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Meteorite research . . . page 15

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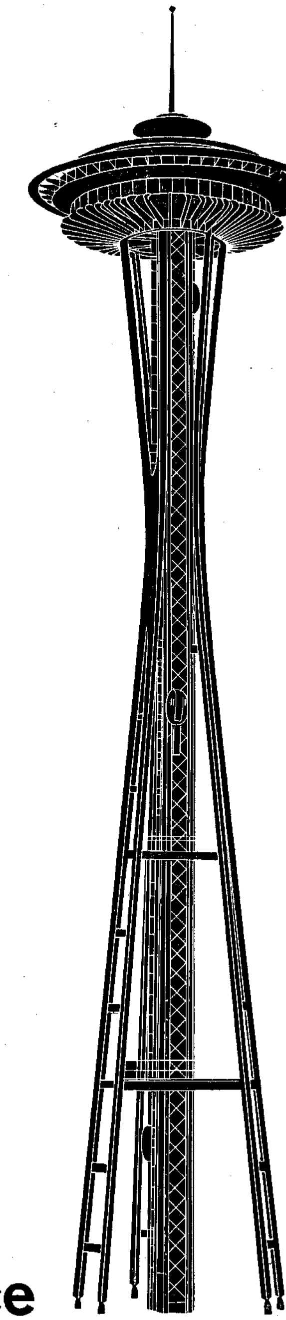

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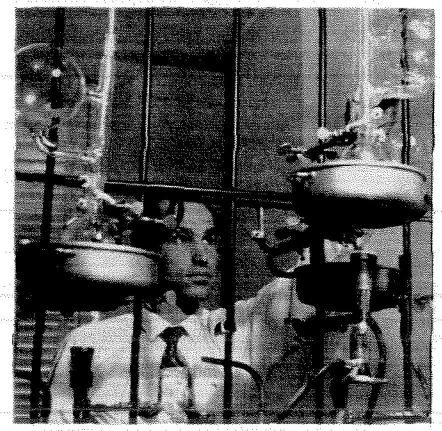

On Our Cover

Egon T. Degens, assistant professor of geology, does a chemical analysis on organic matter in meteorites. The glassware represents a set of evaporation lines for distilling large quantities of acids, organic solvents, and water – which are used to extract various types of organic constituents from meteorites.

A number of scientists are convinced that meteorites which flash into the earth from outer space contain remnants of extra-terrestrial life. When Dr. Degens recently received some meteorite samples, he decided to try to prove or disprove this theory. On page 15, the results of his experiment appear in "Meteorite Research."

Solomon W. Golomb,

author of "Genetic Coding" on page 9, is assistant chief of the communications systems research section at Caltech's Jet Propulsion Laboratory, and lecturer in electrical engineering at Caltech. A graduate of Johns Hopkins University, he received his MA (1953) and PhD (1957) from Harvard University.

Dr. Golomb became interested in genetic coding in 1956, shortly after he came to JPL, and has collaborated with members of the Caltech biology division and other mathematicians in the studies of genetics relating to information theory, combinatorial analysis, and coding theory. Dr. Golomb's article is based on a talk he gave at a joint Biology-Electrical Engineering seminar held at Caltech on January 10.

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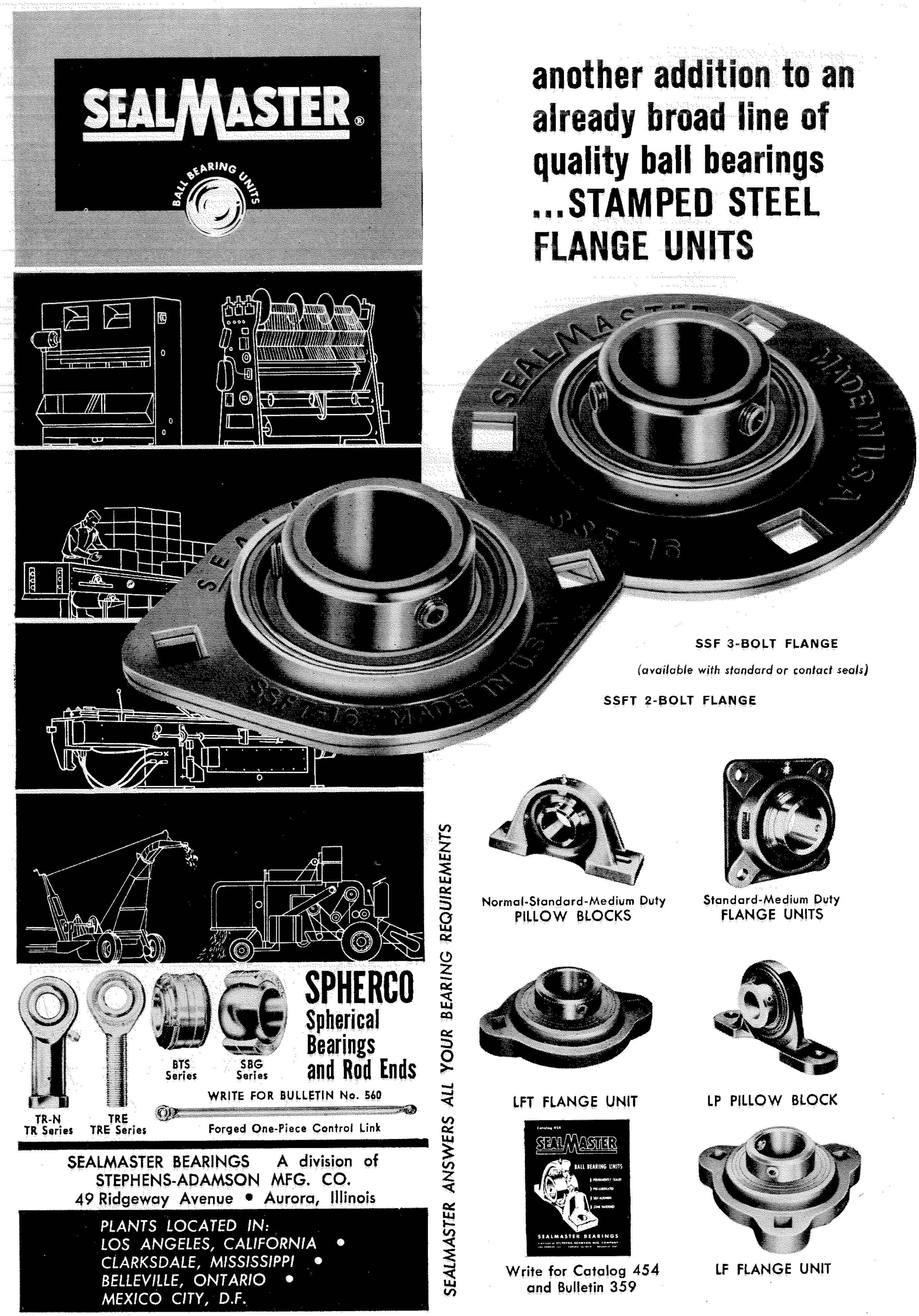
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Books

Statistical Mechanics

by Norman Davidson
McGraw-Hill $14.50

Reviewed by Robert M. Mazo, assistant professor of physical chemistry

This book is intended as a text for a graduate course in statistical mechanics, the terminal course for those students who do not intend to specialize in the subject; in fact, it is the outgrowth of Professor Davidson's lectures in such a course at Caltech. It is an excellent text, well written and handsomely produced. Although the cost at first seems rather high, at 2.7 cents per page it provides excellent value for the money, as scientific book prices go these days.

The first third of the book reviews some background material and develops the statistical mechanics of independent particles. This encompasses the theory and practice of the calculation of thermodynamic functions from spectral data, and is the absolute minimum amount of statistical mechanics that every physical scientist should know. The theory is developed by the "method of the most probable distribution," which goes back to Boltzmann. Although more sophisticated and elegant approaches are mentioned, they are not pursued. This appears to be a pedagogically wise choice.

The remainder of the book discusses other applications, including the extension of the theory to systems of interacting particles. Many of these applications are fairly standard in books at this level, but it is a great merit of Professor Davidson's book that many are not. The wide scope of the applications can be illustrated by noting that at one point the student is asked to compute the noise in a simple photocell circuit, while at another he is asked to solve a problem having to do with the configuration of polypeptide chains in solution.

Professor Davidson has coined a new word in this volume; he calls the (hypothetical) objects which obey the statistics of distinguishable particles "boltzons." Indeed, his lively personality and sense of humor are evident throughout. (See, for example, the footnotes on pages 374 and 425.)

Statistical Mechanics is a very worthwhile addition to the growing list of texts on the subject. The student who masters its contents will be well prepared indeed.

Qualitative Elemental Analysis

by E. H. Swift and W. P. Schaefer
W. H. Freeman and Company . $6.75

This volume – by Ernest Swift, chairman of the division of chemistry and chemical engineering; and William Schaefer, instructor in chemistry – puts between hard covers the system of qualitative analysis that has been used in freshman chemistry at Caltech for the past eight years. The system is a simplified form of one developed during the war for the Army Chemical Corps by Professors Swift and Niemann.

This system departs from most conventional qualitative analysis schemes in that the major separations are designed to correlate with the fundamental properties of the elements, and therefore with their electronic structures and positions in the periodic table. The authors believe that such an approach "offers certain unique potentialities for teaching descriptive inorganic chemistry and the principles of chemical reactions."

The Last Problem

by Eric Temple Bell
Simon and Schuster $4.95

Reviewed by Lance Taylor '62

The Last Problem, the last book by the late Caltech mathematician, Eric Temple Bell, is officially a history of the mathematical ideas that led to the famous Last Problem of Pierre Fermat: "To prove or disprove that if n is a number greater than 2, there are no numbers a, b, c such that $a^n + b^n = c^n$."

