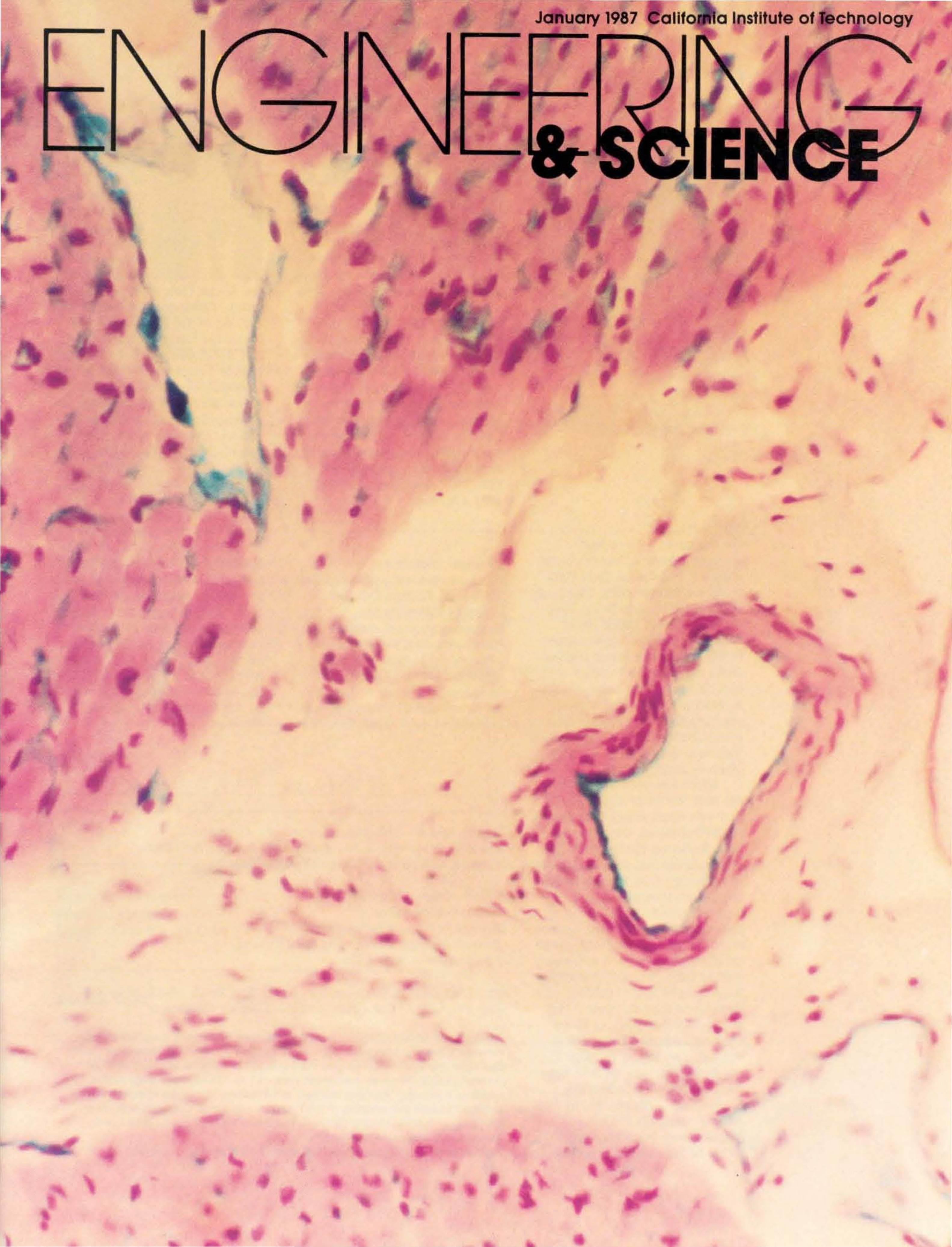
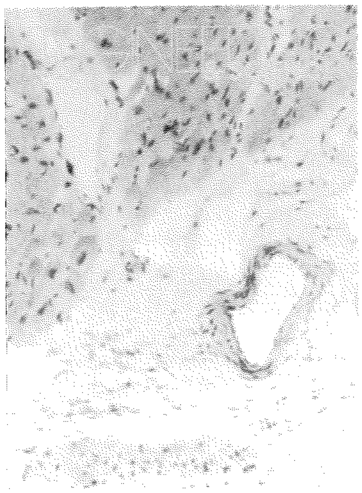
January 1987 California Institute of Technology

ENGINEERING & SCIENCE



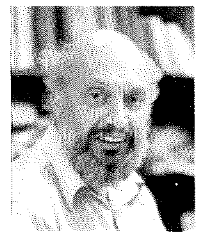
In This Issue



All Heart
On the cover — a section through a piece of human heart muscle. The round, dark pink blobs are muscle cells, which are surrounded by capillaries, here stained blue. A larger blood vessel can be seen (right center) in the connective tissue (lighter pink) between the bundles of muscle fibers. Blockage of such a vessel prevents oxygen from reaching the heart muscle cells, which then no longer contract in unison to function as a pump. Then — heart attack.

Much has been learned in the past few years about how and why heart attacks happen. Jean-Paul Revel, the Albert Billings Ruddock Professor of Biology, believes that these advances in research are at least as important as the transplants and artificial devices that have claimed public attention; understanding the heart's mechanisms on a cellular level will ultimately lead to better ways of preventing heart attacks and of dealing with them once they do occur. His article, "Cell Biology of Heart Disease," adapted from a Watson Lecture, begins on page 2.

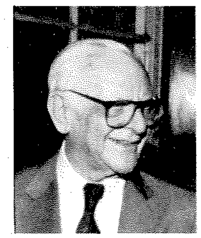
Revel received his BSc from the University of Strasbourg, France, in his native city, in 1949. After earning his PhD in biochemistry from Harvard in 1957, he returned two years later



to join the faculty of the department of anatomy at Harvard Medical School. Since 1974 he has been professor of biology at Caltech, holding the Ruddock chair since 1978.

Revel's own research concerns the way cells communicate with each other, and his electron micrographs of cell structures (not to mention other, more amusing organisms, such as, recently, medflies) are internationally famous. He's also an enthusiastic and popular teacher, achieving an extraordinary 84 percent student attendance at an 8:00 a.m. class.

Personal Diplomacy
Armand Hammer delivered the 1986 Bray Lecture October 20, the week following the Reykjavik summit meeting and Hammer's own successful intervention in the case of the refusenik David Goldfarb. Hammer, chairman of Occidental Petroleum Corporation, was introduced by Caltech President



Marvin Goldberger as "an unusual entrepreneur, diplomat, art lover, and philanthropist," whose relationship with the Soviet Union goes back 65 years. Goldberger described him as "one of the most important forces for international peace and understanding between the United States and the Soviet Union." Hammer's lecture, which described his personal experience in Moscow during the historic encounter and some speculations on the future, "Soviet-American Relations: As I See It," begins on page 10.

The Ulric B. and Evelyn Bray Visiting Lectureships were established four years ago by Mrs. Bray in honor of her husband, a local business and civic leader who had had a long and productive relationship with Caltech. The lectureships bring to campus outstanding entrepreneurs with interests in public affairs. This year's Bray Lecture was given at a dinner meeting of the Executive Forum, sponsored by the Industrial Relations Center.

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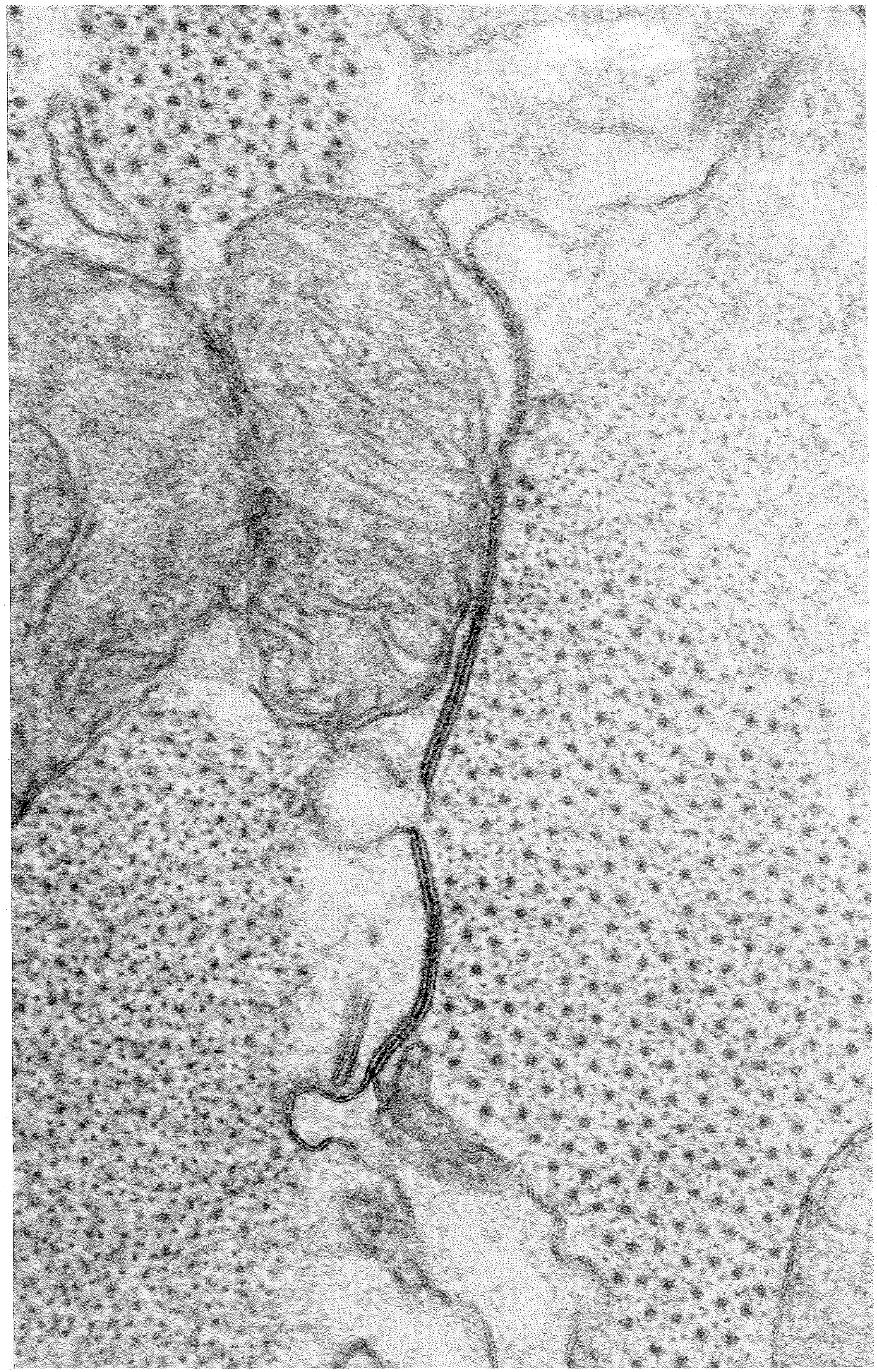


For the heart to work as an organ, cells have to communicate. They do this via gap junctions — the seven-layered structures running vertically through the middle of this electron micrograph. On the right the heavy dots represent cross sections through myosin molecules (25 nanometers across), and the small dots are cross sections through actin filaments. Interaction between these two causes the muscle to contract. The large sausage-like structures are mitochondria, which furnish the energy for this contraction.

Cell Biology of Heart Disease

Transplants and mechanical hearts are not the only route to solving the problem of heart disease. Research on cellular mechanisms is adding to scientists' understanding of how the heart works, why it sometimes fails, and what might save heart attack victims.

by Jean-Paul Revel

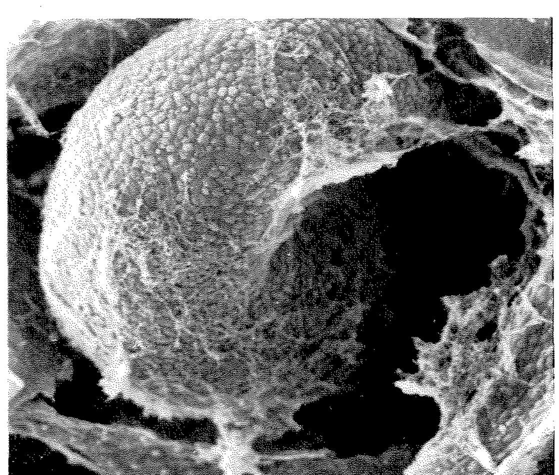
CARDIOVASCULAR DISEASE has been around for a long time; one and a half million people in the U.S. have heart attacks each year. It's something that faces all of us, but it is also a disease that we can do something about.

Heart disease can appear as a slow failure (as in congestive heart disease) that makes itself felt over long periods of time, with your heart eventually just giving out. Or it can be sudden, with very little warning — one, two, three, and you are gone.

If you have a heart attack today, you have an 80 percent chance of surviving. That still leaves 350,000 people each year who don't survive. About 75 percent of people suffering heart attacks are lucky enough to be admitted to the hospital very quickly, and of those, 80 percent survive. Of the 25 percent who don't get to a hospital right away, 95 percent will die.

