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MAY 1979



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COVER

The cover this month is a time lapse photograph of a phototrooping sporangium of Phycomyces. What's that, you say? For an explanation, turn to this month's Focus, "Untangling Life's Mysteries," an interesting look at a chemical engineering research project that delves into the field of molecular architecture. Cover graphics by Brian Sjöberg, from a photo original by Max Delbruck.

published since 1904

The Editor's Outlook

HASN'T IT BEEN FUN!



Isn't it awful? I mean really, why not just pack it all in now and not even wait around for finals. What's the use in putting up with all the grief — those last-minute term papers that are supposed to be umpteen pages long, the six tests all during dead week, the computer program that has drained \$74.33 out your account (and still isn't right), and the final project that is supposed to keep you busy for three months but hasn't been started yet. Probably if you added up an estimate of the hours these various "school activities" are supposed to take, there wouldn't even be that many hours between now and the end of school. And it's all because you put it off, right? It's a symptom of college life, and procrastination at its very worst. Students always seem wracked with guilt and self-flagellation over having gone to Tulagi's instead of writing up a concrete lab or something, and it's not a pretty sight.

Therefore in order to alleviate this tremendous burden of guilt, I'll pass along this tip that one of my good friends, and a fellow ArchE, Jonathan Spencer, told me not too long ago (and which I have since made my life's motto): "The sooner you fall behind, the longer you have to catch up." Try it, it works (as any of my teachers can attest to)! Putting things off has been the name of the game the staff and I have been playing, but hasn't it been fun! Why worry about tests and homework and that dreary stuff when you get to do fun things like staying up all night to finish laying out the last 16 pages of the magazine, or trying to get some copy out of the typesetter (it would be easier to get blood out of a turnip!), or trying to placate an angry printer after you've been stalling him for two weeks on a publication date.

There really have been some fun moments here on the *Colorado Engineer*, though. What about the time we went to our business manager's house for a pizza party and played all sorts of wild party games. At the start of the evening, magazine titles were taped to our backs and we were to cleverly deduce the titles by asking questions. I asked if there was much sex in my magazine. It turned out to be the *Colorado Engineer*... What about the time we went racing around the lobby of the building in our rolling office chairs. Talk about hell on wheels! Or the time we nearly died of hysterics while testing everyone's knee reflex with a beer bottle (empty, of course). Even the CUPD, spines in the fridge, and a side horse bring back fond memories.

Most fun of all was the annual ECMA convention, held this year at Notre Dame University in South Bend, Indiana. Five of us (Terry Clark, Mike Furman, Rich Luxford, Kathy Curlander, and myself) piled into a rented Chevy van and drove the 1200 or so miles non-stop. It was a lot of fun and we met a lot of great people, even Dave Nelson and the other members of the infamous Purdue Engineer Magazine (remember Bob's School of Quantum Mechanics?). On the way back we took the scenic route through Chicago, stopping to touch Lake Michigan; St. Louis, stopping to touch the Mississippi River (us Westerners are easily pleased); and Kansas City. Perhaps the most truly amazing sight, though, was Gateway Arch in St. Louis. Until you actually stand below it and watch it shimmer in the moonlight, you'll never realize what an artistic engineering triumph it really is. But enough of the travelogue.

Some of the great people you meet really make this magazine business much easier and a lot of fun. Many thanks to the girls in the Dean's office (and the CEAE office) for all their help, especially Mrs. Ryan for untangling our convention finances. Thanks also to Dean Maler for his advice and support, Jim and Frank at D&K Printing for having a sympathetic ear for our tales of woe and to Don at Continental Typographics for being able to untangle our mass of corrections and type. And finally, thanks to our advisor, Mr. Barber, whose wise counsel perhaps prevented us from sending the *Engineer* into oblivion long ago.

These "editor's last farewells" often get rather trite and bleary-eyed, but not to worry. I unfortunately will return in the fall for one more semester and will serve in some capacity on this magazine. They're clever, but they can't get rid of me that easily!

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Letters to the Editor

Dear Mr. Sjoberg,

My son, Dr. David E. Clough, professor in the Chemical Engineering Department at your university, recently sent me a copy of the Seventy-Fifth Anniversary Edition for March 1979 of *The Colorado Engineer*.

I read with interest the article by Richard J. Jones on the Moffat Tunnel. It was of much interest as my son had taken me and his mother on an automobile trip over the former rail route prior to the tunnel. This was most impressive and difficult to realize that trains were once pulled over that right of way prior to the completion of the tunnel.

I wish to point out a gross error in a statement in the center column of page 7 of Mr. Jones' article. He states that this tunnel was the first long transportation tunnel within the confines of the United States. He completely overlooks the Hoosac Tunnel in western Massachusetts which was completed in the year 1875 or 52 years before the Moffat Tunnel. This tunnel,

according to the World Almanac for 1977 (page 451), is 4 miles, 1230 yds. in length as well as the earliest of 35 long railway tunnels in the world. The Boston & Maine RR Division, which runs across northern Massachusetts from Boston to Rotterdam Junction, N.Y., goes through this tunnel which passes through the so-called Berkshire Mts. in western Massachusetts. Today it is used only for freight but, when I was attending Rensselaer Polytechnic Institute in the mid-1920's I traveled through it at least four times each year. Trains were drawn by steam engines at the time but the tunnel from Zoar to North Adams was electrified, and passenger trains as well as freights were hauled through by electric locomotives. Prior to electrification it was a real ordeal to endure the smoke and fumes from the steam engines. Passengers were told to hold wet handkerchiefs to their noses to have some degree of comfort.

I trust you will accept my comments strictly as constructive. I couldn't resist giving the an-

cient Hoosac Tunnel due credit.

Yours sincerely,
John W. Clough

P.S. I admit to one error. There is one tunnel earlier than the Hoosac, The Mont Cenis (Frejus), 8 miles, 855 yds., between France and Italy completed in 1871, 4 years ahead of the Hoosac.

To the Editor:

I am currently a sophomore in metallurgical engineering at the University of Missouri at Rolla. Recently I had the pleasure of spending my spring break on the CU campus visiting friends. While there I was given a copy of *The Colorado Engineer* by a member of your staff, Chris Kitze. Finally when I got back home in Missouri I took some time to read my copy of *The Colorado Engineer* and I must say I was quite impressed. The magazine copy I'm referring to was the Seventy-Fifth Anniversary edition, March 1979. I found the feature articles to be both informative and very interesting. Here on the Rolla campus we also have a student designed engineering magazine, *The UMR Engineer*, but with a certain amount of humility I'll have to say that I personally found your magazine to be more comprehensive and exciting than our own magazine. I am certainly no expert in journalism, but being an engineering student, I do know what I like to see in an engineering magazine. In essence, I wish to commend you and your staff for producing such a fine student engineering magazine.

Sincerely yours,
Thomas V. Curtis

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Slipforming: Some Concrete Facts

By Jeff Haberl

High-rise buildings get a new lift from an old technique.



The Amoco Building, currently under construction in downtown Denver, exemplifies the use of concrete slipform techniques.

Contrary to popular opinion, chiropractic manipulation is not the only usage of slipforming in a professional field. In the area of concrete construction, the slipforming of tall vertical structures has yielded very profitable results for the contractor. The building industry has typically used concrete in all areas of construction, and has placed it in the structures in a variety of ways usually using methods which involve placing forms, pouring concrete, and then removing the forms. A different method of concrete construction is the slipform method, in which only one large form is built and then continuously moved along an axis as the concrete is poured and slowly hardens. Originally, the slipforming of tall concrete structures was developed to aid in the construction of silos and storage bins. For many years this was the main application of slipforming in the construction industry, and only recently has it begun to gain wide acceptance in the forming of tall buildings, this being primarily due to the improvements in the alignment mechanisms and the increased control of the concrete mixtures.

The concept of slipforming concrete is actually an extrusion process. The most significant difference being that the work platform is the moving extrusion dye. After an initial, usually traditionally formed starter foundation structure, the slipform is attached and the extrusion process begins. Extrusion, in its usual applications is achieved by a stationary dye and moving material. In the slipforming of vertical structures the material is stationary and supports the moving dye which is propelled upward by either hydraulic, pneumatic or other lifting devices. The speed of the slipform is determined by the curing rate of the hydraulic concrete.

The advancement of concrete technology and, more recently, the increased application of computer controlled batch plants has allowed for readily available consistent concrete mixes. Utilizing such techniques as higher temperature mixes, and fast curing compounds allows for the reduction of the curing time. The utilization of the shorter curing periods allows for the rapid rate of concrete placement and the reduction of the slipforming job time. Using a four foot slipform yields an average climb rate of 16 to 24 inches per hour. Under ideal conditions this can yield in excess of one story per day using a double eight-hour work shift. All of the summertime lackies can marvel at the comparison of erecting, forming, and stripping one floor a day (lackie=lacking a degree).

There are some limitations to the slipforming process. Because slipforming is a vertical extrusion process nothing can be formed that cannot pass through the dye itself. All horizontal attachments must be composed of a shear vertical plate which allows for the welding of the horizontal member after the form has passed and the concrete has cured. The window and door openings are usually arranged in line with each other to allow for the maximum usage of



The multiactivity nature of the slipform can be seen in this photo. The fresh concrete is placed in the hoppers atop the platform. The slipform itself is at the second level and the third level is used for welding the structural endpieces to the embedded plates.

the blackout forms, usually fiberglass or metal. Many of the larger high rise buildings lend themselves well to the slipforming process in that the requirement for windows and doors can be held to a minimum as well as being placed in a consecutive arrangement. One of the most visible problems with slipforming is the fact that the exterior surface appearance and color will vary with both the rate of placement and the type and temperature of the mix that is being poured into the forms. This can usually be controlled by minimizing the exposure of the raw surface and/or using the slipped walls on the inside of the structure making them very difficult to see.

There are, of course, many advantages to the use of the slipforming process. The structural advantages of casting a vertical monolithic core that will resist all of the lateral forces in a tall building allows the architect more freedom with the exterior as well as the interior appearances. Recently, a Texas design firm designed a medium tall structure that utilizes the off-center placement of the vertical core for more usable office space in the area where the usual placement of the elevator/mechanical systems would have been placed. This has presented some interesting asymmetrical design problems for the structural engineer but none that cannot be solved eventually. This off-center placement of the building core presents many new applications that prior to this time had been thought to be difficult, if not impossible to accomplish.

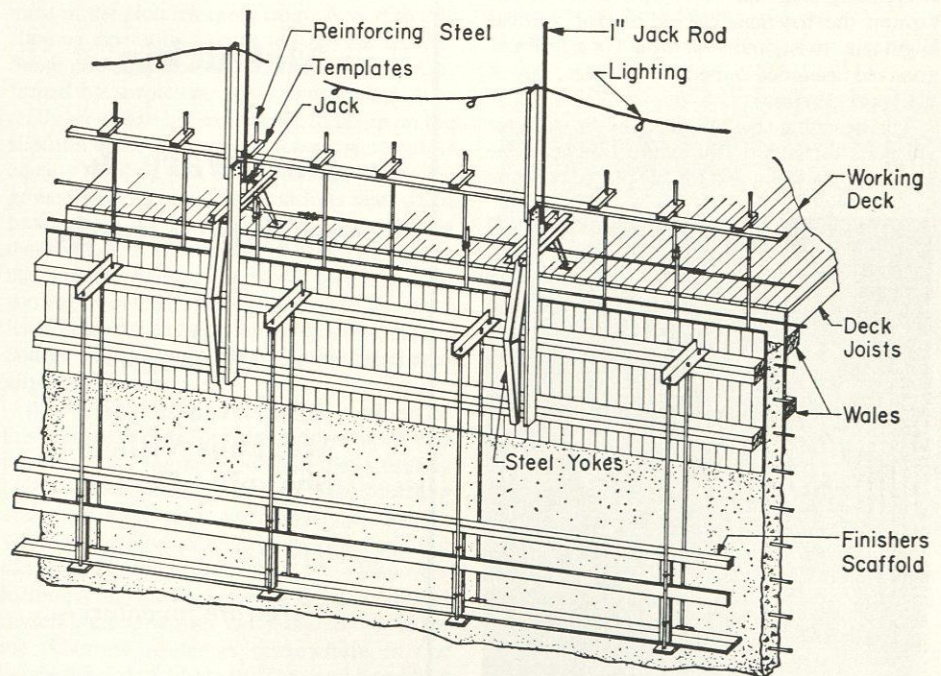
Typically the core of the building is slipped first and the floors are then attached, either in sequence, after the entire core has been slipped, or following the slipping operation depending on the scheduling and availability of crane time. Whichever application is used there is a definite requirement for precise scheduling. The delivery and placement of the material is crucial to the slipforming process. Many of the slipform designs do not allow for enough space for the delivery/placement of the reinforcement steel and the placing of the concrete. Often the crews are scheduled so that the pours are accomplished during one of the eight hour shifts and the reinforcing steel is lifted into place and stocked for the next day's pour during the second eight hour shift.

Another procedure that is used is to slip the core in two halves and alternating the slipping of each of the different sections. This procedure lends itself better to the continuous slipforming process as there is the simultaneous operations of steel and concrete placement being performed. Quite often the exact process is determined by the requirements of the succeeding construction operations. Many times it is more economical to place only a floor a day and allow for the follow-up horizontal steel work to aid in the vertical support of the slipformed core as this reduces the requirement of high, early strength concrete, as well as the precision control of the mixes that is not often available in all parts of the country.

More likely than not the economics of the slipforming control what and when it is accomplished. Slipforms can be adapted to form a tapering structure by using removable joints in the forms that allow for the tapering effect.

Many times this is not feasible because of the very high initial capital expense that is required for the leasing or purchasing of the slipform and backup equipment. Most of the tall chimneys that are built for the utility companies now are built with slipforms. Although the preliminary economics favor the traditional sliding vertical wall forms, many of the rural sites of the power plants force the consideration of unavailable and expensive labor forces. Many times the speed of the slipping operation, even with overtime and double time pay, proves to be of considerable economic advantage. The early completion time means earlier job finish which reduces the loan payments, decreases the total manhour commitment, and especially in winter construction means less time that the expensive heating requirement need be sustained.

