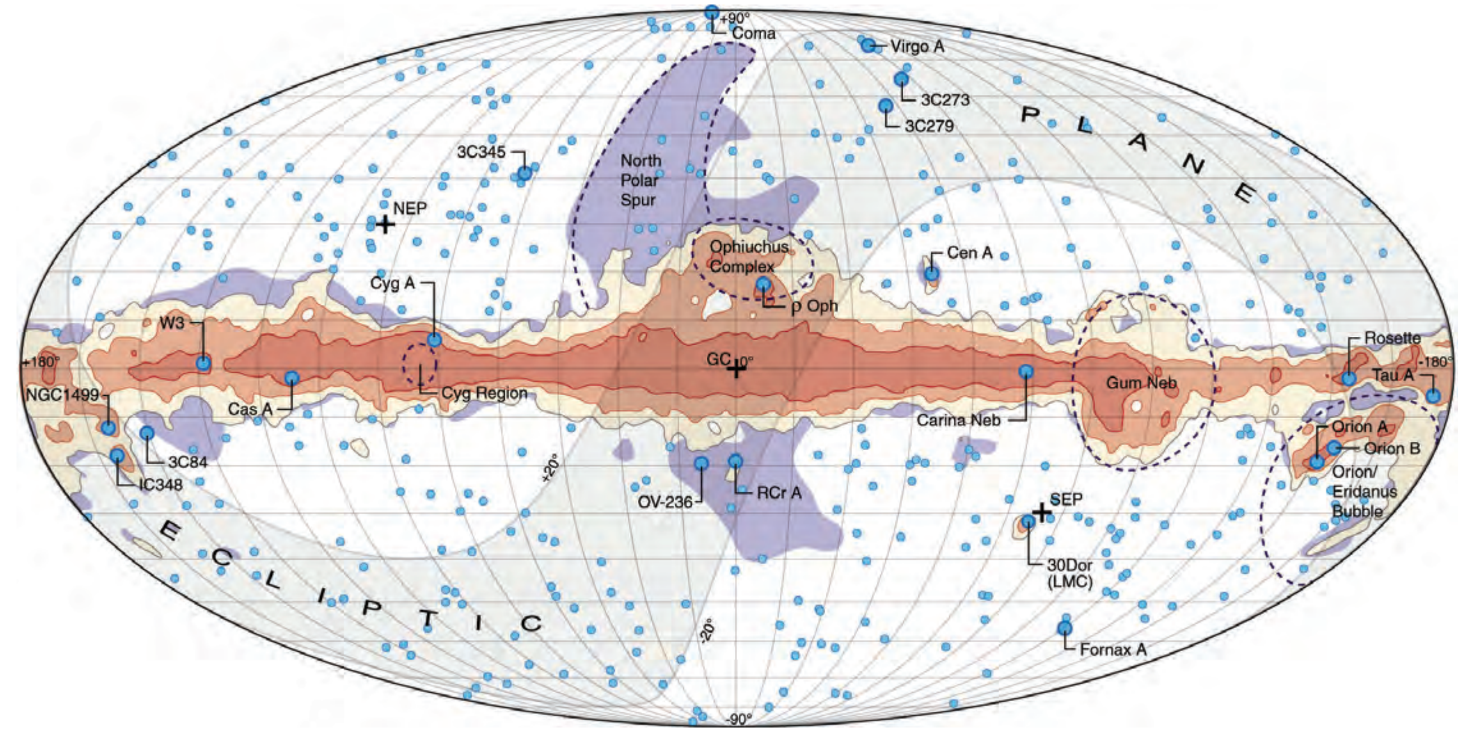
is going on? One proposes that maybe there is an invisible force pushing them together. The other says that no force is needed; their situation can be easily understood if the surface of the earth is curved. Before we praise the second as a visionary, let us consider our own ways of viewing the universe. We believe in an invisible force called gravity that pushes objects together, but this "force" could also be simply understood, as Einstein pointed out, if we simply accept that space-time itself is curved. That is, as we pursue an ostensibly straight course through space and time, matter causes a distortion that curves the path we take so that we move towards it.

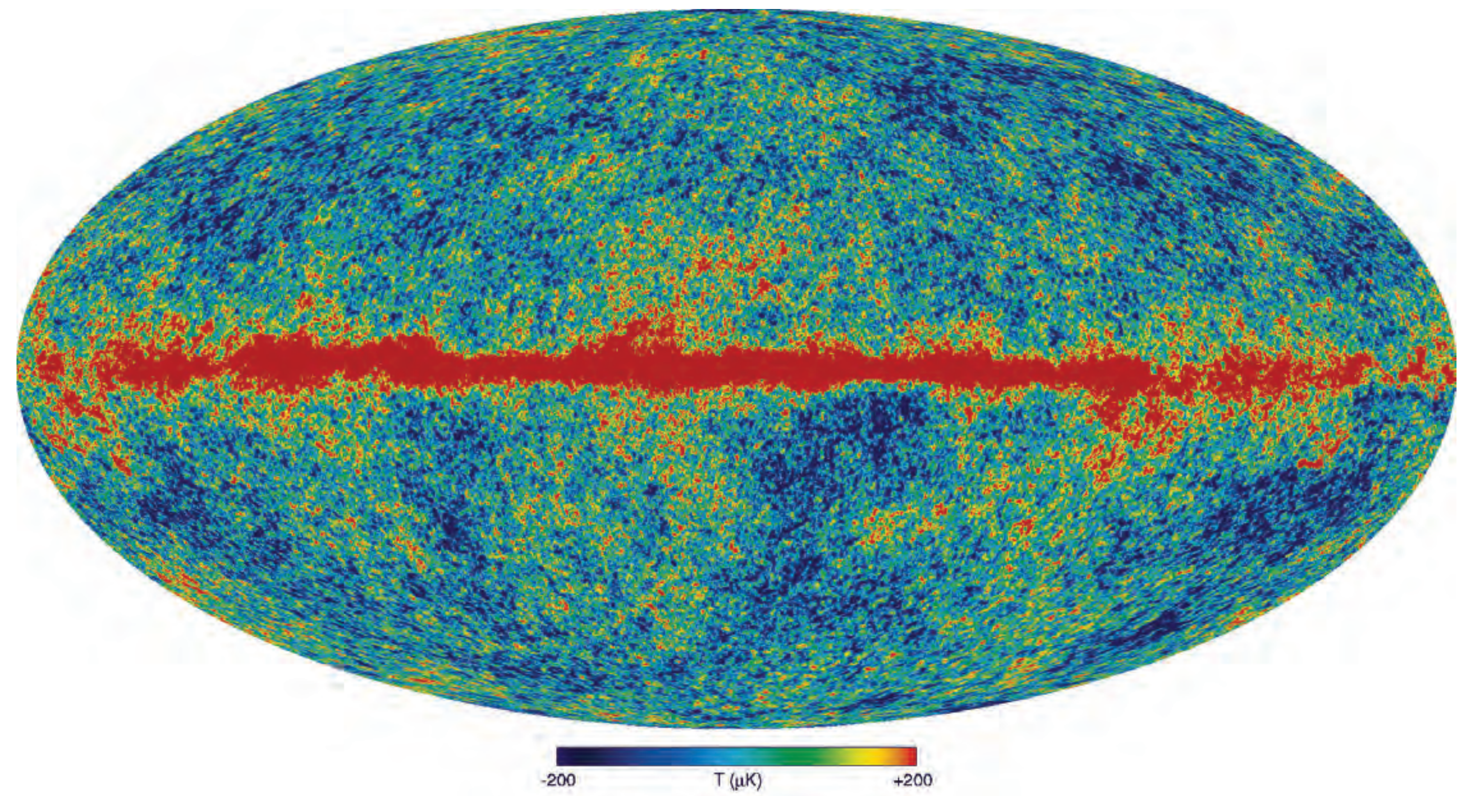
While we can think of matter curving spacetime in the local sense, scientists also wonder whether our universe is globally curved. One way they can find out is by studying the background. Cold spots on the background represent areas of greater mass way back when, because it would take more energy for the photons to escape these gravity wells on their way to our detectors. The hot and cold spots in the early universe can actually be thought of as sound waves—with the hot spots being compressions and the cold spots being rarefactions. Back then, all was plasma, so compression waves traveled through the universe like sound does through air. Since the background preserves things as they were a very long time ago, we can compare the size of these cold spots (the actual size) to the sizes of present day observable objects in space. The larger the curvature of the universe, the smaller the spots on the CMB will appear relative to the observed objects, because the universe acts like a lens.