But I don't want to speak about what happens in hospitals. I'm a biologist, not a physician. As expressed well in a recent review (Atlas and Laragh), "There is good reason for excitement in the potential for rolling back one of the most common causes of death, but no less exciting is the process itself, in which the elaborate, elegantly logical pathways of human physiology are pieced together." We now have the beginnings of biological answers to the question of how a heart attack happens.

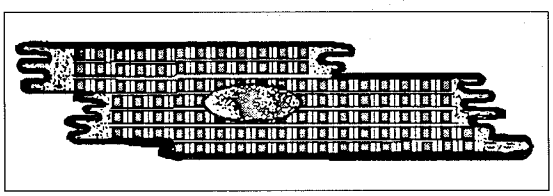
The heart pumps blood through a network of blood vessels 60,000 miles long. Of course

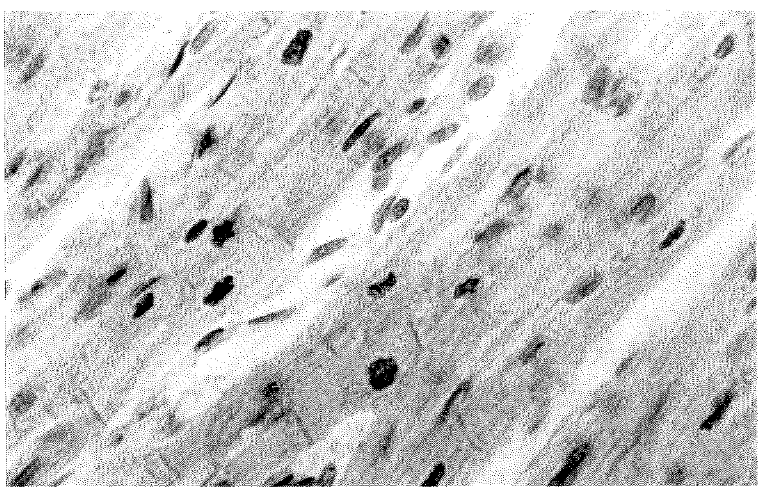


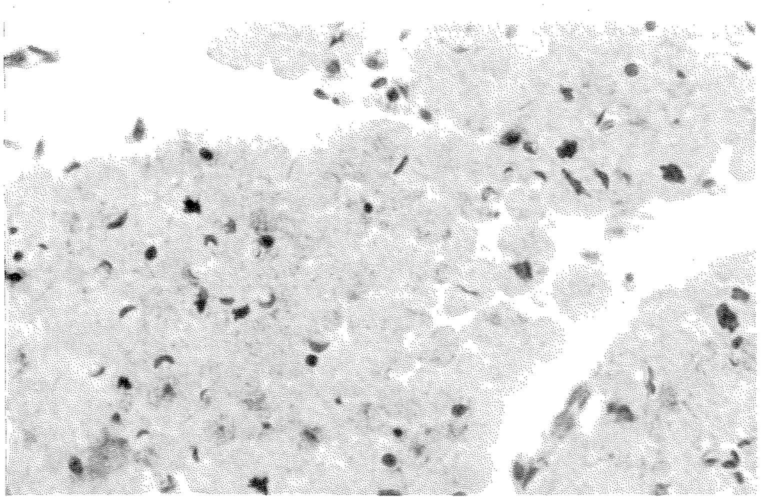
Although the adult heart is a complex organ, it starts out as a very simple tube. Shown here is the heart of a chick embryo observed under a scanning electron microscope.

this isn't linear — it's a branching network — but still it's an enormous length of blood vessel that you end up having to push blood through. And the blood supply is essential. After five seconds without a blood supply to the brain you become unconscious, and by about nine minutes the damage to the brain is completely irreversible. Nine minutes is all you have from the time you fall down from a heart attack to get to someplace where oxygen can be resupplied to your blood.

The heart has four chambers, or pumps — the right and left atria and the right and left ventricles. The blood that has already circulated around the body and is depleted of oxygen enters the right atrium, where it is pushed through a valve into the right ventricle, filling it up. When full, the ventricle contracts strongly and pushes the blood with great force out into the lungs, where it is reoxygenated. Then it comes back into the left atrium and is pushed into the left ventricle, which contracts and pumps it into the aorta and around the rest of the body again.







Shown in diagram (top) is a single heart muscle cell with membrane, nucleus, and cytoplasm filled with contractile elements and support "machinery." Below that are some human heart cells seen through a light microscope. At this magnification only the nuclei and the "ends" of the cells, or intercalated discs, are distinguishable. In cross section (bottom) each heart muscle cell appears as roughly circular. The small crescent-shaped, dark objects between the cells are capillaries.

The heart is able to work as a pump because each one of the heart muscle cells is contractile and they can all be directed to contract in concert. If we mince a heart up into individual cells, put the cells in a dish, and grow them in culture as if they were bacteria, each cell will beat by itself. Left alone the cells beat at different rates, but they will beat synchronously if allowed to make contact with each other. This is where my own interest in the heart started, because my research concerns the structures, called gap junctions, that are part of the contact area. Gap junctions are clusters of small channels through the cell membrane of two contacting cells, through which information in the form of a flow of ions can be exchanged to synchronize the two heart cells.

Although each cell is linked to every other cell and synchronized by gap junctions, there has to be something to set the pace — like a band leader. This role is played by a natural pacemaker (artificial pacemakers perform the same function). The primary one is called the sinoatrial node because it sits at the sinus, the meeting place where the blood vessels come into the right atrium. It sends out the impulse that imparts the beat to the right and left atria. Eventually that impulse reaches the atrioventricular node situated between the atria and the ventricles. The cells in the first node beat the rhythm for the atrium, and after a short delay the atrioventricular node takes up the beat, sending its impulse down the conducting system that then spreads over the ventricle. The whole thing is arranged in such a way that the beat occurs in a nice, even fashion so that the whole heart contracts in just the right way to expel the blood.

The pacemaker establishes an intrinsic rhythm to the heart, but the heartbeat is also controlled by nerves. When you get excited, your heart starts beating very hard and pushes more blood out; that's the sympathetic nerve system taking over. The parasympathetic nerve system inhibits the heartbeats. But this nerve control is not actually essential for hearts to function. When you transplant a heart, the nerves are severed and they don't grow back — yet the heart still beats.

Normally the heart beats 72 times per

minute, but sometimes it can go too fast — called tachycardia — or too slow — bradycardia. Much worse than these is arrhythmia, in which the heart suddenly accelerates and then slows down, doesn't beat continuously, or sometimes has extra beats between regular beats. These are all disease conditions. Once in a while it's all right to skip a beat, but if it happens too often, you have a real problem that has to be dealt with.

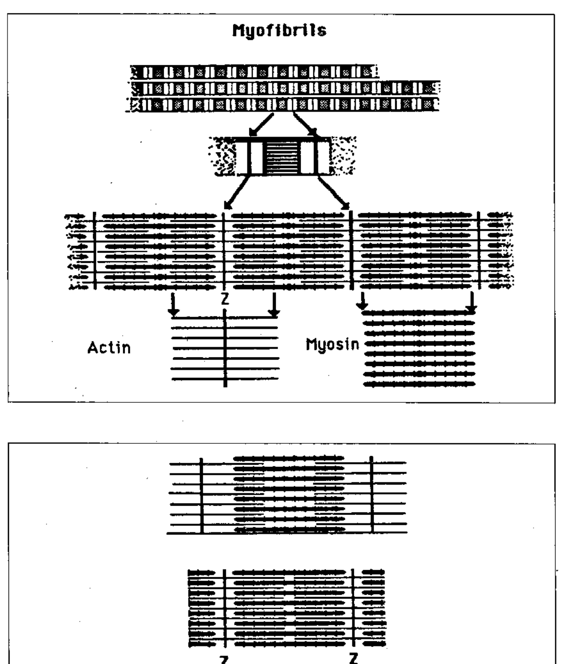
But perhaps the most dangerous thing that can happen to the heart occurs when different groups of cells start to contract on their own instead of responding to the pacemaker. Instead of contracting as a whole to push the blood out, there are now islands of cells contracting independently of each other, resulting in a fluttering and ineffectual contraction of parts of the heart muscle, but no contraction of the heart as a whole. So blood doesn't get pushed out of the aorta, it doesn't go into the carotid artery that carries it to the brain, and you have five seconds before you pass out and only nine minutes before you die (or at least sustain irreversible damage). This fluttering is called fibrillation and is the major cause of death from heart attacks.

The problem can be fixed by a defibrillator, a machine that passes a large amount of current through the chest wall to try to get all the cells to "reset." If you do it at the right time, the pacemaker will say to the cells, "OK, all together now," and they'll start beating synchronously again. Since defibrillators would enable some of the 95 percent of heart attack victims who die on the street to get to the hospital in time, one thing that would help is to have more defibrillators around. But using a defibrillator without knowing what you're doing would be like putting your hand in an electric socket. Some of the newer instruments being designed can sense by measuring currents when the right time to deliver the shock occurs, so that people who are not trained as physicians can use them.

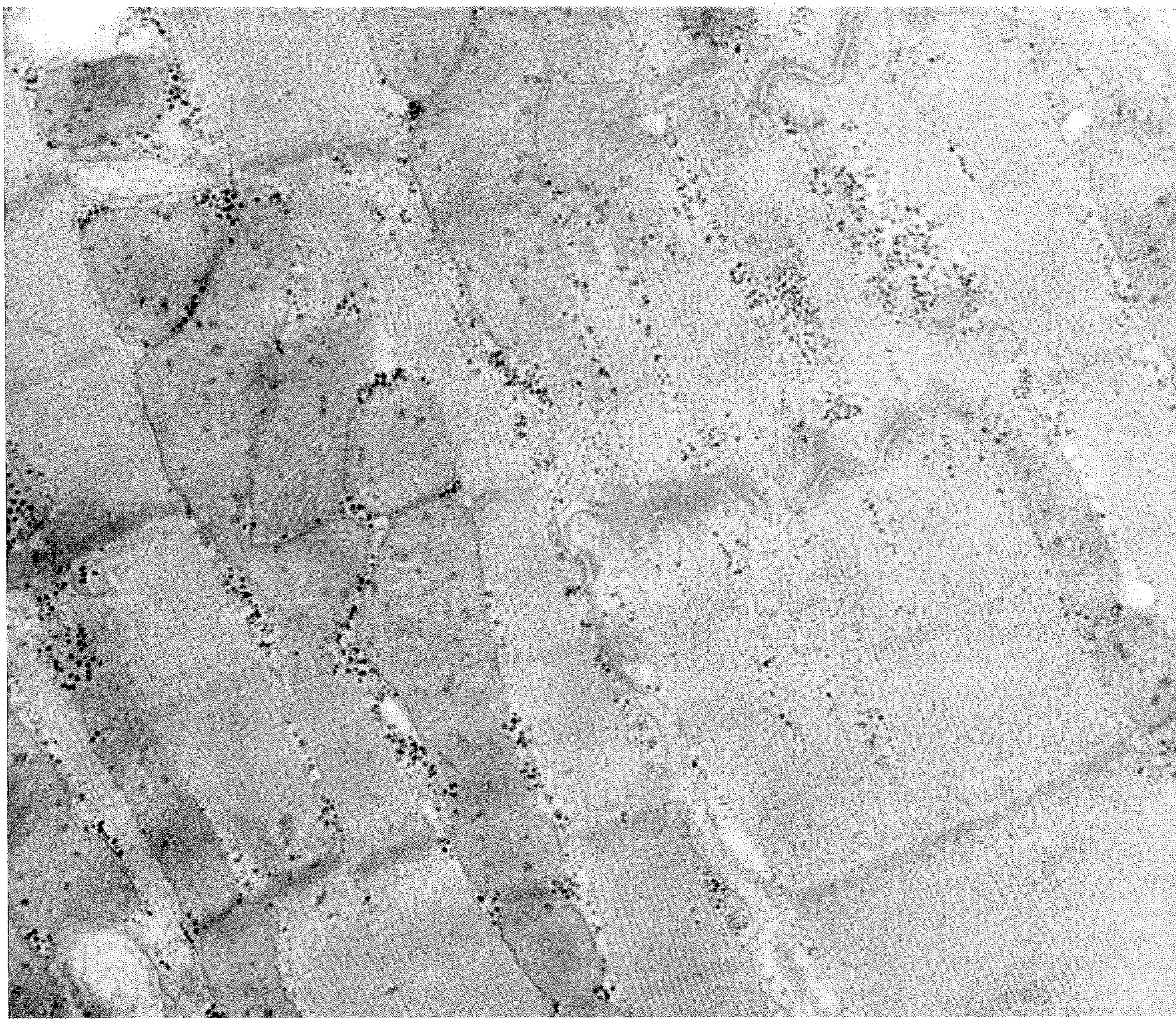
Now, you can't talk about the overall activity of the heart without speaking about the heart cells themselves. A heart cell has a membrane, as do all cells, surrounding cytoplasm containing a nucleus and organelles. The cytoplasm of muscle cells is jam-packed with special machinery. Myofibrils, for example, are the contractile elements that allow the cell to shorten. Mitochondria provide the energy to power the myofibrils. Every myofibril is surrounded by the sarcoplasmic reticulum, a network of tubules that stores calcium and occupies much of the rest of the space in the cell.