There are ideal slipform applications. Typically slipforming yields itself to structures that contain relatively thick walls, few inserts, and continuous shapes. The increased requirements to frame around openings spells complicated reinforcing steel placement, as well as increased labor expense and on-site modifications. The maximum economical amount that proves to yield the most comfortable return is somewhere in the area of 20 to 30 cubic yards of concrete per foot of lift. Below this amount indicates the increased effort of placement around complicated joints and forms. Above this amount requires two shifts placing the steel that is required for the pour, as well as the possible necessity of adding an additional crane for this as well as other sitework requirements. The minimum economical height is more difficult to establish. The primary height requirement is at four stories or more. Below this



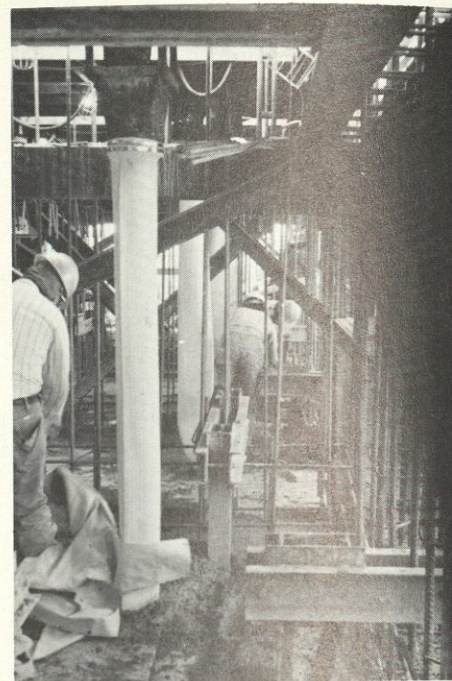
Typical wooden slipform indicating principle components.

amount the contractor needs to consider the possibility of multiple reuse, preferably on the same location. There have been many successful applications of two and three story slips applied to apartment and condominium projects.

The technical procedures seem to vary much less than the different building types that slip-forming can be applied to. The vertical depth of the slipform is normally around four feet, the width or thickness of the form depends on the characteristic of the individual structure that is being placed. The vertical lift that is required for the form to climb the newly placed concrete is provided by hydraulic jacks that are embedded in the concrete. The exact alignment of the climbing operation needs to be carefully monitored in order to prevent the possibility of off-center, twisted, or canted placement. In the earlier applications this was accomplished by a system of water carrying tubes that were interconnected through the pour. As a section of the slip becomes misaligned with the other parts, the water level would indicate the inconsistency. This system was coordinated with the traditional plumb-bob which insured the overall vertical alignment of the placement. Today's methods are similar in theory but utilize much more sophisticated applications. Typically, today's modern contractor, (sounds like a home appliance advertisement) uses laser alignment to aid in the placement of the concrete. The entire platform is guided by lasers that are in place at the bottom of the foundation, (actually it is usually only one laser) that projects two beams upward continuously during the pour. The two beams strike the platform at opposing diagonals from each other. In this fashion the foreman can adjust for vertical alignment, twist, and with the aid of a series of good old fashioned carpenter's bubbles, cant of the entire platform.

The structural characteristics of the slipform are quite ingenious. The entire weight of the slipform, platform, and freshly placed concrete

is literally hanging off of the jacking rods that are embedded in the already placed concrete. The rods are connected to large yokes that receive the load from attached walers, which in turn are transmitting the outward thrust of the fresh concrete, weighing in at 150 pounds per cubic foot, (water in comparison is about 62.4 pounds per cubic foot). The normal design load of the platform and scaffolding is around 50 pounds per foot, square and linear respectively. The strength of the form and the determining characteristics are many times controlled by the deflection resistance requirements that must keep the entire form within a quarter to a half inch of true measurement while the placement operation is being performed. This gives you some feel for the stiffness of the entire framework especially when you consider that normal building codes usually allow somewhere around one-eighth inch of deflection under extreme load applications for the typical living room dimensions. (Now you all can go back to your mechanics of materials texts to see if the author is right; Well I'm just trying to put things in perspective!) One of the more critical load requirements is the resistance of the drag that is being produced from the sliding of the forms against the concrete that is being placed. This is compensated for by allowing the forms to splay out slightly toward the bottom of the form, usually this is somewhere in the neighborhood of one sixteenth of one inch per foot of form measured



The placement of the steel and concrete must be carried on simultaneously as the slipping advances. The tremie sleeves are used to distribute the fresh concrete to different areas of the slip without using buggies.



The laser alignment port on the platform assures accuracy.

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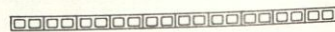
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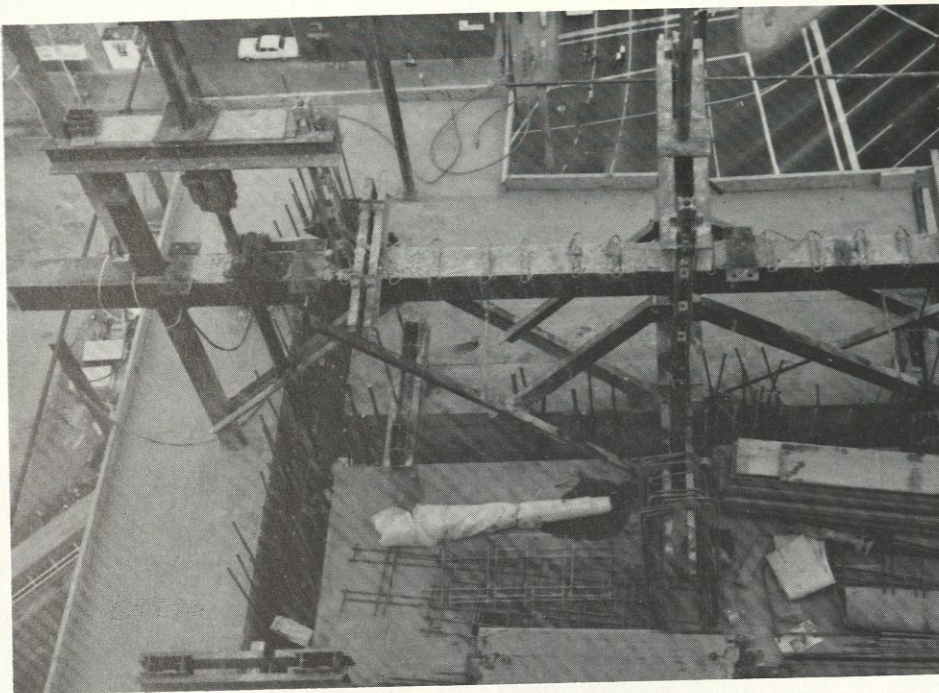
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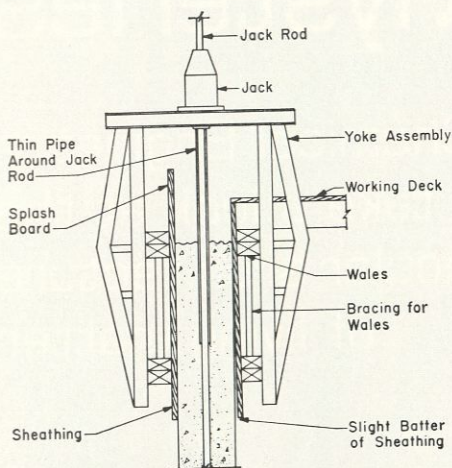
The reinforcing steel appears to be growing up through the slipform from this vantage point. The jacking mechanism in the upper left supports the slipping operation via the structural frame attached to it.

construction site. The organization and planning could really be seen quite clearly in that every operation that each of them was performing was precise, and well coordinated. Basically, it had to be; there wasn't room up there for anything but the concrete equipment and the crew. Well about that time I noticed that I was looking down again, but not at the ground. I was looking at the concrete that had just been placed in the form after the crew had moved to the next area. I was looking to see if it really did move. It did, and about that time my stomach shifted. All of the articles that I had read about the applications never mentioned anything about the effect. As I stood there watching, the concrete was going down into the form, or rather the form was rising up above the freshly placed concrete.

So, I ran over to the side to see if maybe there was a leak or something and the concrete was pouring out below, but it wasn't. In fact I could see the new concrete from the mornings pour and there below was the finishing team. They were smoothing out the pour and checking for any bad spots. As I looked down the man that was welding the structural plates stopped for a minute and looked up with this half lit, half bent Camel in his mouth and saw that I was looking down at him. I'll never forget what he said as he lit up the butt in his mouth. "Quite a view isn't . . . sure the hell beats going to school . . . wouldn't ya say?" and my reply, as I tried to swallow my now defunct stomach, "Ya . . . it sure is." □



The author is shown here atop the rec center inspecting the various slipforms therein. Periodically he can be seen over at Tony's Plants sporting the latest in groovy garb. A cautious approach is recommended in order to eschew obfuscation; cheer up old chump, they are both in Webster's.



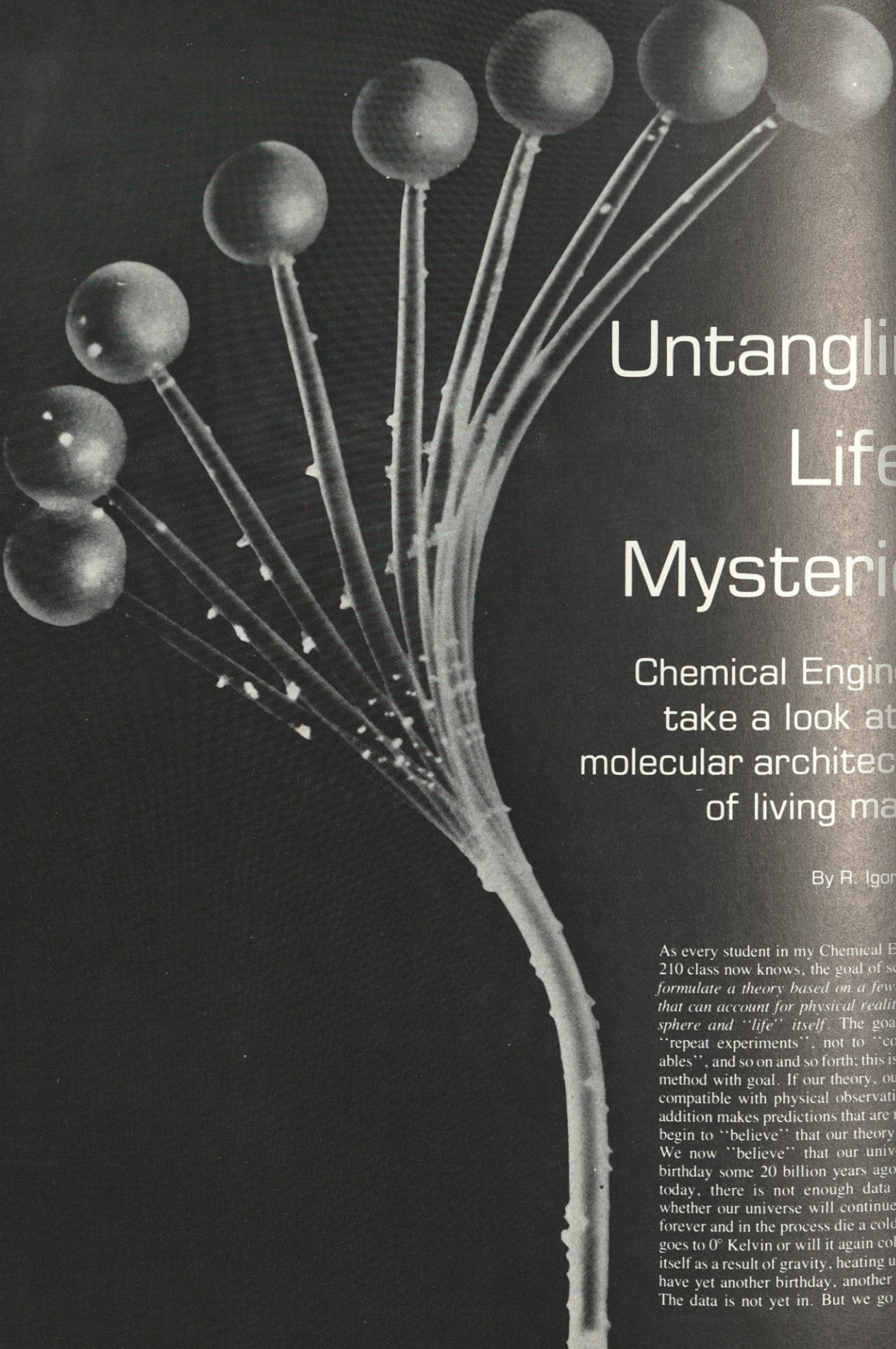
Cross-section view of slipform showing location of jacking rod inside placed concrete. Sleeve around rod allows for clearance gap which eases rod removal.

from the top of the form. That's about the same as most of those EDEE 101 drawings that everyone worked so hard to master, and we surely can't forget EDEE 101. Anyway, the force of the drag that is created by the concrete as it passes the forms can sometimes reach as high as 100 pounds per linear foot of form. Being as how this is maximum it usually is a good idea to set the design requirements in this area, for we wouldn't want the entire slipform to get stuck on the fifty-fifth floor. It creates more of a problem than merely fixing the elevators in the Engineering Center, and we all know how well they work. Typically the form material is made of plasticised plywood, or one inch boards that are placed vertically. The wal-

ers are usually wood or steel I-beams and the yokes resemble large inverted clamps usually made out of high strength steel.

Currently much of the high rise building that is taking place in downtown Denver utilizes a technique of slipformed interior core. The Al Cohen Construction Company, currently building the Amoco Building, the large new complex on the site bordered by Broadway, Lincoln, and seventeenth, right across from the United Bank building was the site from which most of the pictures came from. A visit to this slipping operation contracted by the M. M. Sundt company out of Phoenix Arizona, confirmed by suspicions about slipforming. It is really an unnerving experience to go up on the slipform while the crew is placing concrete. It is equally thrilling just to go that high above the ground without any of the comforts that nature provides on the ground. The first impression that I had as I was riding the personnel hoist was that the grin on the operator's face might be coming from the fact that all he had to do was to let us off and then he could go back down to the bottom where anyone in their right mind usually pours concrete.

As soon as I stepped out on the platform all this seemed to fade for there in front of me was the same old, normal operation that's usually involved with placing concrete. Men scuffling around with shovels and stingers, (concrete vibrators) and the concrete looked the same as it did when I saw it at the bottom when they were loading it into the bucket, only the concrete and myself were now over two hundred feet in the air (Gamow tower is somewhere in the neighborhood of 140 feet). The crew was really amazing, there wasn't the usual yelling and hustling that there normally is on the average



Untangling Life's Mysteries

Chemical Engineers
take a look at the
molecular architecture
of living matter

By R. Igor Gamow

As every student in my Chemical Engineering 210 class now knows, the goal of science is to *formulate a theory based on a few principles that can account for physical reality, the biosphere and "life" itself*. The goal is not to "repeat experiments", not to "control variables", and so on and so forth; this is to confuse method with goal. If our theory, our guess, is compatible with physical observations and in addition makes predictions that are realized we begin to "believe" that our theory is correct. We now "believe" that our universe had a birthday some 20 billion years ago but, as of today, there is not enough data to predict whether our universe will continue to expand forever and in the process die a cold death as it goes to 0° Kelvin or will it again collapse upon itself as a result of gravity, heating up, and thus have yet another birthday, another beginning! The data is not yet in. But we go on and on

being absolutely convinced that we must eventually be able to understand everything and thus be able to predict physical and biological phenomena if we only had enough data, i.e. our scientific faith is that our lack of understanding is simply our lack of knowledge. This premise is not universally accepted; there are many doubts. The question is: is it possible to know everything about a system that there is to know and yet still not be able to predict its behavior? For instance, if every variable governing the weather could be determined and understood could we then predict that the temperature at 2:33 AM next August 20 would be 73°C? Ilya Prigogine, the 1977 Nobel Laureate in Chemistry who just visited our campus and gave a lecture entitled "From Being to Becoming" concluded from his mathematical analysis of "physical reality" that if we knew exactly where we are we would know nothing about where we are going and on the other hand if we knew exactly where we were going we would know nothing about where we are. This is science? It sounds like poetry, it sounds like T. S. Eliot when he said, "To go where you do not know you go by way of not knowing". Or perhaps the real situation is even worse than poetic, perhaps the notion of physical reality is simply absurd. Martin Gardner in his "The Annotated Alice" writes in his introduction

"The last level of metaphor in the Alice books is this: that life, viewed rationally and without illusion, appears to be a nonsense tale told by an idiot mathematician. At the heart of things science finds only a mad, never-ending quadrille of Mock Turtle Waves and Gryphon Particles. For a moment the waves and particles dance in grotesque, inconceivably complex patterns capable of reflecting on their own absurdity. We all live slapstick lives, under an inexplicable sentence of death, and when we try to find out what the Castle authorities want us to do, we are shifted from one bumbling bureaucrat to another. We are not even sure that Count West-West, the owner of the Castle, really exists. More than one critic has commented on the similarities between Kafka's *Trial* and the trial of the Jack of Hearts; between Kafka's *Castle* and a chess game in which living pieces are ignorant of the game's plan and cannot tell if they move of their own wills or are being pushed by invisible fingers."