Why is curvature important? Because the curvature of the universe determines its fate. If the universe is positively curved, meaning that the mass density of space is large enough to "close" the universe like a sphere, the force of gravity will be great enough to cause the universe to recollapse: the "Big Crunch." Or, if the mass density is too low, the universe will be hyperbolic in shape, and expansion will expand forever. CMB analysis has shown the universe to be very close to flat—meaning that it will continue to expand but asymptotically approach zero.

Of course, new research suggests the curvature may not be a good indicator of the fate of the universe after all, since expansion appears to be accelerating for reasons scientists don't understand. The term "dark" energy refers to the energy that is driving this acceleration, with the term "dark" referring to the fact that we can't seem to find it.

Another one of the many insights gleaned from the CMBR is a partial resolution to the horizon problem. We talked earlier of a horizon length—the farthest we can see based on the age of the universe. But if we follow that horizon sphere backwards in time, growing smaller and smaller, as we look for the origin of observed structures, the horizon eventually gets smaller than the structure itself. Therefore, nothing can explain how the different parts of the structure are causally connected. Unless, of course, we turn to inflationary theory, which posits that, shortly after the big bang, a new form of energy caused a brief, massive expansion of the universe—inflation. And inflation, as far-fetched as it seems, is supported by analysis of the CMBR. Remember the "sound waves" in the plasma of the early universe? Observations show that the waves, the primary sources of variation in the universe, were all





The top picture shows an overview of the microwave sky, where the yellow, red and salmon areas indicate an especially strong galactic foreground signal. The lower picture is a full-sky map of the W-Band (94 GHz), giving a relatively complete picture of the CMBR without much galactic foreground (shown in red). Both pictures were constructed by the WMAP Science Team using data from WMAP.

triggered at the same time, only possible if the universe began so small that it was causally connected in the moments immediately after the big bang.

So what about Olber's paradox? Did we solve it yet?

One explanation for why the sky is dark at night is that the universe has only been around for a finite amount of time. Light from stars that are an infinite distance away hasn't yet had time to reach us.

Astronomical redshift also suggests that each successive "sphere" of stars around the earth would contribute less light (and not the same amount as we predicted earlier), because radiation from farther objects is redshifted more, and thus brought down to a lower energy state. ■

Undersea evolution

The role of Zic1 transcription factor in neural crest development in lamprey

By Benji Uy

A CHARACTERISTIC TRAIT OF VERTEBRATES is the presence of neural crests at early embryonic stages. These migratory cells contribute to important developmental structures in vertebrates. Vertebrate chordates are the earliest phylum in which neural crest migration is found. Chordates are characterized by a notochord, a rod-like supporting structure that develops underneath the neural tube. Non-vertebrate chordates, such as cephalochordates (amphioxus) and urochordates (ascidians) are filter feeders and predate vertebrates. They lack a complex, vertebrate-like brain and do not have neural crest cells or neurogenic placodes (6). Thus, the "invention" of neural crest cells is attributed to early vertebrates and is considered to have provided the tools for their predatory lifestyle, such as a strong cranial structure, denticles, and a peripheral nervous system with new bilateral sensory organs.

Lampreys are basal jawless vertebrates whose lineage diverged from jawed vertebrates approximately 500 million years ago. Jawed vertebrates (gnathostomes) such as chick, frog and mouse appeared later in evolution and are typically studied as model organisms for neural crest investigations. Because the hagfish embryos (the only other jawless vertebrate group) are unobtainable, the lamprey presents a unique model to study the evolution of the neural crest in vertebrates.

Determining when gene mechanisms responsible for crest formation evolved is essential for determining how neural crest was invented and how it has been conserved during evolution. The presence of a common neural crest gene network in extant lampreys and higher vertebrates would suggest the presence of those mechanisms in the common ancestor of the agnathans (jawless) and gnathostomes (jawed). Lampreys have most neural crest derivatives but lack some in the trunk (sympathetic nervous system) and in the head (jaws). The fact that many of the genes found in Xenopus at early stages of neural crest development are also present in lampreys (personal communication with mentor) suggests conservation of the neural crest gene network between gnathostomes and lamprey.

Neural crest cells are multipotent neuroectodermal cells originating at the neural plate border between the neural and non-neural ectoderm (1,6,9). Neural crest cells undergo a change of shape from epithelial to mesenchymal cells and emigrate from the dorsal aspect of neural tube extensively throughout the embryo according to well-established pathways (9). They finally settle and differentiate into a plethora of derivatives such as cranial cartilage, pigment cells and the elements of peripheral nervous system (3,6).

Another way of defining neural crest cells involves the expression of neural crest specific genes. Zic1, the knockout target of this experiment, and the Msx1/2 and Pax3/7 family members are early markers of the neural plate border territory. Their expression makes the neural plate border territory competent to respond to subsequent neural crest inducing signals and defines the identity of that territory.

In Xenopus, Zic1 is implicated in the regulation of neural induction and in the patterning of the neural plate border. In early Xenopus neurula, Zic1 and Pax3 are expressed in the border between neural and non-neural ectoderm (neural plate border), as well as the neural territory. Depletion of the Zic1 protein in Xenopus embryos, using morpholino antisense oligonucleotide injections, results in failure of crest formation (4,5).

In this study, we have identified the lamprey Zic1 homolog to patterning in Xenopus. Expression analysis and morpholino knockdown of this gene in lamprey embryos show that, as in Xenopus, this gene functions in the patterning of the neural plate border and therefore plays a role in neural crest formation.

Results and Discussion

Lamprey embryos develop more slowly than average vertebrate embryos. The chorion lifts after fertilization (confirming that the embryo has been fertilized) protecting the embryo from hyper spermiation which causes more than one developmental signal to be produced. The development of lamprey embryos can be seen in Figure 3. Approximately 6 hours after fertilization, the embryos begin to undergo the first furrow and divide into two cells at approximately 6.5 hours. At this point, Ca2+ deposits are used by the centromeres to facilitate cell division. The internal cellular use of Ca2+ causes the embryo to separate from surrounding substrate, in this experiment at the bottom of a crystallizing dish. As the development progresses, the cells undergo further cleavage steps and continue to divide (7). After 24 hours, the embryo is at the blastula stage, having the shape of a hollow ball of cells. Gastrulation starts 3 days post fertilization. Monitoring of this phase is critical because, if an embryo dies, it secretes a toxin which kills surrounding embryos. Thus during the gastrulation period, constant manual dispersion of embryos and monitoring is required. Gastrulation continues until the beginning of the 4th day. On the 4th day, primary neurulation begins. The neural plate begins to condense rather than roll into a neural tube like in other vertebrates. At this time, border specifiers such as Zic1, a zinc finger protein, are present in these early pre-migratory stages in the neural plate border territory. During the 5th day, the neural precursors begin to come together forming a bulge. On the 6th day, when the neural tube forms by a secondary cavitation, neural crest cells begin to migrate from the dorsal aspect. On the 8th day, the neural tube formation is completed. At 7.5-8days, the pre-hatching embryos begin to twitch. At 9 days, secretion of hatching enzyme occurs helping to digest the chorion. By the 10th day, most of the embryos have successfully hatched out of their chorion and begin to move freely on their own. On the 12th day, heart and heart activity are observed (7).