Let's look at the contractile system first. Under the light microscope the cell with its myofibrils looks like a succession of dark and light stripes; the light stripe is called the I-band for isotropic (when you look at it in the polarizing microscope), and the dark one is called the A-band for anisotropic. The Z-line is located in the middle of the I-band, and repeating units called sarcomeres connect one Z-line to the other. These are the units of contraction. Under the electron microscope you can see two sets of filaments in the sarcomeres — dark, thick ones made of myosin and light, thin ones made of actin. The two interact with one another in order for the heart to contract. During contraction the two sets of filaments slide past each other. Of course, they can't go very far (half a micron) because there isn't much room for them to move, and the total contraction of the heart is due to all these sarcomeres lined up in series one after the other. When you sum up all of the shortened sarcomeres, hundreds of thousands of them end to end, you have large movements even though each one moves only a very short distance.

In the relaxed state the filaments overlap less, and in the contracted state they slide in. How do they go from one state to the other? They do it by interacting with each other. At rest they can't interact because a set of molecules, including one called troponin, sits right on the actin filament like a chaperone and



The contractile elements, or myofibrils, are faintly distinguishable as longitudinal striation in the middle picture on the opposite page and more readily recognizable in the electron micrograph on the following page. The top diagram shows the structure of the contractile elements. Two sets of filaments interdigitate — the thick ones composed of the protein myosin and the thin ones of actin. During contraction (bottom) the actin filaments pull in toward the middle of a "sarcomere," which as a result becomes shorter. Summing all the shortenings causes the macroscopic contraction of the heart, squeezing the blood into the arteries.



In this piece of heart muscle seen in the electron microscope one can recognize the myofibrils, although it's difficult to distinguish the actin and myosin filaments because of the thickness of the section. The wavy line running across the picture is an intercalated disk, where two muscle cells abut end to end. Between the myofibrils lie mitochondria, and the small black dots are glycogen molecules, a storage form of carbohydrate.

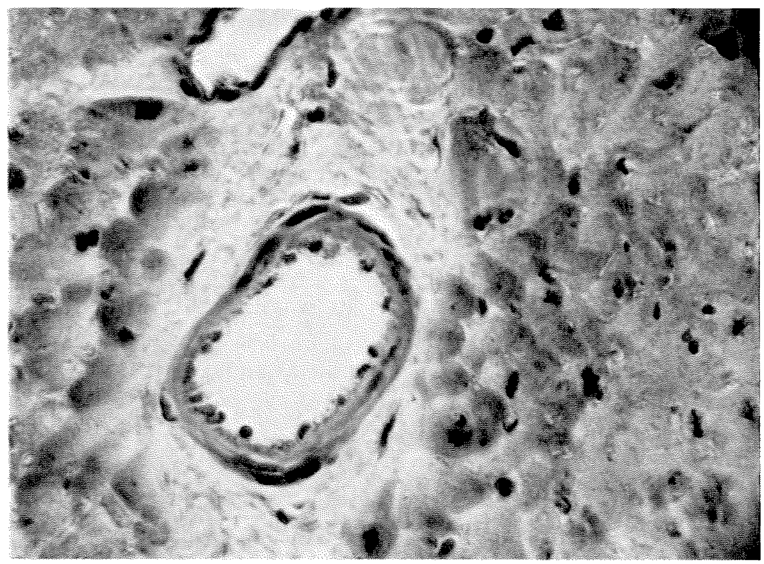
prevents it from interacting with the myosin. If they can't interact, they can't contract. Like all chaperones, this one has faults. In many novels chaperones love chocolates, and if you bring a box of chocolates, the chaperone will sit in the corner and eat them and forget about what's happening in the back room. In the case of heart muscle, it isn't chocolate — it's calcium. This is where the calcium-storage organelle comes in, which has released its calcium as part of the coupling between excitation and contraction. The chaperone grabs the calcium, to which it binds strongly, and, as it does so, it exposes the reactive sites on the actin. The actin and myosin can interact, and everything is very good. But the calcium-storage organelle also represents a mechanism for removing the calcium. And when the calcium concentration in the cytoplasm drops low enough, the chaperone has to give up its calcium. It can now go back and inhibit actin-myosin interactions again, and the heart relaxes. All this happens in each cell every time the heart beats — 72 times per minute.

Now let's look at the ionic events that control contraction of the heart muscle cell. Across the membrane of this cell there is a potential, -90 mV inside, which means that there are more negative charges inside than there are outside. This is an equilibrium potential due to the distribution of sodium ions that are floating around. It's a little like the situation on the Mexican border. The sodium ions, for example, hang around on the outside of the border, unable to cross because the membrane is impermeable to them. They try to get across and can't, so they bounce back. The potassium ions on the inside of the cell, however, are able to move back and forth freely.

When the muscle decides to contract, it does so by means of an action potential — a mechanism caused by leakiness of the membrane to sodium ions. In the resting state they couldn't get across the membrane border, but during passage of the impulse to contract in the form of an action potential, the cell says, "OK guys, we'll let you in." So the sodium ions can come in. This brings in positive ions from the outside, which makes the inside less negative. The membrane potential drops; the cell is depolarizing, with the major consequence that when the cell becomes sufficiently depolarized, a gate suddenly opens that allows some calcium ions to come in too. These calcium ions then react with the calcium-storing organelle, causing it to release all its calcium and diverting the "chaperone." Now actin can react with myosin, and the muscle contracts.

After a relatively long time (all of this takes milliseconds), the inside of the cell has become even more positive, so potassium ions can leak out in a grand fashion, and they do. An outward leak of positive ions is the same as adding negative charges to the inside, so the membrane starts to repolarize — it becomes more negative inside, and pretty soon calcium can't come in any more because its gate closes again. That shuts off the whole system. All the calcium released in the cytoplasm will be picked up by the calcium-loving organelle, the myosin and actin stop interacting, and the muscle can relax. We end up with both sodium and potassium on the inside, and a membrane molecule (Na,K ATPase) that acts like the border police rounds up all of the sodium ions and kicks them out. Each time it kicks out two sodiums, it can take in three potassiums. Eventually all the sodium will be out and most of the potassium will be in, and we are ready to start the whole story all over again. This all works just great, but there is one hitch. Processes such as pumping the calcium into the storage organelles and rounding up the sodium ions require energy, which we get in the form of a molecule called adenosine triphosphate (ATP), manufactured by the mitochrondria. The mitochrondria take in phosphate, fuel in the form of sugar derivatives, and oxygen, and make CO_2 and ATP out of them. Where do they get the oxygen? From the blood supply.

All cells make ATP and use it to carry out any function in the body that requires energy, so they all need oxygen from the blood. Since the cells of most organs use only about half of the oxygen that passes by them, those organs can increase their demand for oxygen and still find plenty available. But the heart uses 80 percent of the oxygen that goes by it in each pass. There's almost no marginal reserve. This brings us to the importance of the coronary artery system — the blood supply to the heart. Although the heart pumps blood, it doesn't use the blood that it has inside of it for its own needs. The coronaries service the heart muscle's needs. When there's a blockage in one of the branches of the coronary arteries, a small portion of the heart muscle doesn't get the oxygen it should get.



A small artery in a human heart shows circularly arranged smooth muscle cells and dot-like nuclei of the endothelial cells, which form the inner ply of the vessel. Occlusion of such blood vessels leads to damage of the surrounding area. If the area is large enough, this can impair functioning of the heart as a whole and lead to sudden death.

One of the scenarios for the consequences of such a blockage goes like this: Within seconds the calcium starts to leak out because the mitochondria stop working. We have no more oxygen; it can't get in because the blood flow has stopped. If the mitochondria have no more oxygen, they can't make ATP. Even then, the cell has still one way to make a little bit of it — about 4 percent of the total ATP can be made by a mechanism that doesn't require oxygen, but this produces lactic acid. The acid leaks out of the cell, and since it is a negatively charged compound, it has to take a positively charged compound with it. Since potassium is the most abundant positive ion inside the cell, you start losing potassium from the inside. The overall effect of this and other changes is that the membrane potential of affected cells drops from -90 mV to -60 mV during the early stages of a heart attack.

As the membrane partially depolarizes,

synchrony is impaired. Gap junctions close, cell-to-cell communication is disrupted, and the whole system starts to fall apart. What is especially devastating is that even though only one particular area of muscle has been badly affected by a lack of blood and has a membrane potential of -60 mV, the rest of the muscle is perfectly normal with a potential of -90 mV. But when regions of the heart muscle have different potentials, electrical currents flow between them. Such currents can reenter the muscle anywhere and start a contraction. So cells contract by themselves and not on the well-orchestrated orders from the pacemakers. This starts the process we know as fibrillation. The heart muscle stops working as a pump, and the body collapses.

Let's assume that we do the only apparently reasonable thing we can do — get oxygen to the heart so it will work again. One obvious way is to circumvent the blood stoppage. If it is due to a blood clot, we can try to dissolve the clot as quickly as possible. So we inject enzymes that very specifically dissolve fibrin, the molecule that holds blood cells together in a clot, and circulation gets reestablished. Unfortunately, as part of a continuing cascade of events, compounds accumulate in the cell which can generate peroxides when oxygen becomes available again. The peroxides that form can damage the cell and the rest of the machinery. The physician tries to reestablish circulation to the cells as fast as he can. If he doesn't, the patient may die; if he does, he'll kill the cells, which explode from the effect of all the peroxide. So he's damned if he doesn't and damned if he does. One exciting possibility being explored to prevent this is to break down hydrogen peroxide with the enzyme superoxide dismutase and thus reduce the amount of cell damage.

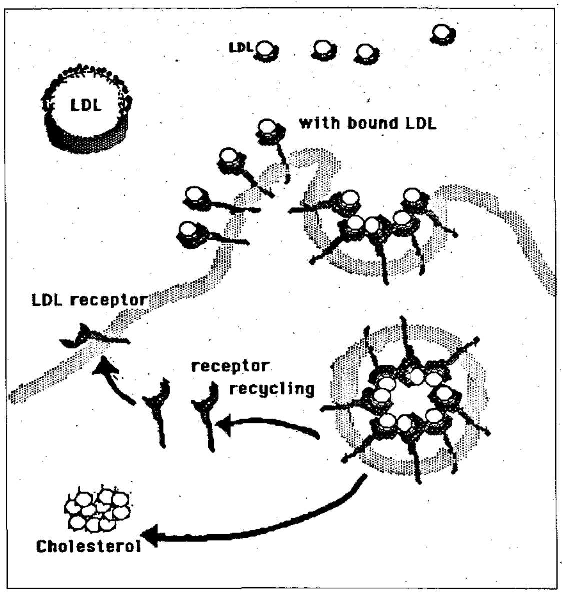
But instead of just trying to save something after the fact — opening up a clogged blood vessel — we ought to be trying to prevent it from occurring in the first place. So we have to figure out what causes the clog. First something goes wrong with a branch of the coronary artery. Arteries have an inner lining — the endothelium — and beneath that lies a band of elastic tissue, which gives them resilience. Surrounding this are some smooth muscle cells, which can change the diameter of the vessel and thus control the amount of flow. Smooth muscle cells are usually well behaved. They just do their job and nothing else. Normally they don't multiply, except in the embryo, but during heart disease something very peculiar happens: The smooth muscle cells start to proliferate and make a big bump on the wall of the blood vessel, partially occluding it. Also accumulating at this bump are scavenger cells. Both smooth muscle and scavenger cells become filled with fat, forming what in the jargon is called a plaque. Blood platelets, which normally circulate through the vessel, pile up at the bump and along with other cells form the beginning of a clot.

One theory about early events leading to a heart attack goes as follows: If the wall of the blood vessel is damaged, the blood platelets stick to the site as a reaction to the injury. The platelets can penetrate through the blood vessel wall and secrete platelet-derived growth factor (PDGF), which stimulates the smooth muscle to grow. This leads to the formation of the bump on the wall. An alternate theory runs slightly differently: Muscle cells secrete their own growth factor, but the endothelium secretes heparin, which inhibits this growth factor from acting. When the endothelium is damaged, less heparin is produced, allowing the growth factor free rein to force the muscle cells to divide and make the bump.

Whichever theory is correct, neither explains how we end up with all these fat droplets deposited in the cells. The culprit is cholesterol. Cholesterol is a molecule that's insoluble in water. So how does it get carried in the blood, which is an aqueous medium? It does it by jumping onto a submarine — a particular molecule called low-density lipoprotein (LDL). The LDL carries the cholesterol, keeping it high and dry, while the whole complex is soluble.

LDL gets out of the bloodstream by binding to a receptor on the surface of liver cells. When enough receptors have LDLs attached to them, they are taken into the cell, where the receptors are separated from the LDL and sent back to the surface to continue their jobs. Cholesterol is accumulated inside liver cells as fat droplets.