On the other hand the *Colorado Engineer* asked me to write about my research not about the "meaning of reality, or the meaning of meaning", but the two concepts are not easily separated. Our laboratory for a number of years has been trying to untangle the molecular mechanisms dictating the behavior of a living system. Clearly the behavior of any living system is a direct result of its atomic and molecular structure. But like the weather, behavior cannot

be predicted, cannot be determined from its atomic and molecular structure. The property of life can be viewed as an emergent property. Wetness of water, the refractive index of water is an emergent property that arises when oxygen and hydrogen atoms combine and those properties cannot be deduced from the physical properties of oxygen and hydrogen alone. The goal of our research is thus to understand behavior, its function, of a living organism in terms of its molecular architecture, its structure. The goal is to understand "life", to understand "behavior", as an emergent property arising from its "molecular architecture."

For a number of years our laboratory has been trying to determine the "molecular architecture" of a living plant cell wall. We have chosen as our model system the giant unicellular light responding fungus *Phycomyces blakesleeenanus*. Biologists choose model systems for the same reason physicists do: they are amenable to experimental analysis. The solid foundation of atomic physics lies firmly on the shoulders of a single atom, the hydrogen atom. Clearly the uranium atom is not just a big hydrogen atom but the general principles first elucidated for the hydrogen atom can be applied, with reasonable success, to the uranium atom. It is hoped that by the study of behavior in simple systems such as bacteria, protozoa, mice and rats, etc., we may discover principles that apply to the understanding of human beings. For instance, it has recently

been shown (Howard Berg et al. of CU) that the popular *E. coli* bacterium can, at least in part, control its food uptake by using an honest to goodness memory system. Many are loath to think that the basic mechanism of our memory pattern is the same used by *E. coli*. But the molecular mechanism of memory in bacterium is as much an enigma as the molecular mechanism of memory in human beings.

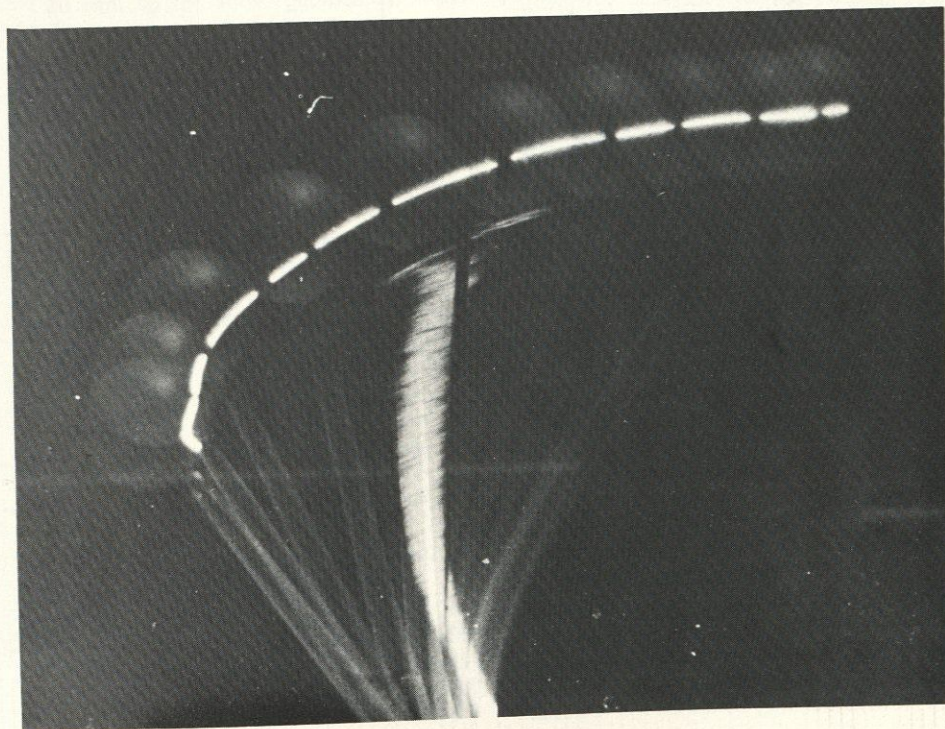
Phycomyces blakesleeenanus, is our simple, although behaviorally complicated model system. Figure 1 is a photographic portrait of a mature *Phycomyces* sporangiophore. Few people apparently have ever actually found *Phycomyces* in the wild; below is a paragraph from a *Phycomyces* review article amusingly describing where it has been found.

Little is known about the natural history of *Phycomyces*. During the last 150 years, it has been found growing on the walls and timbers of an oil mill in Finland, in oil mills in Saxony, on litter under beech trees in England, on refuse on a warehouse floor in Hull, England, on a decaying wasp nest in Ireland, on dead wood in Urbana, IL, on human feces in a cave near Rome, Italy, and on peaches in a refrigerator in Cold Spring Harbor, NY; it has been isolated numerous times from mouse, rabbit, and horse dung.

Phycomyces appears to be quite unique not only in the fact that it possesses a well-defined

Fig. 1 A time lapse photograph of a phototroping sporangiophore of *Phycomyces*. The sporangiophore is "blind" in the red light but

extremely sensitive in the blue. Photograph taken by Dave Dennison, Dartmouth University.



handedness but unique in that this handedness reverses direction twice during sporangiophore development. In the maturing sporangiophore, the direction of spiral growth which is clockwise as seen from above (using the common convention used for wood screws etc., this is called a left handed spiral) changes to counterclockwise for a few hours and then reverses itself once again to a clockwise rotation. It appears to us that this dramatic change in handedness must directly reflect the underlying mechanism of cell wall synthesis itself. The number of possible models that one can construct which would not only be compatible with cell wall extension but also be able to account for these reversals must, we feel, be rather limited. If we can eliminate all possible models except for one, we can begin to feel secure that we are correctly understanding the molecular nature of cell wall growth. On the other hand, it is always possible that given all conceivable models no one model is compatible with observations and thus we would arrive at a paradox. However, all our present observations can be explained by a single model.

In general, plant cells grow by a different mechanism than that used by animal cells. In animals, the cell increases to some critical volume and then divides leaving two smaller daughter cells in its place. In plants, and in particular filamentous fungi such as *Phycomyces* the first event of cell wall elongation is a weakening of the cell wall. Because of the large internal pressure in plant cells, the turgor pressure, the cell naturally increases in volume by a simple stretching. Whether the stretching is unidirectional, bidirectional or tridirectional of course depends on the nature of the structure of the cell wall itself. The internal weakening of the cell wall is a result of one or more enzymes called "cell wall loosening enzymes." Such an enzyme has been isolated by Bob Cohen, University of Florida in Gainesville, from the stalks of *Phycomyces*. There is also good evidence that the fibrils that cause the rigidity of the cell wall are in a right handed spiral configuration. If the cell wall becomes soft and stretches parallel to the longitudinal axis as a result of one or more cell wall loosening enzymes, one of two or both things can happen to these fibrils. First, the fibrils will have a tendency to reorient toward the longitudinal axis. Since this reorientation will occur along the entire periphery of a cylindrical stalk the net result will be a clockwise rotation. On the other hand, the fibrils may also yield to the internal force by slipping by one another without changing their net orientation in the cell wall. This slippage will result in a net counterclockwise rotation. In slippage, we must necessarily break the intermolecular bonds that bind the fibril in coherent bundles. In reality, we feel that both slippage and reorientation may be occurring simultaneously in the growing cell wall. We feel that this play between slippage and reorientation may be the answer to a seem-

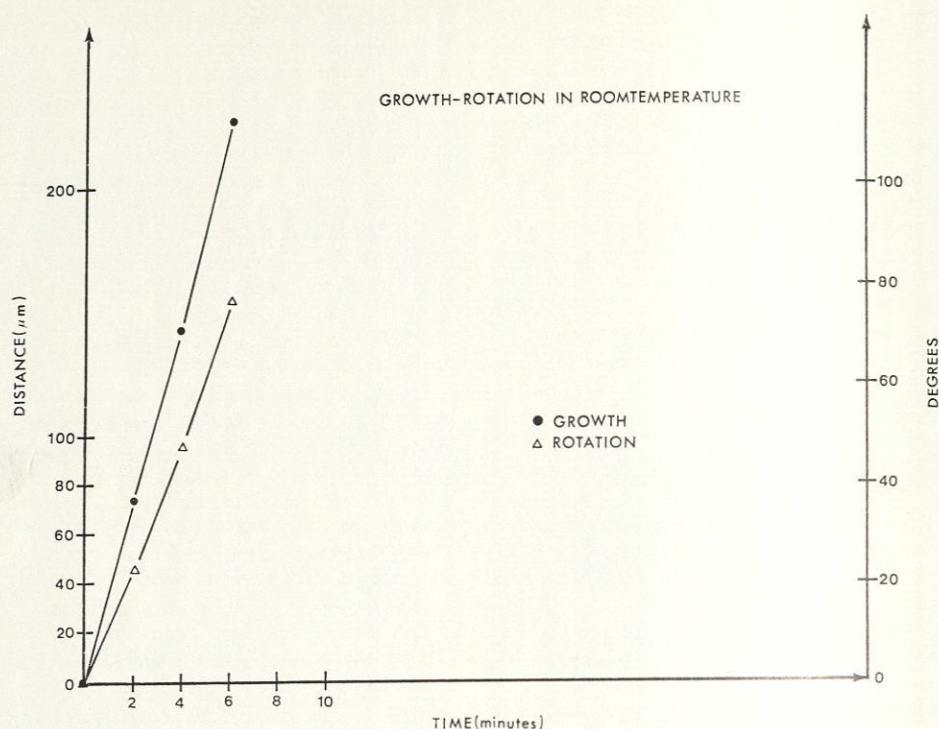


Fig. 2 Total elongation (left axis $\circ$) and total rotation (right axis Δ) measured at room temperature (22°C) are plotted as a function of time. Data were obtained from a series of photo-

graphs of a sporangiophore so marked that both elongation and rotation could be determined by a trigonometric reconstruction.

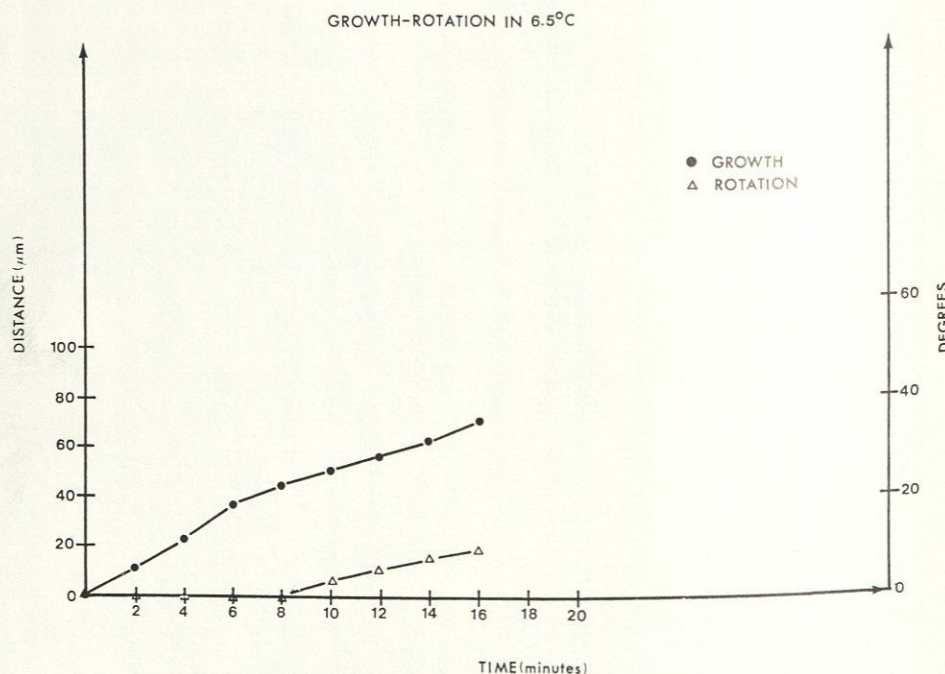


Fig. 3 Identical experiment except it was conducted at 6.5°C and 30°C respectively. The sporangiophore's were allowed to adapt to the new temperature for at least one hour. At both

the high and low temperature, the rotation component of spiral growth was more effected than the elongation component.