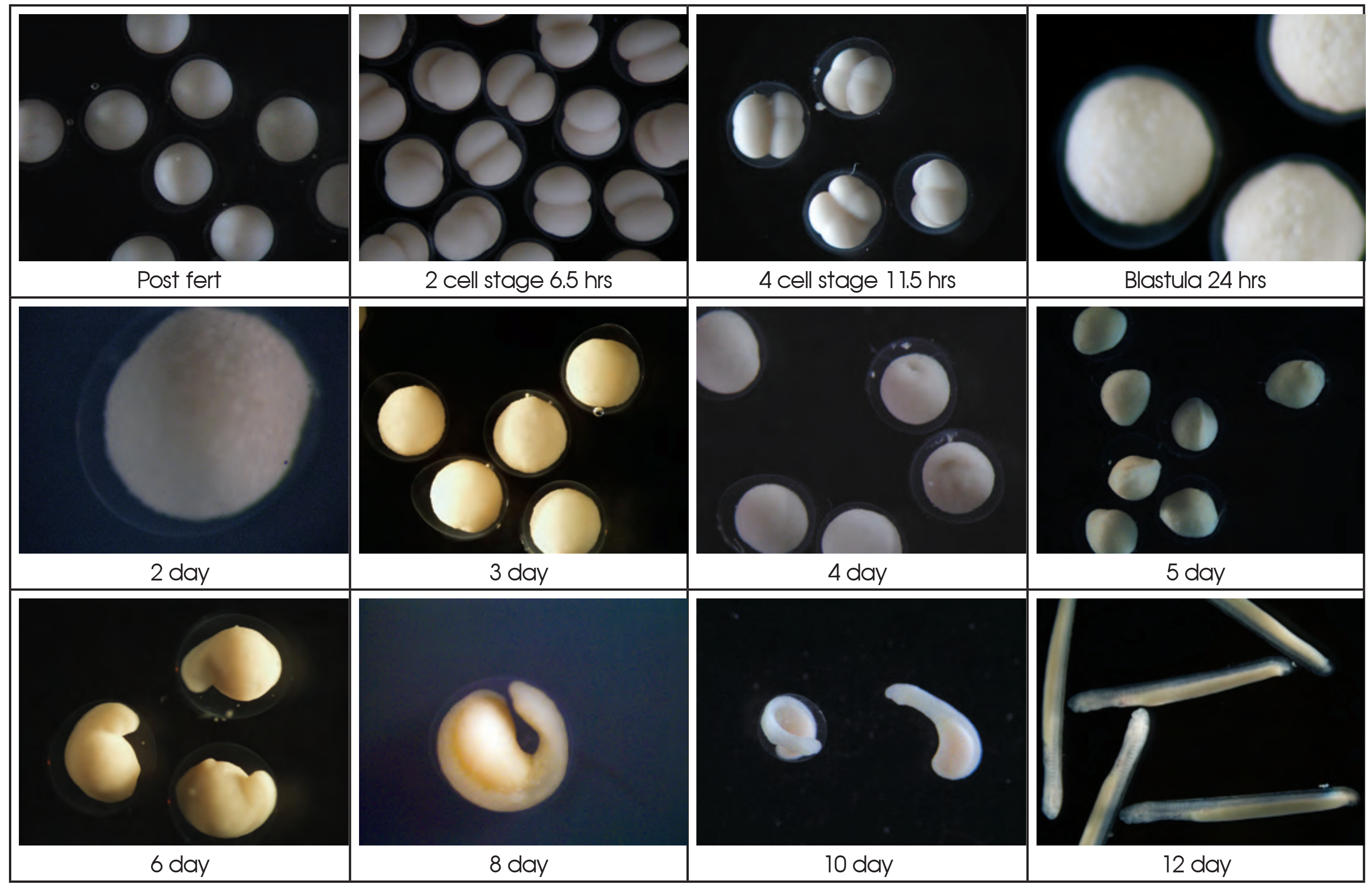


Figure 3: Cell cycle of lamprey embryos starting from post-fertilization to the 12 day stage larva.

The Expression of Zic1 in Lamprey

Zic1 is expressed in the neural precursors, as well as in the border territory between neural and non-neural ectoderm at 4 days of development (Figure 4). By 5 days expression is found in the dorso-lateral aspect of the neural rod and at 6 days in the dorsal part of the neural tube and the developing somites. This expression pattern is similar to Zic1 expression in Xenopus embryos during comparable developmental stages.

Zic1 Protein Knock-down in Lamprey

We performed the protein knockdown of Zic1 gene, using anti-sense morpholino oligonucleotides, a method previously used in higher vertebrate model organism embryos to study gene function. We used translation-blocking morpholino designed to complement the target sequence on the Zic1 messenger RNA, positioned upstream and encompassing »

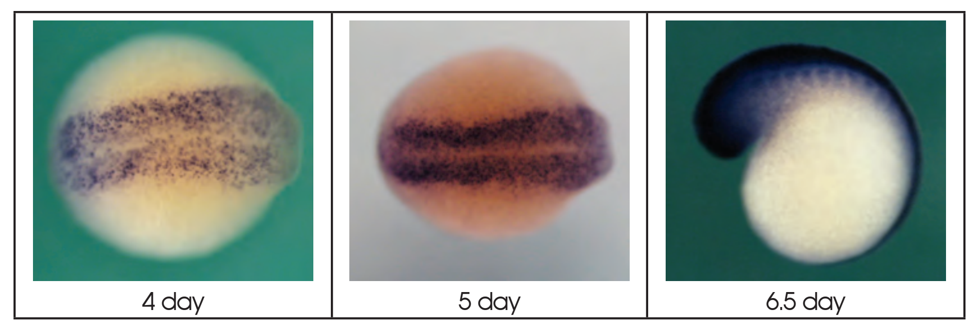


Figure 4: Zic1 expression in lamprey embryo as visualized by in sito hybridization.

PHOTOGRAPHS BY Benji Uy

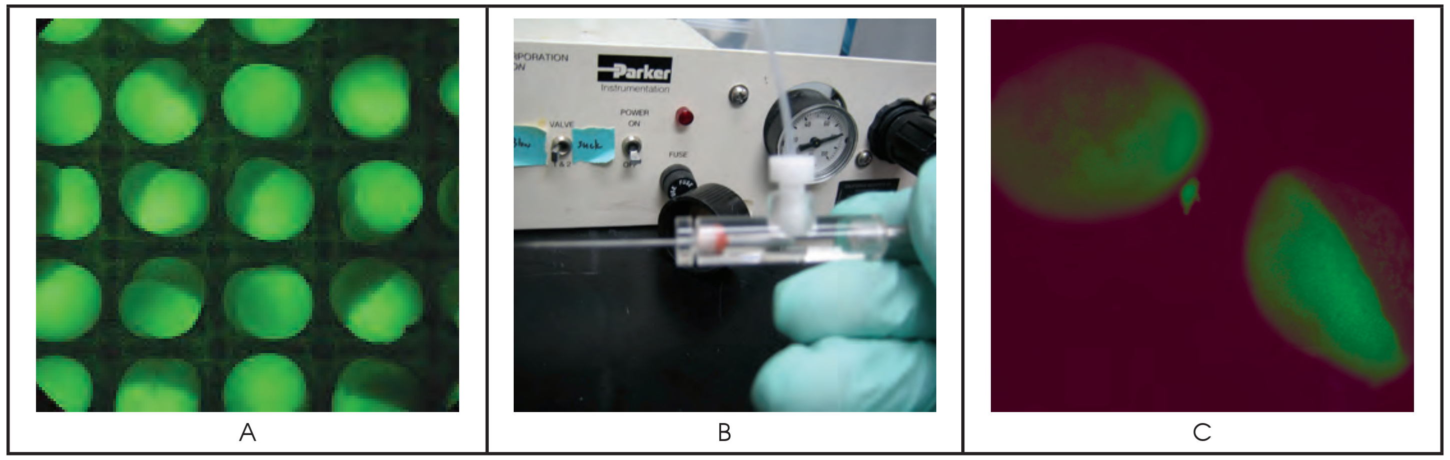


Figure 5: (A) Embryos injected at the 2 cell stage with FITC labeled Morphalino antisense oligonucleotides. The cells have undergone their first division and are starting the second division. (B) The pico-spritser used to inject and deliver mopholino into the cells. (C) 6 day embryo pre-selected for unilateral distribution of the morpholino.

the translation start site (ATG codon). Rather than a 5' ribose member ring and anionic phosphates, morphalino antisense oligonucleotides have a 6-member morpholine ring and non-ionic phosphorodiamedates (2). The binding of the morpholino is specific to corresponding mRNA and mechanically obstructs translation of the protein. By injecting the lamprey embryos with these anti-sense oligonucleotides, translation of the protein is inhibited. More precisely, these antisense oligonucleotides are designed to bind to complementary bases on mRNA just upstream or encompassing the translation start site.

We injected fluorescent labeled Zic1 morpholinos into a single blastomere at the 2-cell stage, thereby limiting the integration of the morpholino to only one side of the embryo (Figure 5). The embryos were allowed to develop to neurula stage (6 days), when the first neural crest cells appear or larval stage (12-14 day), and fixed for in situ hybridization analyses.

The experimental embryos were then hybridized with antisense RNA probes coding for several markers of the nascent bona fide neural crest (SoxE1, FoxD3, AP-2, c-Myc, Id) or markers of the neural plate border/dorsal neural tube (Pax3/7 and Msx).

As previously reported (5), the transcription factors SoxE1 and FoxD3 lie downstream from Zic1 and are responsible for specification, survival and differentiation of neural crest. In lamprey, SoxE1 and FoxD3 are clearly expressed in the forming neural crest in the dorsal aspect of the neural tube in 6 day neurula (Figure 6).

The inactivation of Zic1 leads to a defect in both SoxE1 and FoxD3 expression on the injected side. The non-injected side serves as an internal control. The expression signal of AP-2 was decreased on the injected side.