This happens normally in the liver and adrenal glands, which have a lot of cholesterol. Michael Brown and Joe Goldstein, who won a Nobel Prize last year for their work, studied a disease called familial hypocholesterolemia (FH). FH is a fairly common disease in which the receptor for LDL is defective. Most of the people who have FH — one out of 500 of us — are heterozygotes; that is, they have one good



LDL, rich in protein, is made soluble by attaching to a protein, seen as a dark crescent in the upper left corner of the diagram. LDL receptors (left center) in the cell membrane bind to LDL. The receptors cluster (right) and are taken into the cell in a special vesicle. The fat portion accumulates in the cell, and the receptor itself is recycled back to the surface.

gene and one bad gene. These people have *some* good receptors for LDL but not as many as normal, and they have heart attacks at 30 to 40 years old. Those with two bad genes have almost no good receptors at all and have heart attacks in childhood. The defective LDL receptor in FH means that LDL does not get taken up by the liver, and so there's a high level of LDL in the bloodstream at all times. Just why there is deposition of cholesterol in the heart under these conditions is not understood at this point. But with high levels of LDL in the bloodstream cholesterol accumulates as plaques in the blood vessel walls, in the scavenging cells, and in the smooth muscle.

A recent theory puts the blame for this accumulation on some lipid peroxides that cause injury to the endothelium and make the smooth muscle cells, which normally would not take up much LDL, take up lots of it. Why do we care whether there is deposit of fat in the blood vessel wall? One reason is that it leads to clogging up the vessel. By reducing the diameter of the vessel, blood flow is restricted, blood platelets stick to the wall, and a clot forms. No blood at all can get through and then — heart attack!

One of the best ways to combat this situation is to prevent the whole affair from getting started. For example, we can keep cholesterol out of our diet, and this helps a little bit. It's not quite as easy as that, because if we don't take in enough cholesterol, our body makes its own anyway. So we also have to have a mechanism to control this self-manufacture. This is difficult, because you have multiple factors interacting with each other, but progress is being made in developing drugs to counteract this. Another thing we can do is to stop smoking. Since smoking reduces the amount of oxygen the blood can carry, you don't have to have a complete obstruction of a blood vessel before the amount of oxygen arriving at your heart is reduced below a critical level.

It hasn't yet been demonstrated whether coffee is bad for you, although some studies indicate that it might be. But I've also read an article that claimed it was bad only if boiled. Alcohol, on the other hand, is good for you, because it relaxes you. Too much is no good. But none at all is bad too.

Hypertension also contributes to the kind of heart attacks I've been discussing because it puts extra stress on the heart. Narrower blood vessels make the pressure higher than it would be normally; this can often be controlled by diet and medication. Scientists have also recently discovered a hormone with the beautiful name of atrionatriuretic factor. Produced by the heart itself, it actually lowers blood pressure by working against other hormonal systems that increase the pressure.

New imaging tools — such as nuclear magnetic resonance (*E&S*, January 1986) — and other diagnostic techniques are being developed to pinpoint where the blood vessel obstruction is and how big it is. This can help physicians choose the best way of dealing with a particular case. Better transplant technology and a better understanding of the mechanism by which hearts are rejected will also save lives. Quick response by trained personnel will also help, that is, people trained in cardiopulmonary resuscitation (CPR). Most of those who enroll in CPR courses are about 20 years old, and that's very nice, but they're not the ones who are usually having heart attacks. The 50- and 60-year-olds should learn CPR — and not just wives in order to save their husbands. Women are smoking more and eating the same stuff that men do and are rapidly catching up with the men in incidence of heart attacks.

Scientists understand quite a bit about the basic biology of the heart, but there is still a lot to learn about the detailed mechanisms by which the heart does its thing. And this understanding will lead us to better ways of dealing with heart attacks. Perhaps an article such as this 10 years from now will be very different; some of the problems that we face today will have been solved. □

Soviet-American Relations: As I See It

by Armand Hammer

The Bray Lecture was delivered October 20, the week following the summit at Reykjavik. David Goldfarb, a molecular biologist and Jewish dissident, had long been denied permission to emigrate and was one of the most prominent of the Soviet refuseniks.

I AM HONORED to have been invited to deliver the Ulric B. Bray Lecture in such distinguished company that includes Mrs. Bray, my colleagues of the Executive Forum, as well as members of the faculty and the student body of Caltech. I feel very comfortable in this role since Ulric Bray was an oilman — at least at heart — and one of the pioneers in the chemical engineering end of the petroleum industry. My subject for the Bray Lecture is "Soviet-American Relations: As I See It," and I can tell you "I see it" a lot better tonight that I did a week ago in the aftermath of Reykjavik.

I went to Moscow while the mini-summit was still going on in Reykjavik, to discuss business matters with top Soviet trade officials. Then I planned to fly to Kiev on Thursday of that week to attend the opening of my art collection at the Kiev State Museum, which was part of the first cultural exchange negotiated after the Geneva summit. I also intended to be at the John Denver concert I helped to organize for the benefit of the victims of the Chernobyl disaster.

But my plans changed dramatically thanks to an old friend, Anatoly Dobrynin, the long-time Soviet ambassador to the U.S. and current Secretary of the Central Committee. We had a meeting last Wednesday evening, the day I arrived in Moscow, to discuss various subjects, and as we were finishing I suddenly said: "Anatoly, I want to take David Goldfarb back to the United States with me."

"Armand," he said, "that's impossible. Matters of this kind take a great amount of time to decide and arrange."

I said, "Well, you have known me, Anatoly, for 25 years and you know that I'm accustomed to doing the impossible. Why don't you try?" Reluctantly he said he would look into it.

Several hours later I had a meeting with a Soviet Deputy Prime Minister when a call came from Mr. Dobrynin, who said "Armand, permission has been granted, providing Dr. Goldfarb wants to go, and his doctors think he is well enough to travel." I asked where he was and was given the address of the Vishnevsky Institute for Surgery.

I immediately drove there and was warmly welcomed by the director, a distinguished surgeon named Dr. Kuzin. He said the patient's condition had improved remarkably over the past few weeks. Dr. Goldfarb had lost one of his legs in the Battle of Stalingrad during World War II, and he was in danger of losing the other because gangrene had set in. Two of his toes had to be amputated.

I was taken to the ward to see him, and it was a sad sight. He was in intensive care. There were three other post-operative patients there, and he was huddled up in one corner of the room. My first words to him were, "Dr. Goldfarb, I've come to take you to the United States tomorrow. Are you ready to go?" His eyes filled with tears. But they were tears of joy. He said, "This is my dream, but can my wife go with me? I can't go without her."

I tried to reach Mr. Dobrynin, and it was only late at night that I found him at his country home. And I said, "Anatoly, Dr. Goldfarb cannot leave without his wife." There was a pause for several minutes. Then he answered, "Go ahead, you have permission to take his wife as well."

Mrs. Goldfarb lived in a two-flight walk-up apartment in an isolated section on the outskirts of the city. I climbed the flights up to the apartment and knocked on the door, and she let me in. I gave her the news. Her first remark was "What shall I do about my job at the Polyclinic?" I said, "Mrs. Goldfarb, you are going to America. You do not need any job. Your son will take care of you." She said, "Would you drive me to the Metro so I can go and see David." And I said, "Certainly."

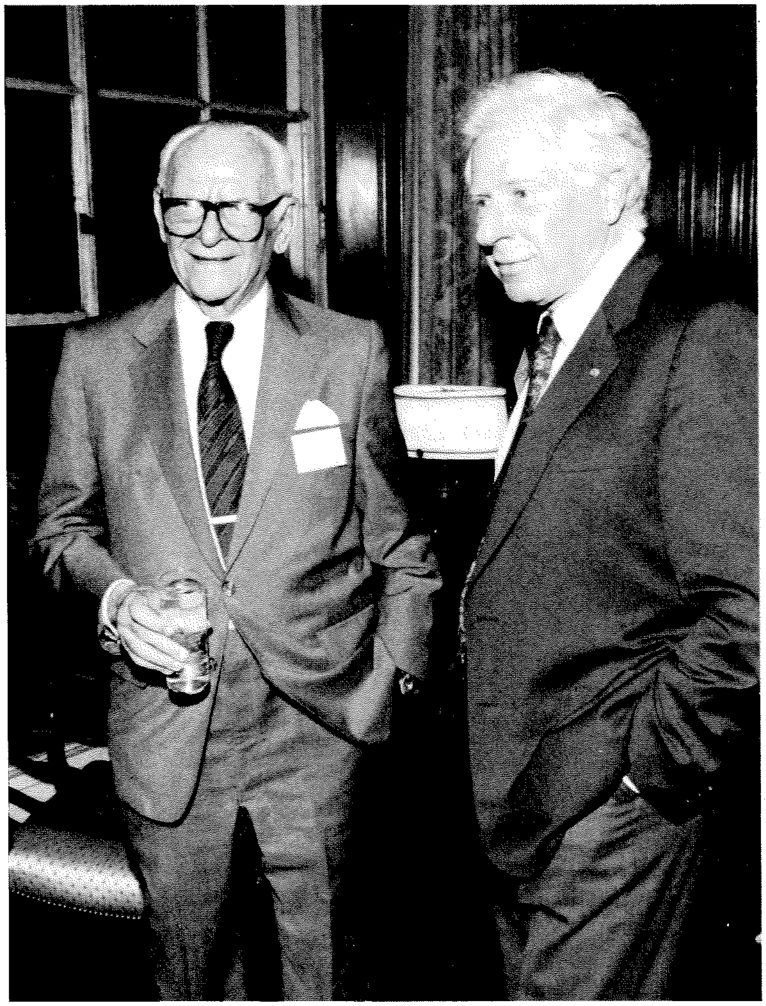
The next morning, I picked her up at her home and we drove to Ovir, the passport office, where a three-star general received us cordially. He already had new immigration passports made up for her and her husband. We then drove back to her apartment, where her daughter, her son-in-law, her grandchildren, and a host of friends had assembled. We loaded 19 pieces of luggage into two automobiles.

We then went to the hospital, where we found David Goldfarb sitting in bed with a big smile on his face, decked out in a brand new set of pajamas his wife had brought him the night before. The doctors and the staff helped me to take his wheelchair and wheel it to the stairway, and then they even carried him down in his wheelchair. Dr. Kuzin and Dr. Vishnevsky were there to see him off. His relatives and friends were gathered, and there was an ambulance waiting for him. We loaded him in the ambulance, and his wife went with him. I started for the airport, followed by the ambulance and by a flock of cars belonging to his friends.

When we got to the airport, the gates opened as if by magic, and we were allowed to go right to the steps of the plane, without any customs or emigration check-up. He said goodbye to his daughter and his grandchildren, and my crew helped to carry him up the steps of the plane. We put him in my study in the plane, where Mrs. Hammer made a bed for him and for Mrs. Goldfarb. I watched the expression on his face as we cleared Russian airspace, and if there was ever a happy man, David Goldfarb was such a man.

While we rejoice that the Scharanskys, the Orlovs, and the Goldfarbs are free, we must be mindful of the thousands of others who are still being refused permission to emigrate.

Before the lecture Armand Hammer greets Evelyn Bray, who endowed the lectureship in her late husband's honor.



Hammer and Caltech President Marvin Goldberger, who had met previously in Moscow, talk with guests at the Executive Forum.

I'm sure the decision to release Dr. Goldfarb went right to the top — to General Secretary Gorbachev — and I believe that this expression of goodwill is significant at this critical moment in the aftermath of Reykjavik.

Postmortems on Reykjavik have come by the droves, but the fact remains that there were some major breakthroughs explored over those 36 hours of marathon negotiations, most of which were on a one-to-one basis between the President and Mr. Gorbachev. There was one thing lacking, I feel, and that was an agreement on the Strategic Defense Initiative.

In my conversations in Moscow and in Washington on my return to the States, I found an upbeat mood, which leads me to expect that there will be further progress after Reykjavik. Senior officials of both governments feel that much was accomplished, and they point beneath the headlines to something that you may find of interest — the need to really understand the Anti-Ballistic Missile Treaty and what is permitted and what is not permitted under its charter.

I was told that throughout the years there has never really been a comprehensive understanding of that document. The heads of state agreed and the treaty was signed, although never ratified by the Senate. Various officials no longer in power have negotiated certain understandings, but there has never been a serious meeting on each side going over the treaty line by line to try to understand what was meant. It is hard to think that the future security of the world may depend on such negotiations, but I am told that this is very true and vital in the next step in the arms negotiations. It was also pointed out to me that both sides did agree in Iceland not to exercise their existing right of withdrawal from the ABM Treaty for 10 years — which again underlines the importance of understanding that document.

I was told — on both sides of the Atlantic — that there is no desire to halt laboratory work on SDI, which indeed may already exist in the Soviet Union, as well as in the United States. The issue is really not to extend it into an arms race in space.

And by laboratory, what do we mean? Is it a cinderblock building with test tubes bubbling away? Or can it mean a vast laboratory complex with full-fledged field test activities to conduct laser experiments and so forth?

I thought it was particularly interesting when one of the Moscow officials said to me, "I don't particularly care if you test these missiles under your SDI, or how you shoot them down, as long as you don't go into space."

I was told by both sides — from men who attended the meetings in that small, spare house on the coast of Iceland — that the chemistry between Mr. Gorbachev and President Reagan was very good, laced with candor and sometimes with humor.