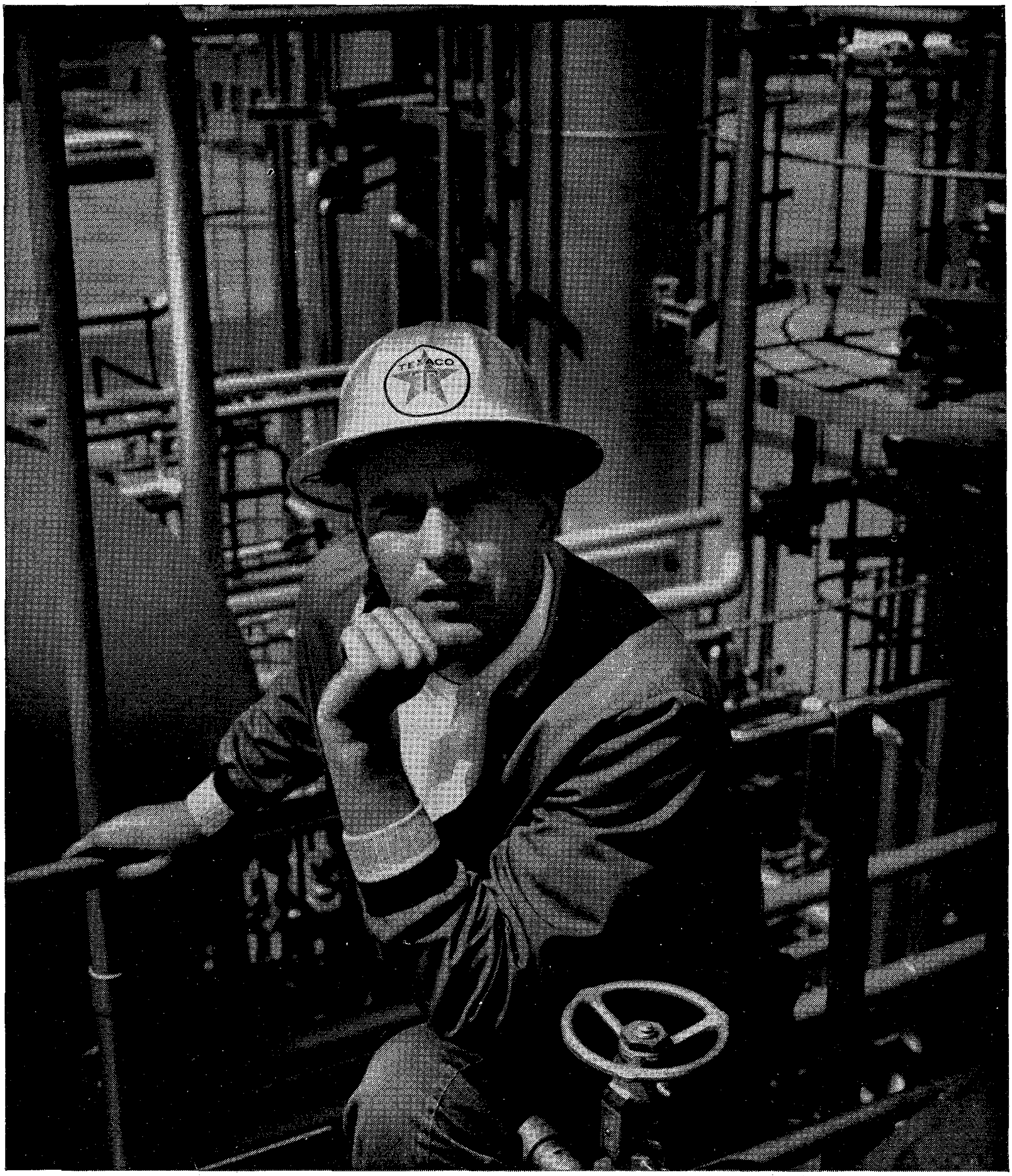
Actually, *The Last Problem* is nothing like what it is officially supposed to be. It is an uneven but fascinating combination of what might well be two entirely different volumes – one being a sort of pocket history of the theory of numbers, and the other being a set of sarcastic observations by a canny Scotsman on men in general and the history of the world in particular.

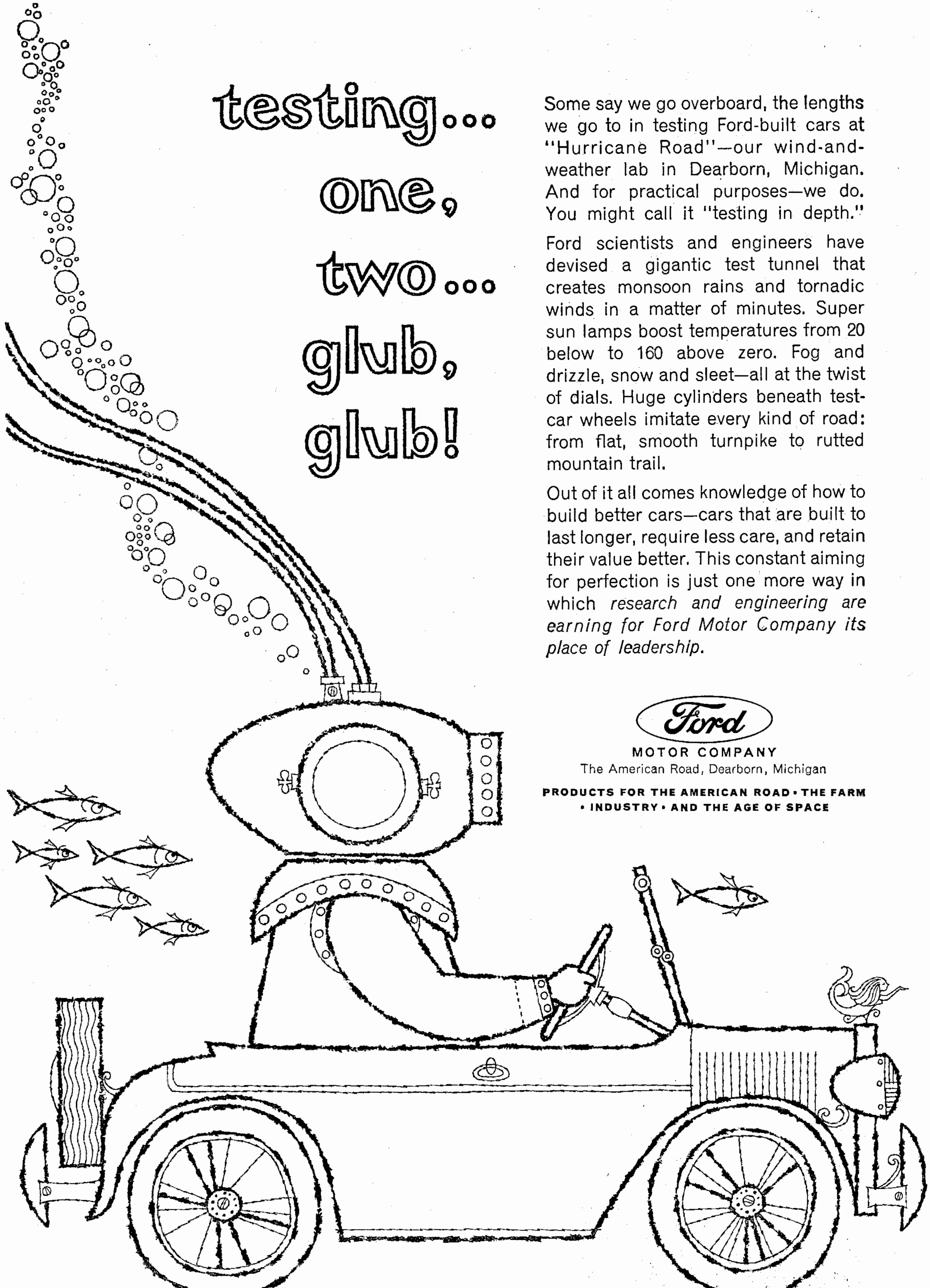
What Bell does is devote a chapter or so to one "culture" or "civilization," like Babylon or early Alexandria. For each culture, he then spends about half his time talking about its history and rulers, and the other half talking about its mathematics, especially that part relating to number theory and the Fermat problem. Thus, he devotes 30 pages to Babylon, 15 of these to mathematics, and the other 15 to random topics in Babylonian history like temple prostitution or the cleverness of the Babylonians in boiling their river water.

Following this method of history through juxtaposition, Bell carries his saga of numbers from early Mesopotamia up through the 17th century France of the curious Fermat. He weaves, more or less, a consistent history of number theory – providing the reader is very diligent in pursuing all the various Celebrated Theorems of eminent and long defunct mathematicians which are scattered sporadically through the book.

Bell's success with social commentary is a bit less lustrous, however. What he says is funny, most of it, and some of it is even to the point (judging from a poor historian's knowledge), but it still doesn't quite fit in with the mathematical aim of the book. If you are interested in a history of the Fermat Problem, do you really care that much about funny remarks about Caesar and Cleopatra (especially since George Bernard Shaw made the same remarks, only funnier, some years ago)? On the other hand, if you are interested in a satiric view of history, why not look in *1066 and All That*, and forget about mathematics?

All of which is not to say that *The Last Problem* doesn't have merits, which it does. However, for all its wit and for all of its interesting and wryly-presented mathematics, *The Last Problem* is still a tour de force that fails.

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ENGINEERING AND SCIENCE
April 1962, Volume XXV, No. 7

GENETIC CODING

A mathematician considers the problem of how genetic information is encoded for transmission from parent to offspring.

by Solomon W. Golomb

How is genetic information encoded for transmission from parent to offspring? It has been known for many years that the vast amount of information required to specify a complete organism is somehow embodied in the chromosomes of each of the cells of that organism. The occurrence of such probabilities as $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ in Mendelian genetics already suggests an underlying *discrete* genetic mechanism. However, it has only been during the past dozen years that significant progress has been made toward explaining how this information is stored. Specifically, it has been demonstrated that it is not the protein matter in the chromosomes, but rather the nucleic acid, a different type of compound, which bears the genetic information.

The nucleic acid in the chromosomes is a type called *desoxyribonucleic acid*, or *DNA* for short. The DNA occurs in long strands which are in fact known to be paired helixes. Each strand may be regarded conceptually as a long segment of punched tape, in which four types of notches are punched to constitute a message. Chemically, these "notches" are four distinct side-groups, called *nucleotides*, which are attached linearly to the DNA stalk, at regular intervals. Thus the DNA strand is a message written in a four-symbol alphabet, where typically there are several thousand symbols per strand of DNA, and several thousand strands of DNA in the various chromosomes which make up the complete genetic blueprint of the organism.

Mathematically, the four symbols in the genetic code may be designated A, C, G, and T, the initials of *adenine, cytosine, guanine,* and *thymine,* the names of the *bases* corresponding to the four nucleotides. In some organisms the only nucleic acid used is single-stranded RNA (ribonucleic acid), but in most cases, double-stranded DNA contains the genetic information. In the paired strands of DNA, one member of the pair is clearly redundant, since A in one strand is always opposite T in the other, while C in one strand is always opposite G in the other, and conversely. It is believed that each strand serves as a template for the manufacture of the other, and that every time the cell divides, the paired DNA strands all separate, and replicate by the simple expedient of attracting the "complementary" nucleotides needed for the second strand.