The expression of other neural crest specifiers, c-Myc and Id are not altered on the injected side of the neural tube; however, c-Myc and Id hybridization signals in the somites of the injected side decreased compared to the non-injected, control side. Conversely, Id and c-Myc hybridization signal in the somites of the Zic1 morpholino-injected embryos was decreased compared to the non-injected, control side. This suggests that both Id and c-Myc expression is regulated by Zic1transcription factor in somites.

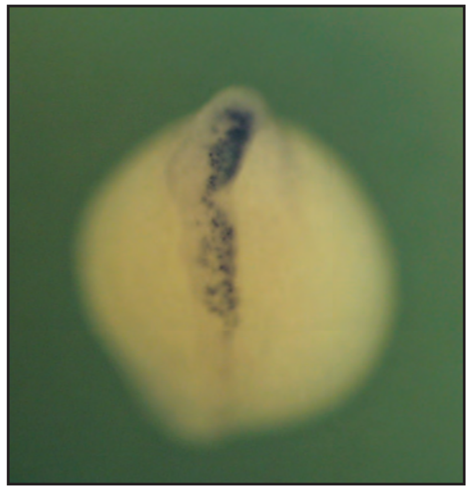


Figure 6: Expression of SoxE1 neural crest markers in the wild type 6d lamprey embryo.

While Msx expression was unaltered on the injected side of the Zic1 morpholino-injected embryos, the expression of Pax3/7 was expanded.

In the majority of the Zic1 injected embryos, the neural tube seemed enlarged on the injected side. The extra bulging tissue expressed Pax3/7 marker but lacked the usual somite expression.

The expression of various neural crest and neural plate border markers in the Zic1 knockdown embryos elucidates the relationship among these genes which are responsible for neural crest specification, migration and differentiation. The expression of early markers of the bone fide neural crest, such as SoxE1, FoxD3 and AP-2 is missing on the Zic1-depleted side of experimental embryos suggesting that, as in Xenopus, Zic1 is essential for the proper neural crest formation and the expression of these markers. The expansion of the neural tissue of the injected side, shown by the widened Pax3/7 expression domain, suggests that as in the case of neural plate border genes in Xenopus (Msx1 and Pax3; [4]), Zic1 may be involved in the patterning of this neural plate border territory. When the Zic1 protein is depleted, the undifferentiated neural crest identity of this territory is lost and possibly replaced by specific neural function. The neural crest markers are lost and neural crests fail to form properly.

Zic1-depletion and Neural Crest Derivatives

In order to assess the long-term effects of the Zic1-depletion, we have allowed a certain number of morpholino-depleted embryos to develop to later stages (10-15 days) of embryonic development. The early embryonic depletion of Zic1 protein seems globally to affect the formation of all neural crest derivatives.

At the 10 day stage, cranial ganglia formation appears to be affected as exemplified by an abnormal expression of the Delta1 marker in the trigeminal and vagal ganglion injected side (Figure 8B, arrowheads).

At 12 days, another neural crest-derived sensory structure, the dorsal root ganglia, fails to express SoxE1 (Figure 9, arrowhead). Otherwise, the embryo apparently develops normally.

At 13 days, the number of melanocytes in the Zic1 injected side was significantly reduced (Figure 10).

Finally, neural crest derived cartilage bars in the lamprey branchial basket fail to express SoxE1. (Figure 11).

In conclusion it seems that Zic1 inactivation of the neural plate specifying border globally impacts neural crest cell formation and, therefore, tends to affect all neural crest derivatives.

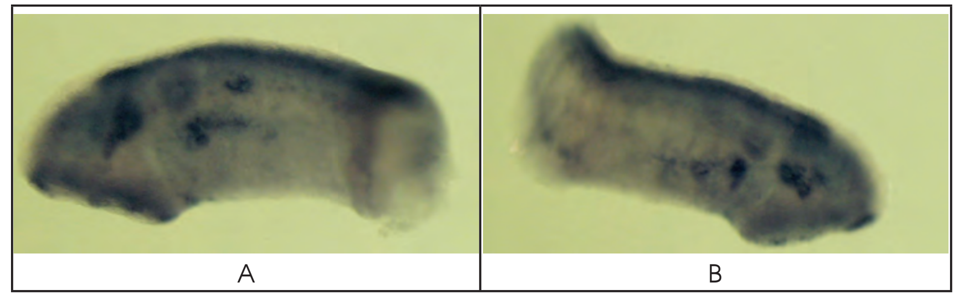


Figure 8: (A) Control side. (B) Zic1 injected side.

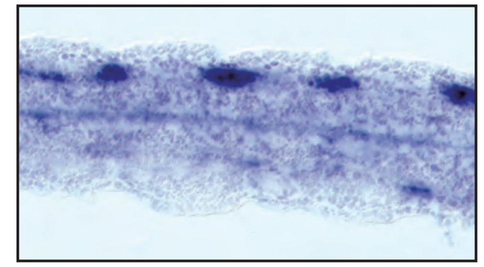


Figure 9: 12 day lamprey, dorsal root ganglia expression in the presence of SoxE1 probes.

Conclusion

The neural plate border specifier Zic1 is expressed in the lamprey border territory in a similar manner to the Zic1 expression pattern in Xenopus. Furthermore, as in jawed vertebrates, Zic1 inactivation seems to affect proper neural crest formation, inhibits expression of neural crest markers and causes long-term defect in neural crest derivatives. Thus, the role of Zic1 in the neural crest development appears conserved in lamprey, a basal jawless vertebrate, suggesting that this portion of the regulatory network was invented prior to divergence between jawless and jawed vertebrates and that Zic1 was probably utilized in the ancestral vertebrate.

Animal Care

Adult mature and maturing lampreys were obtained from Hammond Bay Biological Station, Michigan. Since lampreys usually die after they mate, the mature female and males are kept at 12ºC in order to slow down the decomposition process and increase the number of fertilizations possible. The number of eggs fertilized each time varies but usually ranges from 1000 to 4000. The maturing animals are kept at 18ºC until they reach the final stage of maturation and are ready to spawn. Markings on the dorsal fins are kept in order to keep track of the animals as the quality of egg and sperm varies.

Fertilizations

The embryos are fertilized in 18ºC Sparklets water, in a crystalyzing dish. After 6 hours past fertilization, embryos which have been fertilized begin furrowing and are therefore pre-selected for injections or further development. Following the first division, all embryos are cultured in 0.1x MMR (Marc's Modified Ringers) at 18ºC. MMR is a salt solution and 0.1X concentration allows for further development of the embryos in close to isotonic conditions. MMR solution is autoclaved to prevent bacterial and fungal overgrowth. Each day, the embryos are checked, ringers changed and dead embryos removed. After the 3rd day, the surviving embryos must be dispersed in order to protect them from the toxin secreted by dying embryos.

Morpholino Injections

FITC-labelled antisense morpholino oligonucleotide against lamprey Zic1 gene (Zic1 MO; 5'-CGCCTCCAGAAGCATCGCGTGCGGT-3'), was injected into a single blastomere at the two-cell stage and at 5 days of development, the embryos with unilateral integration of the morpholino were pre-selected using fluorescence microscope. Embryos are then fixed using in MEMFA (MOPS/EGTA/MgCl2 salts and 4% formaldehyde), and dehydrated to 100% methanol and kept at -20ºC.

In Situ Hybridizations

Prior to in situ hybridization procedure, the embryos are re-hydrated to 1xPBS and dechorionated. DIG labeled antisense RNA probes against the genes of interest in this study were synthesized according to the standard procedures. In situ hybridization was performed according to previously described standard procedures (8). After the in situs were completed, pictures were taken in 75% glycerol/PBS.

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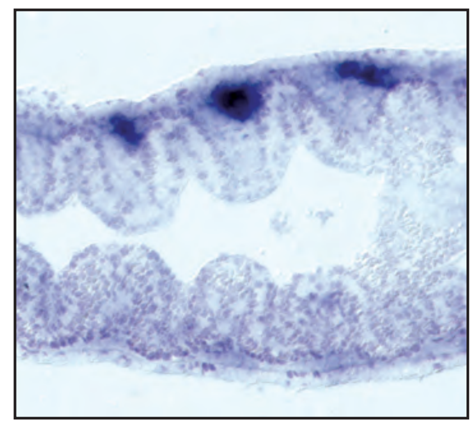


Figure 11: Lamprey Branchial Basket probed with SoxE1 displaying the presence of cartilage bars.

