Engineering and Science

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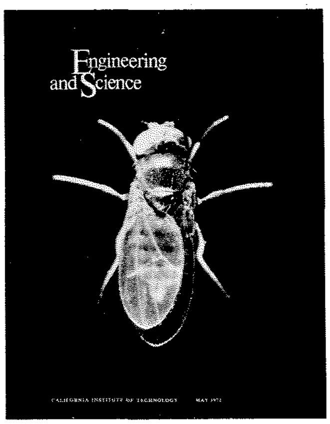

In this issue

Textbook for Geneticists

On the cover—a mosaic specimen of the fruit fly, *Drosophila melanogaster*. This is one of hundreds of millions of fruit flies that have been bred in thousands of mutant, normal, and composite forms in the last 50 years at Caltech. When Thomas Hunt Morgan originally chose *Drosophila* for genetic studies in 1906, he could hardly have imagined that the species would provide the basic material for more genetic research than any other organism—that it would, in fact, be so ideal for those studies that a whole school of genetics research would bear its name. And what scientists of the "*Drosophila* school" have learned about the fruit fly they have also learned about man. Genes in the fly are identical in principle with those in human beings.

The information acquired from *Drosophila* about the linkage of genes into linear arrays on the chromosomes, the production of mutations, recombination of genes by crossing over, sex determination by X and Y chromosomes, and the role of genes in development seem to be only a prelude to the future's more integrative studies of the nervous system and behavior. "From the Gene to Behavior" by Seymour Benzer (page 4) describes some of his recent work with the versatile and instructive fruit fly.

Outline for the Universe

James Gunn, assistant professor of astronomy, recently spoke to the Research Directors' Conference at Caltech. "The Shape of Space" (page 14) is adapted from that talk.

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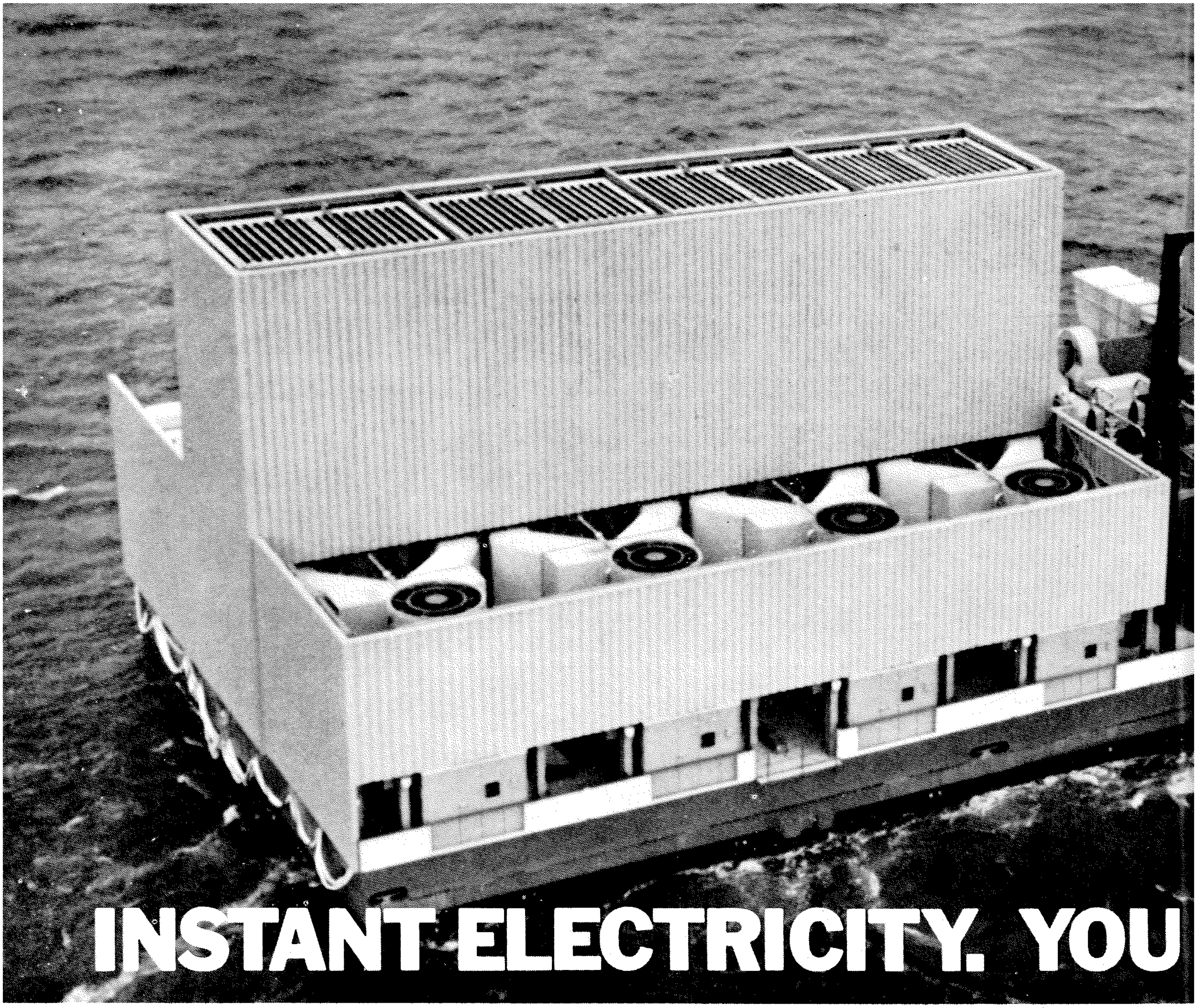


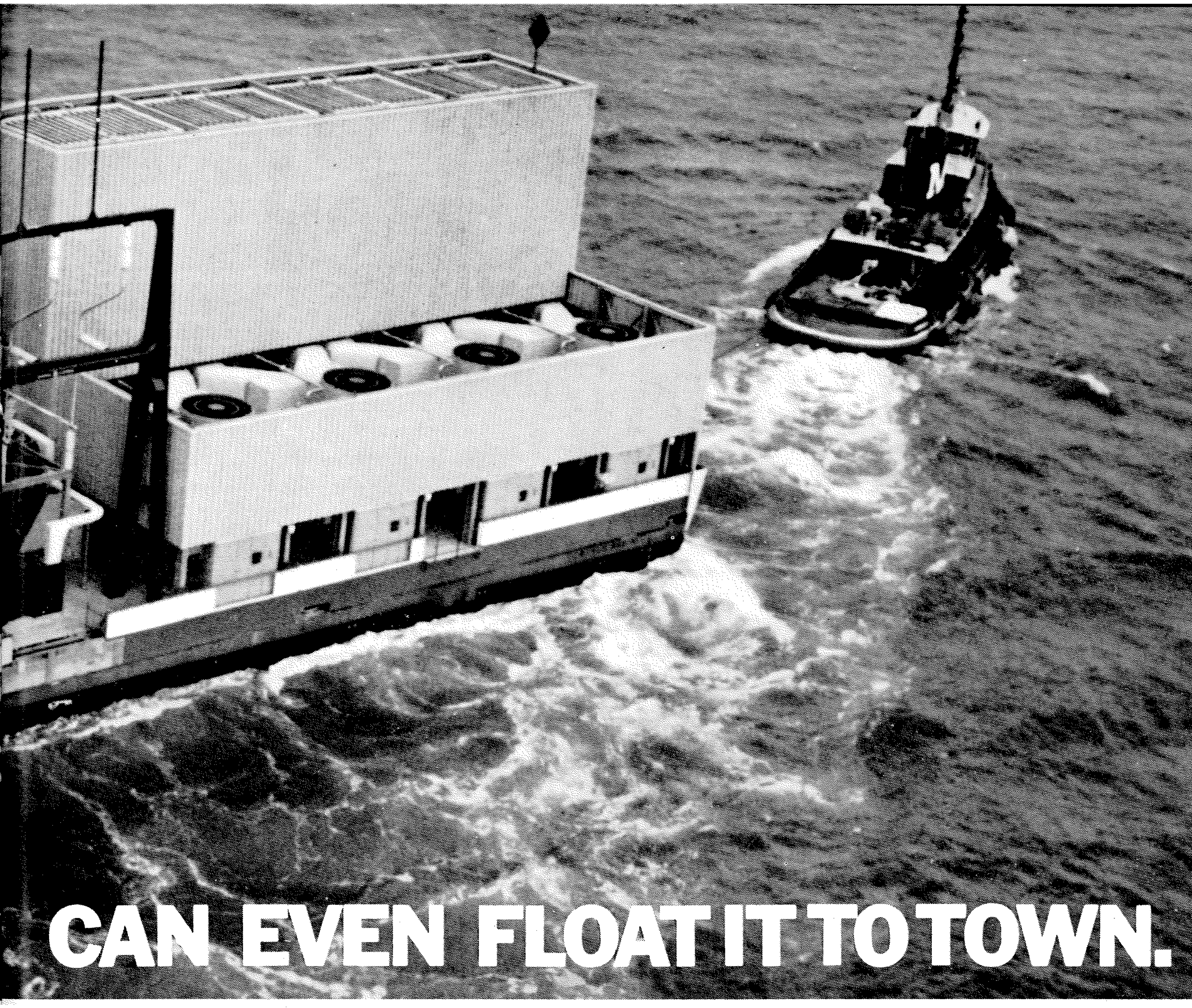
Portable gas turbine generators, mounted on barges and trucks, are being plugged into existing power networks to boost capacity. And nickel's helping make it happen.

One tool that more power companies are using in both their short- and long-range efforts to close the generating gap is a down-to-earth cousin of the jet aircraft engine, the gas turbine.

A typical turbine, hitched to a generator, can produce enough power to light a city of 25,000 people. (Above, *eight* turbines are ganged on one barge. Combined output: 156,000 kilowatts!)

The beauty of the turbine is that it can be bought and set up almost anywhere in a matter of weeks. And it can be turned on and off in mere *seconds*. Which makes it ideal for those muggy summer evenings when everybody gets home and hits the air-conditioner button at once.

Gas turbines have proved such a boon to utilities that sales of them are soaring. Last year, they actually accounted for more than *one fifth* of power companies' total new generating capacity.



At the volcanic heart of the turbines, where temperatures reach 1,800 degrees, only specially designed superalloys can be used. Almost all of these alloys contain a high proportion of *nickel*—up to 78 percent. Nickel is vital for the properties required for dependable turbine service. It helps to provide alloy stability and corrosion resistance.

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And that helps all around.

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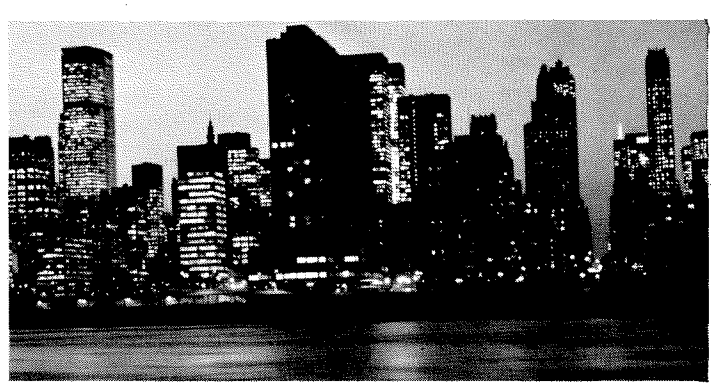
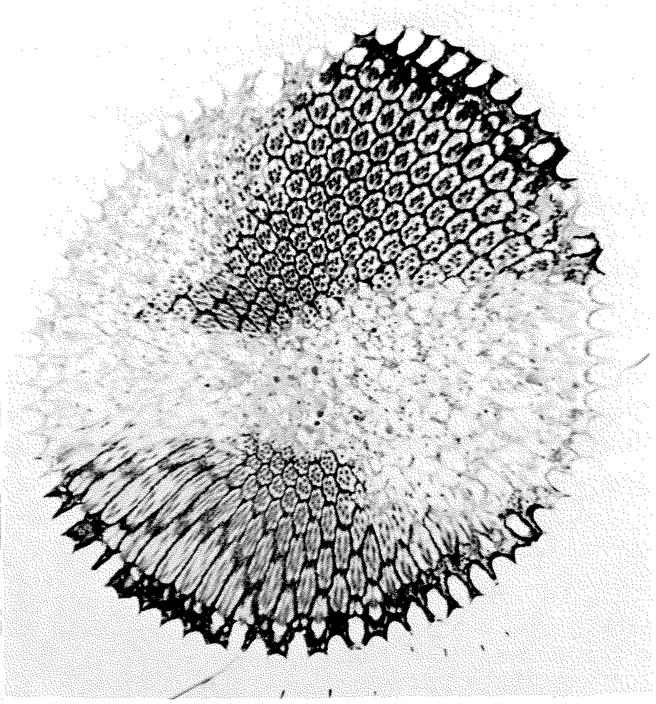


INTERNATIONAL NICKEL HELPS.

From the Gene to Behavior

by Seymour Benzer



Mosaicism—the mingling of patches of tissue of unlike genetic constitution—is one of the most promising fields for genetic research. In this section of a Drosophila *compound eye, the normal areas show precise arrays of photoreceptor elements; mutant areas show extensive degeneration. This degeneration can be used as a cell marker to trace the lineage of the photoreceptor cells.*

Splitting the gene and running its map into the ground was exciting while it lasted, but molecular genetics, pursued to ever lower levels of organization, inevitably does away with itself: The gap between genetics and biochemistry disappears. Recently, a number of molecular biologists have turned their sights in the opposite direction, i.e., up to higher integrative levels, to explore the relatively distant horizons of development, the nervous system, and behavior.

When the individual develops from an egg, the one-dimensional information contained in the linear sequence of genes on the chromosomes is somehow translated into a two-dimensional blastula, which later folds and produces a precise three-dimensional array of sense organs, central nervous system, and muscles. Finally, the ensemble interacts to produce behavior, a phenomenon which requires four dimensions, at the least, to describe. The genes contain the information for the circuit diagram, but little is known about the relationship between this primary information and the end result. How the tags of specificity are parceled out among the neurons so that they form the proper network, or even what kinds of molecules carry the specificity are, at present, complete mysteries. The problem of tracing the emergence of multi-dimensional behavior from the genes is a challenge that may not become obsolete so soon.

It is well established that the genes speak strongly in determining anatomical and biochemical features. It should not be surprising if, to a large degree, the genes also determine behavioral temperament, although, of course, environmental influences can also play a large role. All behavior is inevitably the resultant of both components. To discern the genetic contribution clearly, the thing to do is to keep the environment constant and change the genes. This is not easy to do with human beings; they are notoriously uncooperative and unwieldy

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Seymour Benzer, professor of biology, is distinguished for his work on genes in viruses and bacteria—studies for which he received the 1971 Lasker Award in Basic Medical Research. "From the Gene to Behavior" is adapted from his talk on the occasion of receiving that award and describes the work in which he is currently engaged.

experimental subjects, particularly if one must wait generations for the results. For this reason, the molecular biologists who have turned to studying behavior have cast around for more favorable model organisms. There immediately arises the problem that the simpler an organism is, the less likely it is to exhibit behavioral patterns that are relevant to man, while the more complex it is, the more difficult it may be to analyze.