To recapitulate, genetic information is stored on an organic tape called DNA, with the data inscribed using the four-symbol alphabet of A, C, G, T. By pairing a "positive" with a "negative" copy of the tape, when cell division occurs, the positive makes a new negative, and the negative a new positive, thus allowing replication to continue indefinitely.

Many years ago the mathematician John von Neumann described the design of a computer-like machine which would be capable of making duplicates of itself. It contained a punched tape with full instructions for building just such a machine, and the final instruction was to duplicate the tape. Von Neumann didn't know it at the time, but nature was already *using precisely this technique.*

Knowing that there is a coded message, the next question is: What is the content of the information which has thus been encoded; or, in operational terms, how is the tape "read," and what is built on the basis of the blueprint? By and large, the activities in which a cell engages consist mostly of the manufacture of proteins out of the basic sub-protein building blocks known as *amino acids*. There are 20 or more distinct amino acids which may be used for this purpose. It has been widely conjectured that there is a direct interpretation, or decoding, whereby several consecutive nucleotides of the DNA uniquely specify the occurrence, when decoded, of one particular amino acid.

(Actually, the nucleic acid RNA plays an important intermediate role. It appears that the true sequence of events is that the DNA message is first replicated onto "template RNA," a sort of temporary storage, and then shorter strands of "soluble RNA" perform the task of locating the amino acids, and of aligning them along the RNA template. These matters will be brushed aside rather high-handedly as "mechanical details" during the remainder of this discussion, with the RNA alphabet of A, C, G, U being treated as equivalent to the DNA alphabet of A, C, G, T.)

A basic tenet of "orthodoxy" is that the code used is the same for all terrestrial organisms. This tenet is supported by the fact that all known earthly creatures confine themselves to the same 20-odd amino acids as basic building blocks for protein, whereas if the code were evolving along with the life forms using it, other amino acids which are just as simple chemically as many of those used would be expected to come into the picture.

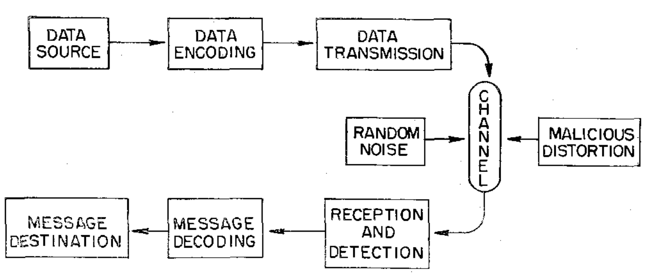
The viewpoint of communication theory

Any discussion of communication theory begins with a diagram of a general "information system" (below).

In the case of genetic information, the "data source" may be regarded as any conceptually complete description of the organism in question. The "data encoding" is the representation of this description in the form of DNA tape. The "data transmission," the "channel," and the "reception and detection" then refer to the sequence of steps whereby the DNA message is transferred to template RNA, and thence to soluble RNA, up to the point where the correspondence between nucleotides and amino acids is established. The "message decoding" is the formation of the protein molecules specified by the original DNA sequence, and the "message destination" is the new organism which results. If desired, one may "close the loop" by considering successive generations of this process, and in so doing, a "natural selection filter" could be inserted to incorporate Darwinian evolution into the model.

Although the diagram below shows "random noise" entering only into the "channel," as in radio communication systems, it is more realistic to recognize that errors can occur at every stage of reading information out of one box and into the next, and even when information is sitting quietly in storage. The "malicious distortion" (or "jamming") box can be interpreted as virus activity, where the intent of the organism to replicate itself is subverted by some operation on the coded sequence, into making many replicas of the virus instead.

General Diagram of an Information System



By examining this diagram of an information system, one may hope to determine both necessary and optional features of the genetic code, which could then be tested experimentally. A partial list of "desirable coding features" would include:

1. Efficient Use of the Channel
2. Self-Synchronization
3. Error Correction
4. Anti-Jamming
5. Convenient Decodability

It must be possible to recover the encoded information completely, unambiguously, and by means of the available chemical machinery. Another essential feature is *synchronization.* There must be some reliable method of deciding when the code group for one amino acid has ended and the next begun. On the other hand, *efficient use of the channel* is an optional feature. The information theory methods of Claude Shannon, Robert Fano, and David Huffman of MIT would suggest short code words for the frequent amino acids and longer code words for the infrequent ones. However, the decision as to relative frequencies would have been made so early in evolutionary history that it might bear little or no relation to the amino acid frequencies in organisms currently available. Moreover, the problems of data handling created by non-uniform word length could easily outweigh the advantages of a shorter average message length. The possibility that the genetic code incorporates features to combat random mistakes *(error correction)* or to combat malicious distortion *(anti-jamming)* is certainly mathematically intriguing, but far from being an essential requirement, a priori, of the genetic code.

If there is a valid function for the mathematician in such a field as this, and I firmly believe there is, it is to propose mathematical models for the biological situation, to deduce consequences and properties of these models, and to submit the consequences and properties for verification or refutation by the experimentalist. Then, by retaining those properties verified, and discarding those refuted, more and more precise models can be constructed, until the process finally converges to a mathematical model which is a completely faithful replica of the experimental situation. As a matter of fact, the history of the genetic coding problem actually exhibits such an interplay between models proposed and crucial experiments to reinforce or discard them.

Historical background

It was the cosmologist George Gamow who first proposed that it might be reasonable to formulate hypotheses concerning the nature of the DNA-amino acid coding based primarily on mathematical considerations of what the code is expected to do (i.e. its function), even in the absence of extensive experimental data about the physical *structure* of the nucleotide sequences. The first assumption Gamow introduced, back in 1954, was "uniform block length," viz. that the same number of nucleotides should be used to code for each of the amino acids. Since with only 2 nucleotides there are only 16 possibilities, which falls short of the 20 or more amino acids actually involved, a minimum *block length* of 3 was suggested. However, there are 64 arrangements of 3 nucleotides, so that an additional constraint seems needed to get the number of possibilities back down again. Gamow suggested that 3 nucleotides were indeed used to code for each amino acid, but that the order of their occurrence did not alter the amino acid they produced. Thus, AAC, ACA, and CAA would all code for the same amino acid. (A code in which more than one code word stands for the same object is called a *degenerate* code.) Miraculously, or so it seemed, this leads to exactly 20 *distinct* amino acids that could be coded for – a highly plausible number. (The fact that it is all too easy to go from 64 words to 20 classes by imposing almost any arbitrary extra constraint has been a persistent curse in the history of this problem.)

Gamow's Code – 1954

1. AAA	11. GGA,GAG,AGG
2. CCC	12. GGC,GCG,CGG
3. GGG	13. GGT,GTG,TGG
4. TTT	14. TTA,TAT,ATT
5. AAC,ACA,CAA	15. TTC,TCT,CTT
6. AAG,AGA,GAA	16. TTG,TGT,GTT
7. AAT,ATA,TAA	17. ACG,AGC,CAG,CGA,GAC,GCA
8. CCA,CAC,ACC	18. ACT,ATC,CAT,CTA,TAC,TCA
9. CCG,CGC,GCC	19. AGT,ATG,GAT,GTA,TAG,TGA
10. CCT,CTC,TCC	20. CGT,CTG,GCT,GTC,TCG,TGC

Properties:

a. Uniform length (triplet code)

b. Overlapping

$$(\text{ATGCT}) \ldots = \begin{array}{l} \text{ATG} \\ \;\;\text{TGC} \\ \;\;\;\;\text{GCT} \end{array}$$

c. Totally decipherable (no nonsense)

d. No error detection or correction

Experimental Fate:

Nature does not use an overlapping code.

Gamow's degenerate triplet code was also an *overlapping* code. That is, after using the first, second, and third nucleotides to describe *one* amino acid, the *next* amino acid is described by the second, third, and fourth nucleotides. An overlapping code of this sort implies strong constraints on the types of transitions which can occur from one amino acid to the next, and it was possible to prove by experiment that enough different transitions do occur that no overlapping triplet code could possibly be involved. This was in fact proved by Caltech Research Fellow Sydney Brenner. The main contribution by Gamow was, thus, not that he solved the problem, but that he recognized and stated it.

It is interesting to note that Gamow's code was *totally decipherable.* That is, no matter what sequence of nucleotides is written down, it will always have an interpretation. It is not possible to write a "nonsense" message. Consequently, also, if an error occurs, the erroneous word will be interpreted without any possibility of error correction.

The main reason that Gamow suggested an *overlapping* triplet code was to avoid the synchronization problem which arises with a non-overlapping code. That is, if ATA and CTG are code words for two consecutive amino acids, there is the danger that, when juxtaposed, . . . ATACTG . . . also contains the triplets TAC and ACT, which might code for *other* amino acids, and if these amino acids happened to form *first,* by whatever chemical process is involved, then the sense of the genetic message would be lost.

Another solution to the synchronization problem was offered by F. H. C. Crick in 1956, using a non-overlapping triplet code with what Crick called the *comma-free* property. A code is *comma-free* if when a b c and d e f are two words of the code (distinct or not), then none of the "overlap" words which appear when the comma is dropped from a b c, d e f (such as the words b c d and c d e) are words of the dictionary. For example, if the words BAT and END were in a comma-free dictionary, the words ATE and TEN could not also be in the dictionary (because of bATEnd and baTENd). Also, no word of the type XXX could be in the dictionary, because of the sychronization problem created by . . . XXXXXX . . . .

Using three-letter words formed from a four-letter alphabet, Crick showed that the maximum number of words in a comma-free dictionary is 20, and exhibited examples of such dictionaries.

Crick's Code – 1956

1. ACA	6. CGA	11. ATG	16. CTT
2. ACC	7. CGC	12. ATT	17. GTA
3. AGA	8. CGG	13. CTA	18. GTC
4. AGC	9. ATA	14. CTC	19. GTG
5. AGG	10. ATC	15. CTG	20. GTT

Properties:

a. Uniform length (triplet code)

b. Comma-free (bat, end excludes ate and ten)

c. Non-degenerate (nonsense exists)

d. Detects numerous errors

Experimental Fate:

Since XXXX and even XXXXX occur in nature, the comma-free triplet hypothesis is false.