GROWTH-ROTATION IN 30°C WITH LIGHT STIMULUS

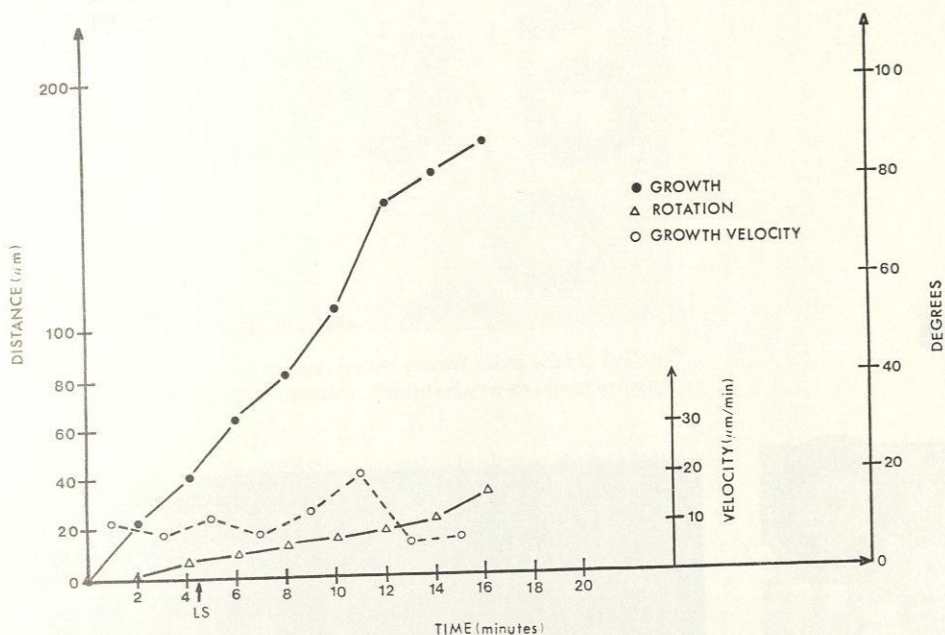
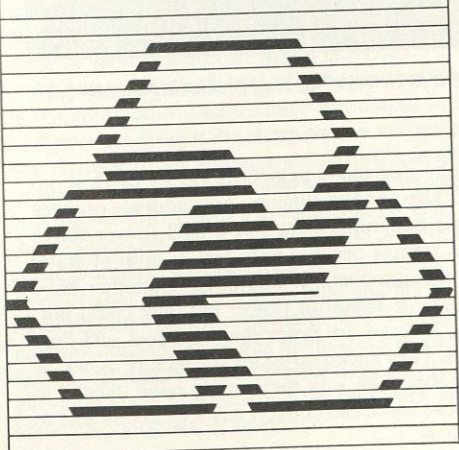


Figure 4 is the light growth response (---o---). A one minute white light stimulus (LS) was given to a fully red adapted sporangiophore.



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ingly bizarre finding of Cohen and Delbrück some twenty years ago in which they reported that even though the net rotation of a mature sporangiophore was in a clockwise direction there exists a small region at the very top of the growing zone that is going counterclockwise.

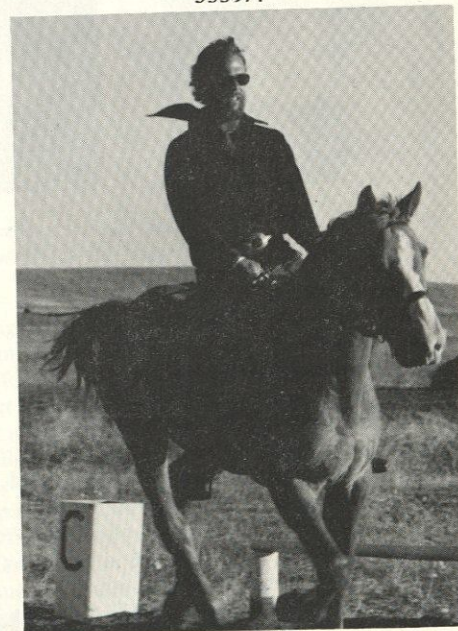
Recent preliminary data taken by Barbel Böttger in our laboratory has verified that the upper region of growth is indeed rotating counterclockwise!

To sum up the above geometries, when dealing with a right handed spiral, reorientation towards the vertical axis will cause a clockwise rotation where parallel slippage or reorientation towards the horizontal axis will cause counterclockwise rotation. The distribution and magnitude of these various mechanisms must be the direct function of the mechanical structure of the cell wall. In 1934, the late E. S. Castle reported that one could separate the rotation component from the elongation component by growing *Phycomyces* sporangiophores at different temperatures. We have continued these pioneering experiments of Castle's and have found that the rotation component of growth is greatly reduced when the sporangiophores are grown either at exceedingly low or exceedingly high temperatures. The optimum growth occurs at 22°C and Figure 2 shows a plot of both the total growth and total rotation at the optimum temperature as a function of time. Figures 3 and 4 show the elongation rotation distribution at 6.5°C and 30°C respectively; clearly both elongation and rotation diminish in value as the temperature conditions become unfavorable. The problem is to explain why the rotation component is more sensitive than the elongation component. We

think we have found the solution. Sporangiophores growing at the two extreme temperatures have shorter growing zones. The bottom 25% or so of the growing zone is growing quite slowly even at optimum temperatures; at either low or high temperatures this region now shows no measurable growth. What apparently is occurring is that we are subtracting the clockwise rotating region that occurs at the lower growing zone but leaving the counterclockwise rotation at the upper region. Since both clockwise and counterclockwise rotation contribute to elongation, the net result would be a decrease in clockwise rotation. In terms of a molecular mechanism, the newly arrived fibrils that appear in the upper region of the growing zone are being displaced in a counterclockwise direction; older fibrils located in the middle and lower growing zone are being reoriented and thus we see the dominant clockwise rotation. At the moment, this explanation seems to agree with all the known observations. In order to further verify this theory, a detailed fine structure analysis of the growing zone must be done. We must now ask how stimuli such as light, stretch, wind, gravity and avoidance modify the distribution of slippage and reorientation. These experiments are now being initiated in our laboratory. □

ACKNOWLEDGMENT

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R. Igor Gamow is an associate professor in the department of Chemical Engineering, University of Colorado. He received a Ph.D at the University of Colorado Medical School in Microbiology-Biophysics. He teaches biochemical engineering courses and also offers a graduate level course in "Animal Locomotion" in which the students learn that it is indeed the "horse" that is nature's optimum running, not, alas, the jogger.

PHOTOGRAPHY

Article and Photos by John Pohle

A glimpse into the world of macro photography.



A spring bloom taken with a lense reversal ring producing an object to image ratio of 3:2.

An aspect of photography that many neglect is *macro* or close up photography. With a Macro lens or attachments, one suddenly plunges into a world where a single integrated circuit or a wild flower above timbeline fills the picture. Insects become monsters, a drop of water becomes a pond. Many photographers at one time or another have desired to get closer to that one beautiful flower but they could not, because their 55 mm lens focused no closer than one foot and they needed to get within inches. They ended up taking the picture as best as they could and forgetting about the way they would have liked it to look. With proper attachments, you can convert any lens to one able to take pictures of small objects.

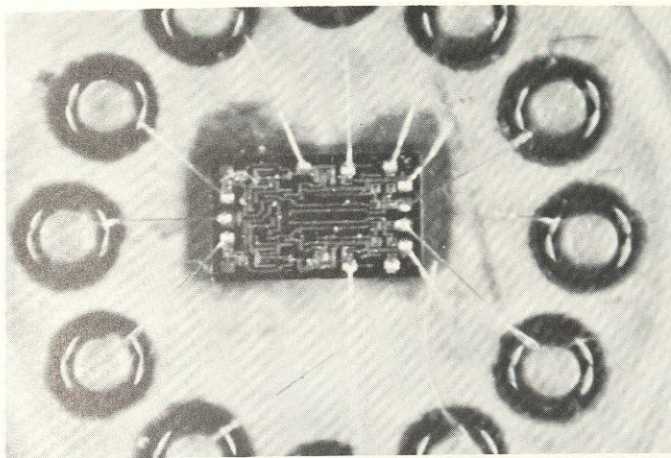


Fig. (1) The picture is of an integrated circuit taken with a bellows attachment which was fully extended. This produced an object to image ratio of 1:3.

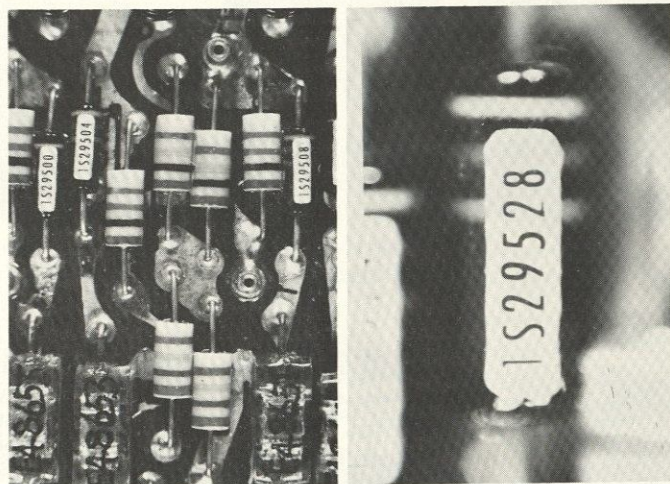
The idea in macro photography is to enable the lens system to focus within inches of the object. If one can focus that close, the object size will be about the same as the image size (on the negative) or in a 1:1 ratio. Anything below a 4:1 ratio could be considered a macro photography lens. Using a diopter, a bellows, an extension tube, a reversing ring, or a macro lens, are some of the ways that this ratio of object to image size can be achieved.

A set of diopters will bring the object within 3-4 inches of the front of the lens. They attach to your lens by screwing onto the front just as a filter would. Diopters are labeled by power, (i.e. 1, 2, 4, etc.) and are additive, so if you attach a 4 diopter to a 2 diopter, you have a total power of 6 diopters. A power of 6 diopters is enough to give you a 2:1 ratio. Diopters are not perfect, if you add too many of them, the picture sharpness will decrease dramatically as you move from the center to the edges. Diopters are convenient because they are light weight and can be attached with their case to a camera strap.

A set of bellows is another way to "go macro". The bellows attaches between the camera and the lens and basically varies the distance between the lens and the negative. If you focus close, the front normal lens moves outward. The bellows increases the magnitude of the movement of the lens away from the camera. A bellows will cost from \$45 up to \$200 or more, depending on the quality. The fully extended 8 inch bellows, used to take figure 1, focused with the object less than one inch from the lens, and this produced about a 1:3 object to image ratio. A bellows is very versatile because you can frame an object to fill the picture exactly. This can be done because the lens-to-film distance is variable, making it ideal for reproducing documents, making slides from prints, or vice versa. The image quality with bellows is much greater than with diopters; even with a 1:3 ratio. Using a bellows is probably the most versatile method for shooting close-ups, but they must be treated with care when extended.

An extension tube is basically the poor photographer's bellows, for it is not continuously adjustable. But comes in a variety of lengths.

A reversing ring is the cheapest way to convert your lens into a macro lens. It does this by allowing you to turn your lens around and mount the front of the lens onto the camera body. A unique optical property of any lens allows this. It will give you about a 1.5:1 ratio. The only way to focus is to move the camera toward or away from the object until it is in focus, a small discomfort for a \$10 attachment. The ring screws into the front of your lens as a filter would and the other side of the ring has a mounting attachment compatible with your lens mount. The quality of pictures obtained from this method is great and it can be attached to a bellows to obtain an even greater magnification. A reversing ring is an excellent piece of equipment for fieldwork because it is as small as a filter, and attaches in seconds.



The left picture is a printed circuit board taken with the bellows collapsed. The right picture is the same but with the bellows fully extended.

Macro lenses are designed for macro and normal photography. This is the best way to go, but they too have their drawbacks. In price, they cost \$200 and up. The focus ring is marked not by the distance to the object from the lens but by the ratio of reproduction so you can read right off the lens what ratio you have. This lens also focuses out to infinity, whereas the bellows, diopters, and reversing ring only focus in a small range of distances. The macro lens, I would say, is the way to go if you are willing to spend the money.

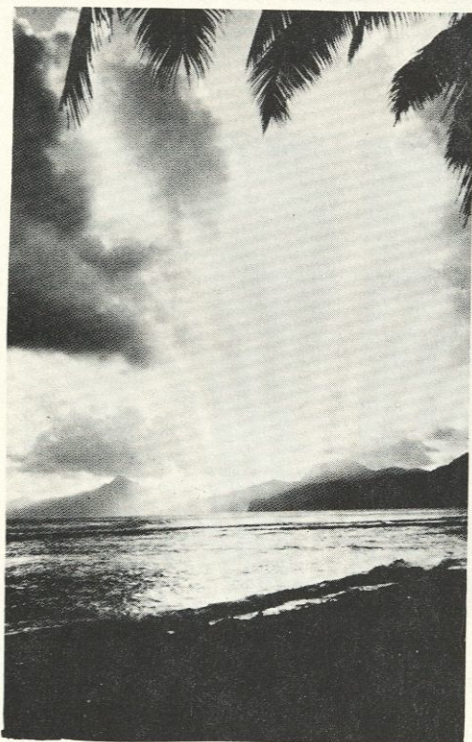
There are obvious differences you will notice as you enter the realm of macro photography. One effect is that the depth of field decreases immensely. When taking a 1:5 ratio shot of the top of a dime, the top may be in focus but the bottom will be totally washed away. Not only that, when one is very close to the object the lens will block most of the light, so light becomes a critical factor. If you are out in the field, a piece of aluminum foil provides a solution. You can shape the foil so it reflects light onto your object. If you are taking pictures of documents or the like, a set of lights aimed so that the lens does not shadow the object is needed. Because you are so close to the object, a stable support for your camera is recommended, or else a very fast shutter speed. All these factors must be considered.

Macro photography is a very rewarding aspect of photography. It allows you to remember some of the little things in life. □

S.S. Universe: Classrooms on the High Seas

Set sail for adventure with a Semester at Sea.

By Nicholas Rowan



The stately white liner streaming into Hong Kong harbor looks like any other cruise ship. A pair of tug boats nudge her neatly into position at the long Ocean Terminal pier. Crowding the rail expectantly are some 500 eager tourists looking from a distance like any other tourists waiting to be turned loose in the glittering shopping arcades, China Product stores and vendor-packed alleys of the Crown Colony.

But look again. This is no ordinary boatload of fat-catting tourists. This is the *S.S. Universe*, a floating college campus operated by the Institute of Shipboard Education and staffed by the University of Colorado. The 500 are all young, ranging from 18 to 23. They are outfitted in sneakers, jeans and T-shirts and they have come to Hong Kong to learn - not to buy, though indeed, they will do some shopping too.

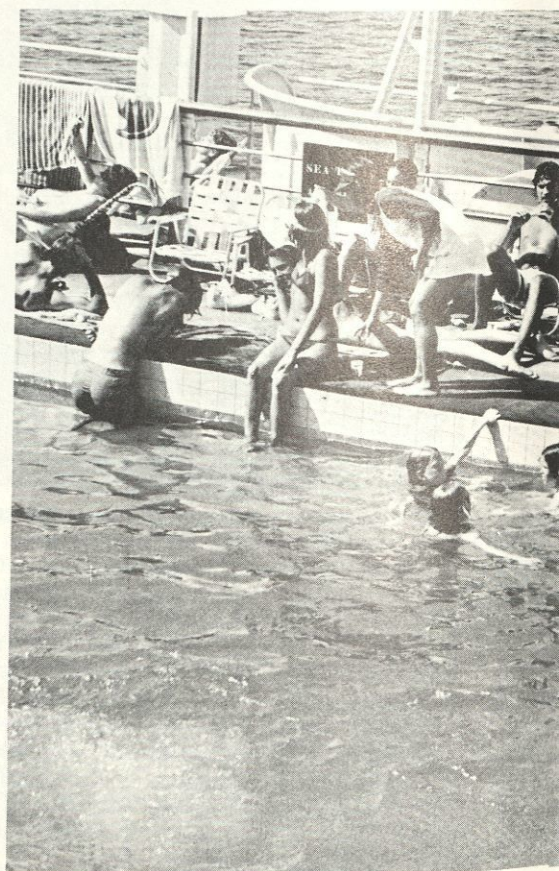
The students of this spring "Semester at Sea" don't only call at Hong Kong. They put

into other ports as well—Pusan, Singapore, Colombo, and Madras. And after they leave this part of the world they sail on to another: through the Suez Canal and into the Mediterranean, to Greece, Spain, Morocco, and on across the Atlantic to Baltimore where the voyage and the semester both come to an end.

