Research Notes

Electrical Conductance in Membranes

A coffee klatsch is not necessarily just a social occasion—at least not when it involves Max Delbrück, professor of biology, and Carver Mead, professor of electrical engineering. One day about two years ago they sat in Chandler Dining Hall discussing their work. Mead was talking about electronic devices and how they handle electric currents; Delbrück was talking about cell membranes and how they transport ionized materials. Delbrück pointed out that membranes and transistors seem to share some of the same phenomena. This struck a chord in Mead, who had just finished some work on very thin insulating layers which represent a physical system very similar to membranes.

With Delbrück's insightful observations as a starting point, Mead and James E. Hall, research fellow in electrical engineering, and Gabor Szabo, of the department of physiology at the UCLA Medical School, began a study of the electrical conductance of membranes. The result is a paper, "A Barrier Model for Current Flow in Lipid Bilayer Membranes," which suggests the tantalizing possibility that further research will reveal processes in living systems that demonstrate the same phenomena as electronic devices do.

In transistors, thin energy barriers act as insulating layers between conductors, and restrict the passage of electrons. In order to get over the barriers, the electrons must expend thermal energy. Membranes appear to present a similar obstacle to ions that attempt to pass through them.

Mead and his fellow researchers considered using living cell membranes, but instead decided to use an artificial membrane—lipid (fat) bilayer—because of the complexity and the number of unknown variables in natural membranes. In addition to being electrically indistinguishable from natural membranes, lipid bilayer membranes have already been studied extensively and are therefore highly predictable.

The behavior of this artificial membrane is dominated by ion current flow, which bears a great resemblance to the flow of electric currents in thin solid films. The bare ions don't pass through the membrane very well by themselves; that would take too much energy. Nonactin, an antibiotic, is needed to act as a carrier for the ions, greatly increasing the ion flow current. The nonactin molecule—shaped like the seam of a tennis ball—has a niche just big enough to hold a potassium ion, which it carries through the membrane and releases on the other side.

By itself in solution, the potassium ion is neutralized by a weak bonding with the water molecules around it. But to get free the ion must expend a great deal of energy, and the struggle leaves it with insufficient energy to get over the barrier. Nonactin, on the other hand, gently pries the water molecules away and slides itself around the ion. The energy expenditure is minimal, leaving the ion-nonactin combination enough energy to maneuver through the membrane easily.

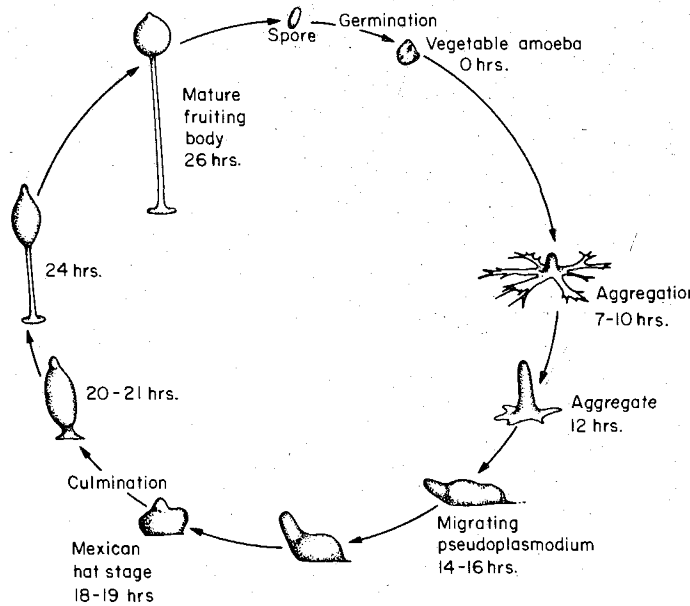
Mead and his fellow workers hope that an understanding of membrane conductance will in turn lead to an understanding of excitability (the one property that living systems possess, but artificial membranes do not), the process by which some sort of stimulus will trigger an electrical impulse. According to Mead, deciphering how this system works has to wait until other studies define the properties of membranes in general.

Slime Mold and Differentiation

One of the puzzles of developmental biology has been the question of cell differentiation—how cells from the same ancestor diversify to perform a variety of specialized tasks in an adult organism.

In humans, for example, after fertilization, development starts from an original cell with a complete set of genes. Somewhere along the line, as the cell multiplies, portions differentiate to become the cells of the various organs and tissues.

Recent findings have shown that, in bacterial cells at least, not all the genes are active at any one time. Specific mechanisms have been revealed which selectively repress or induce the activity of various genes or groups of genes at different stages.