In 1956, at the instigation of Max Delbrück, Caltech professor of biology, Basil Gordon, Lloyd Welch and I obtained some general results of a mathematical nature about comma-free codes using k-letter words from an n-letter alphabet. Welch and I then applied these methods to the biological situation in greater detail in 1957, finding all possible comma-free dictionaries of 20 words with $k = 3$ and $n = 4$.

It was shown that in any message written from any such dictionary, the same symbol could not be repeated consecutively more than three times. When subsequent experimental data showed that nucleotides *were* repeated four and even five times consecutively in the DNA, it was clear that the comma-free triplet hypothesis was not valid – at least not in the form originally envisioned by Crick. (Mathematically, the "no four in a row" is rather profound while "no five in a row" is quite trivial. It is ironic that, experimentally, it was not much harder to observe the fives than the fours.)

On the basis of the best estimates available in 1960, I proposed a type of code dictionary consisting of 24 code words, each six symbols long, where the dictionary is both comma-free and maximally error-correcting. However, the recent experimental breakthrough appears to rule out most of the features of this code from further consideration.

Golomb's Code – 1960

1. TTTTTG	7. GTGGCC	13. AAAAAC	19. CACCGG
2. GCACTA	8. TTCAGC	14. CGTGAT	20. AAGTCG
3. GGATGT	9. TGGCAA	15. CCTACA	21. ACCGTT
4. TACTCC	10. TCAGAG	16. ATGAGG	22. AGTCTC
5. GATGGA	11. GGCACG	17. CTACCT	23. CCGTGC
6. GCTCAT	12. TAGATT	18. CGAGTA	24. ATCTAA

Properties:

a. Uniform length (sextuplet code)
b. Comma-free and orthogonal
c. Non-degenerate (nonsense exists)
d. Error-detecting and correcting

Experimental Fate:

Appears to conflict with experiments of Nirenberg and Ochoa, 1961.

Before turning our attention to the recent revolutionary developments in this field, it is appropriate to mention that many other models, some straightforward and some quite bizarre, had also been proposed for the genetic code during the past eight years. Even where there may have been no influence on the course of biological events, these studies have significantly enriched the literatures of information theory and of combinatorial analysis.

One particularly unusual hypothesis, advanced by a biologist, was that each code word should have the property of coding for any specified amino acid after at most a *simple* mutation – i.e., a change in only one of the symbols of the word. While this postulate has proved to be of no particular merit in genetics, it leads to the notion of "error-distributing codes," which are the precise opposite of the "single error-correcting codes" of information theory, and add considerable elegance to the entire subject.

Recent developments

On November 20, 1961, when I visited the Institute for Genetics in Cologne, I was given two items to read which had just arrived in the day's mail. One was a manuscript by Crick purporting to establish the triplet nature of the genetic code. The other was a glimpse at some partial results of Severo Ochoa of the New York School of Medicine, concerning the nucleotides which seem to be contained in the code words for certain of the amino acids (at least in *E. coli*). It is with such speed that the recent developments in this area have occurred.

Crick had experimented with one of the bacteriophages (bacterium-eating viruses) of the bacterium *E. coli*, and established, at least to his own satisfaction, that all the code words have length three (or, much less likely, some multiple of three), and that synchronization is achieved by starting at one end of the genetic tape, and reading off three symbols at a time. Ochoa, on the other hand, had been extending the work of Marshall Nirenberg of the National Institutes of Health, who had reported several months earlier that the RNA sequence UUUUUU . . . inserted into *E. coli* produced the protein whose amino acid sequence was phenylalanine-phenylalanine-phenylalanine . . . . Ochoa has taken *random* mixtures of various nucleotides, and observed what different amino acids were produced, without learning the exact lengths of the code words, or the specific order of the nucleotides within each code word.

For example, a random mixture of U and C was "decoded" by the *E. coli* machinery, and found to contain not only phenylalanine (presumably from UUU), but also proline, leucine, and serine. Similarly, while AAAAA ... was found to produce *nothing*, a random mixture of U and A yielded tyrosine and isoleucine as well as phenylalanine. A very similar set of experiments by Nirenberg and Matthaei gave largely the same results. Assuming a triplet code, it was even possible to deduce that proline is produced by one U and two C's (in the proper order), while serine is coded by two U's and one C. Some amino acids, notably leucine, definitely seemed to have more than one corresponding code word. The experimental evidence thus leans toward a partially degenerate, triplet code. It is remarkable that Gamow's original guess (page 11) had so many of the correct properties!

A summary of the amino acids and some of the nucleotide combinations which seem to produce them (based on the Ochoa and the Nirenberg-Matthaei data) is given in the following table;

Apparent Correspondence Between RNA Bases and Amino Acids

Amino Acid	*RNA Bases*
Alanine	UCG
Arginine	UCG
Aspartic Acid	UAG
Asparagine	UAA,UAC
Cysteine	UUG
Glutamic Acid	UAG
Glutamine	UCG
Glycine	UGG
Histidine	UAC
Isoleucine	UUA
Leucine	UUC,UUG,UUA
Lysine	UAA
Methionine	UAG
Phenylalanine	UUU
Proline	UCC
Serine	UUC
Threonine	UAC,UCC
Tryptophan	UGG
Tyrosine	UUA
Valine	UUG

For several important reasons, this is not yet the final answer to the coding problem. For one thing, several of the entries will probably change before the list will be accepted as authoritative. More important, the *order* of the nucleotides in each code word remains to be determined. Finally, of the 64 possible triplet code words, a large proportion have not yet been properly tested to see what, if any, amino acid they incorporate.

There is another important kind of data available on the codeword structure; this was obtained when Heinz-Günter Wittman of the Max Planck Institute in Tübingen, Germany, experimented with tobacco mosaic virus (TMV). Mutations were included in the RNA of TMV using nitrous acid, which has the effect of changing C into U and A into G. Then the changes in the amino acid sequence of the "coat protein" of TMV were observed. The mutational transitions are summarized at the right, where the *numbers* on the arrows indicate the frequency with which the particular transition was observed. Note especially how well the part involving proline, leucine, serine, and phenylalanine agrees with the table above, which finds proline, leucine and serine produced from mixtures of C and U, and phenylalanine from poly-U. The rest of Wittman's results can also be readily reconciled with the table.

Proposed experiments

a. One of the crucial features which would distinguish between possible coding systems is the amount of nonsense present. A quantitative comparison of the *amount* of protein produced by either poly-U or poly-C as opposed to random poly-UC (say in equal proportions of U and C) would give very different answers for different coding schemes. The *lengths* of the poly-peptides formed would be informative *if* it is assumed that a nonsense word breaks the chain. The total quantity of protein made would be informative even if the amino acid chain "closes ranks" where nonsense has occurred.

b. Arthur Kornberg, biochemist at the Stanford Medical School, has made the DNA sequence ATATAT ..., which can be used to make the RNA sequence UAUAUA ... . In any triplet code, this groups off as (UAU) (AUA) (UAU) (AUA) ..., and the protein formed may consist of alternating tyrosine and isoleucine. However, it is conceivable that only one amino acid, or perhaps nothing at all, would be produced. There are certain technical difficulties associated with this experiment, but if performed, its outcome would certainly shed considerable light on the entire problem.

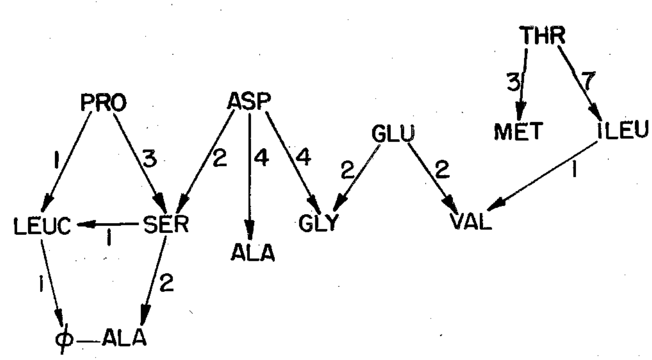
c. If poly-G could be made, it would produce "nonsense" in certain coding schemes but not in others. *This experiment would definitely reduce the* number of possibilities. It might be possible to attach a short poly-G chain to a long poly-U chain, and then observe what prefix (if any) is attached to the resultant poly-phenylalanine stalk.

d. All the code words in the table at the left contain at least one U. It is important to determine whether any of the 27 triplets *not* containing U code for amino acids.

Outlook for the future

If we make a few modest assumptions, the present state of knowledge (or ignorance) concerning the genetic code can be assessed quantitatively. Accepting Crick's conclusion that every code word has three letters, and agreeing that there is only one genetic code in general use, the problem may be formulated thus: Each of the 64 possible *trinucleotides* (triples of RNA symbols, such as AGA and UAC) must be identified either with one of the 20 or so amino acids,

Wittman's Results



or with "nothing." Thus, for each of 64 possible code words, a decision must be made into which of 21 categories to assign it.

Each such assignment represents $\log_2 21 = 4.392$ bits of information, and the entire problem therefore involves the specification of $64 \log_2 21 = 281.1$ bits. Combining the results of Ochoa, Nirenberg, and Wittman, approximately 80 of these bits are already specified. (Knowing that UUU makes phenylalanine immediately supplies 4.392 bits, as does knowing that AAA makes nonsense. Obviously *less* than 4.392 bits is obtained from the fact that at least one of the six triplets UUA, UAU, AUU, UAA, AUA, AAU makes isoleucine.)

At present, then, there are some 200 bits of uncertainty remaining about the genetic code, or 2^{200} ways of filling in the code dictionary consistent with the experimental data at hand. Ultimately, it is hoped that it may be possible to test all 64 triples "directly," for example by attaching each triple in turn as a prefix to a long poly-U chain, and seeing what amino acid (if any) occurs at the start of the resulting polyphenylalanine chain.

Until then, however, it seems worthwhile to make various assumptions regarding the economy, simplicity, optimality, or extremalness of nature's strategy, and explore the consequences of such assumptions insofar as completing the code dictionary by interpolation or extrapolation from the existing data is concerned. Simple experimental tests should then be devised to confirm or refute the assumptions. It would probably be advantageous to write a digital computer program to store and collate all the experimental data as they become available, thereby reducing the clerical effort required to determine whether or not new models for the code dictionary are consistent with the data of various kinds already established.

A useful geometric model for the coding problem is a 4x4x4 cube, containing 64 cells corresponding to the 64 triplet code words.