The coming Fall semester is an extremely exciting voyage. The *S.S. Universe* will depart September 12 from San Francisco visiting Honolulu, Taiwan, Hong Kong, Manila, Singapore, India, Kenya, Cape Town, Rio de Janeiro, Venezuela, Jamaica, and arrive in Florida on December 21. Subject to the approval of the government of the Peoples Republic of China, Semester at Sea students will have the unique opportunity to visit Canton and nearby cities while the *S.S. Universe* is in Hong Kong (October 7-11).

There is one big advantage to shipboard education. Instead of bringing history, art and the diverse cultures of the world into the classroom, the *S.S. Universe* does it in reverse — it brings the class-room right to the great historical sites of the world.

Actually, the notion of a floating campus is not new. Dean James E. Lough of New York University first conceived the idea back in 1925. As Dean Lough envisioned it, the program would serve as "a college year of educational travel and systematic study to develop interest in foreign affairs, to train students to think in world terms and to strengthen interna-





The 18,000 ton S.S. Universe is air-conditioned and stabilized and is modified for

academic purposes. It contains a student union, theater, library, classrooms, dining

room, sports facilities and swimming pool. Each cabin has a shower and toilet facilities.



tional understanding and good will." But the ship failed to sail on schedule for lack of students. Finally, with the support of the University Travel Association, the first "Floating University" (that was its name) set sail in September, 1926. The ship was the former S.S. *Ryndam*, leased from the Holland-America Line.

Since 1926 the floating campuses have had their financial ups and downs as well as their ups and downs at sea. The 1929 crash closed out the first era of shipboard education. But in 1961 a group of businessmen in Whittier, California revived interest in the idea and approached the Holland-America Line for another ship. The result was the motorship *Seven Seas*. However, the Whittier-sponsored program had difficulty recruiting qualified professors and was unable to provide proper academic credit. Chapman College in the neighboring town of Orange, California finally agreed to take on the program in the spring of 1965.

Five years later Hong Kong shipping magnate, C.Y. Tung, who runs Orient Overseas Lines, conceived the idea of utilizing the old *Queen Elizabeth I* for a floating campus. The great lady of the seas had finished her glamorous days on the high-speed trans-Atlantic run, and of course had served gallantly as a troop ship during World War II. C.Y. Tung refitted

the vessel from stem to stern, turning the huge liner into, not C.Y.'s but "Seawise University."

Newly equipped and ready to circle the globe as a campus afloat, the ship caught fire in Hong Kong harbor in January, 1972. Heartbroken by the fire, but still smitten with the idea of providing a sea-going college, Tung had the 18,000 ton S.S. *Atlantic* refitted into the *Universe Campus*, though subsequently the word campus was dropped from the ship's name. The Academic program was conducted at first by Chapman College, until the University of Colorado took over February, 1977.

It is surprising how well an ocean liner can be adapted to academic use. With the aid of space-saving microfilm, one lounge was converted into quite an extensive library. The ship's salons have been made into classrooms and laboratories. The dining room is now a cafeteria. There is also a student union, bookstore, snack bar and a first-rate athletic plant. A caged-in volleyball court has been constructed just above the swimming pool on the stern. The long decks are great for jogging at sea. Student cabins come in singles, doubles, triples, and quadruples, with and without portholes.

The student body, which numbers from 400 to 500 a semester, is drawn from colleges and universities throughout the United States. There are also a few non-Americans enrolled. Two-thirds of the students are in the second year or third year of university. When the ship is at sea

Available activities include basketball, volleyball, and swimming.



The Mandarin Lounge

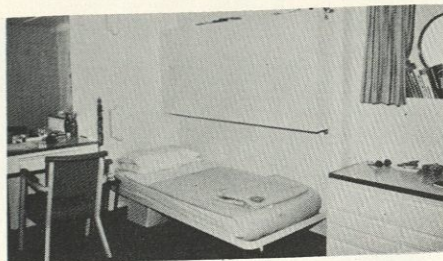
the students and professors are mingling constantly, sharing meals and leisure-time activities, as well as classroom hours. So the customary land-college chasm between professor and student does not exist at Semester at Sea.

Since the ship is in port approximately 50 percent of the semester, students are expected to engage in three so-called "in-country practica" for each course taken. These "practica" relate directly to the academic program aboard the ship.

In ports local professors are also enlisted to give special on-board lectures. In Egypt, for instance, the in-port program included: a briefing by a US State Department officer, an Egyptian dance program performed on board, a discussion of the Arab-Israeli conflict by a professor from the University of Alexandria, a lecture on ecological significance of the Aswan Dam by another University of Alexandria professor, visits to the Egyptian Museum in Cairo, the pyramids, the Valley of the Kings and Queens in Luxor.

The Semester at Sea lasts for three-and-one-half months. Classes meet daily except Sunday. Most Semesters at Sea, classes average between 15 and 20 students, and are conducted with emphasis on maximum student involvement. The maximum academic load permitted is 15 hours, the minimum is 9 hours. The cost for one semester, depending upon accommodations, range from \$4875 to \$5995.

There are two dozen professors plus admin-



An outside Double Cabin

istrative personnel aboard the S.S. Universe. Courses range from anthropology to business administration. There are classes in communications, business, economics, geography, and of course, oceanography, just to mention a few. Upon completion of the semester students receive an official University of Colorado transcript which meets all the requirements for transferability.

All the extra-curricular activities of a land-campus also exist aboard ship. There is a student council, choir, drama club, yearbook, and student newspaper called quite naturally, *The Log*. At night there are dances, talent shows and sometimes fund-raising events to help finance international projects which the ship is trying to assist in.

Dan Houston, a geology major from the now-defunct Methodist University comments: "This is the best academic program I've ever had. I've never had teachers who are this good, and I've never had more interesting classes."

Another student, Sparky Hilker of California, says, however, the professors expect too much. "they seem to forget that we are not on a regular campus. We need more time to digest what we observe in port. This is a very intensive education."

Sometimes the students find they are in for great surprises. One of the most celebrated professors aboard ship, Arthur Goodfreind, delivered a lecture called "The art of creative travel." In it he actually discouraged the students aboard Semester at Sea from sightseeing

in port and suggested rather that they "sight-think." Goodfreind feels that this makes the traveler expect more of what is coming, rather than ending up feeling so rushed and unprepared, as Sparky Hilker claimed he was.

But prepared or not prepared for traveling, most of the students agree that it is the ports of call that are the most interesting part of their education. A big complaint in college is that the things students learn in class cannot be readily applied to the real world. But on the S.S. Universe there is tremendous interaction between knowledge from books and personal experience.

"When I arrive in a new port of call," one geology major explains, "I like to get out into the countryside and observe the geology and ecology. It's interesting how rural peoples seem to live in harmony with nature, when city people always seem to be battling with nature back home."

Michelle LeBaron of Alberta, Canada says "the in-port experience literally creates a whole new world for me. On the train from Kyong-ju to Pusan in Korea another student and I were the only Americans aboard. Everyone stared at us. I gave a piece of candy to a little Korean boy trying to make friends, but it tasted so foreign to him that he threw it away. Another group of Koreans laughed and pointed at us, probably because we were so tall and had blond hair."

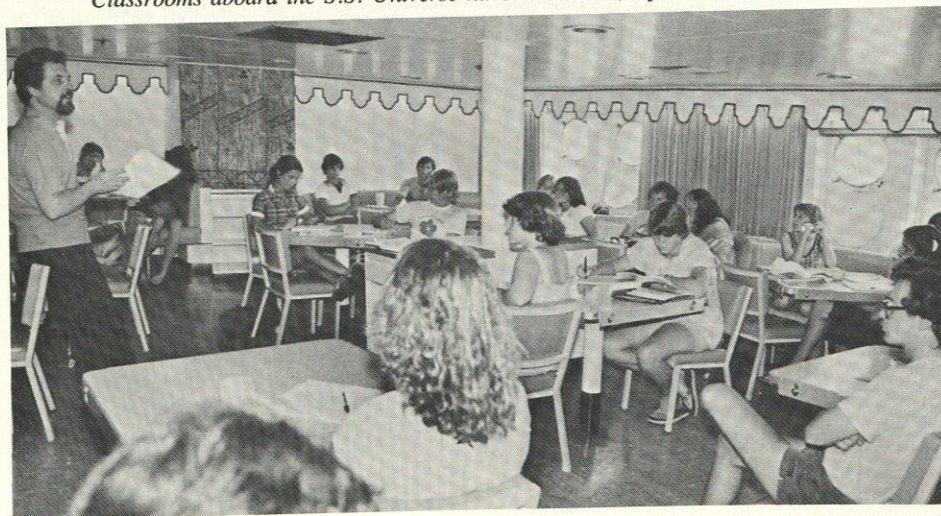
One of the nicest things about Semester at Sea is its informality. Barefeet and "cut-offs" are permitted in class. Many times a student will just strike up a conversation with a professor as he's sunbathing or reading.

Free time on board the Universe is also informal, yet active. There's always something going on; students are usually either studying, reading, exercising, or talking about experiences they had in their last port of call. The swimming pool is probably the most popular hangout for students between classes, as many don their bathing suits, either to swim, tan, study, read, or play backgammon, the most popular game on the ship. Some students, however, prefer to be quiet and alone reading in a deck chair up on the bow.

The Universe, like any other American university, has its share of goings on. There is always a party happening in somebody's dorm(cabin). The student union, a long room with tables and chairs and a stage, serves drinks every night and often a group will get together and play a concert. Another popular activity is camping out on the deck.

Not all of the passengers aboard the Universe are exactly college age. Eva McRae, age 82, goes to class like everybody else, but for her this is more of a cruise. "What I like about the Universe," says Eva, "is the informality. You don't have to dress up for dinner every night. I like the self-service cafeteria. I don't like being waited on. I even make my own bed." □

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Classrooms aboard the S.S. Universe have a relaxed, informal atmosphere.



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The Theory of Special Relativity

Or why I never get asked back to parties

By Eric J. Borg



The following article is the first place undergraduate winner in the Albert Einstein Memorial Essay Contest, which was sponsored by the Society of Physics Students in honor of Albert Einstein's 100th birthday. The story also offers a plausible explanation of why you can't ever find a cocktail napkin when you need one.—Ed. Note

I have often been asked to answer questions, explain things, and even account for natural phenomenon. Oh, nothing new and exciting, just ordinary things. We as physics students are always doing this. I am not unique in this respect at all. We are always doing this on homework assignments, tests, or even when a friend calls up Sunday night to have you explain last week's lectures in physics. I suppose that even at parties one finds oneself explaining, or trying to explain, a recent discovery in physics to those who made the mistake of mentioning it in your presence. This is a tremendous disadvantage to you because it results in your not being invited back again.

Now the physics student is not the only student who suffers at their desire to enlighten the public at large on their discipline. Every student has this problem. The chemistry student who feels that everyone at the party wants to understand the pi-bond. The political science student who knows what really happened in

Uganda, and believes you're dying to find out. All of us suffer from this problem, which results in the downfall of our social life. Fortunately, most of us control it. However, the physics student is uniquely infected with the knowledge of a phenomenon that only the strongest can hold in, and not attempt to explain to an unfortunate soul. That bit of information is called the Theory of Special Relativity.

The Theory of Special Relativity is unique in that it captures the imagination and interest of people so quickly. It challenges their classical view of the world so profoundly, that the conversation usually starts with, "You mean time really slows down? Things get shorter?" And ends two hours later with someone whispering to the host, "Make sure you don't invite him again." One must be careful in explaining the theory so as to be concise, short, and interesting. Further, one must keep in mind the mentality and the state of intoxication of your audience. If one can do all this and use a little imagination, then they can explain the Theory of Special Relativity and not be asked to leave the party.

The first case is an average student who has little or no math background. To him advanced math is algebra, and physics is a class that he was told to avoid. Be concise, state exactly what the theory is. Do not make mention to the Newtonian or Galilean transformations. You

will only confuse him.

Physics student: "In answer to your question, the theory is founded on the principle that nothing is absolute. Everything is measured relative to your frame of reference. Both space and time vary from reference frame to reference frame. Secondly, the speed of light remains a constant in all inertial frames."

Student: "Would you like a drink?"

Do not give up. You only need to say something that will upset his classical thought. He will then be entrapped by the theory.

Physics student: "Don't you see what that means? If you travel fast enough time slows down and you'll outlive everyone."

Student: "Is that really true? Na, it can't be. Time just can't slow down."

Now you have him. He is good for about fifteen minutes. You must jump into the theory.

Physics student: "Yes, it does. Not only does time slow down, but things get shorter. For example: If you run past me at a very, very fast speed, then when you get in front of me I will say that you are ageing slower and you are thinner. Of course, you will say the same thing about me."

Student: "I will?"

Physics student: "Yes, because as far as you're concerned, I am the one that is moving and you are stationary. Everything is relative."

Student: "Now wait a minute, we both can't

be right. One of us is lying. You can't measure the same thing at the same time and get different answers."

Poor classical person.

Physics student: "Ah, ha. That is the point. You can no longer think of things as being everywhere simultaneously. Things that are simultaneous to you, are not to me. When you ran past me and watched me make the measurement, you saw me make it at the wrong place and at the wrong time."

At this point you have probably lost him. But that is ok, they can't resist to try to show you that you're wrong. Be prepared to be attacked with a barrage of paradoxes.

Student: "Ok, you stay here on earth and I will travel very fast away for a long time. What will happen?"

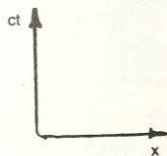
Physics student: "Well, I will say that my clock is keeping the same time, but yours has slowed down. You are ageing slower than me. You will say that it is I who is ageing slower. You will think that your clock is keeping the same time."

Student: "Ah, there, your whole theory is wrong. Because when I turn around and return to Earth, one of us has to be older. But which one? There is your contradiction, you can't tell which one is younger than the other."

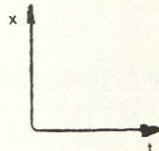
You smile, take a sip of your rum and coke and say, "In order for you to return to Earth, you have to change your velocity, and thus undergo an acceleration. Therefore the theory is no longer valid. It only deals with constant velocities."

Sometimes the situation may be quite different. The person that your talking to might be an engineering student. If this is the case, then he has taken Phys 213, commonly known as "Disneyland Physics." Well, a little knowledge is a dangerous thing. The engineering student knows some of the consequences of the theory, but he doesn't understand why time is slowed down or why lengths shorten. To explain this to him you must use a space-time diagram. It would be best to use a geometric interpretation.

Physics student: "First let me draw you a space-time diagram."

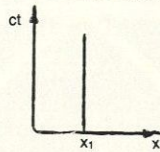


Engineering student: "Wait a minute. You've labeled the axis wrong. It should look like this."