Because of its short generation time and small size, plus the fact that it could be raised on simple laboratory food, the fruit fly, *Drosophila*, was chosen by the school of genetics that flourished half a century ago. The lessons learned from this model organism about the linkage of genes into linear arrays on the chromosomes, the production of mutations by x-rays and chemicals, recombination of genes by crossing over, sex determination by X and Y chromosomes, and the role of genes in development carry over almost directly to human genetics, although there are, of course, variations in detail.

While the fly's nervous system differs vastly from ours, it does work via neurons, synapses, and transmitter molecules, and its development is dictated by genes. A fly has highly developed senses of sight, hearing, taste, smell, gravity, and time. While it does not do everything that man does, it can do a few things that we cannot, such as flying or standing on the ceiling. One must not underestimate the little creature. Perhaps you have seen the remarkable film, *Hellstrom Chronicle*, of which the theme was that the insects were here well before man's arrival and already have seen the dinosaurs come and go. It should be recalled that the fly is not an evolutionary antecedent of man, but is high up on the invertebrate branch of the phylogenetic tree. Some of its independently evolved behavioral patterns are not unlike our own.

For example, sexual courtship in *Drosophila* begins with an encounter between individuals of opposite sex. The male, spying a female, orients toward her, faces her head from one side, holds out and vibrates one wing, produces a species-specific song. After this overture, the male usually runs to the other side and repeats the performance with the other wing, always using the wing closer to the female's head. There follows a series of steps that are only too embarrassingly anthropomorphic. In both fly and man, sexual courtship is a chain of action patterns, each dependent on the previous one for activation of the nervous system to be responsive to the next step.

The role of the genes becomes evident in fly mutants. There exists a class of what may be called *savoir-faire* mutants, where the males are unsuccessful in courtship, due to inadequate performance of one or another of the steps. In a mutant known as *fruity*, discovered by K. Gill, the males pursue each other. A pathetic case is the mutant *stuck*, described by C. Beckman, in which the male is unable to withdraw his penis after copulation. Obviously, most of these mutants would not stand a chance in the competitive natural environment. In the laboratory, however, they can be maintained and studied. Even genes having the most drastic effects can, of course, be maintained in heterozygotes, provided they are recessive.

The richness of the behavioral repertoire of *Drosophila* and its genetic basis is illustrated by some of the known kinds of behavioral mutants, listed in the table below. All the types listed can be produced by altering single genes. Some mutants are congenitally

Some Behavioral Mutants of Drosophila

Locomotor
- sluggish
- Hyperkinetic
- flightless
- uncoordinated
- nonclimbing

Response to stress
- easily shocked
- Shaker
- freaked-out
- paralyzed
- parched

Circadian rhythm
- arrhythmic
- short-period
- long-period

Sexual
- savoir-faire
- fruity
- stuck

Visual
- nonphototactic
- negative phototactic
- nonoptomotor
- negative optomotor

Nerve and muscle abnormality
- photoreceptor degeneration
- lamina degeneration
- wings-up
- drop-dead

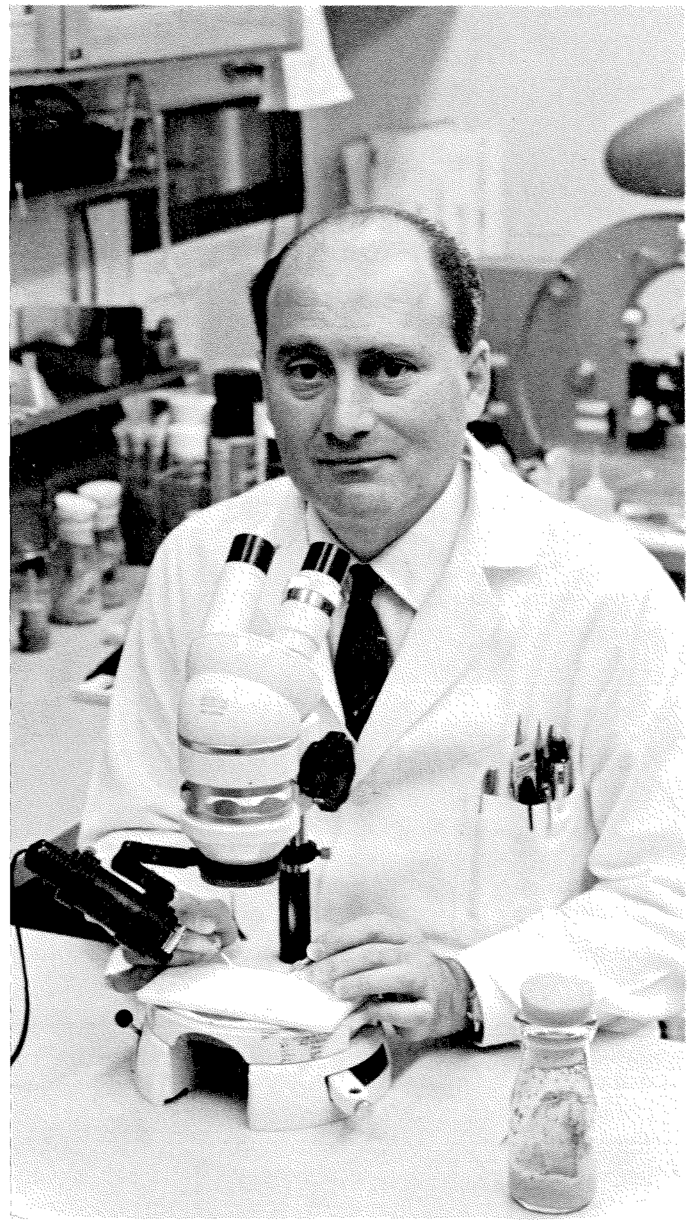
sluggish; others, as W. Kaplan has shown, are *hyperkinetic*. There are mutants that do not fly, though they have perfectly well developed wings. Some mutants are uncoordinated; they stagger over themselves and each other. Others do not climb up a vertical surface, in contrast to normal flies.

Individuals that appear quite normal in ordinary circumstances may harbor hereditary idiosyncracies that show up only under stress. For example, the mutant, *easily shocked*, when subjected to a mechanical jolt, displays a syndrome not unlike an epileptic seizure: The fly takes a few faltering steps, falls on its back, flails its legs and wings wildly, and coils its abdomen under. A male exudes a droplet of fluid; a female is likely to extrude an egg. The fly then goes into a coma, lasting some minutes, after which it revives and walks around as if nothing had happened. This routine can be repeated many times. The mechanism is unknown. We do know that there exist several different genes on the X chromosome alone, which, if mutated, can produce this syndrome.

Some abnormalities become manifest only under anesthesia. In working with *Drosophila*, one often etherizes the flies for examination under the microscope. While normal flies lie quietly for five or ten minutes, mutants known as *shakers* vigorously vibrate all their legs. Another type is one which we call *freaked out*, because, under the influence of ether, it performs grotesque, random gyrations. It is not inconceivable that mutants such as these could shed light on the mechanism of anesthesia and the genetic factors involved in individual idiosyncracies.

Gene changes in flies also produce marked differences in response to extremes of temperature and humidity. A spectacular mutant found by D. Suzuki is *paralyzed (temperature-sensitive)*. It collapses above a critical temperature, normal flies being unaffected. Several such mutants are now known, each with its own critical temperature. Another kind of mutant, *parched*, dies within a few minutes after being placed in a low-humidity atmosphere, whereas normal flies survive much longer.

An important feature of behavior in a wide range of organisms is the endogenous 24-hour rhythm controlling



Seymour Benzer

Some of the lessons learned from <u>Drosophila</u> carry over almost directly to human genetics, although there are, of course, variations in detail.

activity, which has become personally evident to everyone in this day of jet displacement to new time zones. The fruit fly, too, shows a natural circadian (around one day) rhythm, and here it is possible to clearly demonstrate the role of the genes. The name *Drosophila*, by the way, means "lover of dew." Adults normally eclose from the pupal stage around dawn, when all is moist and cool. The young fly must expand its folded wings and harden its cuticle, and it is important to time emergence carefully, to minimize the risk of desiccation or easy visibility to predators until it is able to fly. The fly has, in fact, evolved a highly ingrained biological clock, which has been studied extensively by C. Pittendrigh and others. In a cycle of 12 hours of light and 12 hours of darkness, adults emerge mostly during a few hours around dawn; those that miss this interval tend to wait until dawn on the following or successive days. The rhythm persists even in constant darkness (provided the pupae have previously been exposed to light); once primed, the internal clock continues to run on its natural cycle. The activity of an adult fly, once emerged, is similarly controlled by an internal clock. Maintained in constant darkness, its locomotion can be monitored by a photocell, using infrared light, which the fly cannot see. At a certain time, the fly begins to walk around for about 12 hours, then becomes very quiet, as if asleep on its feet. Next day, at the same time, within an hour or so, activity begins anew.

The genetic control of this clock is clearly shown by the fact that one can obtain mutants with abnormal rhythms, or even no rhythm, as my student Ronald Konopka has done. *Arrhythmic* mutant flies eclose at arbitrary times of day. After emergence, they are typical insomniacs; in constant darkness, their locomotor activity is spread randomly over time. A *short-period* mutant has an excellent rhythm, but runs on a natural cycle of 19 hours rather than 24. A *long-period* mutant runs on a 28-hour cycle. In a normal world, these mutants would appear always to wake up too early or too late. One need not look far to find human analogs of these types. It is possible that genetics may be a strong component of this personality trait.

Suppose that one wishes to analyze the visual system genetically. To obtain blind mutants, say, one can select for the loss of the fly's normal response of running toward light when agitated. The progeny of mutagenized males are readily fractionated by means of a counter-current distribution technique, analogous to partition chromatography for separating molecules between two liquid phases, except that the two phases in this case are light and darkness. The population can be "chromatographed" in two dimensions, based on multiple trials for movement toward light, then away from light. Normal flies consistently move toward light but not away from it. However, one also obtains mutants that respond differently. Certain mutants run neither toward light nor from it. These *sluggish* types in some cases show obvious anatomical defects, but in others they appear outwardly normal. Some mutants are *runners*, and move very vigorously, whether to or from light (or even in the dark). One also obtains the reverse of normal, i.e., negatively phototactic. Finally, there is even the kind that acts simply *non-phototactic*, showing a normal tendency to walk, but irrespective of whether it is to or from light. These flies behave in light just as do normal flies in the dark, suggesting that they are blind.

Such *non-phototactic* mutants have been studied by W. Pak and M. Heisenberg as well as by our group at Caltech. In certain mutants, the photoreceptor cell responds, but fails to trigger off excitation of the next step in the visual pathway. In other cases, the genetic lesion affects the response of the primary photoreceptor cells so that no signal at all is observed. In another type, the signal is small and greatly delayed. Histology of the latter reveals that the photoreceptor elements, present in the young adult, degenerate with age, not unlike genetic conditions known in man. Thus, the fly's eye may provide a model system for various kinds of blindness. Although many different mechanisms could result in such disorders, mutant material provides perturbations which can be used to analyze normal function.

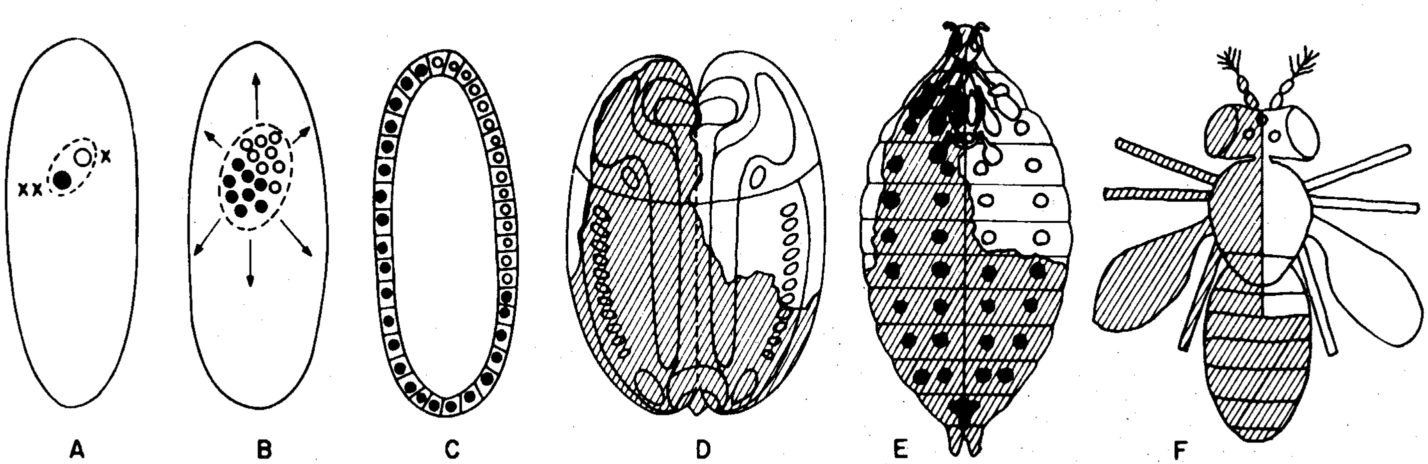
A basic difficulty in pathology, whether in fly or man, is to identify the primary defective focus that causes an observed condition. This focus may lie in an altogether

The fly has evolved a highly ingrained biological clock that governs its daily activity rhythm; the rhythm is genetically determined.

different region of the body from the affected organ. Certain cases of retinal degeneration in man, for instance, are due not at all to a defect in the eye, but are caused by insufficient absorption of dietary vitamin A by the gut. This question recalls the familiar conflict in medical history between humoralism and solidism. A neat way to make the test would be to excise the defective organ and transplant it in place of the corresponding one in a normal individual. If it is a matter of a circulating humor, the transplanted organ should function normally. If the solid organ is at fault, it should still be defective in a normal host.

In *Drosophila*, one can, in effect, do precisely such experiments by using genetic techniques; mosaic individuals can be produced that are composed of parts having different genotypes. One way of doing this is to utilize a fly strain which has a special ring X chromosome that tends to get lost during an early nuclear division of the developing egg, as shown in the drawing below. If the experiment starts with a female egg which has this ring for one of its two X chromosomes, this produces one daughter nucleus which still has both X chromosomes and another that contains only one X chromosome. In *Drosophila*, the latter (XO) type nucleus produces male tissues. The nuclei, after about a dozen divisions, migrate to the surface of the egg, forming a blastoderm. The groups of nuclei stay roughly intact, so that the XX (female) group tends to populate one area of the surface, while the XO (male) group covers the remainder. Since, in *Drosophila*, the orientation of the first nuclear division spindle is arbitrary with respect to the axes of the egg, the dividing line between XX and XO tissues can cut the embryo in any way, in some cases longitudinally down the middle, in others transversely, or at an angle. When, after larval growth and metamorphosis, the adult fly emerges, it is a gynandromorph, i.e., consists of female and male parts.