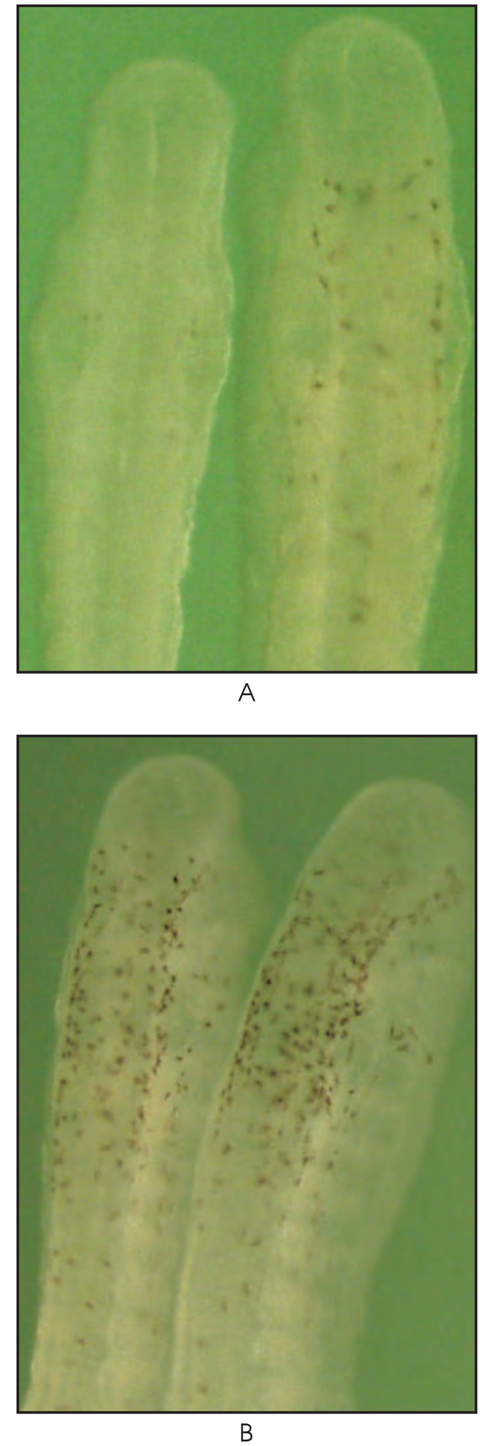
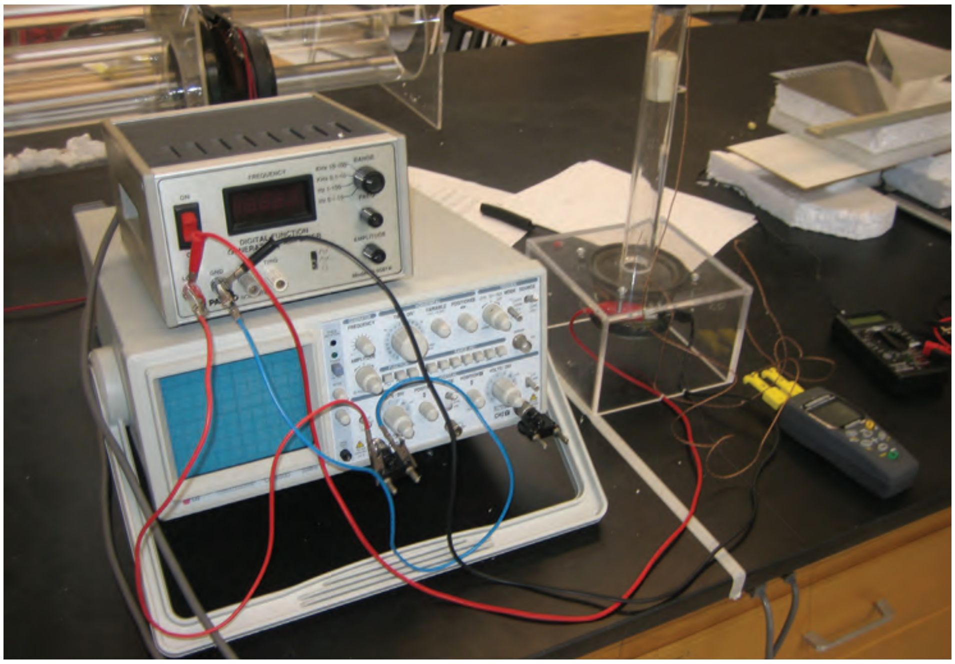


Figure 10: (A) 13 day wild type Lamprey. (B) Zic1 injected lamprey.

Keeping their cool

Two seniors tackle acoustic refrigeration



By Eliza Eddison and Zack Mirman

ACOUSTIC REFRIGERATION is a process that produces a temperature gradient through the resonance of standing sound waves. Sound waves in a resonating chamber set up standing waves at certain frequencies. This experiment should provide a relationship between frequency, voltage and temperature. Voltage, as measured by thermocouples, will be compared to the variable frequency created by the speaker.

A basic concept in physics is that of the standing wave in a resonating chamber. Sound waves from a fixed source at certain frequencies fall into a set pattern (in effect, "stand"). This is the same phenomenon that occurs when a finger plucks the string of an instrument, though the sound waves in this experiment have no linear medium to pass through and, as such, are invisible. This experiment was first published in the American Journal of Physics in December of 2002 by Dan Russell and Pontus Weibull. The experiment yielded a 46 degree Fahrenheit temperature gradient across a stack made of film and wire. In this open-closed system, the formula for the wavelength at the first harmonic is $4L=\lambda$ with L representing length of tube. Two copper and constantan thermocouples were created and placed above and below the stack. The system was closed on the top with an aluminum plug. The speaker was screwed onto the Plexiglas box-shaped base of the apparatus, facing upwards into the tube, and attached to a frequency generator equipped with oscilloscope.

In our recreation of the experiment, we modified and replaced various pieces of the apparatus. The main difference is the stack, which in the original experiment design was made of fishing wire pasted vertically on a piece of photographic film. This was then tightly wound together and lowered into the tube.

We replaced it with a ceramic stack with many small holes in close proximity. The ceramic stack has been shown to increase the temperature gradient more efficiently and is better built than the film tightly wound around pasted wire. The actual apparatus was recreated in very similar dimensions to the original acoustic refrigerator. We also added a means to tighten the seal on the tube to make the aluminum plug more effective. We are seeking the same theoretical point as the original experiment: a pressure maximum and a particle displacement minimum. However, we believe that it will be different given the three dimensional nature of the waves that were considered to be two dimensional in the original experiment.

Setup

We made a Plexiglas tube-and-box setup for the experiment. The base was 16.4 cm x 16.6 cm x 11.0 cm, and the tube is 25.4 cm high with an inner diameter of 2.5 cm. We drilled four holes into the base in a square pattern in order to affix the speaker in the base with screws. We created a thermocouple, a temperature sensor that can be used to convert thermal potential difference into electric potential difference, by soldering two copper and one constantan wire together and affixing the two unattached copper ends to a voltmeter. After experimenting with this thermocouple, we found that, though it worked, its level of accuracy was well below what we required for our experiment. We then ordered the Omega Thermometer HH66R, which accommodates Types K/J/T/E/R/S/N thermocouples (though we only are working with type K).

We filed the ceramic stack down to the appropriate diameter for the tube, at a size able to be moved if thus required but not when unwanted. We filed down two equal semi-circles in the base of the apparatus to feed the positive and negative leads in to affix to the speaker while maximizing closure and therefore efficiency of the system. We added a rubber lining to the top of the tube where the aluminum plug is inserted in order to tighten the seal and prevent heat loss. After we placed the leads for the thermocouple above and below the stack, we hooked up the thermometer to a computer to read the output of the data.

Next Steps

We are now ready to begin taking data points. Our two variables are the height of the ceramic stack in the tube and the frequency of the sound emitted from the speaker. Using the simple formula: $v = f\lambda$, relating velocity to frequency of wave and the wavelength in two-dimensional systems, we have calculated a range of frequencies to test for the resonant frequency. These frequencies are between 373 and 746 Hz. We will test for the other variable by moving the stack down and up in set increments for every frequency using a string and needle system we rigged on the stack to pull it up, and a broad based pusher to gently push it down. We will then plot the data points on graphs and calculate the optimal intersection of stack placement and wave frequency.

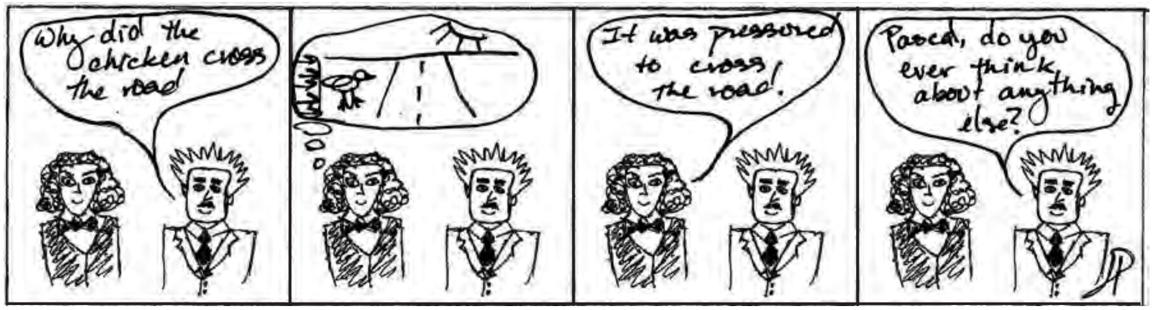
Once this intersection is found, we can test smaller increments of frequency and placement within this range in order to find the absolute maximum temperature gradient which can be produced in our thermoacoustic refrigerator.