The somewhat schizophrenic slime mold, Dictyostelium discoideum, *is proving of great value to scientists studying how cells differentiate. In its 26-hour developmental cycle it expresses both animal and plant characteristics, making it difficult to pinpoint its exact evolutionary niche.*

On the larger biological scale, this provides a conceptual basis for understanding how different cells may inherit an identical genome (chromosomal gene grouping) but allow its unequal expression to develop the great specialization required to yield nerves, muscles, liver, and other organs and tissues.

But in higher organisms—conceptual understanding notwithstanding—it has not been possible to obtain detailed information about this developmental process and the number of genes involved at each step. This is impossible in organisms such as mammals, because of the large numbers of genes involved; man carries 750,000 around in each of his billions of cells.

In order to discern the nature of these steps in a more complex organism than a bacterium, graduate student Richard Firtel and James Bonner, professor of biology, have been studying a cellular slime mold, *Dictyostelium discoideum.* The advantage in studying this particular organism is that, despite its complexity, it has a relatively small genome of not more than 20,000 genes, and it has a startling ability to transform itself from a heap of disorganized, amorphous separate and identical cells, into a discrete organism made up of only three kinds of cells.

The slime mold's place in evolution still isn't known. It is sometimes grouped with fungi in the plant kingdom or with protozoa in the animal kingdom. At present it is certain only that the slime mold combines certain animal and plant characteristics and is among the higher organisms in that its cells have distinct nuclei and mitochondria.

In its vegetative stage, the mold's cells grow and reproduce separately, dividing to produce more cells. This stage lasts until all the food (amino acids) in its immediate neighborhood is used up. The cells then stop dividing. If placed in a wet environment, they clump into groups of a few thousand cells each. Each clump evolves quickly into a slug-like creature called a grex. Cells move up the supporting stalk of the grex to form a cap that is shaped somewhat like a Mexican hat. Other cells migrate into the cap and turn into spores that are dispersed when the cap disintegrates. These spores then drift off to start other slime mold colonies.

During the 26 or so hours that the mold takes to gather, form the grex, and sporulate, at least 15 separate enzymes take part in the developmental process. Each appears at a specific, different time during the sequence. The mold's genes, made up of DNA, are used to produce RNA as a messenger. This RNA migrates out of the cell's nucleus and tells the cell's protein-building machinery what to make.

To study the differentiation process, Firtel and Bonner extract messenger RNA from slime mold cells at each of four stages—vegetative, early slug, late slug, and Mexican hat. They then employ the technique of hybridizing RNA to DNA to determine how much of the RNA of a particular stage is unique to that stage and how much of the genome is used at each stage. With this technique, normal DNA—a ladder-like double strand of building blocks—is heated until it comes apart, leaving a single DNA strand. RNA produced by the mold is added. When the two are mixed, the RNA attaches itself to the portion of the DNA that made it. The amount of time this process takes depends on how much DNA there is. The rate of attaching (reannealing) decreases as the size of the genome increases. This is another reason why it is technically difficult to work with mammalian DNA. In mammals the attaching process takes about a year. In the slime mold it takes only two days.

Firtel and Bonner's research indicates that, during the period from the vegetative stage to the beginning of sporulation, 60 percent of the slime mold's genome is expressed in the form of RNA molecules. Two-thirds of this 60 percent consists of genes represented at only one of the stages (vegetative, grex slug, or Mexican hat), while one-third is probably involved with spore formation and germination. About 20 percent of the genome produces messenger RNA that is present through all stages of development, and the remaining 20 percent is probably involved in turning the other genes on and off.

Sound Waves on the Sun

Alan Stein, who got his BS from Caltech only last June, has already made a name for himself in the history of science—almost without trying.

He will probably only be mentioned in a very minor footnote. But mentioned he will be, nonetheless, as the discoverer of "Stein Waves"—sound waves on the sun.

The unkempt and irrepressibly eccentric Stein is not cast in the image usually connected with scientific discovery. Cruising around campus in an unbuttoned shirt, dirty jeans, and a pair of sandals that have seen better days, Stein had more fun taking photographs and talking to people than staying pigeonholed in a laboratory.

An expert photographer, he spent the last year on the staff at the Big Bear Solar Observatory, working under Harold Zirin, professor of astrophysics and a staff member of the Hale Observatories. The discovery of Stein Waves was made last summer. Stein was studying motion picture films taken of the sun when he noticed concentric dark rings radiating outwards from certain areas on the film. He had not seen anything like this before, so he took the film to some graduate students. Equally baffled, they took the film to Zirin. He didn't know either. The phenomenon was unofficially named after Stein, and the name has stuck.