To adapt this system to the problem at hand, given a recessive behavioral gene, that gene is recombined on the

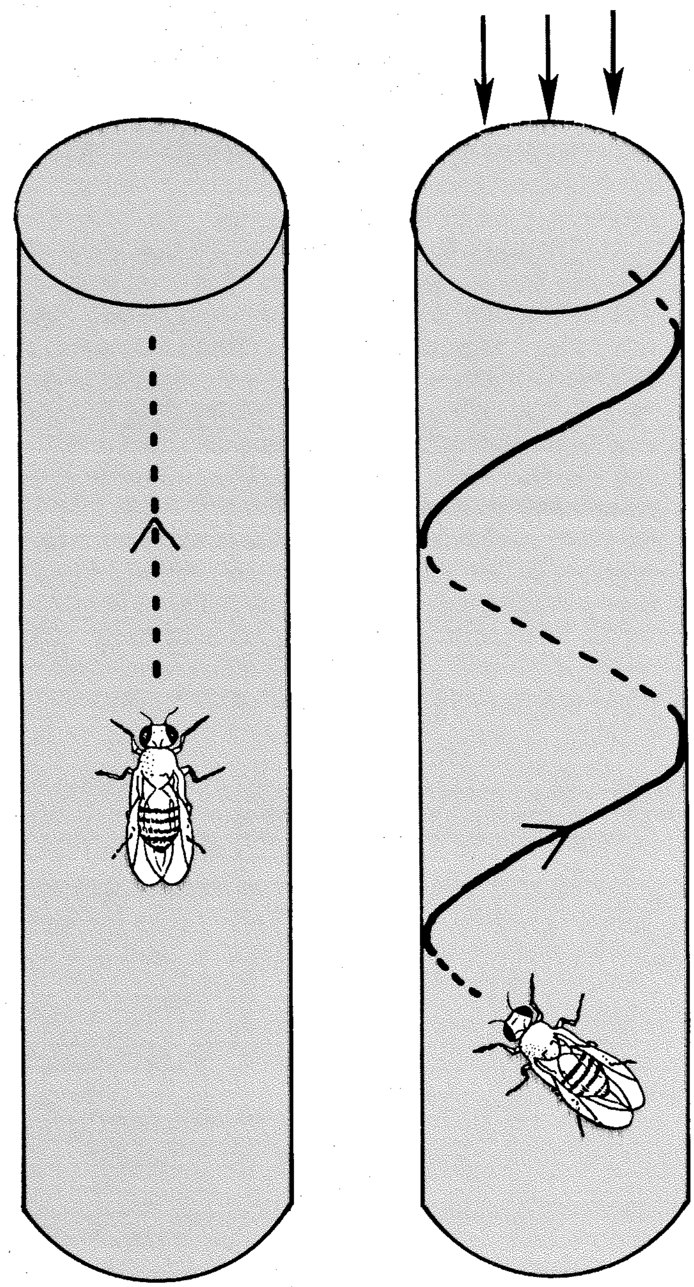


A mosaic fly may be formed by the loss of one X chromosome during the first nuclear division (A). The nuclei then migrate to the surface of the cell (B), and form a composite blastula (C). The fate map of the embryo (D) presages the map of larval structures destined to form the adult body parts (E), and the mosaic fly after metamorphosis (F).

(non-ring) X chromosome with other recessive marker genes that affect phenotypes visible in the adult, such as white eyes, yellow body color, and forked bristles. In the XX body parts, these marker genes will be dominated by the corresponding normal genes on the second X chromosome, but in the XO parts, the mutations will be expressed. Examination of the surface of the fly identifies the parts that are normal and those in which the mutant genes have been uncovered. One can then select, from among the random gynandromorphs produced, ones in which the dividing line falls in desired ways. Thus, individuals can be obtained having a normal head on a mutant body, or vice versa, or even flies having one mutant eye and one normal one.

A normal fly, when placed in a vertical tube in the dark, climbs more or less straight up, utilizing gravity as a cue. If there is a light source on top, the fly still climbs straight up, since the phototactic orientation response, which the fly achieves by moving in such a direction that the light intensities on the two eyes are kept equal, indicates a direction consistent with the gravity cue. Yoshiki Hotta and I have investigated flies that are mosaic for various nonphototactic genes. If one puts a 50-50 mosaic (one eye good, the other eye bad) into the tube in the dark, it climbs straight, as a normal fly does, since its gravity sense is unimpaired. But if a light at the top is turned on, the fly now traces a helical path, always turning the mutant eye toward the light in a futile attempt to balance input signals (right). The electroretinogram likewise is defective, showing that the action of the mutant gene is upon the eye itself, and not via lack of some circulating substance.

The gynandromorph technique also can be used to good effect in analyzing behavioral phenomena. For instance, where is the origin of the circadian rhythm in the fly? Some preliminary work has been done by Konopka with gynandromorphs in which part of the body has one rhythm gene combination, while the rest of the body has a different one. The results indicate that the clock is closely associated with the head; a fly with a mutant head runs on a mutant rhythm, even if all the rest of the body is normal. An especially interesting case arises when half



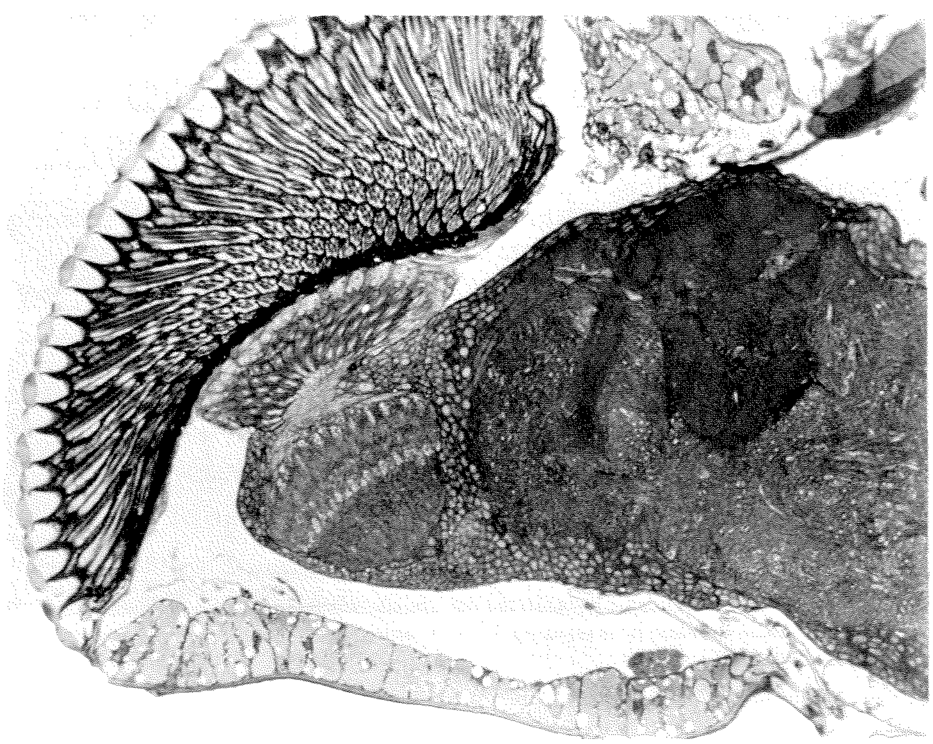
The climbing path of a mosaic fly with one blind eye—in darkness—is straight (left), but with a light shining from above the same fly will trace a helical path (right), turning the mutant eye toward the light in a futile attempt to balance input signals.

Experience thus far with the fly as a model system for unraveling the path from the gene to behavior is encouraging. In any case, it is fun.

the head is normal, the other half mutant. In such "split-brain" flies, the rhythms observed seem to be neither one nor the other but more complex. Just as Roger Sperry has done for human split-brain subjects, it may prove possible to learn how the two "hemispheres" of the fly brain interact to produce normal behavior.

The pursuit of the primary focus of a behavioral phenotype may lead to unexpected results. One mutant, which we call *wings-up*, raises its wings shortly after emergence to a position perpendicular to the body axis, and keeps them permanently in that position. Is this a defect in the wing itself, its articulation, the wing-controlling muscles, or a "psychological" quirk of the nervous system? Hotta and I studied mosaic flies and found that the character is more closely associated with the thorax of the fly than with the head or abdomen. However, it does not reside in the wings or, indeed, anywhere on the thorax cuticle, for in some mosaics the entire thorax surface may be normal, yet the wings are held up, and vice versa. In the fly, the raising and lowering of the wings during normal flight occurs indirectly, by alternating action of vertical and longitudinal muscles that change the shape of the thorax. In the *wings-up* mutant, all these indirect flight muscles are defective, while other muscles are quite normal. Electron microscopy shows an almost complete lack of myofibrils in the affected muscles. In flies heterozygous for this gene, myofibrils are present, but in contrast to the very precise striations in normal flight muscle, the Z-bands are highly irregular, as if there were a deficit in the amount of Z-band substance produced. If this is the case, it calls to mind the syndrome in man of nemaline myopathy, in which the converse seems to apply, the genetic defect causing an excess of Z-band molecules.

Another recently discovered mutant that Hotta and I have investigated is one we call *drop-dead*. For the first day or two after emergence, the adults show normal behavior, such as walking, flying, geotaxis, phototaxis, and mating. At some unpredictable time, each individual becomes less active, walks in an uncoordinated manner, falls on its back with limbs struggling, and dies. While the transition from apparently normal behavior to death occurs within only several hours, the time of onset of the



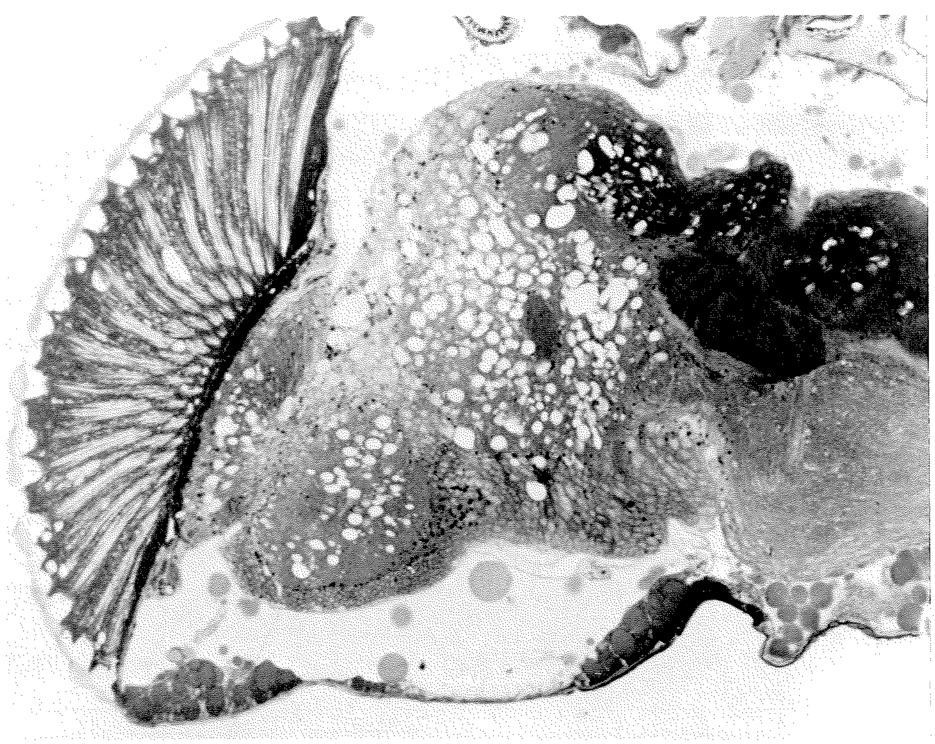
This horizontal section of the head of a normal Drosophila *shows the eye at the extreme left, the optic ganglia at the left of center, and the brain.*

syndrome is highly variable. It is as if some random event triggers off a cataclysm. The death rate depends surprisingly little on temperature.

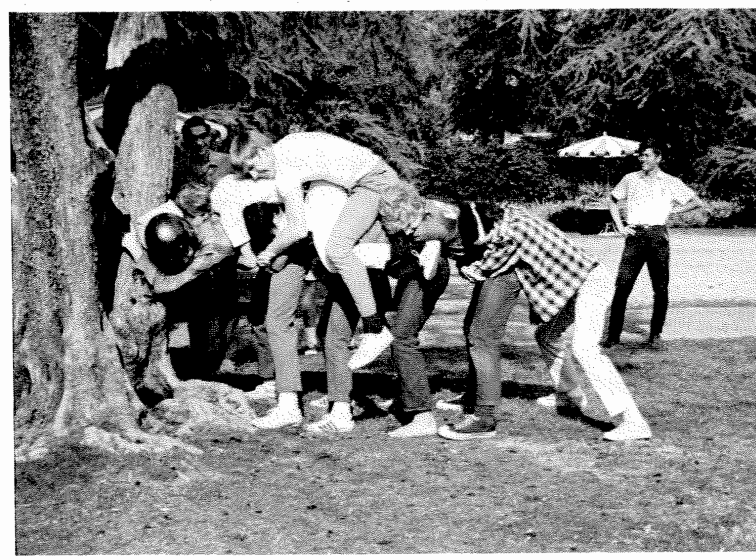
Mosaic analysis shows that whether a fly drops dead or not is most closely correlated with the genotype of the head, rather than the thorax or abdomen. However, there do occur occasional mosaics where the entire head surface is normal, yet the fly drops dead, and vice versa. This suggests looking inside the head to the brain. Histology of *drop-dead* mutant flies, fixed before staggering has set in, shows fairly normal appearance of the brain. However, whenever a fly that is already demonstrating staggering symptoms is examined, the brain is found to be shot full of holes. The holes tend to be concentrated around certain regions of the brain, as shown below.

This syndrome recalls the many kinds of hereditary brain degeneration in man. For instance, the gene for Huntington's disease leads to degeneration which appears to start in a specific brain region and is followed by more general deterioration, production of involuntary movements, incapacitation, and death. Although the gene is sooner or later expressed in all individuals carrying it, the age of onset of symptoms is highly variable. In fact, the distribution of incidence versus age for *drop-dead* is roughly similar to that for Huntington's disease, one day in the life of a *drop-dead* fly being roughly equivalent to a decade for an affected human. One must not, of course, push analogies such as these too far. The gene for Huntington's disease is dominant and autosomal, while *drop-dead* is recessive and sex-linked, and, needless to say, a fly is not a man.