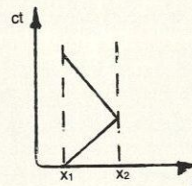
Physics student: "No, no, no. Let me do it

my way. You'll see why later. Now a stationary object at x_1 will look like this."



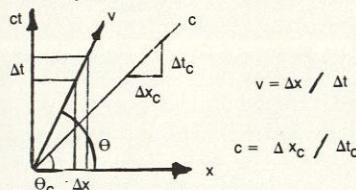
Engineering student: "Correct."

Physics student: "An object that moves to the right, stops at x_2 and moves back to x_1 looks like this."



Engineering student: "Correct."

Physics student: "Now let's take a car moving at velocity V ."



Engineering student: "Wait, what is that other line for?"

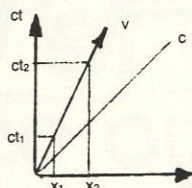
Physics student: "That represents the speed of light. Remember $\theta \geq \theta_c$."

Engineering student: "Why?"

Physics student: "Because nothing can travel faster than the speed of light."

Engineering student: "Oh, right."

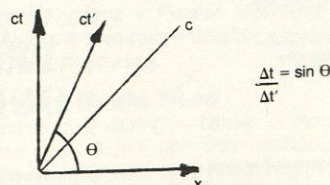
Physics student: "Now let's say that two events, one at t_1 , and the other at t_2 , occur in this car. The picture would look like this."



Now because the car has a velocity, the events are separated by time and space. $t_2 - t_1 = \Delta t$ and $x_2 - x_1 = \Delta x = V\Delta t$

Engineering student: "Correct."

Physics student: "Now we must use the concept of relativity. On the car itself, the events are only separated by time. The events occur at the same place in the car's coordinate system. Therefore the car's time axis must lie along the car's velocity vector, like this."



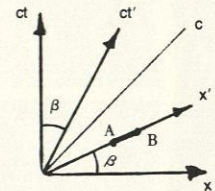
Engineering student: "Correct. What else could it be? But where is the car's x axis?"

Physics student: "Well to find that out we must use the second postulate. The speed of light is constant in all inertial frames. So the x axis must be drawn such that the car's frame of reference has the same velocity for the speed of light. In other words,

$$\frac{\Delta x_c}{\Delta t_c} = \frac{\Delta x_{c'}}{\Delta t_{c'}}$$

$$\frac{\Delta x_c}{\Delta x_{c'}} = \frac{\Delta t_c}{\Delta t_{c'}} = \sin \theta$$

This means that the car's coordinate system looks like this, relative to the other coordinate system.



If AB is a length in the car's coordinate system then it will have a length $AB \cos \beta$ in the (X, Y) coordinate system. From the geometry you can see that it will be shortened."

Engineering student: "Correct. Say, that diagram is kind of neat. Too bad none of it's real."

Physics student: "What do you mean none of it is real? Didn't I just show you that this really happens?"

Engineering student: "Well you never see it in real life, so it can't be worth anything."

Physics student: "Oh ya, well what about $E=mc^2$? You're going to tell me that you don't see this in real life?"

Engineering student: "Well ok, but how do you account for that one?"

Now you're in trouble. How in the middle of Harry Neilson blurring on the stereo, the alcohol and the wet cocktail napkins are you going to explain four-momentum? Well, use your finger. No, not that one. Just wave your hands a little.

Physics student: "Well to give you a very simple model, think of trying to accelerate a mass up to the speed of light. You might do this by hitting it with something. As you transfer momentum to it, it starts to speed up. But as it approaches the speed of light it can't go any faster. Yet momentum must be conserved. Therefore, the mass of the object must increase. Since momentum is related to energy, and now to mass, then energy and mass must be related. In fact they are, and the proportionality factor happens to be c^2 ."

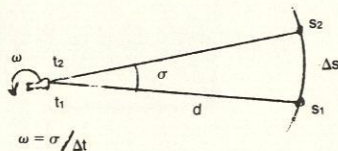
At this point the engineering student is face down on the floor. While you have been talking, he has been drinking. You have been talk-

ing for a long time. Draw your own conclusions.

The third case or class of student is your fellow physics student. When at a party the two of you play a game. You try to talk using terms so that nobody around you has any idea what your talking about. This way you impress them. More importantly though, you try to impress each other with the depth at which you understand the theory of special relativity. This is done by tying to out paradox the other.

Physics student #1: "Ok, let's say that your shining a flashlight at a distant wall. We will say that it is curved so that all parts of it are equally distant from you. Now you rotate the flashlight at a very fast but constant angular velocity. That spot will move faster than the speed of light. But nothing can go faster than the speed of light, thus the paradox."

Physics student #2: "Hand me a napkin and let me draw this out.



The spot doesn't leave S_1 until $t_1 + d/c$. And it arrives at S_2 at $t_2 + d/c$.

$$\Delta t = t_2 + \frac{d}{c} - (t_1 + \frac{d}{c}) = t_2 - t_1$$

$$v = \frac{\Delta s}{\Delta t} = \sigma d = \omega d$$

$$\Delta s = \sigma d$$

So if $\omega = 4 \text{ sec}^{-1}$ and $d = 10^8$ meters, then the spot's velocity is $4 \times 10^8 \text{ m/s}$ which is indeed faster than the speed of light. However, the spot is not a real object. It is only an image. The theory states that only real objects can't go faster than the speed of light. So your paradox is solved."

Physics student #1: "Well, then how do you explain mesons?"

The fourth class of student is the math major. It is best to stay away from them. They will only demand rigorous proofs to trivial mathematical techniques.

The theory of Special Relativity is a fascinating theory. It allows one the freedom to make thought experiments, not unlike the ones that its creator Albert Einstein used to develop the theory. This March 14th we celebrated his 100th birthday. His theory of Special Relativity

was certainly not his most famous or most important, but it has touched virtually every person in the world. Albert Einstein and $E=mc^2$, are household words. I feel that it is a privilege to be one of those who can share and appreciate his gift to mankind. Even if it does mean that I don't get asked back to parties. □



Eric Borg is a senior in Engineering Physics. His love of physics is based on the fundamental questions that are raised in his classes. Interests include skiing, backpacking and looking for parity violations.

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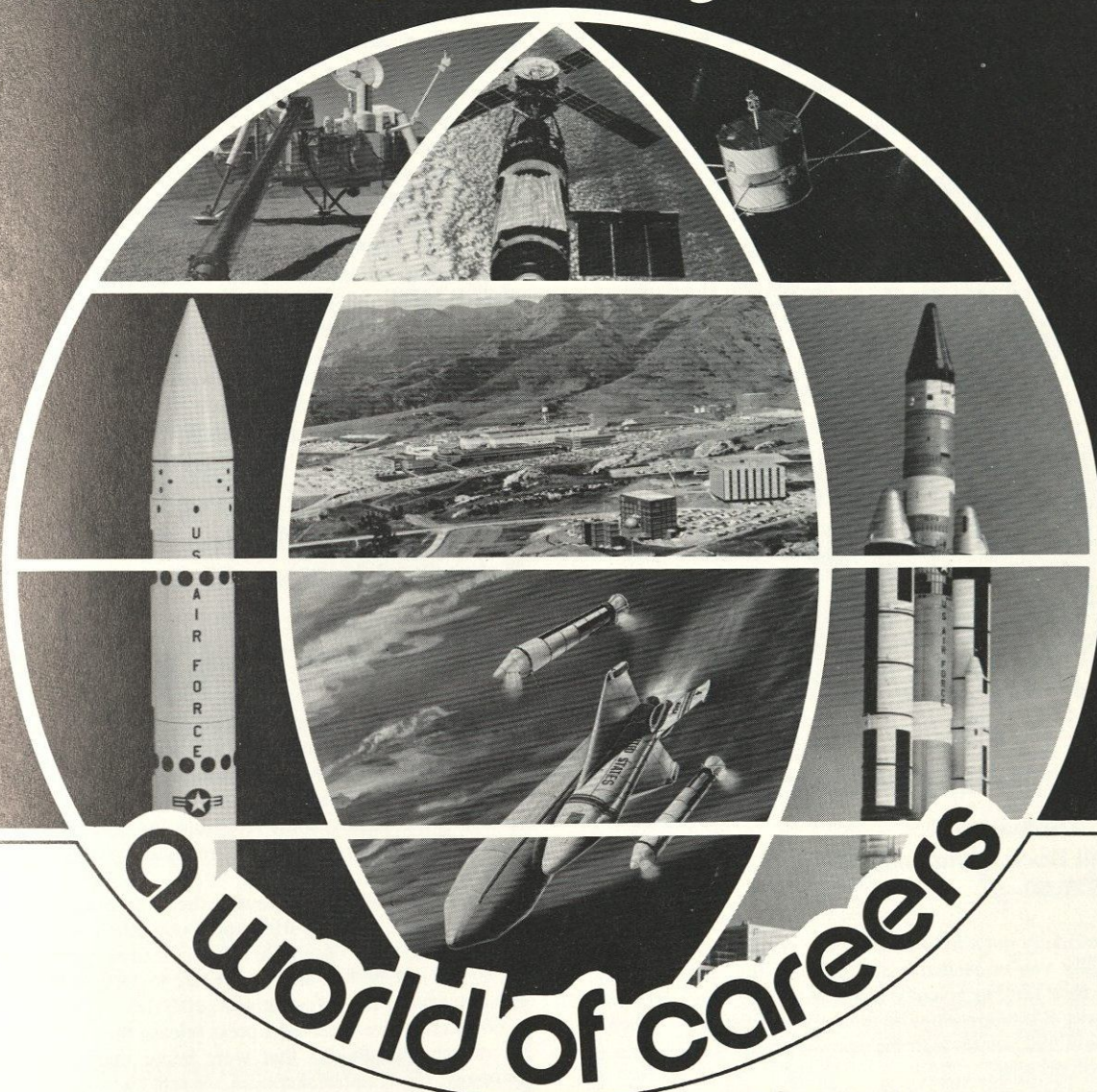
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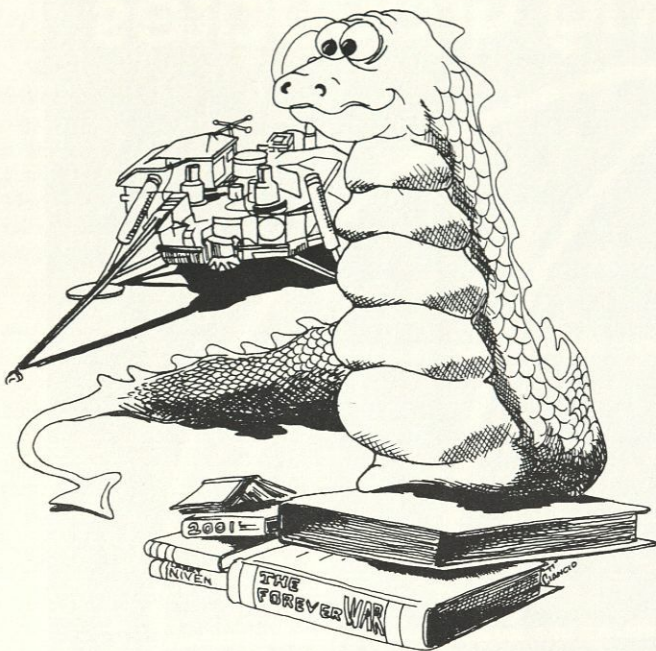
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Book Reviews

by Brian Sjoberg

Architectural Working Drawings

by Marvin J. Thomas, AIA

McGraw - Hill Book Company, 1978

207 pages, \$17.50

At last you've finally got a summer job. You've been searching for months and finally you've landed a drafting job. But, oh no, they expect you to know how to actually draft and draw things and do everything the way it's supposed to be done. Even EDEE101, which you thought would pull you through the summer, is just a hazy memory. What do you do now?

Why not run out and get a copy of *Architectural Working Drawings* to help you remember and refine all those things you once knew. As dull as the title sounds it is really quite an interesting book, and one that reads very well.

The book starts out with the basics that everyone should practice when they start drawing. How to set up an efficient drafting station, how to keep proper project records, how to file them, and admonitions to keep drafting quality and spelling at acceptable levels.

Architectural working drawings, as the author notes, are the actual drawings that are used to build the buildings, and are part of the contract documents. They are not detailed shop drawings nor are they fancy architectural renderings. The book doesn't go into those two areas, but then it never makes any attempt to, as the title indicates.

The author looks at drawing sheets and their organization. He goes into how to arrange borders and title blocks, and how to set up identification and reference systems. Then he goes into a system for developing a drawing and lettering technique, how to properly identify different materials and their various symbols, how to improve a drawing's readability, and perhaps most important of all, how to letter correctly. I've looked at many a set of plans over the past few summers and I know how hard some of them are to read. Some of the lettering is atrocious, not because it is messy, but because the letters are so slanted or

misshaped. He also goes into details and schedules which are often poorly done. He has many examples of how a good door or room schedule should look, and what should be included in them. Dimensioning also deserves a chapter, and he illustrates the proper technique quite well.

There is a long chapter on metric conversions, which is some what of a surprise since traditionally the construction industry has only dealt with inches and feet. He stresses how hard it would be to change the system, and he advocates using both measurement systems until the changeover is complete.

He lists many references and even has a six page checklist of things that you should check before you certify a drawing finished.

All in all it is a very interesting book, whether you've got a summer drafting job, or want to build your own house, or just want to improve your drafting technique.

**Design Manual
for Solar Water Heaters, \$5.00
Illustrated Solar Energy Guide, \$3.00
Estimating Solar Energy
Available for Collection, \$3.00
Solar Pool Heaters, \$2.00**

by Alan Goldberg

Horizon Industries, 1978

The solar energy field is a fast growing and potentially a very lucrative new area that industry, both here and abroad, is now entering into at an ever increasing rate. Along with the well-known and established companies that are beginning to enter the market, are a plethora of smaller companies, some reputable and some not. They offer anything from innovative new ideas to rehashed schemes that never work in the first place.

Books, also, fall into somewhat the same categories. There are big companies like McGraw-Hill and Doubleday, and small companies that rarely are heard of outside a specialized market. Then there are the good ones and the bad ones. Some are just worthless and others offer genuine advice and information.

So recently, we received a press release that informed us of a small set of solar handbooks that were being marketed by a California company. Being rather skeptical, we sent away for them to see exactly what they might be. To say the least, it was a pleasant surprise. Although each of the books is rather short, they are very informative and interesting. They read quite easily and include many diagrams and tables to help clarify the text.

Each book in the set is a separate entity into itself (and can be purchased separately). They all offer background information on the basics of solar energy and then some direct applications of it.

The *Design Manual for Solar Water Heaters* is perhaps the longest and best prepared of the set. Since heating hot water is sometimes judged the most efficient use of solar energy, this booklet is especially interesting. It has insolation tables and other pertinent information that is needed to figure out the sunlight striking any area at any given location. Although the tables are not exhaustive, they would probably provide the average solar enthusiast with an accurate enough figure for most applications.