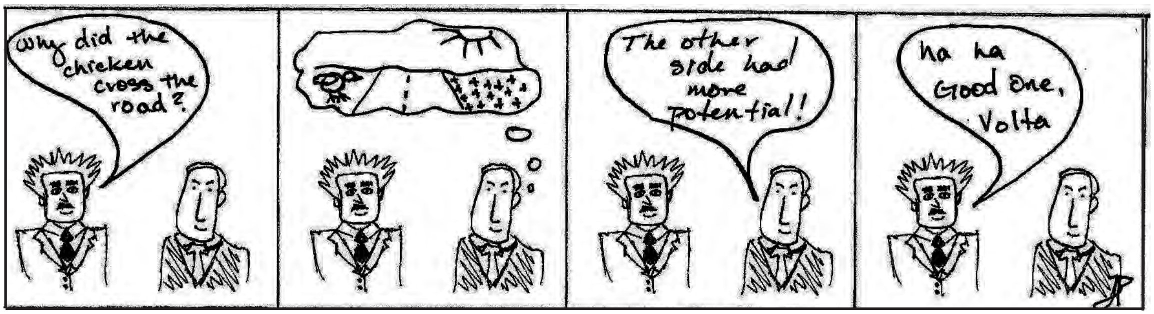
PHOTOGRAPH BY Justin Chow

SCIENCE SMILES

The ol' Chicken Crossing the Road

By Jerry Porter



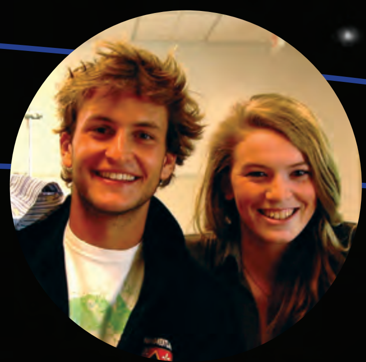


Be Practical

By Zack Mirman

This year in DSSR...

20 seniors researched 10 scientific topics ranging from acoustic refrigeration to acne-causing hormones during Dr. Nassar's 3rd period class.



Zack Mirman and Eliza Eddison

The Use of Sound Waves in Refrigeration

Benji Uy and Charles Sheng

Examining the Genes in Worms

Lizzie Sparks

CO2 Lasers: Industrial Technology for Cutting and Welding

Allen Miller and Justin Chow

The Role of Hormones in Acne

Matthew Kremer, Marc Firestein and Jerry Porter

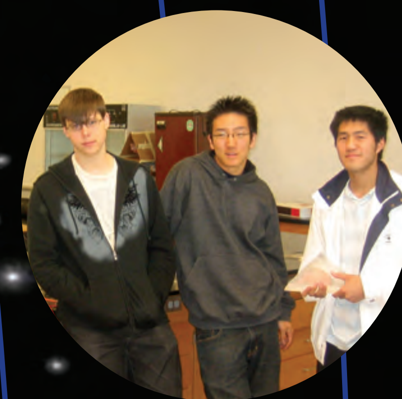
Electromagnetic "Air Hockey" and The Applications of Hydrogen Fuel Cells

Adam Gold

Exploring Cosmic Microwave Background Radiation

Cameron Lazeroff-Puck

The Exploration of Circuitry and Very Low Frequency Transmissions



Albert Chen, Leland Farmer and Brian Ko

Evanescent Waves and Microwave Interferometry

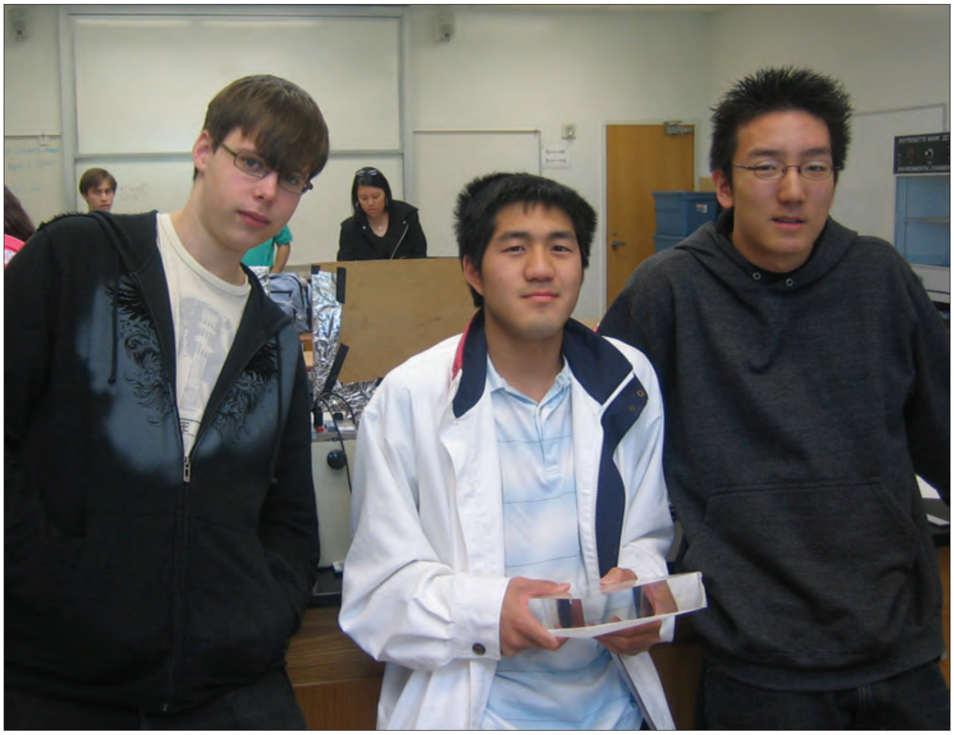
Michael Casey, Sarah Park, Alfredo Ramirez and Madeline Young

Maximizing the Efficiency of Solar Cells

Dani Kudrow

The Uses of Thermonic Valves in Amplification

PHOTOGRAPHS BY Justin Chow, Eliza Eddison, Allen Miller and Emiliano Rios



LELAND FARMER, ALBERT CHEN AND BRIAN KO

Taking tech to a new level

2 projects use cutting-edge technology to run experiments

Microwave Interferometers

BY ALBERT CHEN, LELAND FARMER AND BRIAN KO

Our group spent most of the year developing a microwave interferometer setup that allows us to conduct various experiments using a microwave receiver/transmitter.

Interfermoters are important because they can be used to explore certain classical and quantum physics effects such as interference, diffraction, microwave tunneling, standing waves, etc. but on a larger scale (longer wavelength than light gives easier measurement).

The basic setup consists of a microwave transmitter and receiver facing each other and an open space in the center where objects can be placed to affect the reception of the signal from the transmitter. The receiver can be rotated to change the angle between the receiver and transmitter. In the diffraction experiment, we placed two foil-covered plates next to each other with an open slit in the middle to allow microwaves to pass through only through the opening.

Based on diffraction we expect to be able to receive a strong signal from the transmitter at every few degrees as the transmitter is rotated and a weak signal in between the strong signals. To demonstrate the microwave tunneling effect, which shows that microwaves can pass out of a prism and back into it, we used a block of triangular plastic with the transmitter and receiver perpendicular to each other. The waves should enter the prism and internally reflect to the receiver, but the signal should be weaker because the waves have shifted slightly so that the receiver does not pick up the entire transmission.

We have recorded data for standing waves, diffraction, and interference, and are still taking down data for the microwave tunneling effect. The data is still undergoing analysis, and we are currently trying to match the results of the experiments to known quantum physics effects.

CAMERON LAZAROFF-PUCK

INSPIRE

BY CAMERON LAZAROFF-PUCK

INSPIRE is an acronym which stands for the "Interactive NASA Space Physics Ionosphere Radio Experiments." Beginning in 1990, the INSPIRE Project has monitored very low frequency (VLF) radio signals which occur in the earth's magnetosphere. These signals can be manmade as in the case of the LORAN navigation system transmissions or can occur in natural phenomenon such as lightning. These VLF signals are audible on any AM radio as static.