In summary, gene changes can alter behavior in many different ways, and by very diverse mechanisms, by affecting the development and function of sense organs, the central nervous system, or motor output. Mutations provide an incisive tool for producing perturbations by which the normal system may be dissected and analyzed. Genetic tricks such as production of mosaic individuals are powerful in pinpointing the relevant components. Experience thus far with the fly as a model system for unraveling the path from the gene to behavior is encouraging. In any case, it is fun.



In horizontal section, the brain of a drop-dead *mutant at the stage of pronounced staggering is shot full of holes. The holes extend into the optic ganglia.*



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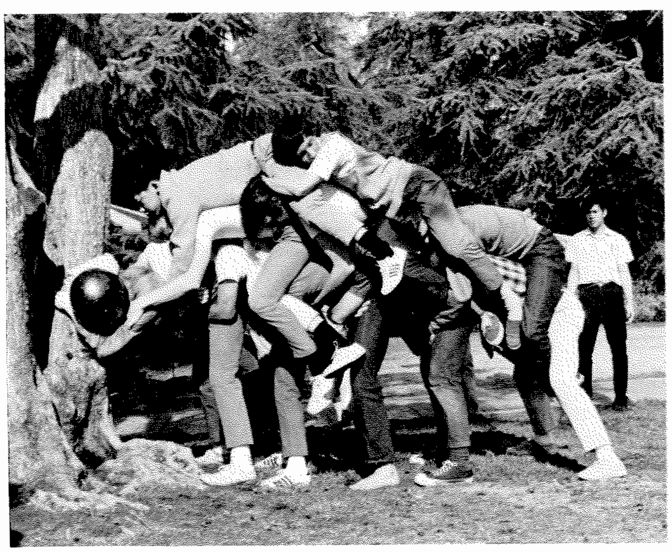
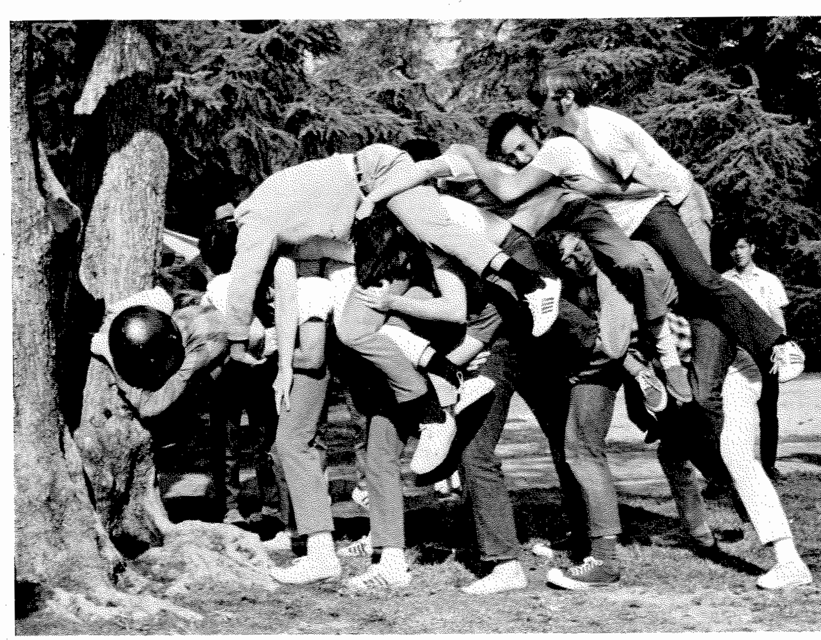
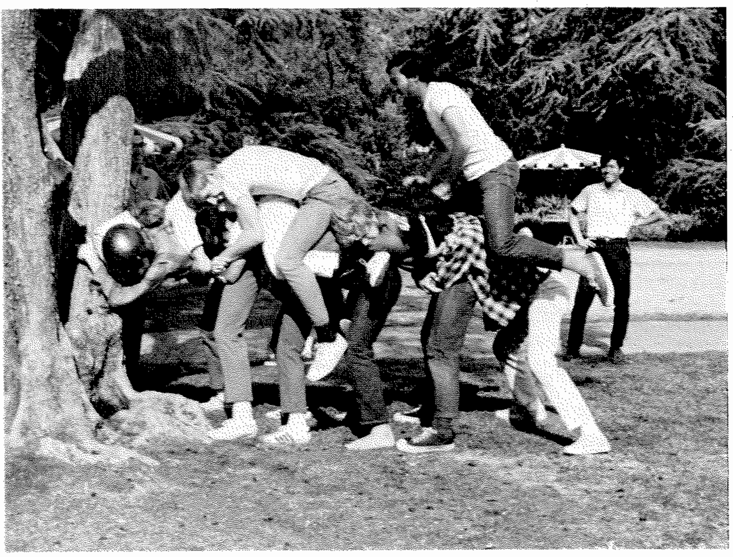
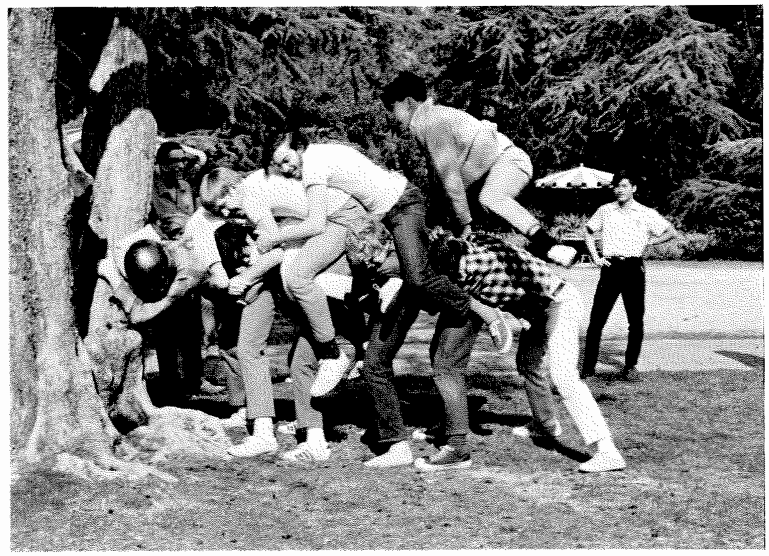






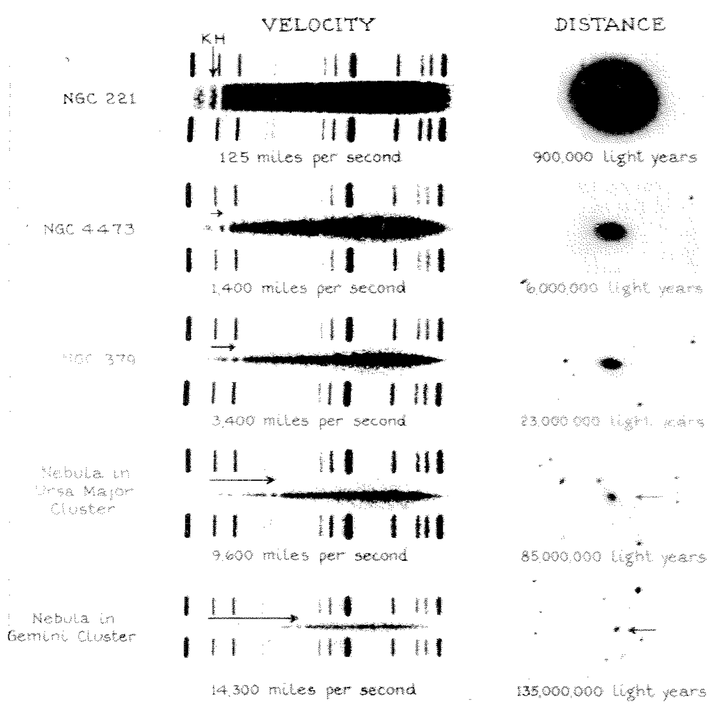


Spring

THE SHAPE OF SPACE

by James Gunn

There is only one universe, doing —as far as we can tell—rather simple things. But do we understand those things?



The velocity-distance relation for various extragalactic nebulae provides the basic observational evidence for the expansion of the universe. The greater the distance of a nebula from the earth, the greater the velocity of its recession and the more its spectra shift to the right, toward the red.

One of the most fascinating questions to which we can address ourselves is the ultimate one of beginnings and ends, and cosmology is largely devoted to seeking answers to that question. But, as it turns out, it is difficult to discover anything about the universe as a whole because of the extreme distances and faintness of the objects involved.

In assessing the findings of cosmologists, we must pay attention to a few powerful caveats. There is, first of all, the enormous conceit involved in our thinking that we can go to the laboratory and measure a few milliliters, liters, or even a few thousand kiloliters of something and then deduce laws to describe the evolution and properties of the universe as a whole. Second—and combined with our conceit—is a common trait, to which scientists are as prone as anyone else: our enormous powers of rationalization. We observe something in the universe, develop a theory that appears to explain it, and we're happy. But have we really explained anything? In the case of cosmological theories, it is very difficult to say. In other fields of science, it is not so difficult, because someone else can follow up and verify or disprove the results; the experiment can be repeated; other cases can be observed.

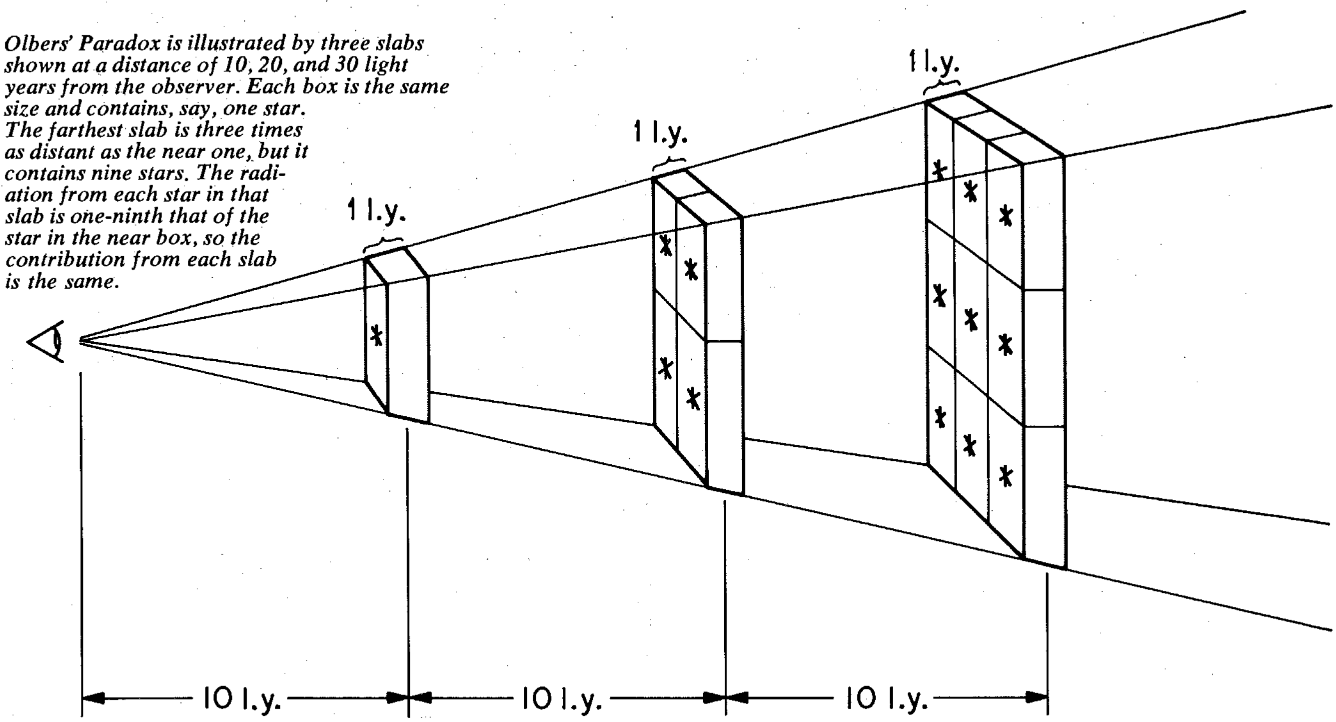
But there is only one universe. The universe is doing, as far as we can tell, rather simple things. But whether we really understand what is going on or not is quite impossible to say. We are not in a position to repeat the "experiment." We are not even in any position to perturb the experiment in any significant way to see how it behaves. That is perhaps not entirely unfortunate, but in any case it makes investigation rather difficult.

Despite these difficulties, the universe—or that portion of it we can see—presents a few facts for us to work with.

The sky at night is dark;
The universe is expanding;
The universe seems to be isotropic about us.

First, the darkness of the night sky is a very remarkable fact, for—as we shall see—it is not immediately obvious that it should be. Second, when we say the universe is expanding, we do not mean that the solar system, the stars in our galaxy, each aggregate of stars, and each galaxy are expanding. Rather, the galaxies—the so-called island universes that make up the "particles" of the universe—are receding from us and from each other. The distant ones are doing so at very great speeds. It is in this sense that the universe seems to be expanding, and it is manifested as the famous red shift in the spectra of distant objects. If we interpret the red shift as a normal Doppler shift—that there

Olbers' Paradox is illustrated by three slabs shown at a distance of 10, 20, and 30 light years from the observer. Each box is the same size and contains, say, one star. The farthest slab is three times as distant as the near one, but it contains nine stars. The radiation from each star in that slab is one-ninth that of the star in the near box, so the contribution from each slab is the same.



will be a decrease in the frequency, or an increase in the wavelength of light (toward the red) from an object receding from us—we can say that the reason for such a shift is that the most distant of these galaxies is receding from us at a significant fraction of the velocity of light.

The third fact with which the universe presents us—that it is isotropic around us—is in many ways the most remarkable fact of all. What we find is that the universe looks very much the same in any direction we choose to look. For example, if we pick two areas of the same size at random—one from the northern and one from the southern sky—we find about the same number of galaxies in one as in the other. The same sort of structures seem to exist in each.

Another phenomenon illustrates this isotropy even better: the background black body radiation of the universe. There turns out to be, in space, an infrared radiation field with a temperature of about 2.7 degrees Absolute, which comes to us from all directions. The temperature seems to be constant to within a tenth of a percent no matter where we look in space. It is generally believed that this radiation is residue from a very early epoch in the universe, the so-called Big Bang. So, not only is the universe highly isotropic now, it has been so for a very long time.

Let's look at the implications of these three facts in greater detail and see where they take us.