The other booklets, *Estimating Solar Energy Available for Collection*, *Illustrated Solar Energy Guide*, and *Solar Pool Heaters*, are all arranged along these same lines, with varying degrees of emphasis placed on solar heat design.

One interesting aspect of the *Solar Pool Heaters* manual was the section on passive ways in which to heat the water, with such various ideas as covers, enclosures, and windbreaks. They also gave formulas

on how to estimate the dollar cost of energy savings by using solar heat. However, since swimming pools are not really that popular in this part of the country, maybe this particular book is not too relevant.

One note of warning might be in order. If you consider yourself fairly knowledgeable on the subject of solar energy, and already have an extensive library, then these books are not for you. They are written for the novice and condense a lot of information into a short amount of space. But they do it well, and offer a lot of interesting information.

For more information (this is not an endorsement) contact: Horizon Industries, 12606 Burton St., North Hollywood, California 91605.

Another solar publication slipped into the office this week along with all the other mail. Called "Solar Energy Digest," it is a short monthly newsletter-type magazine that offers information on solar energy. Although it is without photographs, diagrams and actual "solar plans", it does offer a great number of very short stories on various solar activities going on throughout the world. Its main advantage is the great number of addresses included in these stories, which make available a wide array of contacts in the solar field — researchers, suppliers, manufacturers, and universities doing solar work.

For more information (send \$1.00 if you want a sample copy) write: Solar Energy Digest, PO Box 17776, San Diego, California 92117.

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Do You Wear GLASSES ?

Here's an effective new eye-exercise program that can produce astonishing results in a very short time . . .

The Bettervision Eye Clinic is now offering a program of eye-exercises that can safely correct most cases of poor eyesight—**so that glasses or contact lenses are no longer needed.** Originally developed by Dr. William H. Bates of the New York Eye Hospital, this method has been widely used by the Armed Forces, schools, clinics, and thousands of private individuals, for the treatment of:

- **nearsightedness**
- **farsightedness**
- **astigmatism**
- **middle-age sight**

For many years it was thought that poor eyesight was just bad luck, or something you inherit from your parents. Scientists now know that most eyesight problems are caused by accumulated stress and tension—which squeeze the eyeball out of shape, and affect the muscles that do the focusing. The result is the eye cannot form a clear image, and the world appears to be blurry. In people over 40, the natural aging process is also an important factor.

No matter what your eyesight problem the Bates Method can help you. This is a health care program, and will benefit everyone who follows it—children, adults, and seniors.

It is important to understand that glasses do not cure a visual problem. They are simply a compensating device—like crutches. In fact, glasses usually make the condition worse. Because they make the eyes weak and lazy, a minor problem often develops into a lifetime of wearing glasses.

The Bates Method corrects poor eyesight by strengthening the eye-muscles and relaxing the eyeball. You do simple easy exercises that increase your focusing power, eliminate eyestrain, and bring your eyesight back to normal.

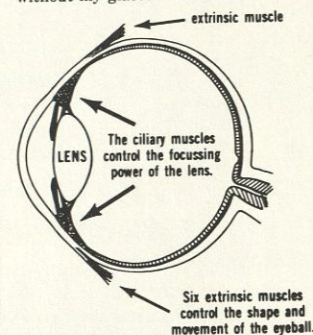
Because the Bates Method deals with the **basic cause** of your eyesight problem, you can expect to **see** a definite improvement in as little as 1 or 2 weeks. Even if you have worn glasses all your life—things will become clearer and clearer, and you will have flashes of good vision . . . as you go through the program, these flashes become longer and more frequent . . . gradually blending into **permanent better sight**—at which point the exercises are no longer necessary.

We usually find that people whose eyesight is not too bad can return to 20/20 vision in about a month. Even if your eyesight is really poor, within 2 to 3 months you should be able to put away your glasses, once and for all. Read these case histories:

Aldous Huxley—Nobel Author
"My vision was getting steadily worse, even with greatly strengthened glasses. To my dismay I realized I was going blind. On the advice of my Doctor I decided to try the Bates Method. There was an immediate improvement. After only 2 months I was able to read clearly without glasses. Better still, the cataract which had covered part of one eye for over 16 years was beginning to clear up."

Rev. Frederick A. Milos, M.S.
"By following the simple exercises given in this program, I have completely recovered my vision. Now I can read for long periods without my glasses."

Ron Moore—Technician
"I originally went to the Clinic to deliver some equipment—and ended up trying their eye-exercise program. I am near-sighted, and have worn glasses for 15 yrs. In just 3 weeks after starting the program, my eyesight has already improved to the point where I can now drive, do business, and watch T.V.—all without my glasses!"



This program has been specially designed for the individual to exercise at home. Written in simple non-technical language, it gives you **all** the guidance you need to regain natural healthy vision in just 1/2 hour a day: illustrated booklet, complete step-by-step instructions, plus special charts and displays to ensure you make rapid progress. The program is fully guaranteed and there's nothing more to buy.

By following this program, you will soon be able to see clearly without glasses. It's up to you. Ordering the Bates Method can be one of the best decisions you ever made. So do it now—before you get sidetracked and forget. Fill out the order coupon, attach your check for \$9.95 plus \$1 for postage and handling, and mail it to us today!

If you have any questions regarding this program, please call us at (415) 763-6699. Our qualified operator will be glad to help you.

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Engineering Procedure From an unknown but astute source:

"Every new engineer must learn early that it is never good taste to designate the sum of two quantities in the form:

$$1+1=2 \quad (1)$$

"Anyone who has made a study of advanced mathematics is aware that: $1 = \ln e$ and that: $1 = \sin^2 x + \cos^2 x$

$$\text{further: } 2 = \sum_{n=0}^{\infty} \frac{1}{2^n}$$

"Therefore, Eq. (1) can be expressed more scientifically as:

$$\ln e + (\sin^2 x + \cos^2 x) = \sum_{n=0}^{\infty} \frac{1}{2^n} \quad (2)$$

"This may be further simplified by use of the relations:

$$1 = \cosh y \sqrt{1 - \tanh^2 y} \text{ and } e = \lim_{Z \rightarrow \infty} \left(1 + \frac{1}{Z}\right)^Z$$

"Equation (2) may therefore be rewritten:

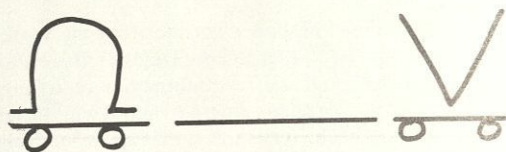
$$\ln \left[\lim_{Z \rightarrow \infty} \left(1 + \frac{1}{Z}\right)^Z \right] + (\sin^2 x + \cos^2 x) = \sum_{n=0}^{\infty} \frac{\cosh y \sqrt{1 - \tanh^2 y}}{2^n} \quad (3)$$

"At this point, it would be obvious that Eq. (3) is much clearer and more easily understood than Eq. (1). Other methods of a similar nature could be used to clarify Eq. (1) but these are easily discovered once the reader grasps the underlying principles."

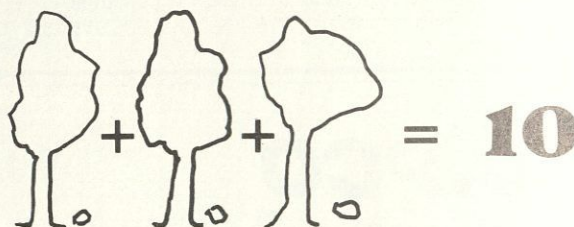
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What Does It Say?

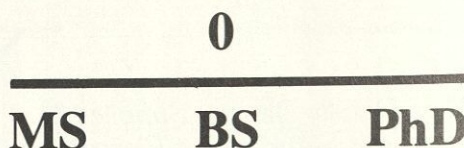
1.



2.



3.



Q: What happened to the two peanuts in the park?

A: They were assaulted!

Q: How many pre-meds does it take to change a light bulb?

A: Nine. One to stand on the ladder and eight to pull it out from under him.

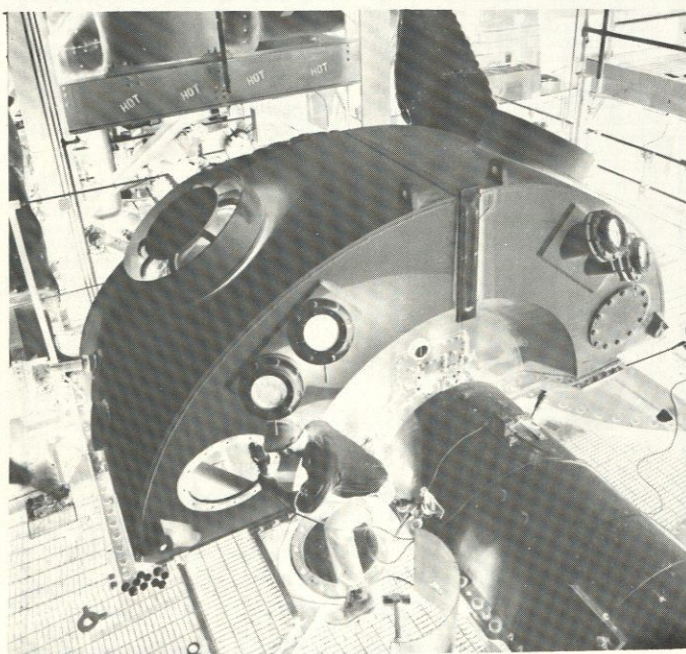
This exclusive photo, recently made available to the *Colorado Engineer*, shows President Jimmy Carter preparing to enter the reactor core of the Three Mile Island nuclear generating facility near Harrisburg, Pennsylvania, where he plans to personally inspect the crippled reactor. The President, a former nuclear engineer, seems unconcerned by the "HOT" warning signs and the strange ethereal light. He was heard to comment, "This gives new meaning to that old phrase, 'Nuke them till they glow.'"

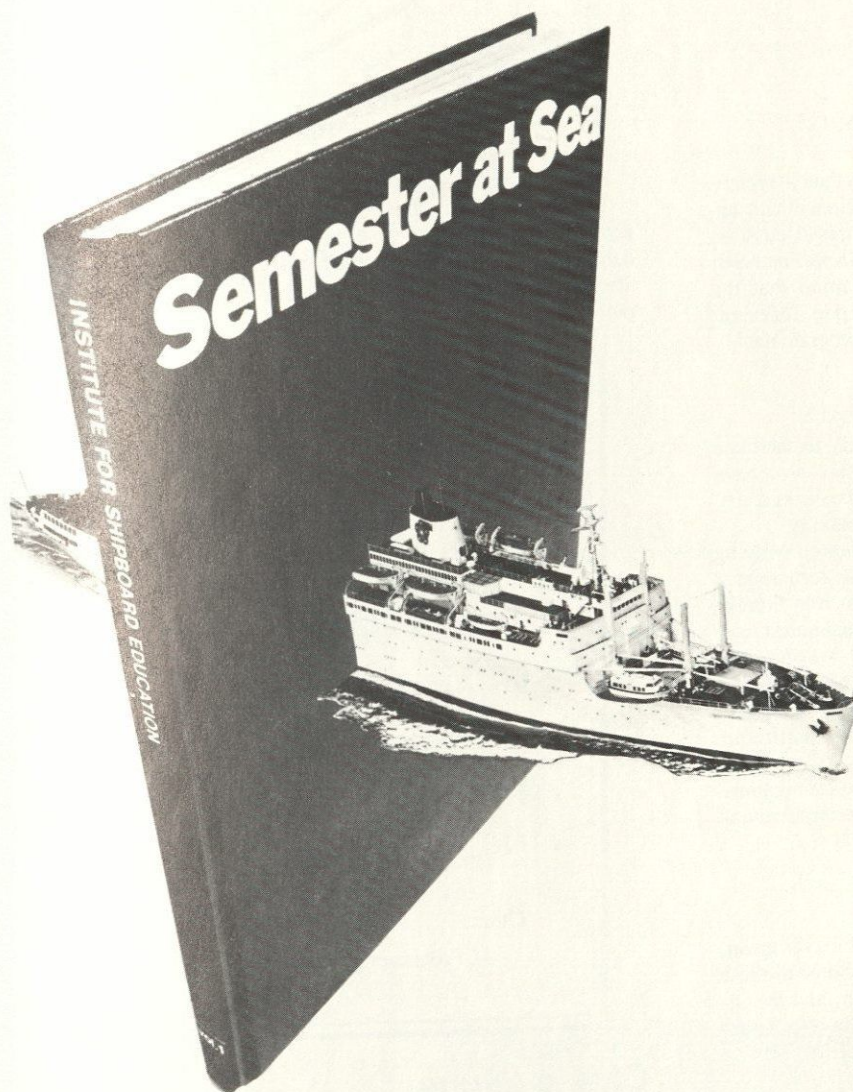
3. Three degrees below zero.

1(t)(h)urd equals ten.

2. T(h)(ree and a t(h)(urd plus t(h)(ree and a t(h)(urd plus t(h)(ree and a

Answers:





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CALCULATOR UPDATE

By Kiyoshi Akima

There are several types of personal calculators others than the scientific calculators available to engineers today. This article will concentrate on some of the more popular. For the purposes of this discussion, they will be divided into the following categories: Business/Financial, Statistical, Programmable, and "Other". Bear in mind that the categories are not distinct, and there is considerable overlap, for example a calculator could be Business/Financial and also programmable.

Business/Financial

Business/Financial calculators are designed primarily to facilitate calculations involving time and money. Many of these also have statistical capacity to deal with calculations involving business statistics. Two of these also have limited programming capability.

All of these calculators make easy work of problems involving compound interest. Some examples are loan payments, accumulated interest, and remaining balance. These calculations merely involve entering the known values for the number of periods, the interest rate, the payment the present value, and the future value, and pressing a key to calculate the unknown value. This all but eliminates the need for bulky tables. Some have additional features such as the use of 360 or 365 day years for interest purposes, or the generation of amortization schedules.

Other features found on some of these are bond/note calculations, depreciation schedules, discounted cash flow analysis, internal rate of return, and built-in calendars.

Statistical

Statistical calculators allow easy calculations of such things as mean, standard deviation, and linear regression and estimate. Some of these can also calculate the normal, or Gaussian, distribution, and the inverse. As mentioned earlier, many of these machines also offer financial capabilities.

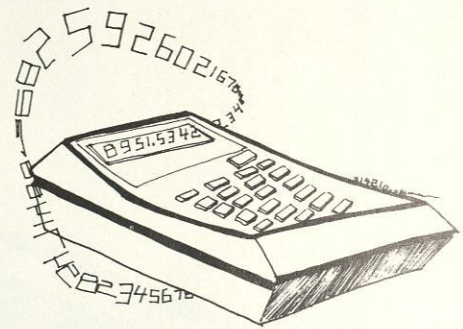
Programmable

Programmable calculators will "remember" a series of calculations and repeat them at the touch of a key. They allow repeated calculations with different sets of data. They are also useful for iterative calculations. In general these are the most powerful calculators available, since most financial and statistical calculations can easily be programmed.