I am pleased to hear that, because I have been a long-time advocate of having the leaders of the two superpowers meet so they can get to know each other regardless of their differences and ideology.

I remember before the meeting in Geneva last year, I had a meeting with Mr. Gorbachev. I asked him then — because no date or place had yet been set for the Reykjavik meeting — what he thought about the meeting with Mr. Reagan. He said, "I think it would be a good idea to have such a meeting, but your president doesn't want peace. He wants war." I said, "Mr. Gorbachev, you are mistaken. If you read President Reagan's speech in January, you would see that he said we must have peace with the Soviet Union. Why don't you meet him and size him up yourself?"

Later I was told when I met Mr. Reagan at the Oval Office, that things were moving quickly and that they thought the meeting would be held in Geneva in November, which did take place. The editor of *Pravda* said to some correspondents that he thought that my intervention with Mr. Gorbachev helped. I hope it did.

When I was in Moscow on the first day of the recent mini-summit, I turned on the radio and heard the news and saw that they were making good progress. The next day I was shocked when I heard that the meeting had broken up, and that everyone had said it was a failure with nothing concrete accomplished about setting up a full-set summit in Washington. I thought how sad it was that these two men had fallen apart. I heard Mr. Gorbachev's press conference on the air. The man was so emotional that at one time he had to stop; he could not go on. And I believe he was thoroughly sincere and shaken up over the fact, as he said, that we were so close to an agreement and we fell apart on one thing — insistence on the American side that SDI should continue.

I have made a proposal which I hope will help get us back on the track. Mr. Reagan told Mr. Gorbachev at the conference that once we have developed SDI, we will share it with the Soviets. And according to the information I received (this has been published), Mr. Gorbachev answered, "You will not even share how to measure milk with us, much less the secrets of the cosmos. So let's not waste time talking about that."

Mr. Reagan also said, "Well, if a third party or madman got control of nuclear weapons that threatened both of us, wouldn't we have a shield to be protected?" And Mr. Gorbachev is said to have answered, "Do we have a trillion dollars for that? There are other ways to handle a madman."

Since I am convinced that President Reagan is sincere in offering to share with the Russians when or if SDI is ever developed to the point of deployment, why not share it immediately? Why not invite the Russian scientists to come over and participate in a U.S. laboratory which we will set up? There is a precedent — not as big — but several years ago we had a joint mission to space together. We shared a lot of information and a lot of secrets at that time.

Dr. Goldberger, whom I have discussed this with just now at the table, reminded me that he had had a meeting with his counterpart in Russia and found the Soviet scientists open and ready to discuss all matters of mutual cooperation.

Now, I know there are a lot of skeptics who will say that you can't trust the Russians. But Gorbachev has offered inspection on the ground, inspection in the air. We can verify what they have done. I understand they have been working on SDI. We can make it a condition that their laboratories must be open to us as well.

I think at least it deserves our setting up a team of experts at a think tank — perhaps the Rand Corporation or some other body like that — to study this question. It's worth studying to find out if it is impossible to work cooperatively with the Russians. They think we want to gain superiority. They think we want to be able to protect ourselves so we can launch a first strike on them. Now it sounds absurd, but that's what they fear. I hope that same thought will be given to the suggestion that I have made to allay those fears.

And now, I would just like to close by saying that I have had two dreams in my life. One has been to find a cure for cancer, and I think we are making great progress. Dr. Steve Rosenberg, with whom I have been working closely, has done remarkable things. About half of the 60 patients he has treated have had more than 50 percent of their tumors disappear or shrink. And just lately he has developed a new product which is a hundred times more powerful than interleukin-2, and as soon as he gets permission to test it on humans, I think he'll make further progress.

But my greatest dream of all, of course, is to be able to bring the two superpowers together and establish a meaningful peace, so that we will not be at war with the Russians, but will compete with them in trade, science, cultural activities — and let history decide. We don't buy their ideology. Gorbachev said to me, "You will never destroy socialism." I said, "Socialism doesn't work. The only country it works in is Hungary where they mix it with capitalism." He smiled. I think he'll find that out.

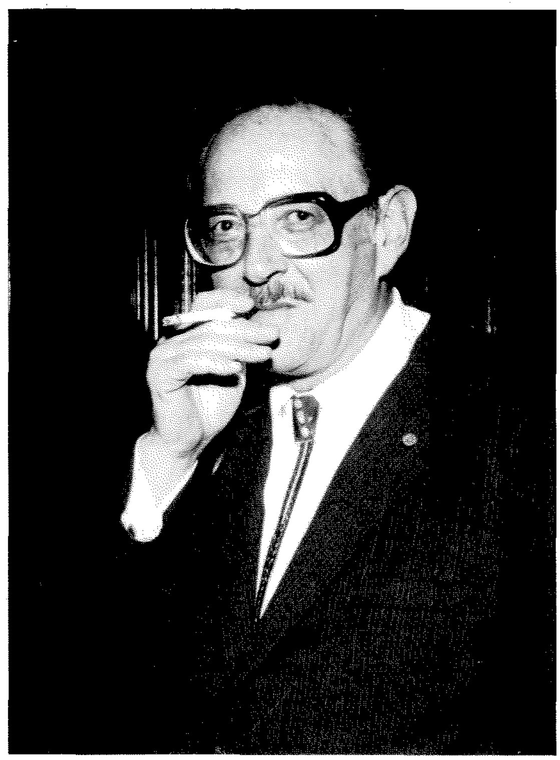
In the meanwhile we have to avoid an accident. We have to avoid a possibility of war of any kind that could lead to a nuclear action, which could lead to the destruction of all of us. □

Caltech Applauds Crafoord Laureate

On November 20 friends and colleagues of Gerald J. Wasserburg gathered at Caltech's Athenaeum to honor him as recipient of the 1986 Crafoord Prize. Awarded annually by the Royal Swedish Academy of Sciences, the prize for work in mathematics, astronomy, geosciences, or biosciences is one of the scientific community's most prestigious honors. The award cited Wasserburg, the John D. MacArthur Professor of Geology and Geophysics, for his "major impact on our knowledge of the universe, focusing on the origins and history of the solar system and its component bodies. His work has established a time scale for the development of the early solar system and the formation of the planets, the moons, and the meteorites."

Wasserburg's laboratory, which he dubbed the "Lunatic Asylum," is world renowned for its precise measurements of tiny amounts of radioactive isotopes, whose decay on a fixed time scale has provided Wasserburg a means of dating moon rocks, meteorites, and interplanetary dust. He also served for many years as adviser to NASA in planning the Apollo space programs. He was recently named chairman of the Division of Geological and Planetary Sciences.

Wasserburg received the $138,000 prize (shared with Claude Allègre of the University of Paris) and gold medal from Sweden's King Carl Gustaf in September. The November dinner, coordinated by Barclay Kamb, gave colleagues from Wasserburg's 31 years at Caltech the opportunity to offer toasts and recollections. Short excerpts from those remarks appear on the following pages.



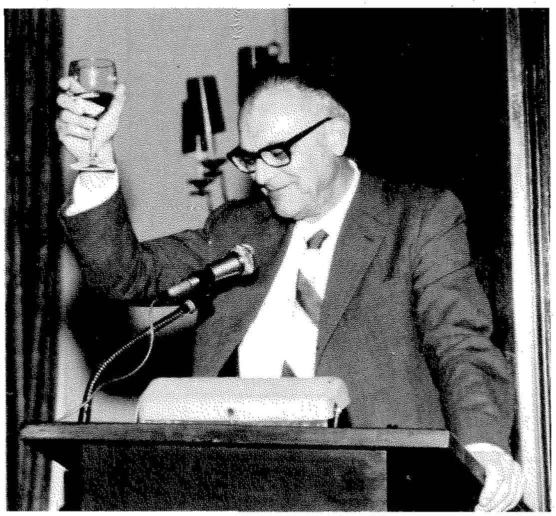
Above is the real Jerry Wasserburg, winner of the 1986 Crafoord Prize. At left, in caricature, he attacks the moon, which appears to be undergoing "terminal cataclysm," a term invented by Wasserburg for the moon's last bombardment by proto-planets, which formed its current surface. Other guests at the "Mad Tea Party" are, clockwise from left: Sam Epstein, Harold Urey, Dimitri Papanastassiou, Clair Patterson, Paul Gast, and Willy Fowler. Moon creatures cavort about various souvenirs of Wasserburg's career, including some famous lunar rocks and a broken sword representing his frequent battles with NASA on matters of science policy and space exploration. COMPLEX is the Committee on Planetary Exploration of the National Academy of Sciences, which Wasserburg headed for many years.

photos by Florence Helmberger

Jerry Wasserburg and his wife Naomi pose with the Crafoord gold medal.

"The Crafoord Prize is considered comparable to the Nobel Prize. It's a prize in what I might call the "higher sciences" — that is, those sciences that involve a higher organization of matter and higher complexity than is dealt with by the physicists and chemists. Those sciences include the biological sciences, higher mathematics (which is certainly *higher), astronomy (what could be higher than astronomy?) and also the earth sciences, which might be called the* lower *higher sciences."*

Barclay Kamb
Professor of Geology and Geophysics
(The picture — not the moon but the surface of a cell — is a gift to Wasserburg from Jean-Paul Revel, the Albert Billings Ruddock Professor of Biology.



"Join me in a toast to Jerry, a consort of Swedish royalty, a man of quality, a man of exquisite taste in science and other things, and a man who keeps us intellectually honest — most of the time. And in a very, very personal sense a man whose steady stream of oracular pronouncements over the years has posed a very significant challenge to my analytical capabilites of understanding and has tested my intelligence and my endurance. Prosit!"

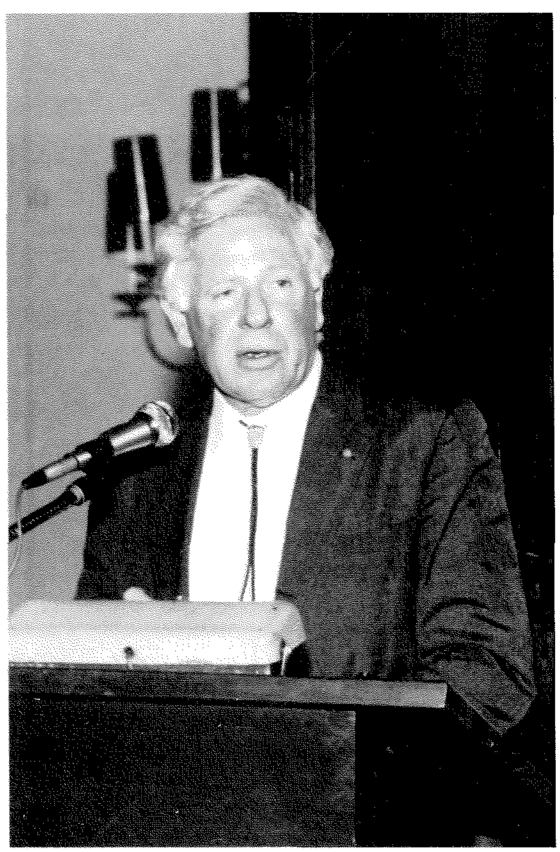
Rochus Vogt
Vice President and Provost; R. Stanton Avery Distinguished Service Professor and Professor of Physics

"It is now 31 years since Jerry left the University of Chicago and came to Caltech as a young man with a head full of ideas and a pocket full of isotopes. And he proceeded to build around these things a very special Lunatic Asylum. Since then, as I've tried to understand isotope geochemistry, it seems that Jerry has not only measured isotopes, but has also invented quite a few. On behalf of the number one division of geological and plantary sciences I invite you to join me in a toast to the number one medalist in geochemistry and cosmochemistry."

Peter Wyllie
Professor of Geology, former chairman of the Division of Geological and Planetary Sciences

"I first met Jerry when I arrived at the University of Chicago and began teaching a course in quantum mechanics. There was a young person sitting in the front row — very bright-eyed, bushy-tailed, obviously intelligent, paying close attention to every word I said; in fact he was prepared to criticize almost every word that I said. . . Now, 36 years later, Jerry is still hyperactive, bright-eyed, bushy-tailed, obviously intelligent, and in spite of all of these characteristics very lovable. . . . As a result of his great intelligence, his tenacity, his hard work, Jerry has received many honors that reflect on him, his family, and upon Caltech. Jerry, we're extraordinarily proud of you."

Marvin Goldberger
Caltech President



Long-time colleague Sam Epstein (left), the William E. Leonhard Professor of Geology, praised Wasserburg for being "unusually well prepared to be a leading figure in the great leap forward that took place in the geosciences in the last 30 years." He also called him "a warm, caring person" but one who "plays a terrible game of cribbage."

"Jerry makes all of us toe a tough line, but in doing so he helps us immeasurably, and I am for one infinitely grateful to him. Jerry not only asks questions; he answers them. In areas of my own interest Jerry's answers are the definitive ones. He has determined the average age of the chemical elements in our galaxy; he has determined the time of formation of the solar system; he has established the chronology and evolution of the earth, the moon, and the meteorites; I could go on and on. To reach these answers Jerry has invented and produced ultra-clean, high-precision mass spectrometers, which are capable of measurements on samples of the order of one ten billionth of a gram and even less. . . . In this day and age when many conjectures in geology, physics, astronomy, and especially cosmology receive instant acclaim, a period of popularity, and then pass into oblivion, Jerry's work has stood out for endurance with the passage of time. Jerry has shown us that careful, precise, significant measurements can bring us a true and permanent insight into the nature of the physical world. On that insight the rest of us can build."