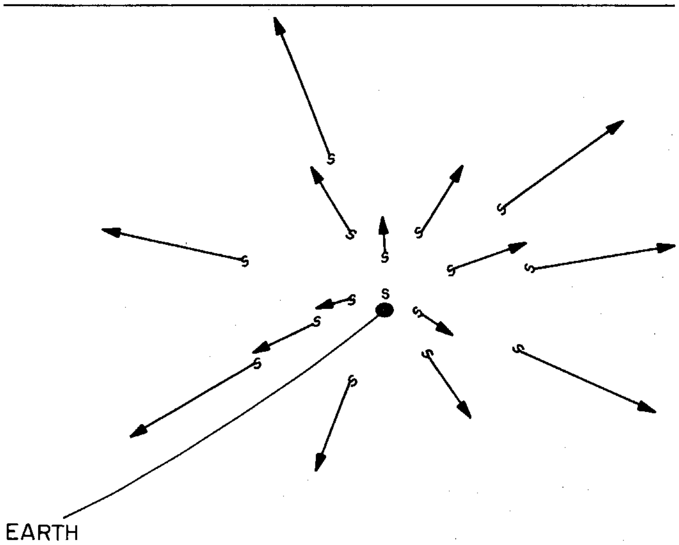
Around the turn of the 19th century, the German astronomer Wilhelm Olbers raised a very important theoretical question which highlighted a paradoxical contradiction between the evident "fact" of the darkness of the sky at night and the assumptions of cosmologists of the time which indicated that it should not be so. Now known as *Olbers' Paradox*, the question deals with the total radiation we would expect to receive on earth from all the stars in the universe. The radiation received from one star depends on both the energy it radiates in the form of light and its distance from us, because the flux of light (the rate of flow of energy across a surface) that we receive on earth is just proportional to the apparent area of the star. If the sun were moved twice as far away, its apparent size would be only half what it is now, and it would appear to be only one-fourth as bright. This means that four suns at twice the present distance would provide exactly the same amount of light as the sun does now. Thus, the light from the stars depends only on the area of sky covered by the stars and not on their individual distances. It can be seen from the drawing above that if stars fill an infinite universe uniformly—as it was believed in Olbers' time—the area of stars covering the sky in a shell, say, one light year thick is independent of the distance to the shell. But there are an infinite number of such shells, stretching to infinity, so the brightness should be infinite. But even

The fact that we seem to be in the center of the universe smacks philosophically of the anthropocentrism of the Middle Ages.

before "infinity" is reached, the sky would be covered with stars and the night sky would be as bright as the surface of the sun.

When Olbers introduced this paradox, it was the stars of our galaxy that were under discussion. But even though the stars in our galaxy do not go on forever in space, we are not released from the paradox. For when the stars of the other galaxies are taken into account, we are brought back to the same difficulty—whether the galaxies go on forever despite the vast distances separating them.

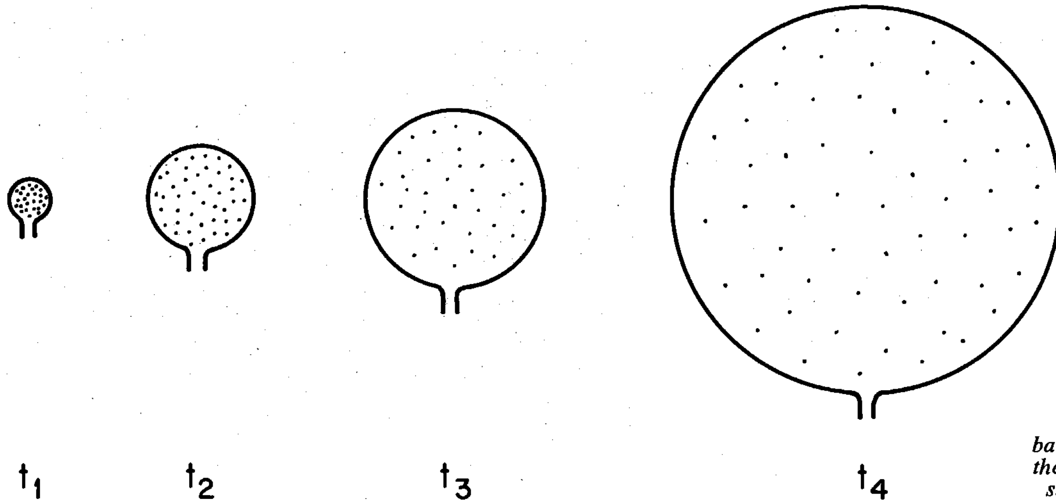
But, happily and obviously, the night sky *is* dark and not bright. It is the Big Bang, the expansion of the universe, that provides an escape from the paradox. Olbers assumed the universe was static, that the stars and galaxies were at rest. But if we assume an expanding universe, we find the light from the more distant of the galaxies is less than it would be if they were at rest at the same distance. The higher the recession velocity of a distant galaxy, the weaker the radiation received from it. Since the most distant galaxies move with successively higher velocities, the farther they are from the earth the less of their radiated light is received by us. We would receive almost no radiation from galaxies at the edge of the observable universe, which are moving at velocities close to that of light.



To an observer on earth, the galaxies in the universe seem to be expanding at a constant rate away from us. If we assume that there is no acceleration, we must also assume that all galaxies left the same neighborhood at the same time—now estimated to be about 19 billion years ago.

Also, as we look out into the universe, we are looking back in time as well. Since the speed of light is finite and we can look no further back than the Big Bang, the observable past of the universe is finite, not infinite. Albert Einstein's Theory of General Relativity predicts that we reach the epoch of the Big Bang at just the distance at which objects are receding at the speed of light, so the two solutions to Olbers' Paradox are really the same.

The expansion of the universe, while it explains many things, is the source of an exceedingly bothersome worry: Not only is the universe expanding, but it seems to be expanding away from *us* in particular. The relation between velocity and distance seems to be a linear one. If a distant object is receding at a given rate, an object twice as far away is traveling twice as fast. The velocity is computed by multiplying a constant (called the *Hubble Constant*) by the distance to the object. This formula, essentially, is *Hubble's Law*, and was first derived from measurements made by Edwin P. Hubble at the Mt. Wilson Observatory starting in 1923. Since everything is receding, it is reasonable to ask: If it has always traveled at the same speed, how long ago did a given galaxy leave the neighborhood of our own? It is easy to see that since the object twice as far away is traveling twice as fast, the time of departure for one and all is precisely the same. This leads to the conclusion that there was a time at which all these galaxies were on top of us, and some mighty event began their flight. We measure the age of the universe from this event. Our estimate of this number, the *Hubble Age*, has undergone tremendous revision in the last 20 years as new experimental data and observations have been taken into account. Currently, the best estimate for the age of the observable universe, determined in this way, is about 19 billion years. We are not aware of any structures that are older. Most are considerably younger. The earth, for instance, is estimated from geological evidence to be about 5 billion years old.



A two-dimensional universe that satisfies the Cosmological Principle and yet lets an observer see a universe as apparently expanding away from him is illustrated by the surface of an ordinary balloon. As time increases from t_1 to t_4, the balloon expands and the dots on the surface expand away from each other.

Now, the fact that we seem to be in the center of this show is a bit perturbing. The universe, as we have seen, seems to be highly isotropic around us; it also seems to be expanding about us. It all smacks philosophically of the anthropocentrism of the Middle Ages when the earth was assumed to be at the center of a set of crystal spheres beyond which there was heaven. It looks as if we are in some sort of highly privileged place from which we observe the universe. We have learned to regard this idea with some repugnance. Is there some way around this difficulty?

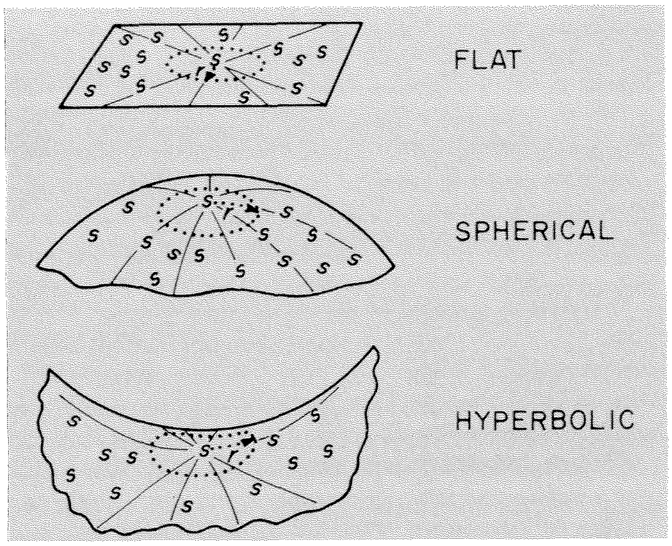
If the universe is at all reasonable and if we are not in a privileged place or a privileged time, the universe should obey a pontifical-sounding thing called by cosmologists the *Cosmological Principle*. It simply says: *We are not in a privileged place and no matter where you are in the universe you must see essentially the same thing.* A corollary to this principle is the idea of cosmic time. The Cosmological Principle doesn't make sense unless we can say *when* we should compare regions of the universe, since the universe expands and changes with time. What the principle must say is that there is a time by which everybody in the universe can set their clocks, so that if everyone looks at the universe at the same cosmic time they will see essentially the same things.

One thing is clear immediately, and that is that the universe—if it obeys the Cosmological Principle—cannot consist of a great expanding lump with us in the center, because an onlooker at the edge of such a lump would never see an isotropic universe. Can we, in fact, reconcile the observed isotropy—which seems to put us squarely in the center of something—with the Cosmological Principle?

That we can, at least in principle, remove ourselves from the center and still maintain these two ideas is illustrated by the diagram above. This shows a two-dimensional "universe" which seems to satisfy the Cosmological Principle—the surface of an ordinary rubber balloon. Suppose one glued little paper galaxies to its surface. To each galaxy its neighbors would appear to be receding as the balloon was filled. Each one thinks it is at the center of the expansion because every point on the surface of the balloon is just like every other point. As the balloon is inflated, the membrane expands uniformly, and the galaxies get further and further apart. This seems to satisfy both the isotropy and the observed expansion.

One could also do this with a very large two-dimensional flat rubber sheet being pulled with equal strength on all sides. If you had little galaxies glued to it, they would also expand uniformly away from each other. And unless you knew beforehand where the center of the sheet was, it would be impossible to locate the center by any kind of measurement you could make from a galaxy on the sheet.

So here are a couple of expanding two-dimensional cases which seem to satisfy the Cosmological Principle. What about the real world of three-dimensional space? What shape can it be? We know that ordinary space is describable by three dimensions, and the locations of points by distances in three directions—say, north, east, and up. Presumably, one can go as far as one likes in any one of those directions and keep going forever. Space seems to be Euclidian (flat) on any scale we can measure. But it is not at all clear that space is Euclidian on the very largest of scales. We haven't been able to penetrate space far enough to make any definitive measurements. We can, however, ask what the possibilities are mathematically. Infinitely many? Or is nature kinder than that? Do we have only a limited range of possibilities to select from? Any choice must meet the requirement that the space have precisely



The three possible shapes of space are flat, spherical, and hyperbolic (or saddle-shaped). They are illustrated here on two-dimensional surfaces, but the same possibilities exist in three dimensions—and in all higher dimensions.

the same properties everywhere and in all directions—it must be homogeneous and isotropic.

The restrictions are strong enough that one can show that there are only three possibilities for this kind of space. We have already dealt with two of these possibilities in two dimensions—flat and spherical. There is a third. In two dimensions the analogue is called a pseudosphere, which is a saddle-shaped surface. Flat space is infinite and unbounded. A line drawn in any direction extends endlessly; parallel lines remain parallel and the same distance apart. The curvature of this space is zero. Spherical space is finite but unbounded. A line drawn in any direction will not go on forever, but neither will it come to end. It will eventually close upon itself—making a circle. Parallel lines in spherical space, extended far enough, eventually meet. The curvature of this space is said to be positive. The curvature of the saddle-shaped space is negative. It is infinite and unbounded. Parallel lines drawn in this space eventually diverge from one another. Lines extend in any direction without end and without meeting themselves. Such a space is also called "hyperbolic."

These three possible shapes of space are illustrated, in part, in the diagram to the right. It turns out that these three kinds of space exist not only in two and three dimensions, but in all higher dimensions. If our space were nine-dimensional, there would still be only these three cases for the curvature.

If three-dimensional space were flat, it would obey all the laws of two-dimensional Euclidian flat geometry. One of these laws is that the sum of the angles of a triangle is 180 degrees. Another is that the circumference of a circle is 2π times the radius. In spherical space the sum of the angles of a triangle is more than 180 degrees, and the circumference of a circle is less than that of a circle in flat space. In hyperbolic space the sum of the angles is less than 180 degrees, and the circumference of a circle is greater than that in flat space. Space must be one of these three varieties if it is to obey the Cosmological Principle. Which one is it? And how do we determine it?

In two dimensions it is possible to determine whether an unknown surface is flat, spherical, or saddle-shaped by finding out whether the area of a circle drawn on it increases as the square of its radius, or whether it increases slower or faster. In three dimensions the question is how fast the volume of a sphere increases with its radius. The space is flat, spherical, or saddle-shaped according to whether the volume increases as the cube of the radius, or whether it increases more slowly or faster. The shape of the space we are living in, then, could in principle be determined by first counting the galaxies making up the universe at increasing distances out into space and then by seeing how this number changes with distance, since the Cosmological Principle demands that the number of galaxies per unit volume be uniform.

But we cannot determine the volume (and therefore the shape) of space directly because we cannot determine distances with sufficient accuracy. We must seek other means. We must again consider the expansion of the universe, investigate the forces acting on the expansion, and determine how they relate to the density of matter and the "total energy" in the universe.

Let's take a chunk of the universe, make a bubble, and talk about the behavior of the stuff within this bubble. If we make the bubble small enough, we certainly can explain its behavior by the everyday physical laws we know. It is a curious consequence of the Cosmological Principle that this same bubble must be typical of the universe as a whole, since every piece of the universe is like every other. Thus if one understands this bubble, one understand the whole universe—if one knows how the bubbles fit together.

Consider such a bubble. What makes it expand? One can show quite convincingly that the forces that might drive the expansion are probably much too small to do the job. The universe seems to be expanding because it once got going that way and has been coasting ever since. There seem to be no forces that could even significantly alter the expansion, except for a very important one—gravity. How is this force affecting the universe?

Again, there are three choices; three things that can happen in a universe acted upon by gravity alone; three states of energy.

The energy can be zero. A good analogy is the case of a rocket being launched from the surface of the earth. The rocket can be launched at precisely the escape velocity of the earth, so that it climbs up very slowly and eventually gets as far away as you like. But all the while it is slowing down more and more, so that it reaches infinity with zero velocity.

The energy can be positive. You can push the rocket out a bit faster than the escape velocity. That means that once it gets beyond some point it really no longer feels the gravitational field of the earth very much. And so it continues from there to infinity with essentially constant velocity.

Or the energy can be negative. You could fire the rocket with not quite enough energy to escape the earth's gravitational pull. In this case it will reach some maximum distance, pause, return to the earth, and crash with the same speed as that with which it was launched.