The Four Layers of the 4x4x4 Cubic Model of the Genetic Code

UAU	CAU	GAU	AAU
UGU	CGU	GGU	AGU
UCU	CCU	GCU	ACU
UUU	CUU	GUU	AUU

UAC	CAC	GAC	AAC
UGC	CGC	GGC	AGC
UCC	CCC	GCC	ACC
UUC	CUC	GUC	AUC

UAG	CAG	GAG	AAG
UGG	CGG	GGG	AGG
UCG	CCG	GCG	ACG
UUG	CUG	GUG	AUG

UAA	CAA	GAA	AAA
UGA	CGA	GGA	AGA
UCA	CCA	GCA	ACA
UUA	CUA	GUA	AUA

Fortunately, 4x4x4 models of this type are available in toy stores as "boards" for three-dimensional tic-tac-toe! It is clear that the biological problem is to decide which amino acid to put in each of the 64 cells. (Thus, "phenylalanine" should be written into the cell indexed UUU.)

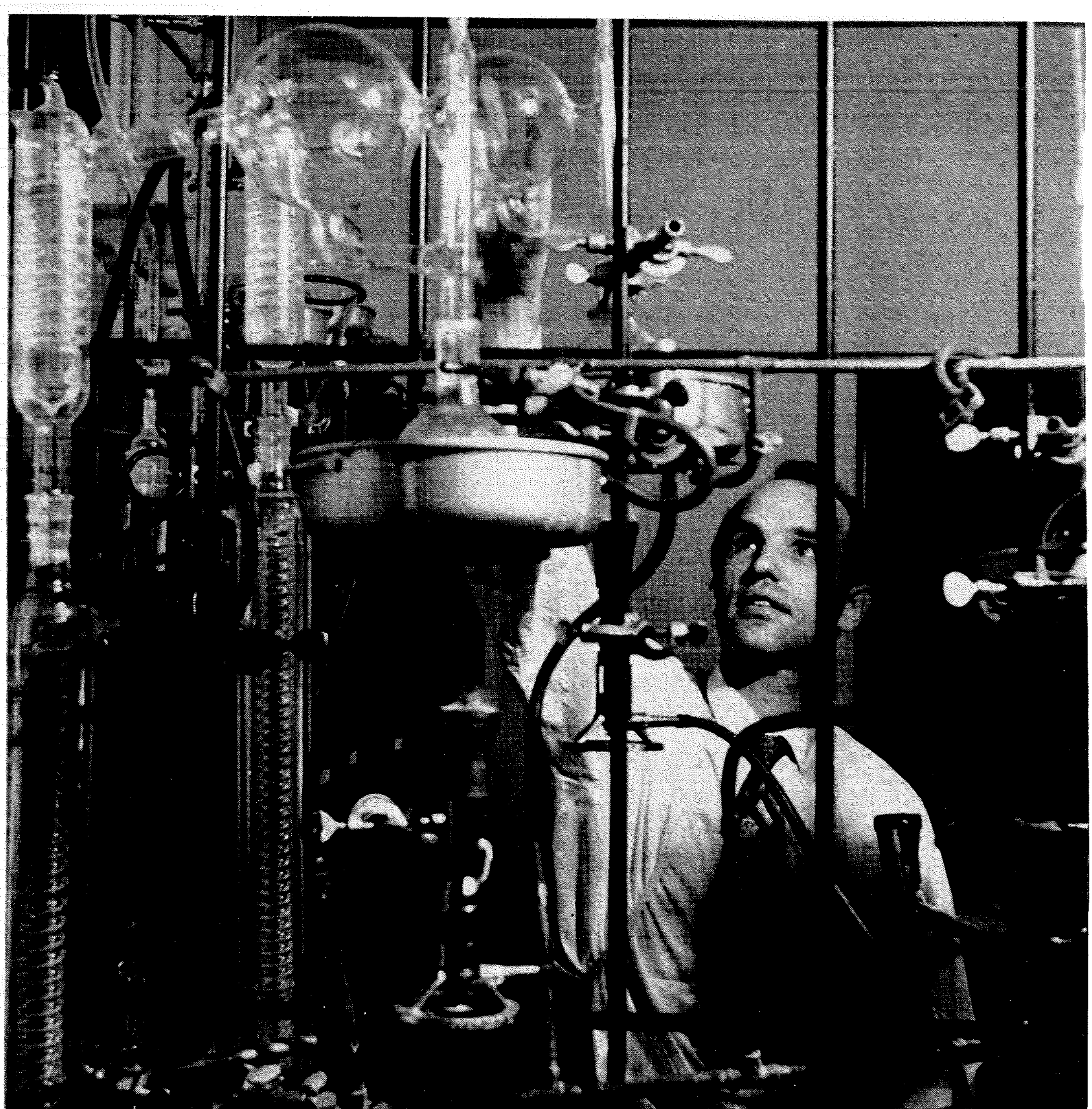
The code words not containing U form a 3x3x3 sub-cube. The cube above can be partitioned into eight 2x2x2 sub-cubes, each containing permitted paths for Wittman's nitrous-acid-induced mutations. Considering the 4x4x4 cube as a three-dimensional chess board, two cells differ by a "single mutation" if and only if a *rook* can go from one cell to the other in a single move. In many ways, this geometric model significantly simplifies the problems of thinking about the genetic code.

The solution of the coding problem will not be the end of genetics research, any more than learning to read is the end of education. In fact, the deciphering of all the code words for all the amino acids represents somewhat less than learning to read, in that it does not include the "punctuation." That is, in addition to code words for the amino acids themselves, there must be encoded instructions to "start protein formation," "stop protein formation," and so forth.

In the terminology of the digital computer field, the storage in the nucleic acid includes *program* as well as *memory*. Wittman's study of tobacco mosaic virus indicates that significantly less than half of the nucleotides in TMV are involved in coding for the "coat protein." There is strong evidence that the nucleotide sequence has significant *regulatory* functions, so that it determines not only what proteins can be produced, but how much of each protein to make, and when. In particular, when certain nutrients are absent from the medium, a bacterium produces the necessary enzymes (proteins) to synthesize these nutrients; but the presence of the nutrients inhibits the production of the enzymes. A complete understanding of the "digital control system" involved in protein synthesis is still many years off, and is sure to engage the serious attention of an ever increasing number of microbiologists.

Looking far into the future, I envision a keyboard with the symbols A, C, G, and U. An operator will type out any sequence of his liking, feed it into a "tape-reader" for processing, and out will crawl the newly designed organism. Later, a more advanced model keyboard, using a "compiler language," will enable the operator to type directly in terms of amino acids and "punctuation marks." I must admit that biologists who understand the technical difficulties are loath to share this vision, but an unconcern for details of implementation is one of the chief advantages of being a mathematician.

As recently as a year ago, the possibility of putting borrowed or synthetic RNA into a convenient organism to obtain the corresponding protein seemed remote indeed. Yet Nirenberg put the RNA strand poly-U into *E. coli*, and got out poly-phenylalanine, a protein almost certainly never made *in vivo* before. Recently, experiments have shown that RNA strands borrowed from many organisms can be inserted into *E. coli* to produce their usual enzymes. This wasn't quite how Dr. Frankenstein went about it, but I believe the implications are even more remarkable.



METEORITE RESEARCH

A number of scientists are convinced that meteorites which flash into the earth's atmosphere from outer space contain remnants of extra-terrestrial life. When Egon T. Degens, assistant professor of geology at Caltech, recently received some samples of meteorites from Drs. H. E. Suess and G. Goles at the Scripps Institution of Oceanography in La Jolla (half of their precious supply) he decided to try to get some data which would prove or disprove this theory.

Meteorites that hit the earth are believed to be strays from a belt of countless thousands of them, called asteroids, that orbit around the sun between the planets Mars and Jupiter. One theory is that they are fragments of another planet that was somehow

In studies on meteorites, Dr. Degens wears a protective gas mask as he makes a chromatographic analysis of biological material in a tank containing highly poisonous solvents. This analysis separates one kind of biological material from another.

shattered. Using radio-isotope age-dating techniques, Caltech geochemists have determined that all the meteorites that have been found so far are about 4½ billion years old.

The samples that Dr. Degens received were two different kinds of meteorites – one known as the Bruderheim chondrite that fell on frozen ground in Canada in 1960, and the other called the Murray carbonaceous chondrite that fell in Kentucky in 1950. (Meteorites get their names from the areas in which they are found.) Both are so porous that bacteria could easily enter any part of them.

The meteorites have a hard, thin coating of melted rock, which presumably developed from friction when they entered the earth's atmosphere. The coating was cracked because of the subsequent quick cooling or impact with the earth. Microbes could be sucked into the meteorites through the cracks, along with air rushing in to fill the vacuum immediately or shortly after entering the earth's atmosphere. Also changes in barometric pressure may produce something like a "breathing" effect, flushing certain constituents into or out of the meteorites.

In the Caltech geology laboratory, small pieces of the center parts of the meteorites were ground into about a tablespoon of fine dust. The samples were not sterilized because they had already been handled without any such precautions.

With his co-worker, H. J. Reuter, postdoctoral research fellow at Caltech, Degens developed a special micro-analytical technique for examining this material. By chromatographic analysis, the scientists extracted and separated a complex of compounds that only living things could have synthesized in this particular combination. These were free and combined amino acids, amino sugars, nucleic acids, and simple sugars.

The fact that the *same* biological residues were found in both samples is significant. From the mineralogy of meteorites it is reasonable to assume that chondrites have been subjected at one time in their long history to high temperatures – as high as 1,800° F.; while the carbon-containing chondrites remained fairly cool at all times – no higher than 200°.