Willy Fowler
Nobel Laureate, Institute Professor of Physics, Emeritus

"To me he has been a good friend, but another thing he has done is provide respectability to the solar system. Those of you who have wasted taxpayers' money on NASA programs must realize that not many astrophysicists some years ago thought that the solar system amounted to a hill of beans. This attitude was turned around by the application of nuclear physics in the work started by Harold Urey, the work on isotopic composition of the elements — the understanding of the processes that led to the generation of elements. The ability to look back before what is knowable, using lunar samples, meteorites, pieces of the earth, to find out what's there — that's what has made Jerry's work so creative and so distinctive. We now know something about 5 billion years ago."

Jesse Greenstein
Lee A. DuBridge Professor of Astrophysics, Emeritus

"Getting Jerry Wasserburg to Caltech was quite an educational experience in itself. In 1954-55 we had two openings in the geology division for young assistant professors, and at that time we had identified what we thought were three really outstanding candidates. We finally solved our dilemma . . . [*by doing*] *everything short of putting the division gem collection in hock, and we hired all three. That was a vintage year — they all had brilliant careers. (The other two were Leon Silver and Clarence Allen.)"*

Bob Sharp
Robert P. Sharp Professor of Geology, Emeritus

"As a field geologist, Jerry taught me a very thorough lesson — on the outcrops he questioned all of my precepts. So since then I have always followed two major principles: 1) Always ask questions, and 2) always question the answers (distinctly Wasserburg). . . . In describing how he has approached the work and what has made the difference, I think it comes down to two things: One is a capability to analyze situations and look ahead and see what the consequences of these are. The other is that driving desire to be on the cutting edge of technological excellence. . . ."

Arden Albee
Professor of Geology
Dean of Graduate Studies

The Experts Speak

THERE ARE STILL a lot of dirt roads in Haywood County, Tennessee. When the rains come, any schoolbuses attempting to negotiate these roads get mired in the mud, so children are often required to walk several miles to the highway in foul weather. Most of the people who live up those dirt roads are black, but until recently the Haywood County Road Commission, which decides which roads to pave, was all white. According to J. Morgan Kousser, professor of history and social science and an expert on voting rights, this was the result of an at-large voting system designed intentionally to exclude blacks. Kousser's expert testimony in court may have succeeded in changing this state of affairs forever.

"I like to think that I helped somebody at least," says Kousser. "Some poor kid who had to walk two miles out and two miles back in the rain probably will not have to do that much longer because the road commission has been changed."

It was a near thing, though. Three weeks before the start of the trial challenging the at-large voting system, a black person was elected to the city board of Brownsville, Haywood's county seat. The defense, notes Kousser, clearly intended to rely on this fact to argue that at-large voting systems are not inherently biased against minorities. "They said, 'This proves that racial block voting is not so overwhelming. The good white citizens of Haywood County *will* vote for a qualified black person.' But if you do a simple statistical analysis of this particular election, it turns out that there was almost complete racial polarization. It happened that there were two white candidates who split the white vote almost in the middle. The black candidate got virtually all of the black votes and virtually no white votes. I had done an analysis of every election since 1966, when blacks first started running in Haywood County, and I was able to show this statistically. It just blew their minds."

Kousser is just one of many Caltech professors who are courtroom-tested experts. You don't get to be a professor at Caltech unless you're an expert in your field, but if your expertise bears on a matter of public importance, you may be called upon to testify in a court of law. Recently a number of Caltech's most experienced experts agreed to describe their time on the stand. Their reactions range from "It was great fun," to "It was hell."

The latter opinion is held by Robert Grubbs, professor of chemistry and an expert on polymers. For the last 10 years he's been testifying in a series of cases that concern the patent for the catalytic process used to synthesize polypropylene, a plastic material whose manufacture is a multi-billion-dollar international business. At least six chemical companies are arguing over who owns the patent and just what that patent covers, and they've been arguing ever since the process was discovered in 1954.

Although Grubbs finds testifying to be extremely grueling — he recently spent four solid days on the stand, being examined and cross-examined in minute detail — he acknowledges that the experience has been valuable. "It's an interesting endeavor for academics to get involved in," says Grubbs, "because it forces you to face what happens outside your field. For example, I'm astounded now at the value of laboratory notebooks. I was always a miserable notebook keeper, and I just hope that none of the stuff I did as a graduate student ever comes up in a patent." Expert testimony also pays very well, with fees sometimes exceeding $1,000 a day. Despite this seductive incentive Grubbs says that he'll probably discontinue this work once his children finish college.

(The role of Caltech faculty members as expert witnesses is covered by the same rules that regulate outside consulting activities. These rules limit the number of days per year that faculty members can spend on such activities and, among other things, they prohibit the use of Caltech facilities without permission from the division chairman.)

John Roberts, Institute Professor of Chemistry, also worked on the polypropylene case, but the trial he remembers best involved a herbicide whose patent was owned by the pharmaceutical company Eli Lilly. U.S. Borax developed what Lilly regarded as a similar herbicide and Lilly brought suit, alleging patent infringement. Roberts was retained by U.S. Borax, and a friend of his, a chemist from the University of Pennsylvania, was retained by Lilly. His friend went on very early, testifying that it would be perfectly

"I like to think that I helped somebody at least," says Morgan Kousser, professor of history and social science. "Some poor kid who had to walk two miles out and two miles back in the rain probably will not have to do that much longer."

obvious to one skilled in the art that the Borax herbicide was a trivial modification of Lilly's. His basis for this statement was that the herbicide's activity could be predicted by an equation developed by Corwin Hansch of Pomona College, which is widely used in correlating biological activity with physical properties.

"Well, that wasn't what we expected," recalls Roberts. "I knew about the Hansch equation, but I hadn't put it to any kind of test. I spent quite a few hours trying to figure out what we could say, because it looked as though this would be a reasonable place to use the equation to predict activities and a lot of the needed data were available on related compounds. In the meantime the trial was going on.

"Finally, the night before I was about to testify — I was to be the last witness — I finished my analysis. The Borax lawyers arranged for me to come on the stand after lunch because they didn't want the other guys to have the lunch hour to plan a cross-examination strategy. I went up on the witness stand, and I showed that if you used the Hansch criteria and actually did the calculations, it predicted that Borax's herbicide would be absolutely no good at all. That really took them by surprise. The plaintiffs asked for a recess but were unable to come up with much to cross-examine me about as the trial ended. The next thing I heard was that the parties had settled out of court, after a long trial and great expense. When they do that, they almost never tell you the details of the settlement. I never knew whether I helped Borax get a better deal or not."

"As scientists we cannot walk out of the courtroom feeling toward the opposing expert witness quite the same way lawyers seem to be able to feel toward opposing lawyers," says Clarence Allen, professor of geology and geophysics.

Not knowing how one's testimony affected the outcome of a case is frustrating, but perhaps more frustrating is to have one's expertise ignored. This happened to several Caltech economists when they testified in a case that hinged on the value of the Boston Celtics professional basketball franchise. As Lance Davis, the Mary Stillman Harkness Professor of Social Science, tells the story, he and two other Caltech economists — James Quirk, professor of economics, and Roger Noll, a former Caltech professor and division chairman — were asked to determine the value of the franchise after a dispute arose involving its sale. Following a thorough study, the economists came up with what they believed was the fair market value of the franchise, and both sides in the case pretty much agreed with this figure. (Davis never actually took the stand, although Quirk did. "It's funny," says Davis, "The defense forgot to qualify Red Auerbach, the general manager of the Celtics, as an expert witness. So Jim Quirk was allowed to testify as an expert in basketball but Red Auerbach wasn't.") But the jury chose to ignore the value determined by the experts, finding that the franchise was worth three times as much.

Another expert who has had his expertise ignored is Thayer Scudder, professor of anthropology. An authority on the impact of forced relocation on rural populations, Scudder has testified both in court and before congressional committees on the long-standing Navajo-Hopi land dispute and Congress's plan to resolve it by uprooting entire Navajo communities. "A program involving forced relocation is a bad program, a bad use of options that shouldn't be followed," says Scudder. "In this particular case Congress estimated that fewer than 3,000 people would be involved. We now know that over 10,000 will be relocated. The original cost estimates were something like $50 million. The actual costs are going to be closer to half a billion dollars. It's caused a lot of upset and stress in northern Arizona with political implications. It's undermined the leadership of the Navajo tribe, because they haven't been able to protect these 10,000 people from being forcibly removed.

"On the basis of a theory I've developed I predicted that Congress had underestimated the numbers of people involved, the financial cost, the general stress, and so on. And, in fact, all of these predictions have unfortunately come true. I testified twice before the Senate Select Committee on Indian Affairs and once on the same issue at the district court. It's about the most nerve-wracking thing you can do. Here we're dealing with social science issues, and usually politicians think they're experts on those issues and that there is no real social science theory. They don't accept your expertise. And when you're talking about relocation, it's a big problem because politicians are highly educated, highly mobile people. Mobility is part of their lifestyle, so to them forced relocation is no big deal."

Having to establish one's expertise before a sometimes hostile audience is not the only heartache that academics testifying in court are heir to. A misstatement, even of the most innocuous kind, can be so magnified by a clever lawyer as to overshadow all the rest of one's testimony. Grubbs tells a story about an opposing expert who made a minor error in arithmetic on the stand. In cross-examination this error was amplified, and the expert's testimony was completely nullified. This ruined the expert's reputation in the legal community, and no lawyer ever again asked him for a consultation.

David Wood, professor of materials science, was once asked to testify for the plaintiff in a case that involved an articulated chair of the kind used in beauty parlors. It was the sort of a chair whose seat moved forward as the person sitting in it leaned back. The plaintiff in the case tipped over in the chair and broke her arm. "I fell into a trap," recalls Wood. "The question was: Is the design of this chair proper? One of the factors that came into this was the weight of the chair compared to the weight of the person in it. I had not weighed the damn chair. I examined the mechanism but I hadn't weighed it. On cross-examination the defense asked me, 'How heavy is this chair?' I made the mistake of just making a guess. I said, 'Oh, about 20 pounds.' Later the guy that designed it testified that it weighed 40 pounds." The plaintiff's lawyer was able to ameliorate the damage somewhat by picking up the chair with one hand and waving it around so the jury could see that even at 40 pounds it wasn't very heavy, but there's no doubt that Wood's mistake compromised his testimony.

The danger of developing an esprit de corps is another pitfall that several of the Caltech experts warn against. As Clarence Allen, professor of geology and geophysics, puts it, "As time goes on the opponents in the two teams tend to develop more and more of a team spirit, which is not necessarily in the cause of good science or good technology. They come more and more to be convinced that, by God, their team is right and the other team is wrong. Quite often by the time the case is over they think that not only is the other team all wet, but that they're a bunch of unethical bastards. As scientists we cannot walk out of the courtroom feeling toward the opposing expert witnesses quite the way lawyers seem to be able to feel toward opposing lawyers." Allen cites one case in which two opposing experts ended up bitter enemies for life because each felt the other was prostituting himself to the cause.

"I'm a professor because it's fun to be a professor," says Lance Davis, the Mary Stillman Harkness Professor of Social Science. "I like to teach. I like to do research. I like to write articles. I like to write books. I don't like to testify."

Most of the experts interviewed for this article compared the court of law unfavorably with respect to traditional scientific forums. Wood, for example, said, "I think that the adversary system is not good for getting at the truth of technical or engineering questions." And Allen said, "Some of the people I've known who have become very much involved in expert witnessing become a little bit more lawyers than scientists. They enjoy it; it's a lot of fun. But it's not science. We fight scientific controversies in a very different way — in the scientific journals. Whether or not our material is published is based on peer review, and ultimately no one person, like a judge, says 'You are right and you are wrong.'"

But Morgan Kousser believes that the academic forum and the legal arena each have their advantages in terms of producing solid scholarship. He makes this point in a 1984 article entitled "Are Expert Witnesses Whores? Reflections on Objectivity in Scholarship and Expert Witnessing" (*The Public Historian,* **6**:5-19). Says Kousser, "One of the great advantages for objectivity in being an expert witness is that you get cross-examined and somebody listens to it. You usually have some pretty smart lawyer who has a very large incentive to destroy your credibility. And as a consequence you overprepare and you're overcautious about making blanket statements that you're going to have to backtrack on later. That very often doesn't happen in scholarship. There are so many scholarly journals. The vast majority of papers don't get very tough readings, even by the referees. Very few scholarly papers have all the footnotes checked. It's virtually impossible not to make *some* mistakes, and the number of them is sometimes quite high."

"I think we have obligations as people who are scientists to apply our knowledge to important public policy issues," says Thayer Scudder, professor of anthropology.

And Kousser disagrees with the assertion made by many of Caltech's experts that testifying in court is the most stressful thing that academics can do. "It's not nearly as tough as some academic forums," maintains Kousser. "When I was a first-year graduate student, I had a graduate seminar in which I was on the carpet for two hours with very antagonistic questioning by peers. Nothing has ever been that tough again."