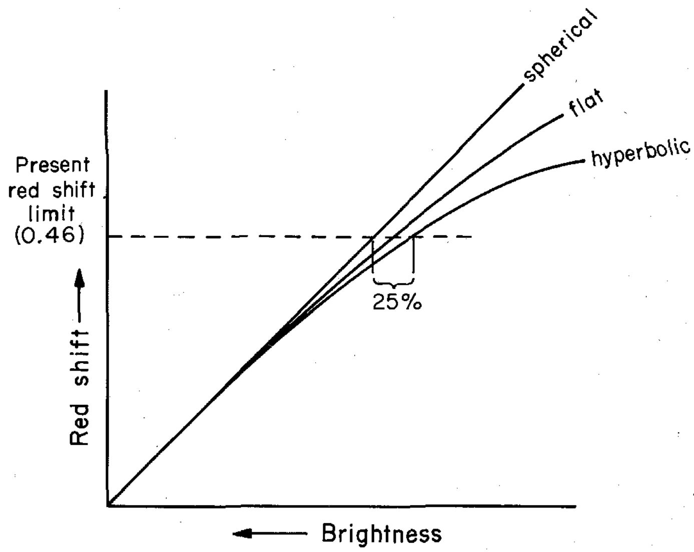
In a similar manner, if the total energy of the universe is zero, the expansion will continue, but it will become slower and slower as time goes on. If the energy is positive, the universe will also keep expanding, but eventually the effects of gravity will become negligible and it will fly apart at a constant rate. If the total energy is negative, gravitation will eventually stop the expansion, and the universe will collapse again in a backward rerun of the Big Bang from whence it came. Gravitation always slows the expansion—the question is simply whether it "wins" or not in the end.

Einstein's General Theory of Relativity predicts that these energy considerations are intimately connected with the shape of space (how the bubbles fit together). It turns out that if the universe has negative energy, space is spherical. Such space has finite volume. There is only a finite amount of stuff in the universe. You could go around the universe and eventually come back to where you were. (You would have to go faster than light to do it, however.) In this case you may recall, the universe will ultimately collapse, so the whole thing is finite in both space *and* time. If the energy is zero, space is flat. If the energy in the universe is positive so that the expansion eventually proceeds unhindered, it turns out space is hyperbolic (saddle-shaped).

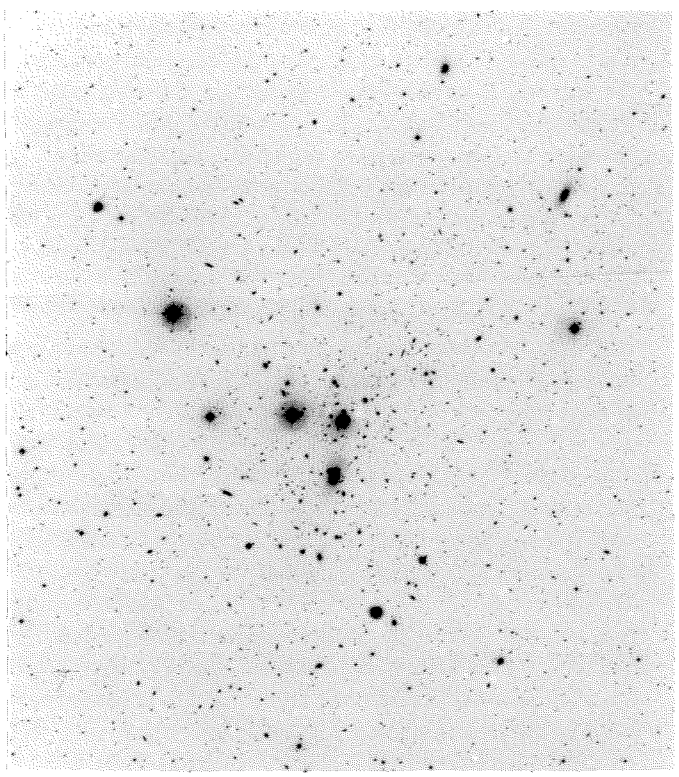
If you wish to believe these predictions of General Relativity, there are several ways to get at the shape of space.

One possibility is to look at the density of matter in the universe. This is a very difficult thing to measure, but would give the answer if we could do it. The higher the density, the stronger the gravitational force which decelerates the expansion. Knowing the density, the law of gravity, and the expansion rate, we can calculate the energy and hence get the curvature. But how does one get the density? One direct way is to use approximately known masses of the galaxies we see. We can then conceptually smear this mass out and find the mean density. That density is equivalent to about 1 atom for every 10 cubic meters. This value for the density implies that the total energy of the universe is strongly positive. Hence, the expansion would continue forever. The universe is infinite and unbounded, and hyperbolic in shape. We must, however, regard this result with a great deal of caution. We are measuring only the density of the matter we can see, and we must assume that there may be more that we do not see for some reason.

There are some people to whom it is philosophically very important that the universe be closed, that the energy be negative, that the universe began at some time with a violent bang and will end the same way. This concept makes a neat little bubble in space-time. There have been some quasi-scientific reasons for the concept, but I don't think they are at all compelling. To have a closed universe of this sort, one needs a density of about 3 atoms for each cubic meter—about 30 times as much as the galaxies contain. This is only possible if, for example, there is a diffuse gas of about this density spread out between the galaxies. Various people have looked very hard to find this material but with little success. On the other hand, it has been very hard to prove it is not there, though some progress is being



The diagram above shows how the received radiation from a "standard bulb" varies with red shift for three examples of space curvature. At the present red shift limit for super-giant galaxies (.46 of the velocity of light), the differences are only 25 percent—too small to be reliably determined in the face of statistical and other uncertainties.



Possible "standard bulbs" against which astronomers can compare distant galaxies are super-giant galaxies such as those within the Coma cluster of nebulae. Quasars will not do because we know so little about them. Super-giants, by contrast, are reasonably similar and of known brightness.

made in this direction. It now appears that there probably is not enough matter to reverse the expansion—but this result is very tentative as yet.

Another indirect way to get at the answer—the one which will probably eventually yield the best data—is to look at the relation between recession velocity and distance. We have seen that this relation is linear, but it turns out this is true only for nearby objects. And for a very simple reason. As we look out in distance, we also look back in time. Gravity has been slowing the universe down; so as we look out, we look back to eras when the expansion was faster than it is at present. Thus, we can measure the rate of slowing down, and, hence, determine the gravitation and the energy. This technique cannot be used directly, for we have no sufficiently good way to measure the distance. We can measure the brightness of distant objects, and, of course, their red shifts, to obtain their velocities. If we know how luminous a source is—its total light output, the "wattage of its light bulb"—we can deduce its distance. If we have a set of "standard bulbs," all of precisely the same power but at different distances, we can expect to see a relation as is shown in the figure above left. For sufficiently distant objects the difference in apparent brightness for different kinds of space is quite appreciable.

What does nature furnish us with that we can use for our standard bulbs? It was hoped that the quasars would do, for they are very bright and can be seen from enormous distances. But they seem to come in all "wattages," and furthermore, there seems to be no way to tell an intrinsically faint one from a bright one. The next best things are super-giant galaxies, which for reasons we do not understand at all seem to be remarkably alike. Furthermore, they are easy to find, since they are always the brightest member of a cluster of galaxies, such as the Coma cluster in the photograph to the left.

These brightest of galaxies are, unfortunately, faint compared to quasars, and so it is very difficult to observe them at great distances. The most distant yet studied is receding at about one-third the speed of light and is not far enough away to tell reliably which curve is the correct one for the shape of space.

Development of light detectors is a field in which technology is advancing rapidly, however, and within the next few years we should be able to study objects which are twice as distant as any we have yet seen.

We may yet know the shape of space.

Research Notes

Electrical Conductance in Membranes

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

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

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

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

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

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

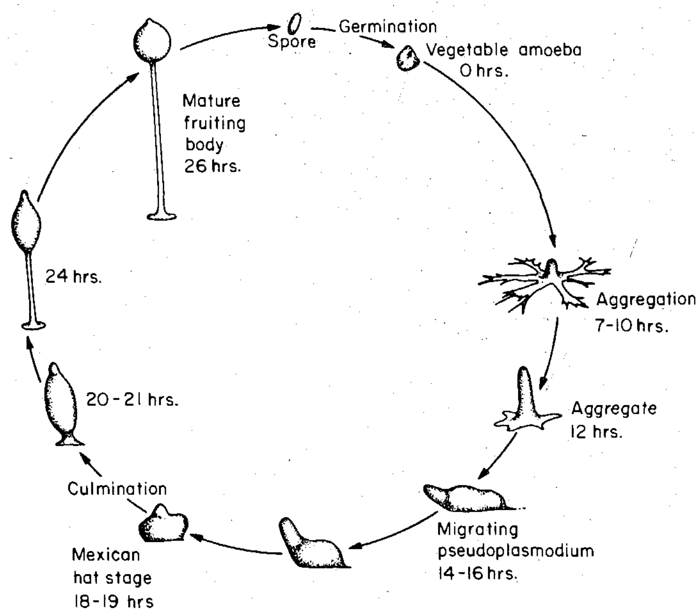
Mead and his fellow workers hope that an understanding of membrane conductance will in turn lead to an understanding of excitability (the one property that living systems possess, but artificial membranes do not), the process by which some sort of stimulus will trigger an electrical impulse. According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

Slime Mold and Differentiation

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

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

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



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

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

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

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

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

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

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

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

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

Sound Waves on the Sun

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

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

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

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

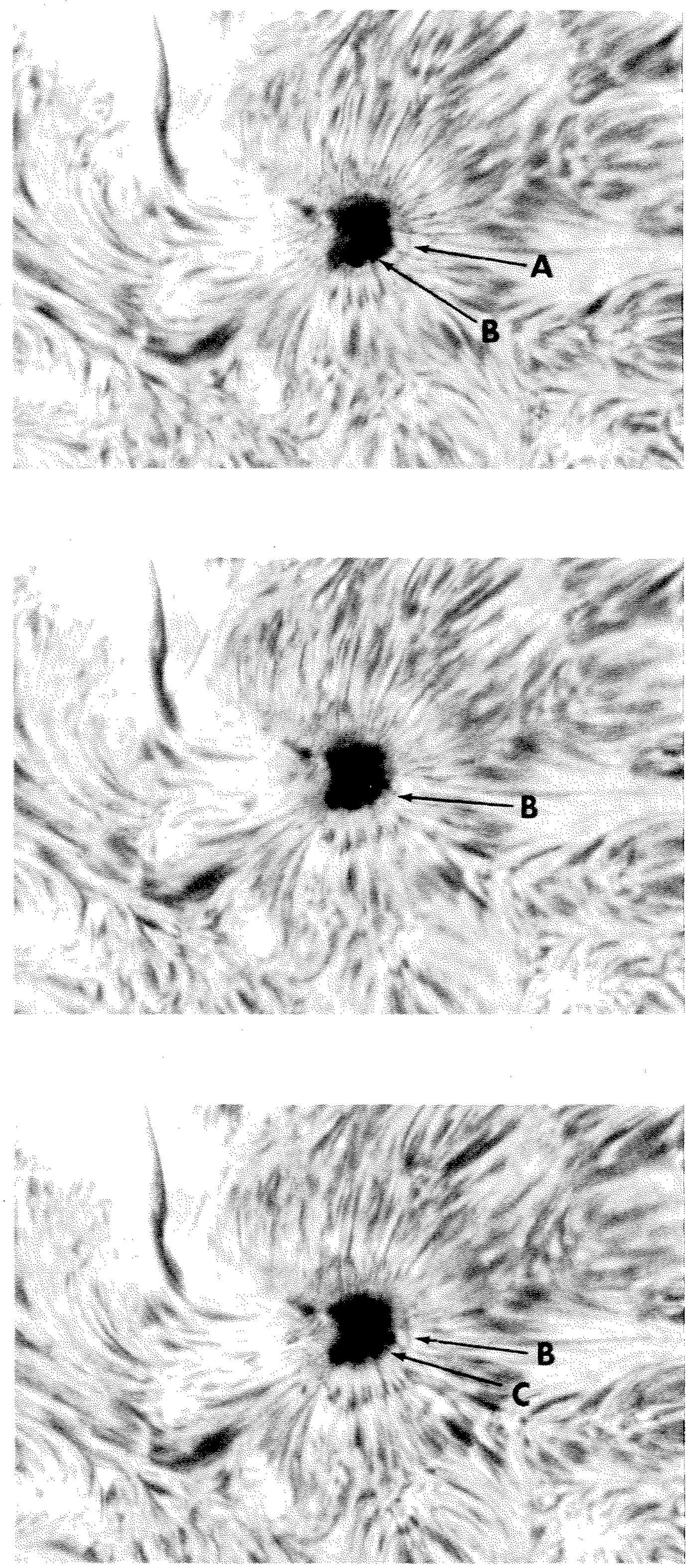
After almost a year of study and analysis, Zirin recently reported on Stein Waves to the solar division of the American Astronomical Society. He believes they are sound waves.

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

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

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

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



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

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

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

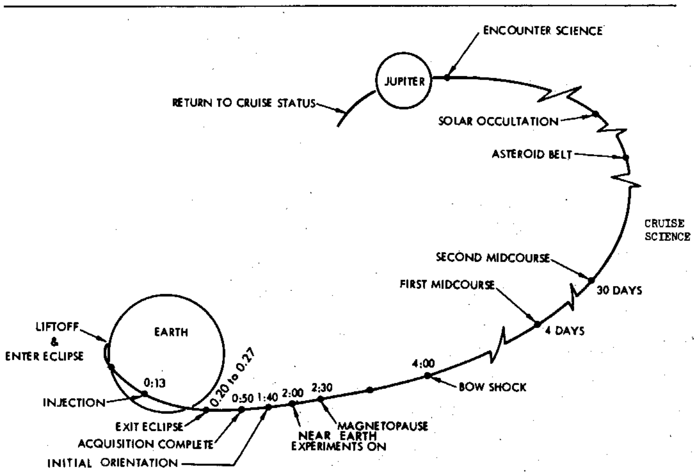
The waves should give scientists a whole new picture of the energy production in sunspots. According to theory, activity in sunspots is "frozen" because of the strength of the magnetic waves in them. But if the Stein Waves are truly sound waves, observers get a whole new picture of the inside of sunspots—one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

Pioneer 10—A Small Spacecraft with a Big Job

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

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

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



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

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

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

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

The Month at Caltech

NAS Elections

Five faculty members were elected to the National Academy of Sciences last month, bringing Caltech's total current membership to 46. The new members are Roy J. Britten, visiting associate in biology; Pol E. Duwez, professor of materials science; Peter Goldreich, professor of planetary science and astronomy; George Housner, professor of civil engineering and applied mechanics; and William B. Wood, professor of biology.