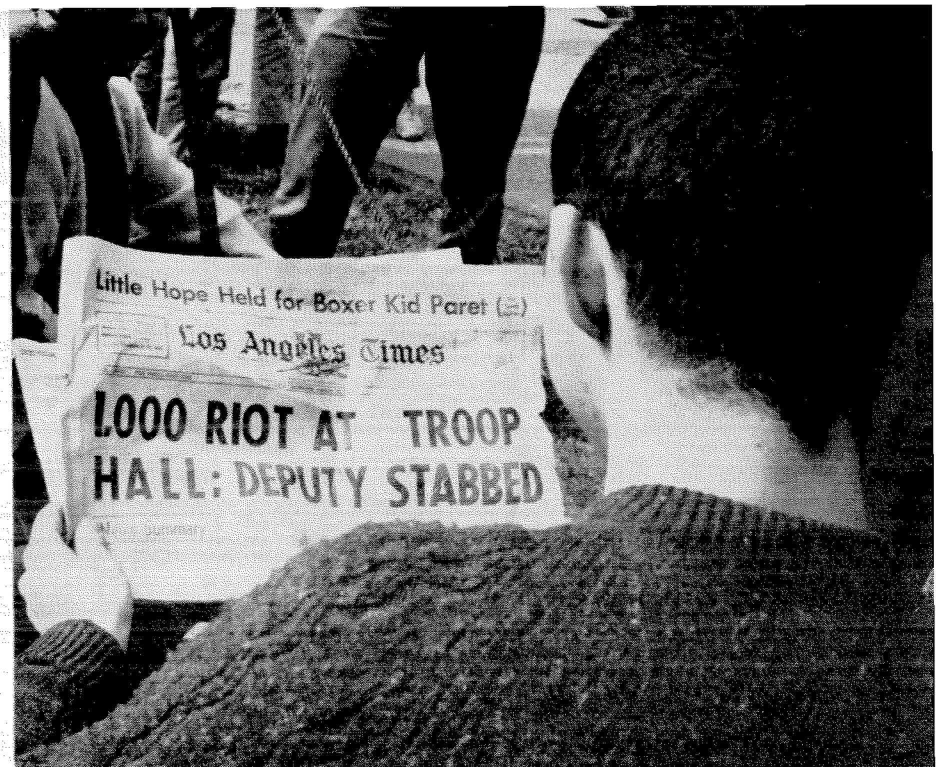
If the biological material in the Bruderheim meteorite is considered to be a form of extra-terrestrial life, then it must be assumed that the material existed after the meteorite went through exceedingly high temperatures. And when the presumed long history of the two genetically different meteorites is taken into account, the similarity of the biological matter found in the two becomes even more puzzling.

After the biological material was extracted from the specimens, the two residues of meteoritic dust were left in dishes covered with filter paper, through which microbes could easily pass. This dust had been thoroughly leached of all delicate biological material originally contained in the meteorites, yet in three weeks, when the dust was re-examined, new biological material of the same type was found – certain evidence of a recontamination.

This research suggests that both meteorites – as well as three others from different parts of the world which have been tested in the same way – represent an excellent environment for the growth of micro-organisms. Apparently the peculiar chemistry of meteorites, in terms of sulphur content, high iron concentration, or the various oxidation states of heavy metals, stimulates the activity of certain terrestrial microbes, and even accelerates the production and accumulation of terrestrial biogenic organic matter.

It may be of interest to add that the organic spectrum of chondrites strikingly resembles the one of oxidizing recent marine sediments, but differs considerably from any other spectrum obtained from any ancient or recent rocks.

Although it would undoubtedly be more attractive and exciting to prove that extra-terrestrial life rides in on meteorites from outer space, the present facts point more in the direction of a simple terrestrial contamination.



Special edition of the Los Angeles Times *(one copy – privately printed) carries advance (and inaccurate) report of the campus riot.*

MORE TALK LESS ACTION

While the Institute's Board of Trustees held its second national meeting on the campus on April 2, just a few short yards away the student body (and a goodly part of the faculty) attended a combination protest rally and riot against parking problems in particular and administrative injustice in general.

The seeds of the demonstration were sown in the early hours that morning by a small band of graduate students calling themselves the S.P.C.A. ("Society for the Prevention of Cruelty to Arnold"). They wished to protest the allegedly unjust expulsion of Physics Grad Student Arnold Lesikar from the graduate houses for violation of campus parking regulations. Their handiwork was seen by those arriving for work and classes early in the morning in the form of a lean-to tent complete with cot, desk, and beach umbrella, purporting to be Mr. Lesikar's new home.

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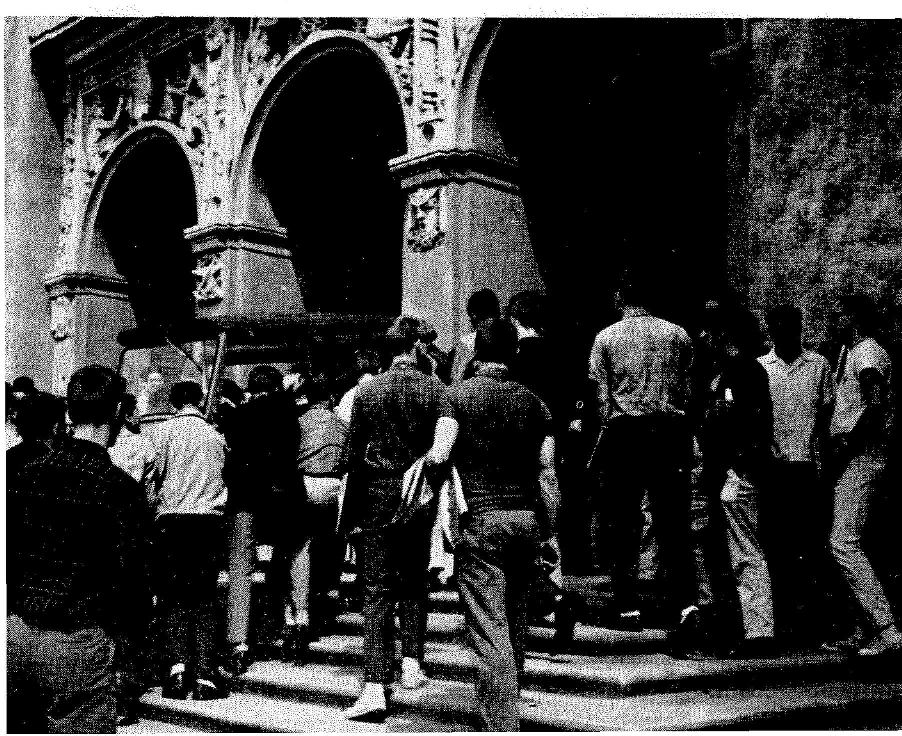
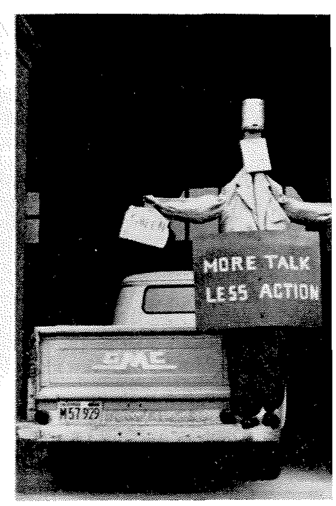




Pasadena police officer and the student body president exchange greetings.

Sleepy remnants of the same group distributed copies of an original "song of protest" entitled "Arnold's Looking-for-a-Home, Worried, Blues." The song, together with a sign emblazoned across the front of Throop, exhorted one and all to come to the parking protest rally at 1 p.m.

An undergraduate, studying the song, was overheard to remark, "I think we're being manipulated by the grad students," a statement typifying the quickness of insight and the intelligence of the Caltech student body. However, serious doubts as to who was manipulating whom arose almost immediately when a small Fiat drove up. Its occupants, a considerable fraction of the Blacker House residents, emerged and carried the vehicle up the steps of Throop. It disappeared into the building amid screams from startled secretaries, only to emerge moments later, thwarted by the thoughtless failure of the administration to provide student parking inside.

In a desperate attempt to proceed according to plan, the S.P.C.A. led the crowd in song, followed by a vegetable riot (consisting of everyone shouting the name of a randomly-selected vegetable). The resulting noise was gratifyingly consistent with the S.P.C.A. credo displayed on a large sign: "MORE TALK LESS ACTION."

After this incident, events diverged rapidly. A crowd of students careened through the upper halls of Throop yelling and pounding on doors. A large B. & G. pickup truck was carried up the steps; being too large to pass through the doors, it was left stranded between the pillars. George Green, the Institute's vice president in charge of business affairs, who seemed to be the focal point of the students' ire, was crucified in effigy, and one of the Institute's electric mail trucks was parked across his office door. Another such vehicle barely escaped the howling mob of students pursuing it across the campus when it inadvertently blundered into the proceedings.

After almost an hour of confusion, the members of the organizing group, overawed by the monster they had created, were breathing sighs of relief that peace and quiet were being restored when a Pasadena policeman arrived. Misinterpreting the basic good will of the onrushing crowd that greeted him he beat a hasty retreat, returning minutes later with a sizable part of the force. These gentlemen, after finally eliciting the story of the disturbance, kindly offered the use of their loudspeaker to continue the rally, but no one seemed to have anything further to say.

Shortly after 2:30, as the last disturbances dwindled away, an S.P.C.A. organizer was located in the bowels of Bridge Lab. "Just typing my application to MIT," he explained.

— *David Bowman '61*
Frank Snively MS '61
John Rogers PhD '61

Personals

1921

Alfred J. Stamm has been appointed Robertson Distinguished Professor of Forestry at North Carolina State College in Raleigh. He has been on the faculty there since 1959.

1925

Caryl Krouser, vice president of Courier Enterprises, publishers of newspapers in California and Arizona, has been named chairman of the board of the Home Income Plan Company of California, which deals with FHA and first and second mortgages. Caryl is also charter president of the Barstow Area Council of the Navy League of the U.S.

1932

Clark Goodman has resigned as vice president-technique of Schlumberger Limited to devote full time to consultation in the fields of nuclear and space sciences in Houston, Texas. He is also a consultant to the Department of Defense and the Joint Congressional Committee on Atomic Energy.

1935

Richard H. Jahns, PhD '43, chairman of the Division of Earth Sciences and professor of geology at Pennsylvania State University, has also been named associate dean of the College of Mineral Industries at Penn State. Dick transferred to Penn State in 1960, after 14 years on the Caltech faculty.

Herbert S. Ribner, professor of aeronautics and astronautics in the Institute of Aerophysics at the University of Toronto, Canada, has returned from a year's leave of absence at the aeronautics department of the University of Southampton in England. His wife and two children accompanied him. His latest appointment is as a member of the Associate Committee on Aircraft Noise of the National Research Council of Canada.

1936

Dean E. Wooldridge, PhD, has resigned as president of Thompson Ramo Wooldridge, Inc., to devote his time to scientific studies. He will continue to serve on the TRW board.

1937

Hung C. Yin, PhD, is director of the Institute of Plant Physiology at the Academia Sinica in Shanghai.

1939

Lt. Gen. Donald N. Yates, MS, (USAF Ret.) is now director of technical planning at the Raytheon Company's division of engineering and research in Lexington, Ky.