Radio signals in the VLF range (0-50 kHz) have the property that their propagation is heavily affected by both the ionosphere and the magnetosphere. When lightning strikes, high energy bursts of radio waves are created in addition to the obvious visual flash of light. The behavior of these VLF waves of radio energy can yield valuable information about the atmosphere, ionosphere and magnetosphere which extends tens of thousands of kilometers into space.

First, the VLF receiver must be constructed. Early on in the year, a VLF-3 kit was purchased and I subsequently assembled it, attaching all the needed switches, capacitors, resistors, diodes and inductors. The receiver was then fitted with a suitable antenna. After all the parts were assembled, the reciever was then ready for testing.

When using the reciever, one must wait until nightfall and listen through a set of headphones. The most common naturally occurring VLF signals, whistlers, produced mostly by intracloud and return-path lightning strikes, sound very similar to a slide whistle. There is also the possibility of observing another rarer phenomenon around the time of sunrise, referred to as a dawn chorus. A database of these VLF signals collected by students and enthusiasts is kept by NASA in their attempt to catalog this phenomenon.

PHOTOGRAPHS BY Eliza Eddison

The Importance of Creativity in Research

JERRY PORTER

BY JERRY PORTER

In the beginning, I selected my project out of pure curiosity. I was playing with my water bottle wrapper in English class, twisting and cutting it and noticing the various resulting loops.

When I returned to class the next day and mentioned my discovery to Dr. Nassar, he thought that there might be something of interest in the strips as, when they were flattened against the table, they created a topographical map of the strip. Dr. Nassar hypothesized that there was a relationship between the topographical map of the strip and the stable state of atoms or elementary particles.

The research I am conducting is on the much simpler side because all I start with is a piece of paper twisted once and scissors. Unfortunately, the simplicity ends with cutting strips of paper in half and becomes more complicated as I draw the resulting loops, noting the number of interlocked resulting loops, number of twists, and the many topographical shapes. The difficulty with the topographical shapes is that there are many ways to flatten a strip of twisted paper.

At first I believed I had discovered four shapes: a figure eight, a bow, a box, and what I called a tooth. Later, when playing with the shapes, I discovered that they are all basically the same. The tooth can be rearranged into a box, the bow in a figure eight. This duplicity is the exciting part of my research; I never know when I am done.

After several days of experimenting, I was certain that I had solved the problem. I wrote equations for the number of shapes, number of loops, and number of twists until it was discovered that the shapes were all the same.

In the future, I have to determine how many more shapes the strips can be flattened into. I also need to find out whether it is possible to neatly flatten sixteen strips to create some new stable pattern. Ultimately, I need to know what do the topographical maps mean?

A Coast-to-Coast Search for the HPV Vaccine

BY CHARLES SHENG

I had the pleasure of seeing a presentation from a key clinical developer of the Human Papilloma Virus vaccine: Dr. Cornelia Trimble at Johns Hopkins University in November. In the United States, malignant neoplasm of the cervix, generally known as cervical cancer, causes 4,000 deaths a year, about 1% of all cancer deaths. However, worldwide cervical cancer causes 200,000 deaths and is the second most prevalent form of cancer in women.

However, cervical cancer is now almost completely preventable. There are many different strains of HPV. Most aren't dangerous, but two strains, HPV-16 and HPV-18, cause cancer. A report published in 1973 by the Johns Hopkins School of Public Health linked HPV-16 and HPV-18 with 99.7% of all cervical cancers. Because of this link, cervical cancer could ostensibly be vaccinated against, given that a vaccine for HPV was not entirely out of the realm of possibility. The vaccine took 25 years to fully develop, but the results were beyond expectations. Gardasil, produced by Merck, has an extremely high success rate and a very low amount of blowback, the gold standard of safe vaccines (the smallpox vaccine, for instance, is not widely distributed because it infects the patient more often than is acceptable).

Furthermore, the vaccine has been shown in early clinical trials to work retroactively. Patients who had high-grade dyslpasia and had presented lesions, treated with a four-month experimental trial at JHMI, saw the lesions eliminated completely. While it is of course better to prevent the lesions from ever occurring, this does provide a last-resort option for those already affected.

However, the success of Gardasil has been limited by government and social objections and is a prime example of the obstacles medical advances in the United States face. In several, mostly southern states, the promotion and distribution of the vaccine has been limited by the belief on the part of parents that immunity to an STD will make their daughters more promiscuous. In this country of limited public healthcare and a powerful religious lobby, not much has been done to change their views.

JUSTIN SHENG

THIS YEAR'S NOBEL PRIZE WINNERS IN SCIENTIFIC FIELDS:

PRIZE IN	WHO	WHAT	WHY IT MATTERS
Physics	John C. Mather and George F. Smoot	They helped discover the anisotropy of the cosmic microwave background radiation and its similarity to an ideal blackbody.	It helped to cement the big bang theory.
Chemistry	Roger D. Kornberg	He studied the molecular basis of eukaryotic transcription.	It defined an exact process by which RNA is created.
Physiology/Medicine	Andrew Fire and Craig C. Mello	They discovered RNA interference-gene silencing by double-standed DNA.	It showed that RNA plays an important role in the regulation of the flow of gene information.

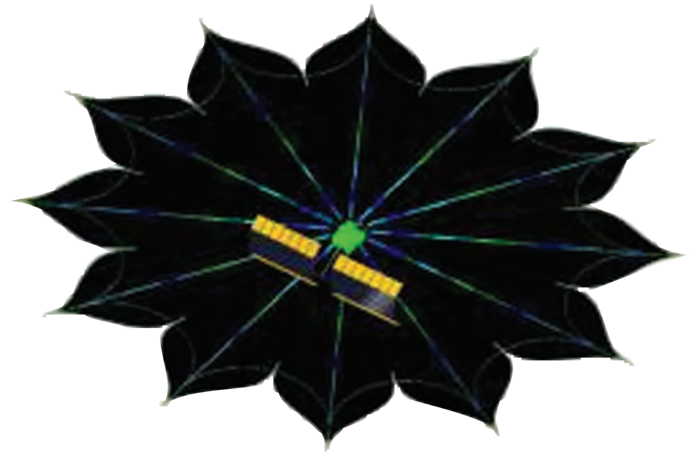
SOURCE: NOBELPRIZE.ORG

TOP PHOTOGRAPH BY Eliza Eddison BOTTOM PHOTOGRAPH BY Allen Miller

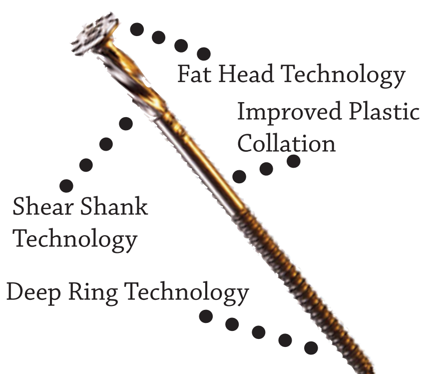
Important Scientific Breakthroughs of 2006

By Jeffrey Hartsough

Although it has not been approved by NASA yet, **starshades** could help shed new light (or shadow) on distant planets. In the past ten years, astronomers have discovered more than 200 planets outside of our solar system. However, glare from the stars these planets orbit prevent scientists from using telescopes to obtain important data about the planets such as their exact size and environments. A starshade is essentially a large parasol which positions itself between the telescope and the star, minimizing glare when photographing the planet. After shielding glare for one planet, the starshade repositions itself to another target, operating in this fashion for two years before refueling.