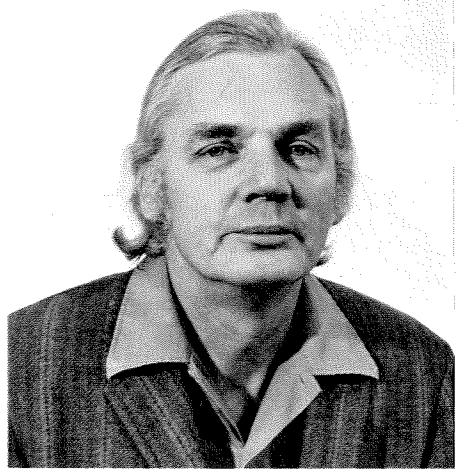
Britten, a staff member of the Carnegie Institution of Washington who has been at Caltech for the past year, has been doing research on DNA. He has found that much of the DNA of higher organisms consists of sequences of nucleotides repeated many times with varying degrees of precision. The discovery of this quality of DNA has opened new possibilities for the interpretation of both differentiation and evolution.

Except for the period 1935-40, Duwez has been at Caltech since 1933. He ranks as one of the world's leading scientists in the field of metals and materials, and is particularly noted for his development of new alloys with his ingenious "splat quenching" technique. Some of these new substances have unusual superconducting and thermoelectric properties.

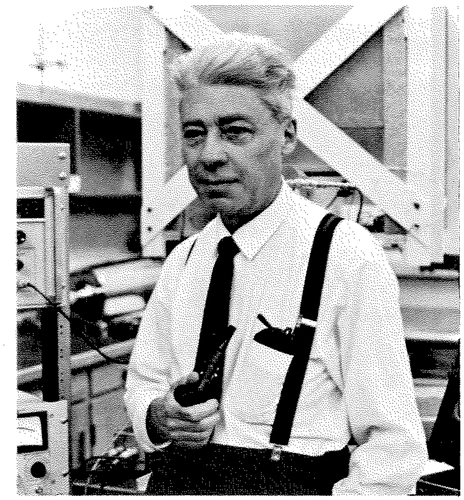
Goldreich has done extensive theoretical work in classical astronomy, geophysics, and neutron star physics. He played a major role in explaining the mechanism of a pulsar, and obtained the first explanations of physical conditions for the maser process in interstellar clouds. He has been on the faculty at Caltech since 1966.

Housner, who is also a member of the National Academy of Engineering, is a noted earthquake engineer. His work on the properties of strong-motion earthquakes is the foundation for much of the current thought about design necessities in a seismic area. Housner was a consultant on California's Feather River Water Project, in the design of San Francisco's rapid transit system, and in preparation of the Atomic Energy Commission's manual on nuclear reactors and earthquakes. He is a Caltech alumnus (MS '34, PhD '41) and has been a member of the faculty since 1945.

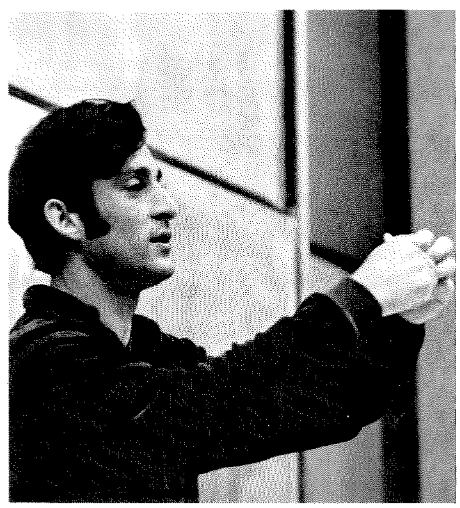
Wood, who has been at Caltech since 1965, did major research toward determining the function of individual genes of the virus T4 from precursor components. During the past five years, he and his graduate students have analyzed the sequence of molecular transformations necessary for constructing the tail fibers of the virus. A significant milestone in understanding molecular architecture, this work won for Wood the U.S. Steel Award in Molecular Biology from NAS in 1969.



Roy Britten

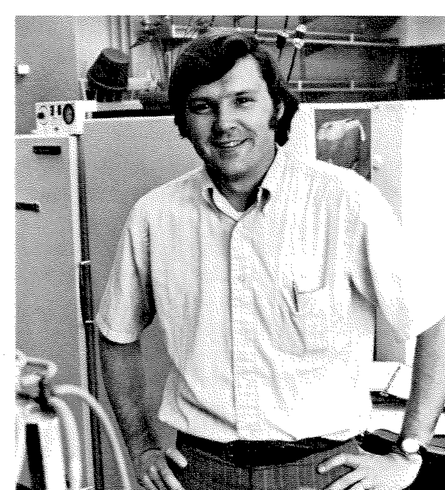


Pol Duwez

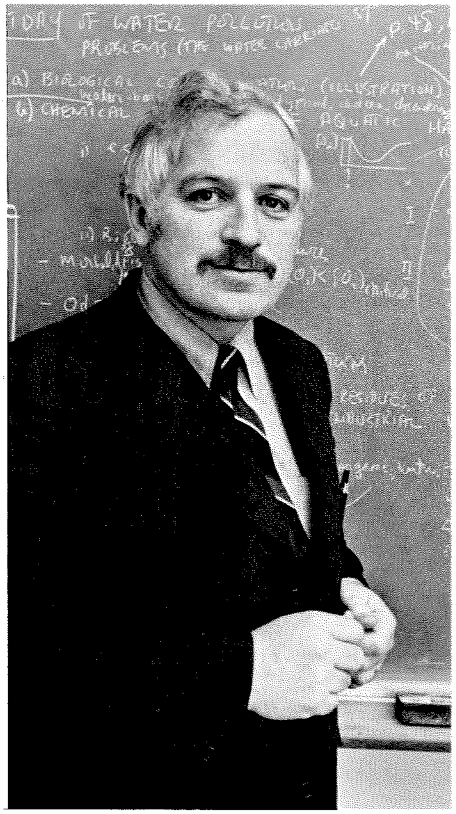


Peter Goldreich

George Housner



William Wood



James Morgan

Morgan Moves to New Environment

James Morgan, 39, professor of environmental engineering science, has been appointed dean of students. He succeeds Robert Huttenback, professor of history, who has become chairman of the division of humanities and social sciences.

Between now and July 1, when his appointment becomes effective, Morgan plans to get ready for his new job by talking with those who know most about it: his predecessor; the other two members of the three-man team who are concerned with student activities and academic problems—Lyman Bonner, director of student relations, and David Wood, associate dean of students—and to as many students as possible. As far as Morgan is concerned, one of the most important activities for a dean is to help adapt the educational opportunities at Caltech to the needs of the individual student, and that's how he'd like to concentrate his efforts.

A native New Yorker—who spent the first five years of his life in Ireland—Morgan received his BS in civil engineering at Manhattan College in 1954 and his MS at the University of Michigan in 1956. For four years after that he was an instructor in civil engineering at the University of Illinois, and then went on to take an MA and a PhD in applied chemistry at Harvard University, where he was a Danforth Teacher. From 1963 to 1965 he was an associate professor of water chemistry and of civil engineering at the University of Florida.

Since coming to Caltech in 1965, Morgan has focused his research on projects relating to water chemistry, the effects of pollution on natural waters, and the improvement of water quality through new treatment processes. His research group has been working on the environmental chemistry of phosphorus, models for complex chemical systems, the use of polymers for removing particles from water, and the behavior of trace metals such as manganese, cadmium, and iron in water.

Since 1967 he has been editor of *Environmental Science and Technology*, a journal on environmental research published by the American Chemical Society. He was one of the authors of the ACS 1969 report on "Cleaning the Environment," and is co-author with Werner Stumm of Harvard of *Aquatic Chemistry*, a widely used advanced text published in 1970.

Morgan expects to spend about half of his time on his new duties, and divide the rest between research and teaching. This is in the tradition of Caltech deans, who have all been chosen from the faculty and have continued some of their academic activities.

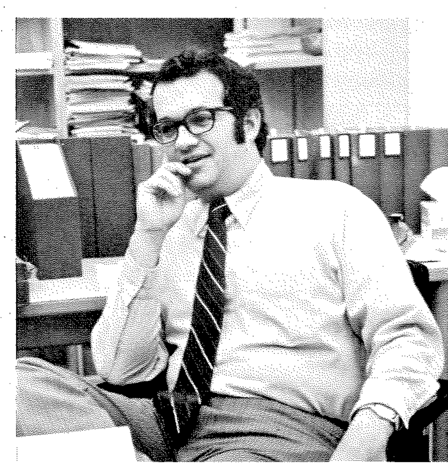
Guggenheim Awards for 1972

Guggenheim Fellowship Awards for 1972 rained on Caltech last month: Three faculty members, a poet-in-residence, and 14 alumni received grants from the John Simon Guggenheim Memorial Foundation in recognition of their past accomplishments and future promise. They are among 372 scholars and artists chosen from 2,506 applicants.

Harry Gray, professor of chemistry at Caltech since 1966, will use his grant to work on the spectroscopy of metalloproteins—leaving Pasadena late this summer for the University of Copenhagen. About March 1 he will go on to the Biochemical Institute of the University of Rome for two or three months, and will probably wind up his project with a short trip to Israel before returning to Caltech in June of 1973.

With his grant, Vincent McKoy, associate professor of theoretical chemistry, will be going to Harvard University in January to spend about three months with the theoretical chemistry group there. He then plans to spend a couple of months

Harry Gray



Vincent McKoy

working on electron molecule scattering with the applied physics group at Yale. McKoy got his PhD from Yale in 1964 and has been at Caltech since that time.

Ronald Scott, professor of civil engineering, will use his award to spend a year as a Fellow of Churchill College of Cambridge University. He plans a three-part program there: giving one formal lecture each term that he is in residence, doing some teaching and research on constitutive relations for soils, and revising a book that he wrote about ten years ago. Scott has been a member of the Institute faculty since 1958.

Diane Wakoski, poet-in-residence at Caltech this term, comes most recently from New York, though she is a native Californian and a graduate of UC Berkeley. Her first book, *Coins and Coffins,* was published in 1962, and since then there have been five more: *Discrepancies and Apparitions, The George Washington Poems, Inside the Blood Factory, The Magellanic Clouds,* and *The Motorcycle Betrayal Poems.*

Ronald Scott

Diane Wakoski

Practical Chemistry

Where there's smoke, there's fire—and in this case it's on purpose. The demonstration was part of a session of Chem 6, a series of informal seminars in practical *chemistry organized in response to complaints by students that their regular chemistry courses were too heavily theoretical. The pyrotechnics show put on by George Rossman, assistant professor of mineralogy and chemistry, was one of the more spectacular of the series, which also covered such subjects as explosives, propellants, poisons, hormones, stimulants and depressants, and addictive drugs. Undergraduate chemistry students Art Ellis and Doug Hounshell organized the seminars with the assistance of Harry Gray, professor of chemistry, and an ad hoc group of other faculty, postdoctoral fellows, and students.*

Fulbright for Anson

Fred C. Anson, professor of analytical chemistry, has been named a Fulbright Scholar to study abroad under the U. S. State Department's educational and cultural exchange program. Beginning in September, he will spend four months working with Dr. Rolando Guidelli of the Institute of Analytical Chemistry in the University of Florence.

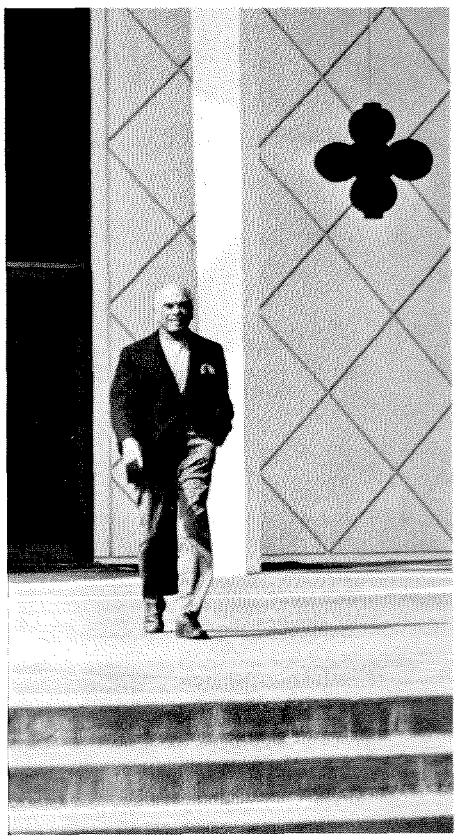
Anson's research involves electrochemical studies of inorganic compounds, and he and Guidelli will be working jointly on investigations of particular chemical substances which absorb on the surfaces of metal electrodes, facilitating the efficient conversion of chemical energy directly into electrical energy.

Anson is a Caltech alumnus, class of 1954, and received his PhD from Harvard. He has been a member of the Caltech faculty since 1957.

Mr. Capra Comes to Pasadena

Mr. Capra came to Caltech on April 17 to give the Monday Evening Lecture in Beckman Auditorium on "A Caltech Alumnus in the Arts."

Frank Capra got his degree here in 1918 in chemical engineering; then went on to a distinguished career in motion pictures—a fact duly noted by President DuBridge when he presented Frank with one of the first Distinguished Alumni Awards at the Institute's 75th birthday celebration in 1966. "Frank Capra," he said, "demonstrates that a Caltech education is not necessarily a fatal handicap to a distinguished career in the arts."



Frank Capra

Capra put in a full day at Caltech on the 17th. He met in the afternoon with students working on the film-making project which he supports. Then his fellow members of the Caltech Associates entertained the Capras at dinner in the Athenaeum before Frank gave his Beckman lecture—to a full house.

During the Capra visit, it was formally announced that Frank and Lucille Capra had given their 14-acre Lu-Frank Ranch to the Institute, for use as a retreat. The $250,000 ranch consists of a five-bedroom house, built in 1956, a caretaker's cottage, a large pool, landscaped gardens that include rare trees planted in 1884, a family orchard with a variety of fruit trees, four acres of avocado trees and one of young citrus trees. The ranch is on gently sloping hills five miles east of Fallbrook, about 100 miles from Caltech.

Achievement Award

C. J. Pings, professor of chemical engineering and of chemical physics, has received the Technical Achievement Award from the American Institute of Chemical Engineers for outstanding contributions to his profession. The citation also commended Pings, who is Caltech's vice provost, dean of graduate studies, and executive officer for chemical engineering, for his excellent record as an administrator.

Ping's research is in the area of liquid state physics, centering on applied chemical thermodynamics and the physics and chemistry of liquids. His work in thermodynamics has led to improved methods of describing the displacement of chemical equilibria, and the techniques he has developed have been adopted by several universities for both graduate and undergraduate courses.

Computer Co-op

Caltech, USC, and UCLA are studying the possibility of setting up a cooperative computer network. The three schools began considering the possibility of sharing computers for greater efficiency and economy last fall—financing their investigation with a $25,000 grant from the Rockefeller Foundation. If the project works out, it may encourage other universities to consider similar sharing, and for this reason the National Science Foundation recently allocated $144,800 to the three schools to conduct a more extensive study.

According to Provost Robert Christy, Caltech's representative on the interschool panel, the Institute spends about $1.3 million a year on leasing and operating its computers. About $500,000 of that amount is funded through various research grants. The other $800,000 comes from the Institute's general fund. Of this, about $200,000 is used for educational purposes and another $200,000 is used for research computing.