Programmable calculators will be discussed in more detail in another article.

"Other"

There is no easy way to classify or describe these machines. They include the basic "four-banger" and special-purpose machines. They range from simple adding machines to game-playing machines to more sophisticated machines. There are several models which will calculate biorhythms and warn you of critical days.



Probably the only calculator in this category of interest to engineers is the TI Programmer. This machine does arithmetic in binary, decimal, and hexadecimal (base 2, base 10, base 16, respectively). It also handles base conversions, ORs, ANDs, and other binary functions. These features make the Programmer useful in working with computers.

This listing is meant to be a partial listing of available calculators and their suggested retail price.

Business/Financial

HP-37E	\$80.00
HP-38E	\$120.00
HP-97A	\$495.00
TI Business Analyst	\$29.95
TI MBA	\$70.00

Statistical

Casio fx-58	\$49.95
HP-32E	\$80.00

"Other"

TI Programmer	\$60.00
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Observations

There are two trends that have developed recently in the calculator market. First, most major manufacturers are now firmly committed to long-life disposable battery calculators. They do not have AC charger/adaptor or rechargeable batteries. They are characterized by liquid crystal displays requiring very little power, and long operating time—up to 3000 hours on one set of batteries.

Second, some calculators are going up in price. The tremendous price decreases that have characterized the market over the past six years were the result of the semiconductor industry's ability to put more and more functions on a single chip. This has progressed to the point where the cost of the chip has become a minor portion of the total cost. Since calculator manufacturers are subject to the same economic factors (labor, materials, transportation, etc.) as other industries, prices are beginning to rise. There may still be some decrease, but they will primarily be restricted to those higher-end machines where the cost of electronic components still constitutes a major portion of the total cost. □

News News

COLORADO BRINGS HOME THE BACON

The *Colorado Engineer* magazine made an outstanding showing at the 1979 Engineering College Magazines Associated (ECMA) convention.

The convention, held this year at the University of Notre Dame in South Bend, Indiana is an annual event that brings together over thirty engineering magazines from throughout the country for seminars and awards competition. The *Colorado Engineer* magazine was presented with the following awards for 1978:

- First Place—Best All Around Magazine (As voted by ECMA members)
- First Place—Best Cover All Issues
- Third Place—Best Single Cover (March 1978)
- Third Place—Best Single Issue (March 1978)
- Honorable Mention—Best Layout All Issues
- Honorable Mention—Best Layout Single Issue (October 1978)
- Honorable Mention—Best Single Editorial (By Brian Sjoberg, October 1978)

Five students represented the University of Colorado at the conference. After travelling 2500 miles by van, consuming six cases of beer in three days, and driving at one point for 25 straight hours, one student was heard to say, "Maybe now everyone will appreciate all the time and effort that *really* goes into publishing this magazine!"

KETCHUM AWARD PRESENTED

The winner of this year's Ketchum Award was John J. McAfee, a graduating senior in Civil Engineering.

The Ketchum Award, given each year to an outstanding student in Civil Engineering, was presented at the the annual Ketchum Awards Banquet, held in honor of Milo S. Ketchum, former dean of the college and a civil engineer. The event was co-sponsored by the Chi-Epsilon fraternity, the American Society of Civil Engineers, and the American Institute of Architectural Engineers.

At the banquet, professor Robert Rathburn was presented the Student Appreciation Award by the graduating seniors for his long service to the CEAE department. The Menoher-Thoman award, given to a promising sophomore in the CEAE curriculum, was presented to John Wood.

Preceding the banquet was the Chi-Epsilon initiation, where 31 pledges were admitted to the fraternity. New officers

were installed, and they are: Stan Ward, president; Stacie Lehner, vice-president; Cindy Loomis, secretary; Jack Sargent, treasurer; Dave Eckberg, marshal; and Tony Cianflone, editor.

Pledge of the Year was Beth Woodworth.

The banquet was held April 22nd at the University Club. Guest speaker for the evening was Professor James D. Foch of the Aerospace Engineering department, who spoke on energy conservation in the home.

CU PROF RETIRES

Professor Robert E. Rathburn, after 39 years of service to the university, will retire at the end of this academic year. Rathburn, a professor in the department of Civil, Environmental, and Architectural Engineering was the head of the Architectural Engineering program from 1946 to 1975. He has taught numerous classes in his field, structural engineering, since coming to the university in 1940. He received his B.S. degree in Architectural Engineering from the University of Colorado in 1937 and his M.S. degree in Civil Engineering from the University of Colorado in 1940. He became an associate professor here in 1950 and a full professor in 1956.

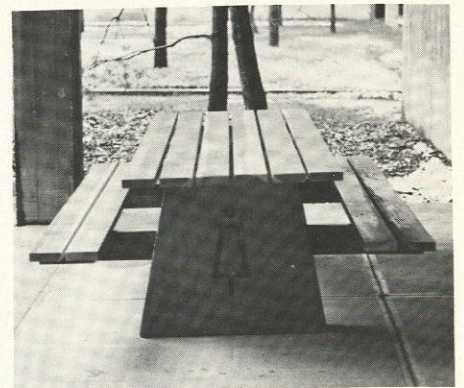
A farewell dinner was held in his honor on May 11 at the Broker Inn. Many of the faculty and students in the CEAE department both from the present and out of the past presented him with an award of appreciation at the dinner, and urged Professor Rathburn to use the gift to help fly he and his wife to South America for a long awaited and well deserved vacation.

Professor Rathburn plans to live the life of leisure on his farm north-east of Boulder upon retirement.

IS IT TAU FOR TABLE AND PI FOR PICNIC?

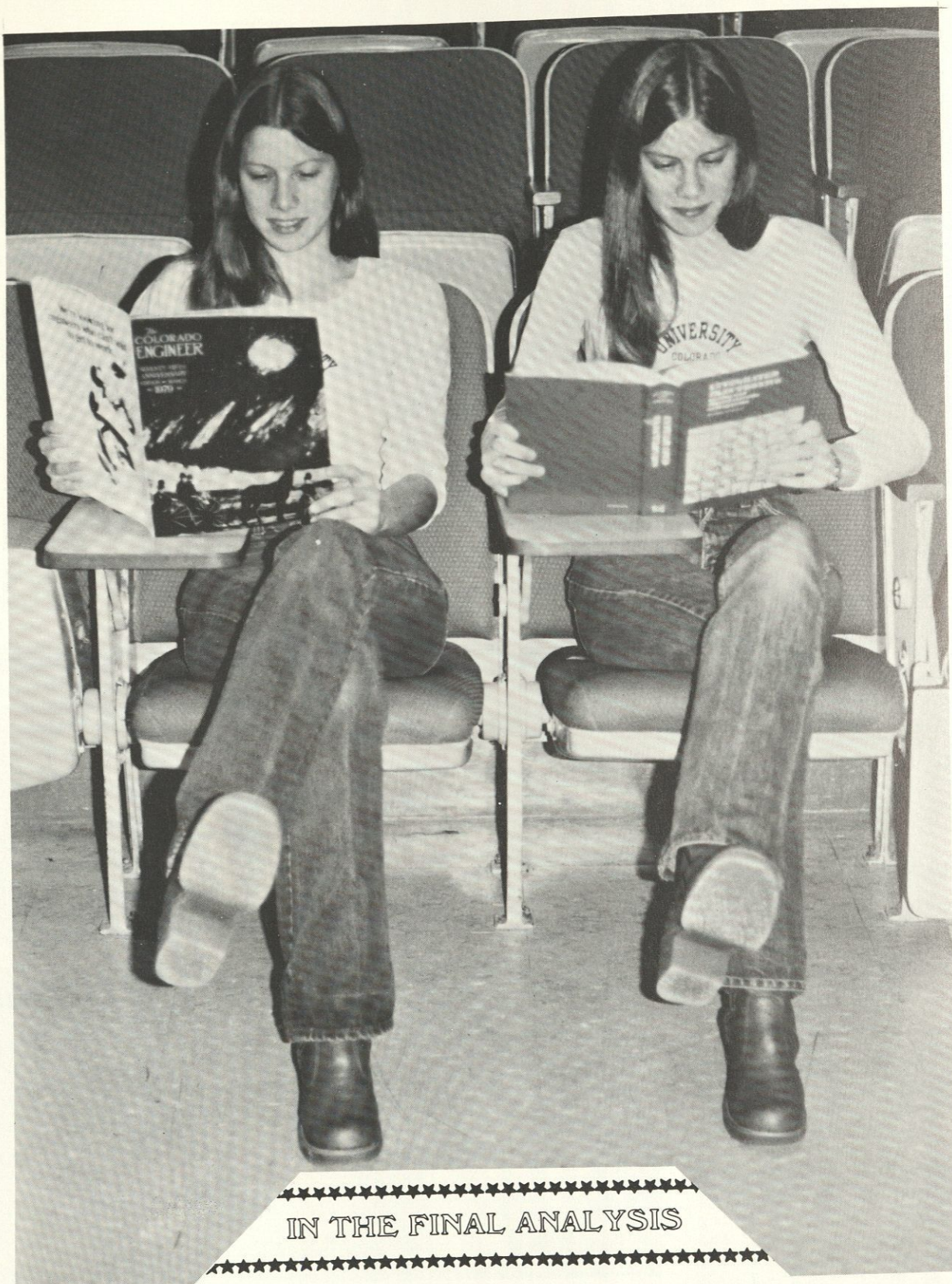
Did you ever wonder where that picnic table came from down in the court yard of the Engineering Center? No, it wasn't stolen from one of the Boulder parks. It was built last fall by the members of Tau Beta Pi, the honorary engineering society.

The fall pledge class built the table, and this spring the new pledges stained and varnished it, along with all the tables in the Real McCoy Lounge. This pledge project was one of the requirements for entry into TBPI, and the officers feel that by sponsoring projects of this nature the organization will become more of a service group and not just something to put on your resume.



Seven awards were presented to the staff of the *Colorado Engineer* magazine at the annual ECMA convention, held this year at Notre Dame University. Pictured from left to right are

staff members Rich Luxford, Kathy Curlander, ECMA executive secretary Howard Schwabke, Brian Sjoberg, Terry Clark, and Mike Furman.



IN THE FINAL ANALYSIS

“Which one do you suppose is smarter?”

Half the oil fields discovered since 1950 wouldn't have produced a single drop had it not been for companies like Halliburton.

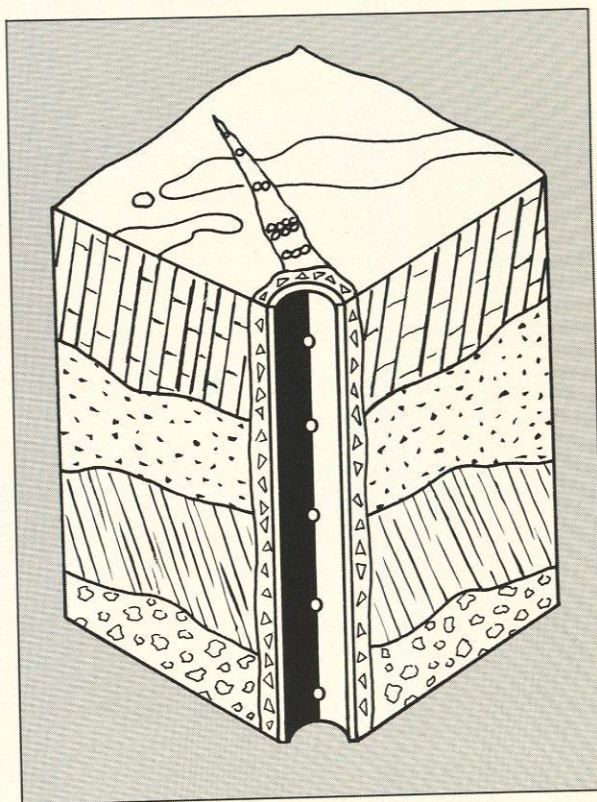
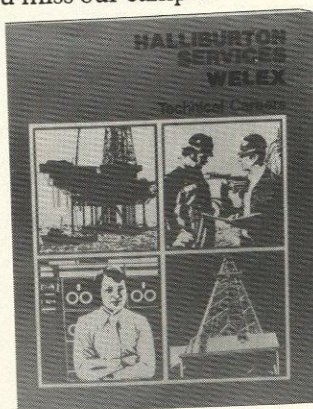
Those fields would not have been produced because they were in formations that would not allow oil to flow naturally to the wells. But the advent of hydraulic fracturing in the late 1940's, a major service we at Halliburton provide, changed that.

With hydraulic fracturing technology, we can actually create flow channels deep in the formation that make it easy for oil to flow to the well. And that helps solve the problem.

Fracturing is just one of the highly technical, sophisticated services we provide to the petroleum industry. Every well drilled in the U.S. and internationally is a candidate for one or more of our services.

Because we're very good at what we do, we're the unchallenged leader in the complex and challenging oil field services business. To maintain our leadership position, we need a few more good people: people who can help us develop new technology to meet the changing needs of the energy industry; people with engineering capabilities who can help us apply that technology to solve very real problems; people who can design and build the complex equipment we use; and people who can help us manage our massive resources efficiently.

We'd like the opportunity to tell you more about Halliburton. If you miss our campus interviews, drop us a note asking for the brochure we've prepared that fully describes our career opportunities. Please write: Bill Baker, Halliburton Services, P.O. Drawer 1431, Duncan, Oklahoma 73533.



Here's how hydraulic fracturing works to improve oil production. Basically, fracturing is designed to increase flow capacity of tightly packed oil bearing formations. High pressure pumps inject thousands of gallons of specially prepared fracturing fluid into the producing formation, often at pressures exceeding 12,000 pounds per square inch.

The pressures force the formation to break open or fracture. Propping agents, usually specially graded sand, are injected with the fracturing fluid to hold the formation open after pressure is released.

Oil flows easily through the fracture to the well, making many wells that otherwise would have never been drilled economic producers.



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At GE, you'll be handed important assignments right from the start. You can do as much of the job as you're capable of doing. If you need help, it's there. If not, nobody butts in.

Here's the kind of thing we're talking about; some recent examples of jobs handled by new GE engineers:

1. *Charles P.* Aerospace systems manufacturing. Develop and document a direct numerical control system.

2. *Steve O.* Design engineering. Design test equipment for attitude control system of new communications satellite.

3. *Norma L.* Steam-turbine manufacturing. Investigate, analyze and obtain funds for solution of shop problems.

4. *Stephanie B.* Medical systems service engineering. Installation and test of new hospital radiographic and fluoroscopic x-ray system.

5. *Mel D.* Field engineering. Appraisal load testing of low and medium-voltage switchgear and power transformers for utility and industrial applications.

There's a good reason GE hands people like that — like you — real work assignments. It's the best way to develop the skills you will need throughout your career. You develop initiative and creativity. And responsibility. And GE also knows there's little to match the glow you feel when you make an important contribution.

You can make your contribution in just about any field of engineering at GE. We're that diversified in disciplines.



If you like the kind of challenge and responsibility that GE offers, we'd like to hear from you. Send for our free careers booklet. Just write:
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