John W. Black has been appointed vice president and manager of the aeronautical systems division of the aerospace group of the Hughes Aircraft Company in Culver City, Calif. He has been with the company since 1940, and was formerly manager of the aeronautical systems division.

1940

William W. Stone, Jr., MS '41, director of the US Army Chemical Corps Operations Research Group at the Army Chemical Center in Maryland, has been promoted to colonel. He has been in the army since 1940, and was last stationed in Korea.

1941

Reuben P. Snodgrass, MS '42, has been appointed a member of the technical staff of the Sperry Rand Systems Group in Great Neck, L.I.

Brig. Gen. Charles H. Terhune, Jr., AE, is the new commander of the Electronic Systems Division of the Air Force Systems Command in Bedford, Mass. He was formerly vice commander of the division. The Terhunes have three children; Mrs. Donna Lynch of Seattle, Terry, and Charles H. III.

1942

George I. Cohn has joined Electro-Optical Systems, Inc., as chief scientist of the fluid physics division. He had been serving as professor of electrical engineering at the Illinois Institute of Technology.

1943

Edward I. Brown is now vice president and general manager of the mobile hydraulics division of Vickers Inc., a division of the Sperry Rand Corporation in Detroit. He was formerly director of engineering in the company's machinery hydraulics division.

1944

Ruben F. Mettler, MS '47, PhD '49, has been elected president and chief executive officer of Space Technology Laboratories, Inc., in Los Angeles. He had been STL's executive vice president since 1958.

Capt. John K. Leydon, MS (USN), associate director (plans) in the office of the Assistant Comptroller of the Navy, has been chosen as one of the 150 participants in the 41st session of the Advanced Management Program at the Harvard Business School, held from February 18 to May 18.

1949

Dr. P. Herbert Leiderman, MS, has been appointed associate in psychiatry at the Harvard Medical School in Boston. He is also a career investigator in the US Public Health Service.

1950

Major Frederick C. Badger, MS, is attending a 16-week associate course at the Army Command and General Staff College in Fort Leavenworth, Kansas. The course is designed to prepare selected officers from all components of the Army for duty as commanders and general staff officers. *Major Leonard Edelstein,* MS, is also attending the same course.

1951

San-Chium Shen, PhD, is a member of the newly organized Institute of Microbiology at the Academia Sinica in Shanghai.

James A. Ibers, PhD '54, writes that he has left the Shell Development Company in Emeryville, Calif., to join the staff of the department of chemistry at Brookhaven National Laboratory in Upton, N.Y.

1952

Ernesto Weber writes from Mexico that he is assistant manager of Minneapolis Honeywell's Mexico subsidiary, where they work with automatic controls for industry, air conditioning, laboratory and biomedical instruments, and the sales, service, and installation of complete system aspects. The Webers have two boys, 8 and 2.

1953

George W. Sutton, MS, PhD '55, is now serving as visiting associate professor at MIT, lecturing on the kinetic theory of ionized gases and magneto-hydrodynamic power generation. He is on a leave of absence from the General Electric Space Sciences Laboratory in Philadelphia.

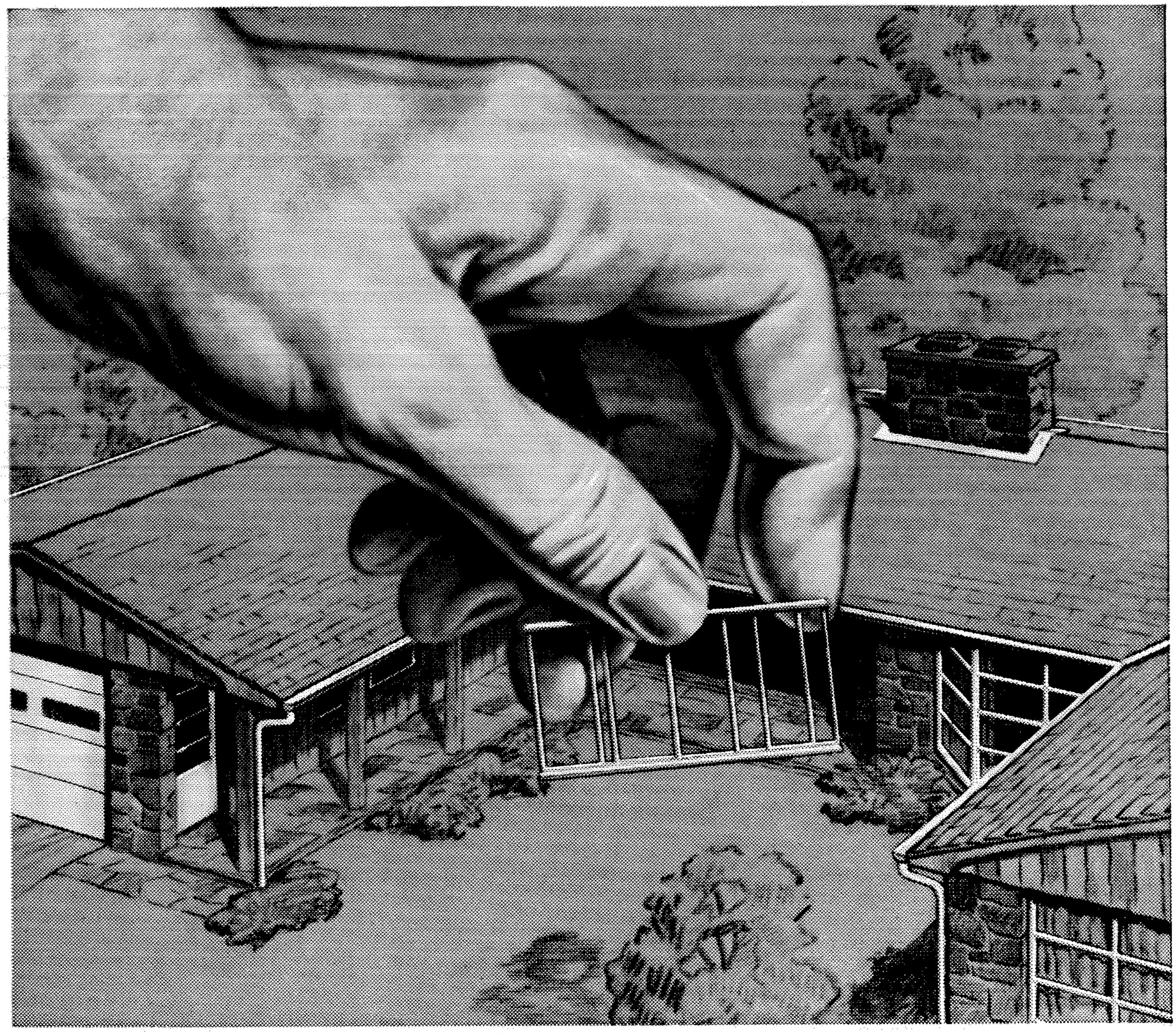
Rolf D. Weglein, MS '54, is now at the Hughes Microwave Tube Division in Los Angeles where he is building up a section devoted to the development of new microwave tube products. He was formerly a senior staff member at the Hughes Research Laboratories in Malibu.

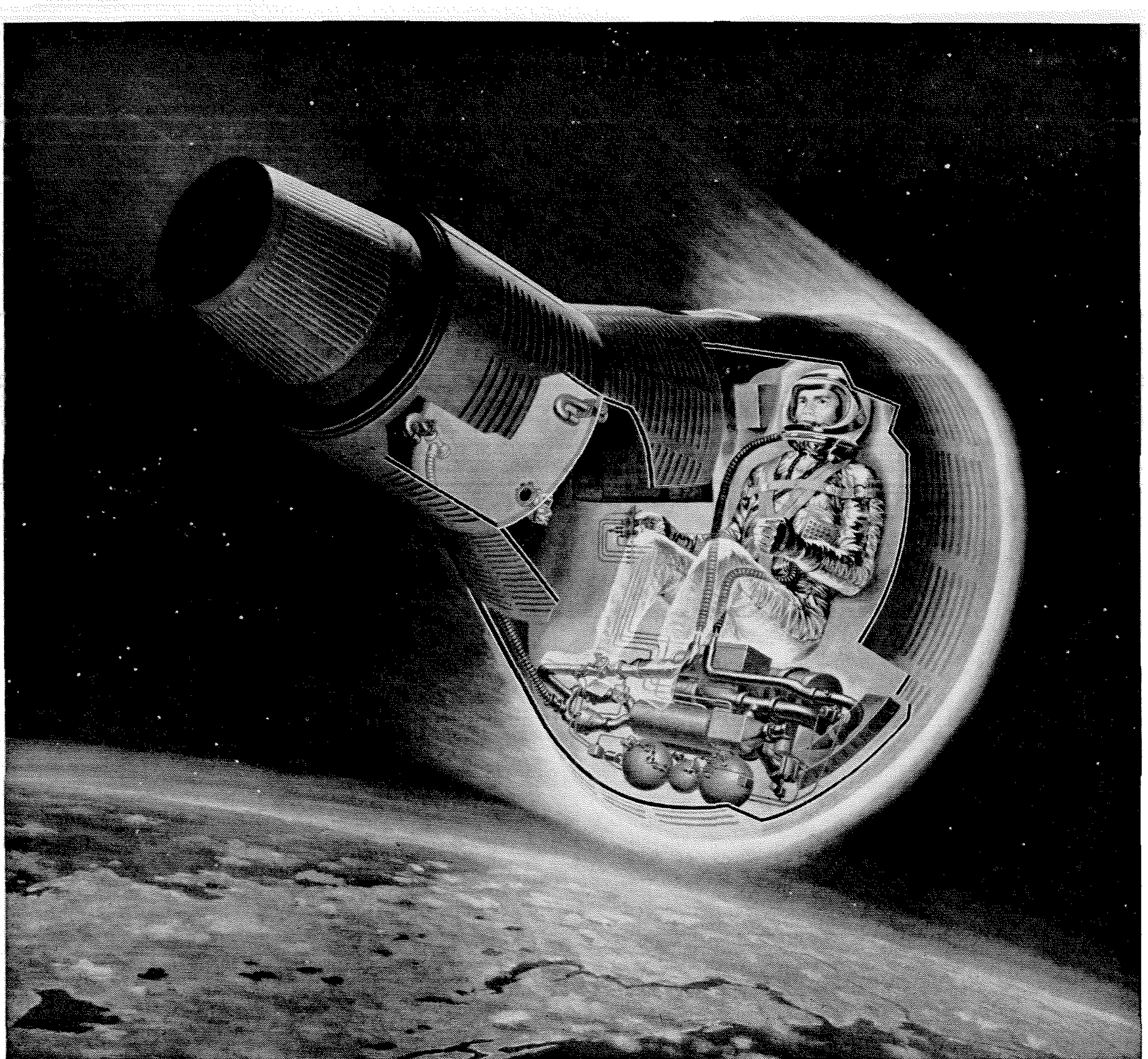
1956

Rex Peters is a project engineer at the Endevco Corporation in Pasadena, where he develops piezoelectric transducers. After graduation Rex spent three years at Edwards Air Force Base. Last December he was married to Helen Gilbreath of South Pasadena.