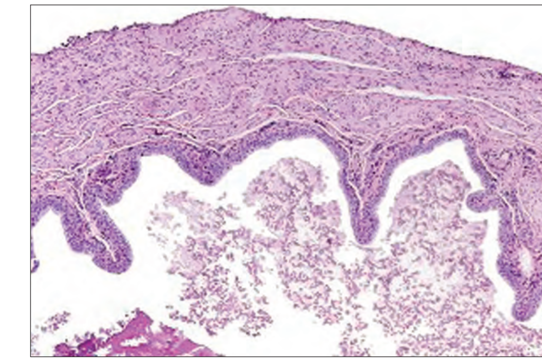
NASA



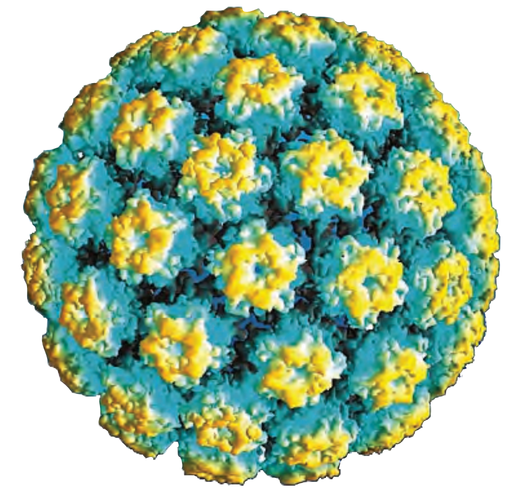
Marsha Labunsky

The **Hurriquake Nail** was developed to simply create a better nail, something that is often taken for granted and given no second thought. What engineer Dr. Ed Sutt, a fastening engineer with Bostitch, realized is that in both hurricanes and earthquakes, the nails that hold the wood together, and not the wood itself, are the first to fail—either by being forced through the wood, pulled out of the wood, or shearing at a joint. Sutt made four changes to the traditional nail: the head of the nail is increased by 25 percent, angled barbs are added to the shaft, the top of the shaft is twisted, and a high-carbon alloy has been used to best balance stiffness and pliability. While the nail increases sturdiness by an amazing 50 percent, using the nails only add $15 to the total cost of an average house—a miniscule investment considering the lives and property it could save.

At Wake Forest University, Dr. Anthony Atala has grown a **working human bladder** in his lab. By molding cells from a patient's bladder onto a biodegradable scaffold and allowing the cells to mature over the scaffold as it dissolves, Atala created a fully functional bladder. Over a four-year period, none of his seven test patients have had rejection problems. The bladder is the simplest organ because it has no blood vessels. Soon, Atala will begin to engineer more complex organs like the heart and kidney. This kind of technology could help eliminate waiting lists for donors.



NIH



Harrison Laboratory

Two pharmaceutical companies developed **vaccines** this year against two strains of **human papillomavirus (HPV)** which are responsible for approximately 70 percent of cervical cancer cases. The vaccine will help to decrease the number of invasive procedures associated with cancer treatment, and is the first vaccine against any form of cancer. This discovery may signal a change in the approach to cancer treatment and prevention in later years through vaccination for viruses associated with the development of cancer cells.

Source for all text: Popular Science Magazine

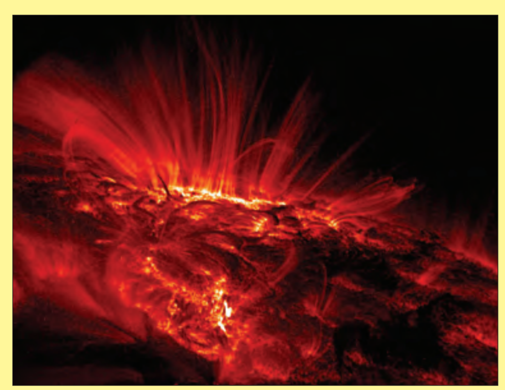
5 Things That Will Boggle Your Mind

By Gordon Wintrob, Allen Miller and Justin Chow

Pictures: NASA (1 and 2), Jerzy Muller (3), Gordan Jovic (4) and the National Science Foundation (5).

Text Sources: NASA, Astronomy Picture of the Day, Australian Mines Atlas, Stormwise and MIT (from left to right).

1 NASA developed aeroponic crops, plants grown in air/mist environments with no soil and very little water, could possibly provide space flights with a supply of fresh oxygen and clean drinking water. Because aeroponic crops grow in clean and sterile environments, they ensure less contamination and faster food production.

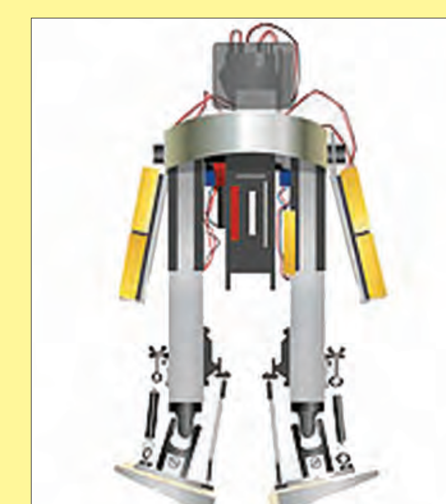


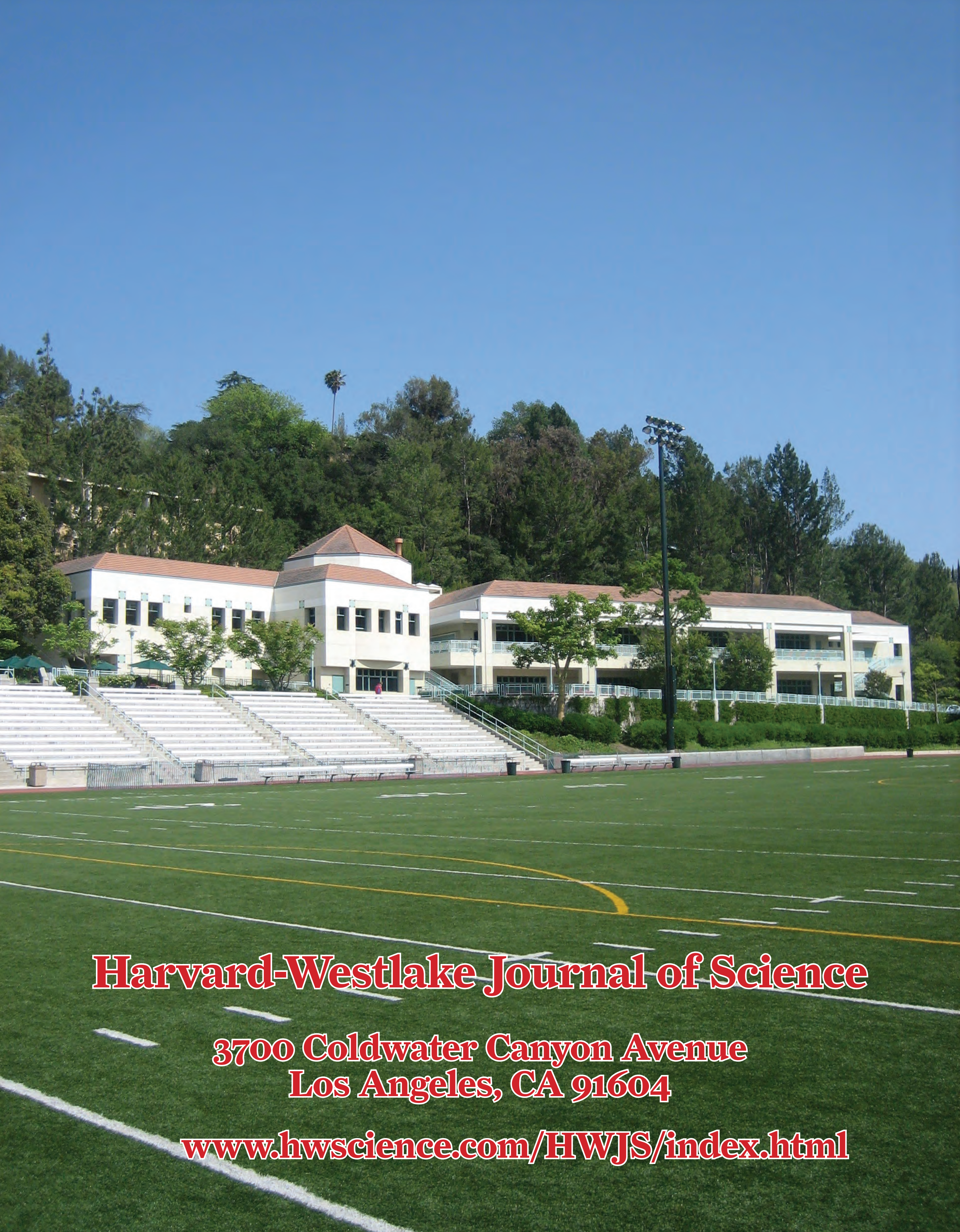
2 The dark spots shown on this ultraviolet image of the sun have temperatures of thousands of degrees Celsius. The radiant loops of gas flowing around the sun spots have temperatures of over one million degrees. The reason for the sun's high temperatures is thought to be attributed to the changing magnetic field loops that channel solar plasma.

3 There is enough gold in the Earth's crust to cover the entire land surface knee-deep. One ounce of gold can be stretched into a wire 80 kilometers (50 miles) long.

4 A bolt of lightning is actually about the same size as a quarter or half-dollar. The light emitted is so bright that the bolt appears much wider.

5 After 20 minutes of walking, this MIT-built robot adjusts its gait to suit its terrain. The robot's ability to adapt to is another step toward more efficient prosthetics and exploration with robots.





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