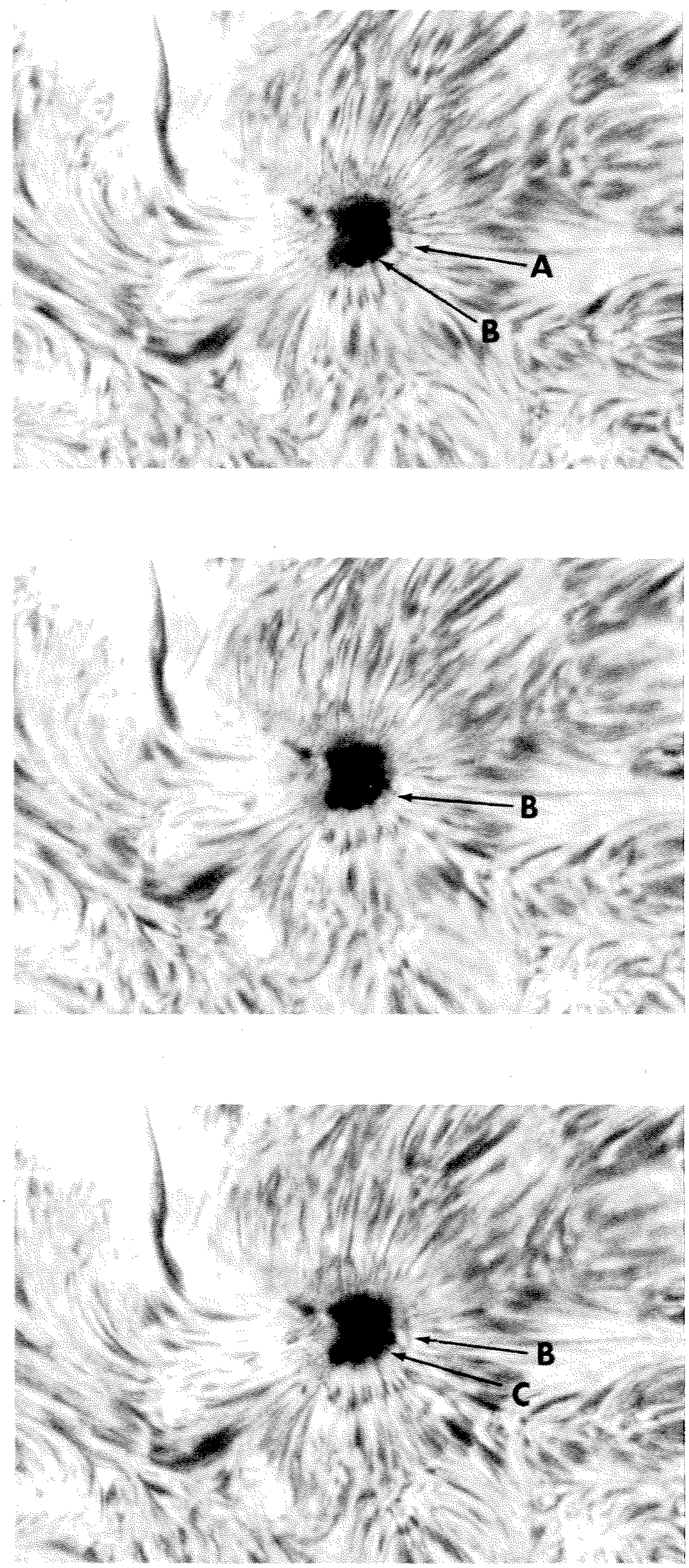
After almost a year of study and analysis, Zirin recently reported on Stein Waves to the solar division of the American Astronomical Society. He believes they are sound waves.

The undulations are about 1,600 miles from crest to crest, travel at 18,000 to 25,000 miles an hour, and follow each other at intervals of about 270 seconds. These are the first "running" waves observed on the sun. Other waves have been observed, but they are the "sloshing" kind that remain in one location.

Zirin at first thought the newly discovered phenomena were magnetic waves. But if they had been, they would slow down as they radiated outward through decreasing magnetic fields. The Stein Waves don't do this; their velocity is constant, as would be expected of sound waves under these circumstances.

The wave fronts, which appear as expanding dark rings, originate in the dark central region of sunspots (umbra) and become visible as they expand outward through the penumbra, a partly dark region of horizontal magnetic field filaments that radiate in spokes from the sunspots. It is likely that the waves are in the sun's gaseous chromosphere, which should be able to transmit sound waves as does the earth's atmosphere.

Even though the waves are acoustical, they could not be heard—even if you could get close enough to listen—because they are about 10,000 times lower than the pitch range of the human ear.