Perhaps this difference in perception has partly to do with an individual's personality. Kousser says that he thrives on the verbal sparring in court, but others enjoy the experience far less. After several bad experiences, Lance Davis has vowed never again to testify in court. "I've discovered over the years that I don't think very quickly on my feet. I'm reasonably good at presenting a case that I've thought about for some time, and I'm reasonably good at answering questions I've thought about for some time, but I'm not so good at answering questions on the spur of the moment that aren't directly related to what I'm talking about. Lawyers are very good at asking questions that you would view as off the wall but that a jury would view as pertinent. In one case, for example, I made a statement and the lawyer asked, 'Well, Professor Davis, is that a speculation?' I thought about this and said, 'It depends what you mean by speculation. If you mean do I know this to be a certain answer, the answer is, hell no, I speculated about it. But if you mean is this the best guess I can make on the basis of 20-years experience as an economist, then it's not speculation.' Now if I could answer like that all the time I might stay in the business, but the trouble is that for every one of those I win I find myself losing on three others. And besides, I just find it terribly wearing, so I've decided that I'm not going to testify again."

Davis believes that academics should think long and hard about their professional responsibilities before doing expert witnessing or, indeed, before doing any outside consulting at all. "The trouble is, you've got a job here," says Davis. "Your job is to do research and to teach students. Except for one publication I've never gained much out of any of my consulting. And that means in some sense that what I'm doing is just trying to earn some extra money. I guess that's a good thing to do, but I also would prefer not to do it at all. I'm a professor because it's fun to be a professor. I like to teach. I like to do research. I like to write articles. I like to write books. I don't like to testify."

Thayer Scudder agrees that it's wrong to be an expert witness just for the money. "The money is never worth it," he says. But he points out that there are other reasons to serve as an expert witness, other reasons aside from earning money or getting publications out of it. Says Scudder, "I think we have obligations as people who are scientists to apply our knowledge to important public policy issues. I deal with issues where I feel a major principle is involved: People shouldn't be forced to leave a home without adequate compensation, without proper mitigation methods. I feel obligated, when called upon, to testify."

And Scudder often refuses any payment other than reimbursement of his expenses for such testimony. Lawyers have ways of discrediting witnesses whether or not they are being paid, however. In cross-examination a lawyer will often ask an expert witness about his fee, and when this often sizable fee is revealed, the lawyer implies that the witness is merely a hired gun who will say anything his employers desire. But a witness who says that he has refused a fee is often branded a biased and fanatical supporter of a cause, a person whose objectivity must necessarily be suspect.

Nowadays virtually any scholar may be asked to serve as an expert witness. A discipline whose subject matter has traditionally been far removed from the concerns of the public forum may at any time suddenly become relevant. Very few biologists, for example, have served as expert witnesses, but with the growth of the biotechnology industry this is certain to change. And the issue of the teaching of evolution in the public schools, dormant since the Scopes trial of the 1920s, is again in the forefront of the public consciousness. Norman Horowitz, professor of biology emeritus, was tapped several years ago to give testimony in a case brought by a group who believed that so-called "creation science" should be given equal time with evolution science in the California public schools. (Horowitz's scheduled appearance on the stand was canceled at the last moment when the plaintiffs dropped the case as long as evolution was not taught "dogmatically.")

Theoretical physics is even further removed from important public issues than is biology, so it's perhaps surprising to learn that Richard Feynman, the Richard Chace Tolman Professor of Theoretical Physics, once served as an expert witness in a local court case. As it turns out, the case did not depend on Feynman's expertise in quantum electrodynamics, but rather on his expertise in community standards as they relate to topless bars. As he writes in his book *"Surely You're Joking, Mr. Feynman!"* (in the chapter entitled "But is it Art?"), Feynman was a frequent habitué of a topless bar called Gianonni's. "I'd sit in one of the booths and work a little physics on the paper placemats with the scalloped edges. . . . I'd watch the girls dance, do a little physics, prepare a lecture, or draw a little bit."

But Gianonni's was raided, and when the case came to court Gianonni asked his regular customers to testify in his behalf. Fearing for their reputations, all of them refused. All, that is, but Feynman. "I didn't consider myself an expert witness, but the lawyers tried to demonstrate that I was one." In court he testified that he frequented Gianonni's five or six times a week, and that Gianonni's other customers included all segments of the community. Gianonni lost his case, but Feynman's fondness for topless bars made all the newspapers. □ — *RF*

Letters

EDITOR:

After enjoying your excellent article on the Institute Archives in November's *Engineering & Science*, I thought you might be interested in the following postscript.

Over the weekend of October 18-19, a broken water pipe in the campus sprinkler system caused a flood in the basement of Millikan Library, home of the Caltech Archives. Since we have suffered flooding before, we carefully keep all collections off the floor. Unfortunately, when a new collection arrives there is nowhere to put it during the processing period except the hallway basement, and that is where the papers of former Caltech President Harold Brown were when the flooding occurred. (See photo on page 19 of your November issue.) For reasons unknown to us the flood was not discovered until Monday morning, by which time the cartons were well soaked.

Fortunately, some quick thinking and action on the part of the staff saved the papers from permanent damage, though for a while drying papers covered every available surface in the Archives. The cartons of Brown papers that are as yet unprocessed remain precariously balanced atop tables, filing cabinets, and each other. All we need now is an earthquake.

Carol Bugé
Assistant Archivist

EDITOR:

"In This Issue" section of the November *E&S*, which had the wonderful and timely article, "The Boat That Almost Was," omitted mention of the "real-time" participation, over one of the Athenaeum luncheon tables, by a substantial group of general faculty in Francis Clauser's saga. In the early stages, Francis had to be pretty circumspect about details, but as events proceeded to the cliff-hanging denouement, those who ate with him were given the full story, copiously illustrated by engineering drawings and graphs on the back of the Athenaeum paper placemats. When developments were coming fast and furious, Francis would wind up commandeering all eight placemats for his presentations, and those of his auditors who had time would listen, enthralled, long after the regular lunch hour was over. Each of the drawings in your article was generated, many more than once, and argued about at length, in these discussions.

The opportunity for this sort of thing can make the Athenaeum lunch time a fabulous experience for the Caltech faculty, and many more of us are now following the America's Cup trials with intense interest and a lot more knowledge than would otherwise have been possible.

Thanks again for the great presentation.

John D. Roberts
Institute Professor of Chemistry

Research in Progress

Potential Planets?

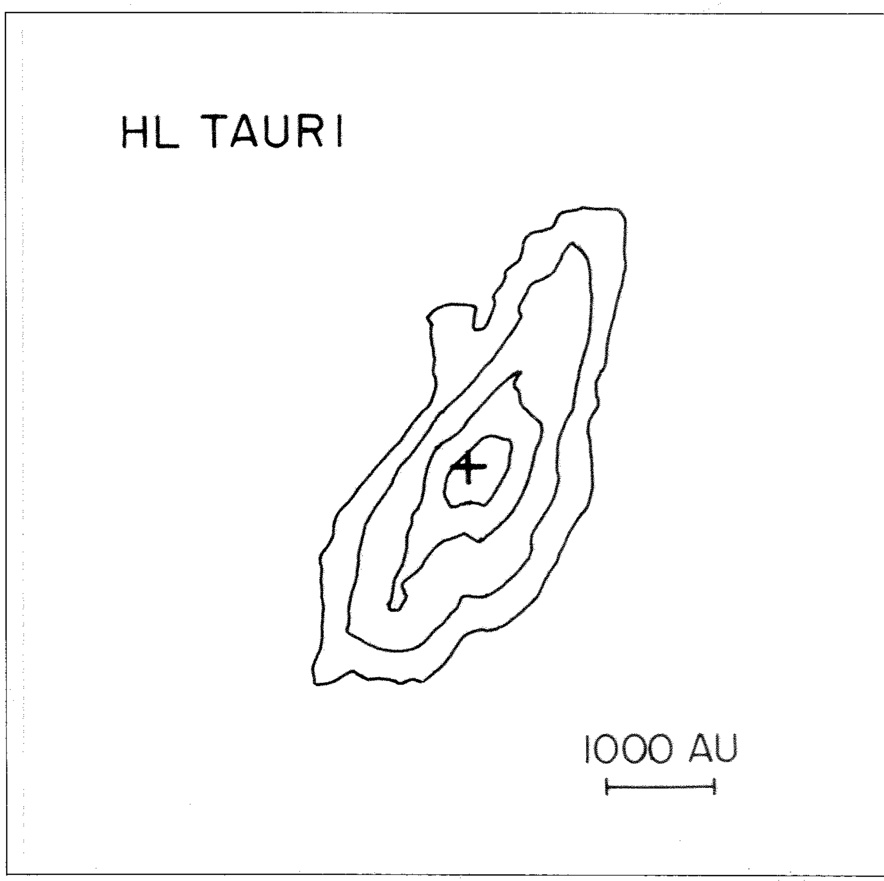
FIVE HUNDRED LIGHT YEARS from here, a star called HL Tauri may be in the process of forming a planetary system. This star, a younger cousin of our own sun, is surrounded by a large disk of dust and gas that is orbiting in accordance with Keplerian laws of motion. This, at least, is the conclusion of a study conducted by Anneila Sargent, a member of the professional staff, and Steven Beckwith, a Cornell University astronomer, using the Owens Valley Millimeter Wave Interferometer.

Over the past few years *infrared* astronomy has revealed circumstellar disks of dust surrounding about half a dozen nearby stars — the dust disk around HL Tauri made news two years ago when Beckwith and his colleagues first discovered it with high-resolution infrared measurements. But by using *radio* astronomy techniques, Sargent and Beckwith have greatly extended their knowledge of HL Tauri with the first direct demonstration that the star's dust disk is accompanied by a disk of gas. Moreover, they were able to prove that the gas close to the star rotates faster than the more distant gas, just as Kepler's laws predict.

This result marks one of the most significant discoveries yet made with the newly constructed Owens Valley Millimeter Wave Interferometer. The interferometer consists of three radio telescopes, each 10.4 meters in diameter. By separating these telescopes by distances of 15 to 100 meters and directing them to the same point in the sky, the astronomers can increase the resolution of their millimeter-wave measurements more than ten-fold, making the three elements of the interferometer the equivalent of a single radio telescope 100 meters in diameter. This makes it possible to see structure on a scale of about 900 astronomical units. The gas disk has a total diameter of 3,000 AU. (1 AU is equal to the distance between the earth and the sun — 93 million miles.) Sargent and Beckwith made their observations between January and March 1986, in five 10-hour stretches.

The infrared measurements made two years ago have a substantially higher resolution than these new millimeter-wave measurements, enabling the identification of the inner radius of the dust disk, which extends just over 100 AU from the star. But dust emits infrared energy in a continuum, making it impossible to determine velocity by Doppler-shift measurements of the infrared data.

The carbon monoxide molecules in the gas disk, on the other hand, emit radio waves at specific frequencies. Because of the Doppler effect, these emissions are shifted to longer wavelengths as the gas recedes from us and to shorter wavelengths as it approaches. By measuring the degree of shift in the wavelength of the radio emissions, Sargent and Beckwith determined that the pattern of velocities in HL Tauri's circumstellar disk is the same as the pattern we see among the planets of our own solar system, where



Five hundred light years from earth, the star HL Tauri (at the cross in this illustration) is surrounded by a large disk of gas and dust. Recent studies with the Owens Valley Millimeter Wave Interferometer have revealed that this disk orbits in accordance with Kepler's laws of planetary motion.

the inner planets move faster than the outer ones.

Current theories of stellar evolution hold that newly formed stars will be surrounded by some of the material from which they are made. This "placental cloud" of gas and dust should be distributed in a flattened disk bound by the star's gravity. As this disk orbits the star, it may begin to coalesce, leading to the formation of planets.

According to current theories of stellar evolution, not all stars will have circumstellar disks that obey Kepler's laws, and not all stars will form planetary systems. Says Sargent, "We plan to examine a sample of other nearby young stellar objects to see what percentage of gas disks have HL Tauri-like velocity structures. Gas may be superficially in a disk-like shape on the plane of the sky, but when we look at the velocity structure within it, we may see a very different velocity structure that would not indicate a planetary system."

According to Sargent, the astronomers are already looking at even more detailed infrared images of HL Tauri — images at resolutions of 50 AU. These suggest that the dust disk may not have a completely smooth elliptical shape. And new receivers at Owens Valley will soon permit them to examine the gas disk at a higher radio frequency. "In addition to doubling the resolution, this will allow us to make some estimate of the size of the dust grains and better ascertain the mass distribution within the disk. And that will enable us to constrain the models that are made of certain kinds of stellar systems — low mass stars about the size of our sun. Of course, we will have to examine circumstellar disks around many more stars to build up an adequate statistical sample. If the National Science Foundation provides funding for three additional radio telescopes to be incorporated into the Owens Valley interferometer, such a study could be accomplished within three years." □ — *RF*

Echoes of the Earth's Core

LOOK INTO ANY ELEMENTARY treatise on geology and you'll find an illustration that makes the earth look something like an onion. This illustration will be labeled with the names of the earth's concentric layers: the crust, 50 kilometers in depth; the mantle, extending down to 3,000 km; and the outer and inner cores, occupying the remaining 3,400 km or so down to the center of the earth.