Christy hopes the computer study will reveal how Caltech might save from $100,000 to $200,000 annually—possibly by eliminating one of its computers and sharing use of an off-campus facility, and still, of course, maintaining the excellent computing service now available.

At present Caltech has two computers: an IBM 370/155 for batch processing and a PDP-10 for interactive processing. In batch processing, numerical data are fed in batches into a computer and stored. When the computer has time from other duties, it processes and analyzes the information. In the interactive process, time rather than quantity of information is the important factor. The machine is constantly in communication with the user at a remote terminal. It responds instantly when the user has a question.

The PDP-10 operates an effective interactive system on campus, but it is not used up to capacity. USC leases and operates a batch processor similar to Caltech's IBM 370/155, but it is not fully used either. UCLA has a much larger capacity machine—an IBM360/91—which it is purchasing.

If a high-speed communications link between Caltech and one or both of the other schools were to be established, USC, for example, could send all its interactive work here, and the Institute could send all of its batch processing work there. Machines at both schools would be operated at their full efficient capacities. If either school needed even more computer time, it could be purchased from UCLA, which could use the money received to help pay for its computer.

One purpose of the current study is to determine the costs of setting up terminals and communications systems, and to balance these costs against possible savings for each school. Another objective will be to estimate the benefits that might result from sharing the facilities as compared with the cost of further development of the individual computing centers.

A first report of recommendations is due in about six months, and the terms of the NSF grant set an 18-month time limit on the study.

Concurrently with the computer study, the three schools will look into cooperative library operations—the goal of this inquiry also being increased efficiency and economy. It will be a two-year study funded by a $126,500 grant from NSF. When it is completed, a written report will be made available to other institutions interested in similar sharing.

Sloan Fellowship

James E. Gunn, assistant professor of astronomy, has received an Alfred P. Sloan Research Fellowship for 1972. Gunn is noted for his studies of quasars and for research that seems to support the validity of the red shift as a yardstick for measuring distance in the universe.

Sloan Fellowships are designed to make possible advances in basic research by young scientists. Gunn, 33, is one of 79 scholars chosen this year from among nearly 600 nominated by their senior colleagues in 46 colleges and universities. Twenty-two other members of the Caltech faculty have received the award since the program was initiated in 1955.

The grants—which average $8,750 per year for two years—may be used for a number of different purposes: for example, purchase of equipment and supplies; for support of technical and scientific assistance, predoctoral and postdoctoral fellows, and summer work; and in payment for computer time and for relief from teaching duties.

J. Holmes Sturdivant 1906-1972

J. Holmes Sturdivant, professor of chemistry, died in Pasadena on April 21 at the age of 66. With his unmatched genius for design, Sturdivant helped make Caltech the mecca of theoretical and experimental structural chemistry it has been for the past 50 years. The principal experimental technique was X-ray crystallography, and he, more than any other person, created the instrumentation required to probe for the positions of atoms in crystals of a wide variety of chemical and biological materials.

For many years, Holmes taught courses in X-ray crystallography, and among his students were many men who became giants in the field of structural chemistry. Through his undergraduate courses in instrumental analysis, he emphasized the importance of understanding the basic principles of each instrument.

In his early years at the Institute, Sturdivant worked closely with Arthur Amos Noyes. The two men found a remarkable community of personality traits and ideas, sharing an almost reverent attitude toward precise, logical thinking and careful execution of experiments. Along with the late Robert Corey, Sturdivant produced the experimental facts which stimulated the advances made by Linus Pauling and other structural theorists of the 1930's and 1940's.

Holmes Sturdivant was Dr. Pauling's first graduate student. Pauling recalls, "He showed great ability in his work and was responsible in large measure for the development of structural chemistry at the Institute."

Ernest H. Swift, who succeeded Pauling as division chairman in 1958, recognized his contributions toward the administrative operation of the laboratories by naming Sturdivant executive officer for the division. Swift and John Roberts, chairman from 1963 to 1968, agree that "only one who has been a chairman can fully appreciate how indispensable Holmes Sturdivant was to the personnel and the many activities within the division."

Making Caltech a desirable place for the men who have made the Institute a world center for chemical science was no mean task in a place remote from the nation's centers of chemical industry and most of the other centers of excellence in chemistry. Chemists all over the country have envied Caltech because of the quality of its laboratories, the mechanical and glass shops, the library facilities, the stockrooms, and the secretarial services. Sturdivant was the guiding influence behind creation of these indispensable adjuncts to productive scientific work.

The most obvious evidence of his skill was in the interior design of laboratories, particularly the Church Laboratory of Chemical Biology and the Noyes Laboratory of Chemical Physics. He also carried on a systematic and imaginative program for progressive rehabilitation of Gates and Crellin laboratories. Finally, in the last months of his life, he undertook a design project which was truly alien to his nature. Earthquake damage to the Gates Laboratory resulted in condemnation of the building. Financial stringency required functional replacement at minimal cost. The decision was made to construct a building to house undergraduate laboratory instruction under a painfully austere budget. Working with the architects, Sturdivant designed a building that will serve the instructional purpose, at least for the immediate future, and one that met the budget requirements. His humor is illustrated in his memo to me of February 23: "I suspect that the administration may ask you within a month your preference regarding the name of the new building. It is now known variously as the Chemistry Laboratory Relocation Building, Noyes Annex, Son of Noyes, and the Hovel. It would be mildly insulting to put anyone's name on it. Perhaps Laboratory for Undergraduate Chemistry would do, with the acronym LUC."

Gardening was one of Sturdivant's many interests outside Caltech. Some others were music and the ballet, and he was knowledgeable about both. His professional affiliations included membership in the American Chemical Society, the American Physical Society, and the American Crystallographic Association.

He is survived by his wife, Arletta, of Pasadena. It was his wish that no memorial services be held.

—George Hammond

Books

SYMBOL SOURCEBOOK
An Authoritative Guide to International Graphic Symbols
by Henry Dreyfuss
McGraw-Hill Book Company $28.50

Reviewed by David Smith
Associate Professor of English

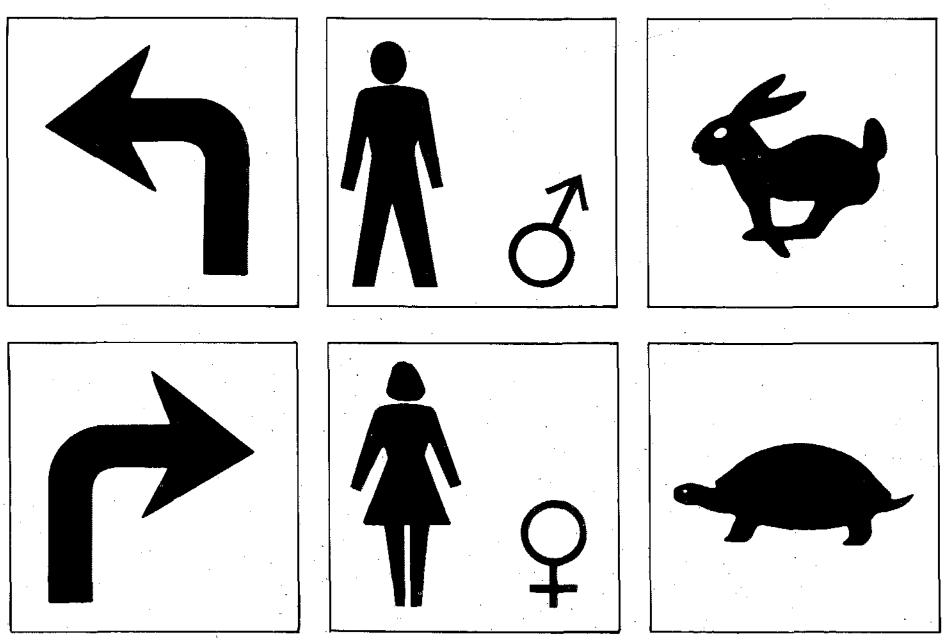
In a world on a collision course with itself, certain traditional luxuries are no longer permissible. Old-fashioned ideas of ethnic superiority, colonialism, dominion are in these times intolerable, if not impossible. But as we work toward encounter, we are faced with the fact that there are nearly six thousand languages and dialects used in the world, making—as Henry Dreyfuss points out—"intercommunication among them range from difficult to impossible." But even were that intercommunication possible, most of us are moving too fast to manage it, to read the signs along the way. Our need is not so much for a universal language, that hope of the Esperantists and others, as it is for a basic and universal system of easily recognizable, unmistakable, and readily figured out visual symbols. It is Henry Dreyfuss's aim to promote such a means of communication. Over the years he has been intimately involved in the creation of many of these symbols as a product refinement designer for many of America's leading manufacturers; and now, as the author of the *Symbol Sourcebook—An Authoritative Guide to International Graphic Symbols*, he has taken the first step toward making systematically available what Margaret Mead calls the "clear and unambiguous signs which must be developed so that members of any culture can communicate across language barriers." It is not a dictionary, which would indicate something like completeness of the system itself, but it is a sourcebook, a first systematic step; and as such it is an impressively creative and authoritative job.

Henry Dreyfuss is a noted industrial designer. He has been an associate in industrial design on the Caltech faculty since 1947 and a member of the Institute's board of trustees since 1963.

One of the problems is the very magnificence and subtlety (and in some cases the difficulty of manipulating accurately) the languages we have developed. They are the repositories of our civilizations, the basis of group memory which is necessary to the maintenance and propagation of our civilizations. The complexities of religion, politics, seduction, philosophy are all within their grasp, and yet, as it turns out, they aren't very good for conveying rapidly and absolutely clearly to anyone and everyone certain basic information. Semiosis breaks down because of the ambiguities, which are, of course, at the root of the richness of language. The yellow, diamond-shaped sign which says "Slow/Trucks," warns us more by its color and shape than by its language, which is, at best, confusing. Are the trucks going slow? Am I to go slow because of the trucks? Southbound on the Hollywood Freeway one encounters a sign which reads, "Merging Buses." The elephantine and surrealistically erotic possibilities of the message cause mind arrest and reverie, neither of which is an aid to alert driving.

Fortunately, the need for a better system of graphic symbols for traffic control has been recognized, and the international system developed in Europe to surmount cross-linguistic barriers is being installed apace in California to surmount speed-induced intra-linguistic difficulties. Even the exits on Los Angeles freeways are now being numbered, numbers being not only nearly universal but also much less confusing graphic sysmbols than "La Cienega and Washington Blvd." But these local problems serve only to point up international and more general need for new systems of basic communication.

Another sign of a good book is that it somehow functions beyond its immediate task, and this a *Symbol Sourcebook* does; for while it begins to satisfy the need for a systematized approach to graphic sym-



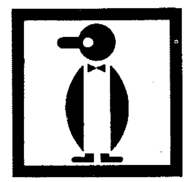
Certain symbols—such as those for Left and Right, Male and Female, and Fast and Slow—are so well known that they are almost universally understood.

bols, it also indicates the complexity of the task. Its very existence should inspire not only designers, but anthropologists, historians, sociologists to work in this field. For instance, since these symbols are often the invention of one man or of a small and finite group of men, their evolving method and structure might usefully be compared by anthropologists to the languages we already have, which are the products of slow accretion modified by the vagaries of cultural and political history. The structural anthropologist might usefully explore how many of the symbol systems are binary, how many trinary, and what such results suggest about human limitations. And the social historian might explore still other areas. For example, though the politics of international industrialism seem largely to have inspired, to have created, the need for this book, an Americanist might well pursue the gradual delexification of American culture and a concomitant rise in graphic symbols not industrial in purpose. One thinks immediately of comic strips, that most artful and American of forms, and of the wonderfully ingenious signs that their makers devised and perfected—the broken heart, the light bulb to indicate an idea (a symbol which has been taken over by a major industrial firm, but one which stems from the heartland of the American mind).

Some of the symbols suggested in the book are confusing but only where they are exploratory, suggestive of possibilities in symbol making. Generally, of course, they are not. Interestingly, the one which is most immediately meaningful is the one Mr. Dreyfuss starts with, the skull and crossed bones, symbol of poison. That fact suggests several possibilities—for one, that use and convention, as in language, help establish immediacy and sureness of meaning. It also suggests that necessity is the mother of invention, and so one of our oldest and most effective graphic symbols is a warning against a venerable and universal danger. But the very existence of a *Symbol Sourcebook*, with its multiplicity of signs and sign systems, stands as proof of the ever increasing need we have for accurate communication at this level, for the number of dangers we face mounts daily. Mr. Dreyfuss's book stands as the best proof possible of its very need.

A New SAT—the Symbol Aptitude Test

Here are some of the less familiar symbols from the multitude in the *Symbol Sourcebook*, and they may not be immediately decipherable. To test your aptitude for sign language, try to determine the meaning of the eight symbols below and check your answers at the bottom of the page.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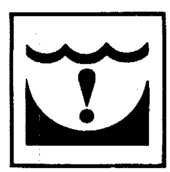
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1. Keep Frozen, 2. Hurricane, 3. Deep Water, 4. Corrosive, 5. Table Poultry, 6. Slippery Road, 7. Spring, 8. Travel Insurance

Letters

Barren Desert?

Los Angeles

Editor:

The articles on energy in the March-April *Engineering and Science* are most interesting. Congratulations. However, it is not clear what you mean by "low quality land" or "barren desert land" on page 7. The casual reader might get the idea you referred to some of the glorious land which gives meaning to "wide western skies" and where live a profusion of exotic plants, such as cactus, so hard to grow anywhere else.

Some of the world's most skilled inhabitants live there, too—who manage such spectacular feats as never taking a drink, soaring for hours, and so on.

Every passenger on an airplane who looks out the window as well as pinches the stewardesses knows you mean the cities by such phrases as "barren." One glance shows miles and miles of regions such as roofs, exterior walls, pavements, etc.—all as barren as God and man can make them, and hence about as low quality as is possible to imagine. Putting solar collectors there affects no life style at all. If made strong enough to walk on, they will be an interesting design feature.

Paul B. Johnson, '47

Thank you for your congratulations, and we join you in your admiration for the natural desert. The barren desert land we refer to is that which has been made barren by man—excluding cities. As we also said on page 7, the federal government owns about 100,000 square miles in the Southwest, a significant portion of which has been used for such purposes as gunnery ranges and the testing of nuclear weapons. By contrast, using some of that land for producing solar energy might be almost idyllic.

A Dissenter Dissents

Pasadena

Editor:

As one of the two dissenters in the faculty meeting of February 21, I take a special interest in the article on graduate degrees in social sciences in the last issue. I would strongly suggest that a new course on the evaluation of polls be included in the curriculum to avoid conclusions drawn from biased samples—like the faculty meeting of the 21st in which most of the supporters appeared and most of the dissenters remained absent. In any case, a more representative sample, I am sure, would eliminate my feeling of loneliness. If I had realized my picture would be next to the article, I would have changed my facial expression.

H. W. Liepmann
Professor of Aeronautics