Radiating outward in successive concentric rings (A, B, and C), Stein Waves—soundwaves on the sun—move between 18,000 and 25,000 miles an hour away from the dark central region of a sunspot.

The waves move outward to the edge of the penumbra, a distance of several thousand miles. Beyond this point it is believed they are scattered and broken up in the sun's seething, turbulent structure. The waves appear related in some way to flashes of light of unknown origin, deep inside the dark umbra. The umbral flashes usually last a minute and are repeated every 2½ minutes. The Stein Waves occur just about once every two umbral flashes. This leads Zirin to speculate that the waves are sound waves that carry the energy generated by the umbral flashes outward.

The waves are visible only under exceptionally good seeing conditions, which is probably why they have not been discovered before. The Stein Waves are best seen in large stable sunspots, sometimes in smaller spots, but never in active, complex spots where magnetic fields are so irregular the waves do not propagate. Out of 20 sunspot groups, Stein found the waves in all but two. In spot clusters the waves are sometimes seen to be emanating from several spots at the same time.

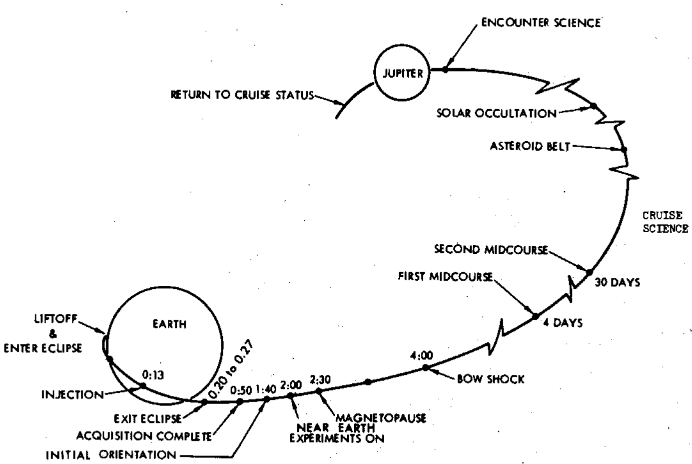
The waves should give scientists a whole new picture of the energy production in sunspots. According to theory, activity in sunspots is "frozen" because of the strength of the magnetic waves in them. But if the Stein Waves are truly sound waves, observers get a whole new picture of the inside of sunspots—one in which there is a great deal of dynamic activity going on.

Pioneer 10—A Small Spacecraft with a Big Job

In a little less than two years scientists will be able to take the closest look yet at the cloud-shrouded planet Jupiter, 400 million miles from Earth.

Pioneer 10, a 570-pound spacecraft loaded with 65 pounds of scientific equipment, was launched March 2 on a 21-month journey to the solar system's largest planet. If it survives its passage through the asteroid belt and through Jupiter's powerful radiation belts, Pioneer 10 will pass within 87,000 miles of the puzzling planet before looping out into interstellar space.

Its job is threefold. Pioneer's main task is to take a close look at Jupiter and send information back to Earth about its radiation and physical characteristics. On the way it will investigate interplanetary space between Mars and Jupiter, where no man-made craft has ever been. And it will study the 150-million-mile-wide asteroid belt—that collection of small bodies orbiting the sun between the two planets.



Pioneer 10 is now almost three months into its 21-month, 400-million-mile journey to take a look at Jupiter.

The instruments aboard the probe will collect information regarding a number of things scientists want to know about: the density and composition of Jupiter's turbulent, changeable atmosphere; the amount of hydrogen and helium present; the amount of flattening at its poles; the composition of its clouds and the reason they are banded; the cause of its Great Red Spot and the planet's intense magnetic field; the reason it traps radiation particles of such intensity that it is one of the strongest radio sources in the sky; and the mass of its moons—several of them larger than our own, or than the planet Mercury.

The amount of heat that Jupiter radiates will be measured by infrared detectors in an experiment conceived by Guido Münch, professor of astrophysics and astronomy, and Gerry Neugebauer, professor of physics—both of whom are also staff members of the Hale Observatories. The instruments will also allow scientists to determine how similar the helium and hydrogen content of Jupiter is to that of the Sun.

Leverett Davis, professor of theoretical physics, is one of several co-investigators with Edward J. Smith of Caltech's Jet Propulsion Laboratory on the magnetic fields experiment, which will measure the interaction of the "solar wind" with Jupiter, and which will map Jupiter's strong magnetic fields, the relationship of the fields to Jupiter's moons, and the heliosphere boundary—the point at which the Sun's influence ends and intragalactic space begins.