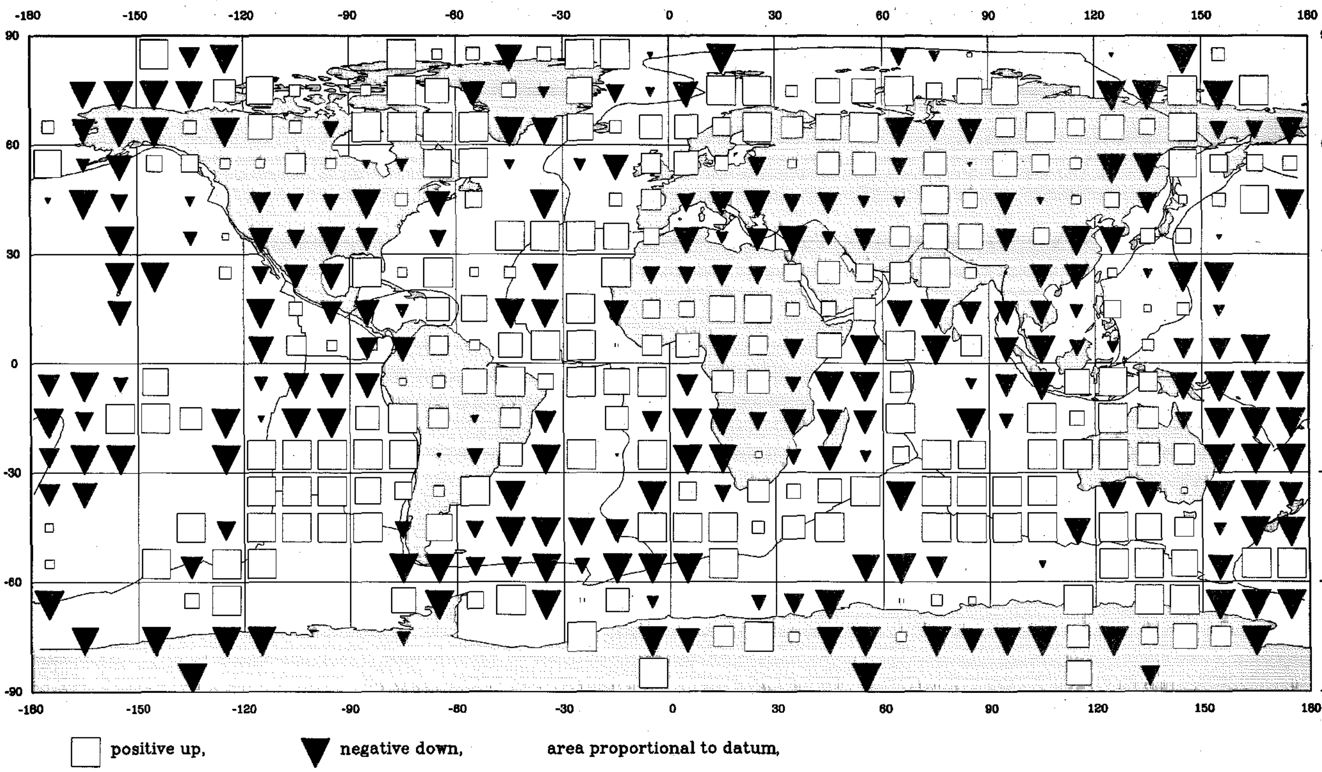
In this kind of illustration the boundaries between the layers always look perfectly smooth, but Caltech researchers have now shown that at least one of those boundaries — the one between the mantle and the outer core — is pockmarked by numerous highs and lows. These underground equivalents of mountains and valleys are thought to result from convection patterns in the semisolid rock of the mantle. Cold, dense, sinking material in the mantle creates the valleys, while hot, rising material creates the mountains.

Mapping those mountains and valleys was a difficult and laborious procedure performed by graduate student Olafur Gudmundsson, Robert Clayton, associate professor of geophysics, and Don Anderson, professor of geophysics. They used the technique of seismic tomography — a means of imaging the interior of the earth with sound waves that is closely akin to the CT scan, a medical technique that provides images of the interior of the human body using X-rays.

In the CT scan, X-rays sent crisscrossing through the body are sensed by a circular array of detectors. The information from these detectors is integrated by a computer that builds up an image based on the density of the different materials within the body. In seismic tomography, earthquake stations around the globe detect the pressure waves that crisscross the earth after earthquakes that occur naturally.

In their studies of the core-mantle boundary, the researchers made use of data gathered from 25,000 earthquakes worldwide with magnitudes of 4.5 and above on the Richter scale. Such earthquakes produce several different types of pressure waves that can be detected by monitoring stations. P waves, for example, are continually refracted by the mantle as they travel from the source of the quake. Eventually, the P waves return to the surface and are detected at monitoring stations. Stations closer to the source of the earthquake will detect the P waves sooner than ones farther away.

Another type of wave, called a PcP wave, travels down through the mantle and is reflected back up to the surface by the core-mantle boundary. The difference in arrival times between P waves and PcP waves is an indirect



Using data from the pressure waves generated by tens of thousands of earthquakes and refracted by the earth's mantle and its inner and outer core (PKIKP waves), graduate student Olafur Gudmundsson generated this map of the topography of the core-mantle boundary. Black triangles indicate downward deflections in the core ("valleys"), and open squares indicate upward deflections ("mountains").

measure of the depth of the core-mantle boundary at a specific point. By comparing the difference in time that's actually measured with the time difference that would be predicted if a smooth core-mantle boundary is assumed, the researchers can build up a map of mountains and valleys. All other things being equal, shorter-than-predicted time differences indicate a mountain and longer-than-predicted time differences indicate a valley.

Unfortunately, all other things are *not* equal. In order to make sense of the data, the researchers must correct for a number of possible sources of error. At the most basic level, they must take into account the fact that the earth is an ellipsoid, not a sphere. But perhaps the most critical corrections involve subtracting known heterogeneities (variations in density) within the mantle as well as variations in the local structure of the earth at the sources of the earthquakes and the sites of the detectors.

Because these correction factors are fraught with many potential sources of error, this new map is of fairly low resolution and contains little detailed information on the exact amplitudes of the deflections at the core-mantle boundary. But it does indicate that the core-mantle boundary contains mountains with heights measured in kilometers under Australia, the Labrador Sea, and off the Pacific coast of South America. There are valleys of similar depths under the southwest Pacific, the East Indies, and southern Europe.

In trying to improve the quality of their maps, the researchers are pursuing two strategies. First, they are continually refining their reference models as details of heterogeneities within the mantle become better known. Second, they're adding measurements from other kinds of waves. PKP waves, for example, pass through the outer core before they are eventually refracted back up to the surface. They provide a nice check on the PcP data since the differences in travel time are reversed. For example, a mountain, which would cause a *decrease* in PcP travel time, will cause an *increase* in PKP travel time.

But PKP waves have a problem of their own: They can be difficult to distinguish from some other waves. To get around this, the researchers are beginning to study PKIKP waves, which pass through the inner as well as the outer core and which can be identified unambiguously. However, the heterogeneities of the inner and outer core are understood in even less detail than the heterogeneities of the mantle.

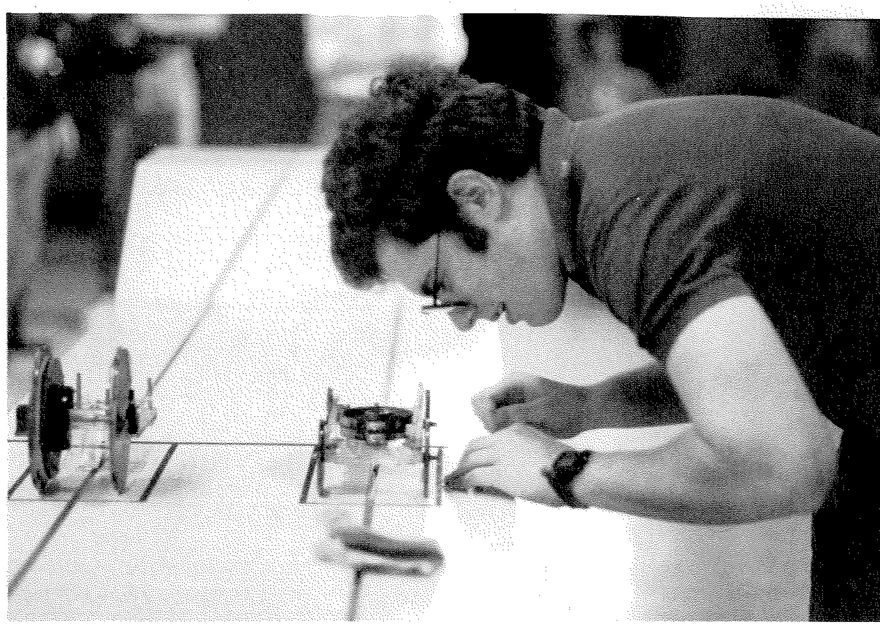
Despite the difficulties inherent in these seismic tomography studies, the existence of highs and lows on the core-mantle boundary seems to have been corroborated by a separate study of a long-known jerkiness in the earth's rotation. The length of the earth's day varies by about five milliseconds over a decade, and this can be explained by the torque produced as the molten nickel-iron of the core sloshes against the ridges and valley walls at the core-mantle boundary. (This study was conducted by Mary Ann Spieth of Caltech's JPL, Raymond Hide of England's Geophysical Fluid Dynamics Laboratory, Robert Clayton and Bradford Hager of Caltech, and Court Voorhies of the Goddard Space Flight Center.) This study seems to indicate, however, that Gudmundsson and his colleagues may have overestimated the amplitudes of the mountains and valleys. Studies intended to resolve these discrepancies are now under way. □ — *RF*

Random Walk

Young Faculty Named by NSF

TWO FACULTY MEMBERS and two former graduate students have won Presidential Young Investigator Awards for 1987. John Doyle is associate professor of electrical engineering, and Kenneth Libbrecht is assistant professor of astrophysics. Robert Arnold, who did his graduate work at Caltech under Michael Hoffmann, is now assistant professor of environmental engineering at the University of Arizona; Michael Hopkins received his PhD in inorganic chemistry for work done with Harry Gray and is now at Los Alamos National Laboratory. Although Arnold and Hopkins are now elsewhere, they were both nominated for the award by Caltech.

The awards, which carry a stipend of up to $100,000 per year for five years in a combination of federal and matching private funds, are intended to help universities attract and retain outstanding young PhDs in the highly competitive fields of engineering and science.



Mechanical engineering student Will Slate positions his vehicle for its final exam.

Astronomers Win Rumford Prize

PROFESSORS Robert Leighton and Gerry Neugebauer have both been named recipients of the Rumford Prize for their pioneering work in the methods of infrared astronomy. The Rumford Prize, established in 1796 and presented by the American Academy of Arts and Sciences, is one of the country's oldest scientific awards.

Leighton, the William L. Valentine Professor of Physics, Emeritus, was cited for his work on the instrumentation and methodology of modern infrared astronomy and for the development of a new family of large, precise reflectors that open the submillimeter part of the infrared spectrum to observation. Neugebauer is the Howard Hughes Professor and professor of physics as well as director of Palomar Observatory and principal investigator for the Infrared Astronomical Satellite. He received the award for conducting the first complete infrared survey of the sky (using the 200-inch Hale Telescope), leading to the discovery of new classes of infrared emitters.

Lester Lees Dies

LESTER LEES, known as one of Caltech's most inspiring teachers, died November 10 at age 66. He had been at Caltech since 1942 and had been professor of aeronautics since 1955. In 1970 he was named professor of environmental engineering and aeronautics and became emeritus last year. He was also director of the Environmental Quality Laboratory from 1971 to 1974. His varied research interests dealt with environmental problems related to energy sources and with problems of high-speed flight, including re-entry into the earth's atmosphere of missiles and spacecraft. A SURF (Summer Undergraduate Research Fellowship) endowment has been established in his name.

Race to the Finish

IT DIDN'T LOOK like a final exam — a 10-foot racetrack set up in Baxter Lecture Hall, and Mechanical Engineering 72a students with a bizarre assortment of "vehicles" they had fashioned over the past weeks out of bags of junk that included tubing, washers, springs, ball bearings, dowels, nuts, and other odd bits and pieces. Erik Antonsson, assistant professor of mechanical engineering, allotted each student an identical junk collection with the charge to make "a device to combine speed and precision to outperform an opponent device." The race was the test.

The vehicles, which ranged from catapults and airplanes to constructions that actually resembled automobiles, competed to deliver a payload from the beginning of the track, over a four-inch-high obstacle, and come to a stop at the end of the track. Winner was junior Will Slate with a car made of Masonite wheels, computer keyboard springs and a complicated negator spring. But grades didn't depend on the outcome of the race, and a good time was had by all — at least a better time than in most final exams.

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We appreciate your consistent concern for the strength and vitality of the Institute. Your spirit, energy, and dedication to scientific inquiry and education have helped Caltech realize many of its goals.

We at Caltech
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