1960

Timothy L. Sullivan, MS, has completed U.S. Peace Corps training for service in West Pakistan. He will spend two years in that country.





Twenty-fifth Annual Alumni Seminar

Saturday, May 19, 1962

Dinner and Evening Program

Huntington-Sheraton Hotel, Pasadena

"POSITIVE, NOT NEGATIVE CONSERVATISM" – RAYMOND MOLEY

Raymond Moley, contributing editor of *Newsweek* magazine, is author of *Newsweek's* "Perspective" page. He also writes a widely syndicated newspaper column. For nearly thirty years he was a member of the faculty of Columbia University, holding the title of professor of public law. He is a native of Ohio and now lives in New York City. From 1932 to 1935 he served as adviser on public policies to Franklin Roosevelt and in 1932 organized and headed the Roosevelt "Brains Trust." He left the Roosevelt Administration in disagreement with its policies, and after 1936 became a vigorous opponent of its increasing centralism. A journalist for 28 years, Mr. Moley is essentially a writer on politics in all its aspects. His list of books includes *After Seven Years* (an account of the Roosevelt period), *27 Masters of Politics, How to Keep Our Liberty,* and *The Practice of Politics.*

Special Exhibits

JPL model of the Surveyor – New graduate student living quarters – Open House, Firestone Flight Sciences Laboratory – Film "The Universe" – Public Affairs Room, Dabney Hall of the Humanities.

Outstanding Lecture Program

Three morning and three afternoon periods, each with four simultaneous lectures. Each lecture will be given twice during the day.

Alumni outside of southern California who wish to attend the Seminar should write the Alumni Office for reservations.

Seminar Lectures

RIDDLE OF THE CELESTIAL RADIO SOURCES
9:30 A.M. and 2:15 P.M.
Gordon J. Stanley, Research Associate in Radio Astronomy

Many types of galactic objects are now known to emit radio waves. The powerful combination of giant antennas and optical telescopes gives much information on the emitting regions. Mr. Stanley reviews the emission phenomena and the use of the radio identifications in extending our knowledge of the universe.

SCANNING PATTERNS OF THE EYE
9:30 A.M. and 2:15 P.M.
Derek H. Fender, Senior Research Fellow in Electrical Engineering.

The eye is never at rest. Even when examining a small object, the eyeball is in constant motion. Is the resulting motion of the image on the retina detrimental to clear vision? Equipment which nullifies the effects of eye movements shows that these motions are essential for the maintenance of sharp vision, and that the eyeball has a position control system which generates the necessary scanning pattern.

SPOTLIGHT ON AFRICA
9:30 A.M. and 2:15 P.M.
Edwin S. Munger, Professor of Geography

The dramatic shift of power in the Congo from white minorities to colored majorities is accelerating this process in the neighboring states. Is South Africa a melting pot or a pressure cooker? Professor Munger, having lived for fifteen years in Africa, uses his recent experience to evaluate evolution versus revolution in Mozambique, Angola, and Rhodesia.

XENOPHOBIA OF THE BODY
9:30 A.M. and 2:15 P.M.

Ray D. Owen, Professor of Biology
Chairman, Division of Biology

Attempts to transplant living tissues or organs from one individual to another generally fail. This is because the recipient's immunological system recognizes materials in the graft that are foreign to the host and responds by destroying the transplant. The material differences evoking this reaction are inherited qualities, so various that each individual is practically unique. Control of graft rejection is vitally important and, for certain conditions, has now been achieved.

PLANTS CANNOT RUN FOR COVER
10:45 A.M. and 3:15 P.M.

Anton Lang, Professor of Biology

Unlike animals, plants cannot escape their environment. They must live with it, and have learned to do so with great skill. They not only adjust to conditions but use them as signals for such states as growth, rest, flowering, and fruitfulness. Professor Lang describes the unique Earhart Laboratory and its work, which has contributed greatly to our knowledge of the important plant-environment relationship.

RANGERS TO THE MOON
10:45 A.M. and 3:15 P.M.

Clifford I. Cummings, Lunar Program Director,
Jet Propulsion Laboratory

Modern Rangers are opening the frontier of moon exploration. Mr. Cummings describes the Jet Propulsion Laboratory's role in the Lunar Exploration Program and shows films of Ranger achievements. Models and actual lunar flight equipment are used to illustrate Ranger's contribution to our space program.

THE SMOG DEMONS: NITROGEN OXIDES
10:45 A.M. and 3:15 P.M.

Neal Richter, Assistant Professor of
Chemical Engineering

Growing evidence indicates that nitrogen oxides are significant in air pollution. Professor Richter discusses their origin in combustion processes, and describes the effects of different types of flames. A "howling" burner demonstration shows the effect of burning conditions on nitrogen oxide formation.

THE WINE OF LIFE: NINE GREAT POETS
10:45 A.M. and 3:15 P.M.

Harvey Eagleson, Professor of English

The lives and works of these men have influenced our thought and language, and they reflect unequaled vitality and intensity of experience. Professor Eagleson's vignettes characterize for us the personalities and poetry of Browning, Byron, Burns, Chatterton, Gray, Keats, Shelley, Wordsworth, and Tennyson.

THE SMALLEST INVADERS
11:45 A.M. and 4:15 P.M.

Robert S. Edgar, Assistant Professor of Biology

A bacterial virus multiplies by invading a bacterial cell and forcing this host to do the work of assembling new virus particles. The virus growth is controlled by a linked circle of about a hundred different genes. Professor Edgar shows photographs of remarkable appearance and activity. The study of virus mutants that lack certain essential functions has shed much light on the process of viral growth.

FUNDAMENTAL PARTICLES
11:45 A.M. and 4:15 P.M.

Murray Gell-Mann, Professor of Theoretical Physics

Recent ideas on the behavior of the sub-atomic particles of which all matter is composed. The "strong interactions," including the forces that hold the atomic nucleus together, are seen from a new point of view. All the strongly interacting particles may be bound states of one another generating themselves by a "boot strap" mechanism.

THE RIDDLE OF THE MOON'S CRATERS
11:45 A.M. and 4:15 P.M.

Eugene M. Shoemaker, Visiting Professor of Geology
Chief, Branch of Astrogeology, U.S. Geological Survey

The origin of the craters of the moon has been debated for years. Geologic studies of impact craters on the earth provide clues to the riddle and suggest what the first moon explorers should look for.

CAN SOVIET RUSSIA BURY US?
11:45 A.M. and 4:15 P.M.

Horace N. Gilbert, Professor of Business Economics

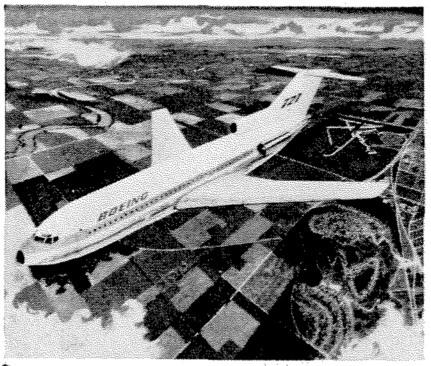
This may be the real issue in the cold war. With the nuclear stalemate there is increasing realization that Khrushchev's boast should receive greater attention. Professor Gilbert questions Soviet ability to compete successfully with the West. The probability is that we can bury Soviet Russia.

CAREER BULLETIN FROM

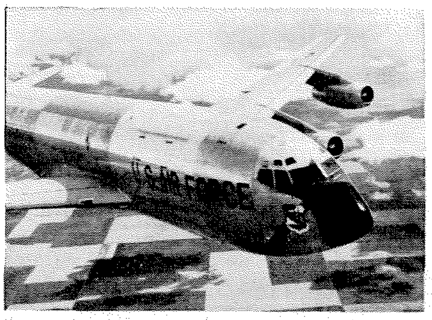
BOEING

The continuing expansion of advanced programs at Boeing offers outstanding career openings to graduates in engineering, scientific and management disciplines. At Boeing you'll find a professional climate conducive to deeply rewarding achievement and rapid advancement. You'll enjoy many advantages, including up-to-the-minute facilities, dynamic industry environment, and company-paid graduate study programs (Masters and Ph.D.).

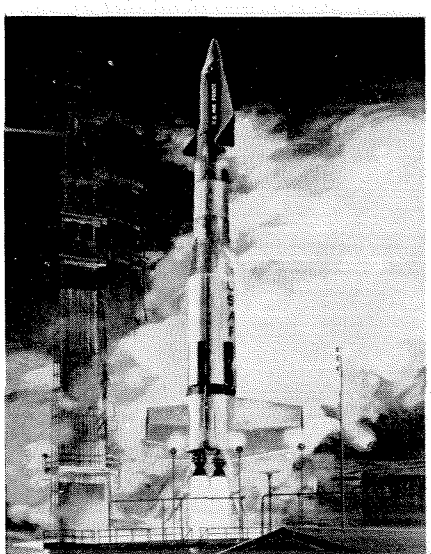
For further information, write today to Mr. Conrad E. Brodie, The Boeing Company, P.O. Box 3822 - UCI, Seattle 24, Washington. Boeing is an equal opportunity employer.



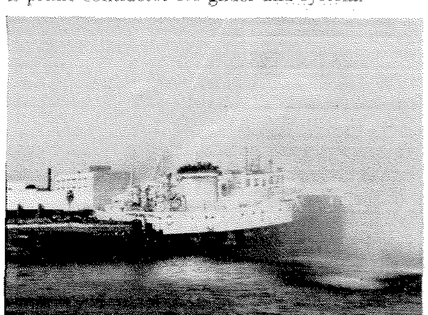
Drawing of newly announced short-to-medium range Boeing 727 jetliner. First 727 sale was largest in transportation history. More airlines have ordered—and *re*-ordered—more jetliners from Boeing than from any other manufacturer.



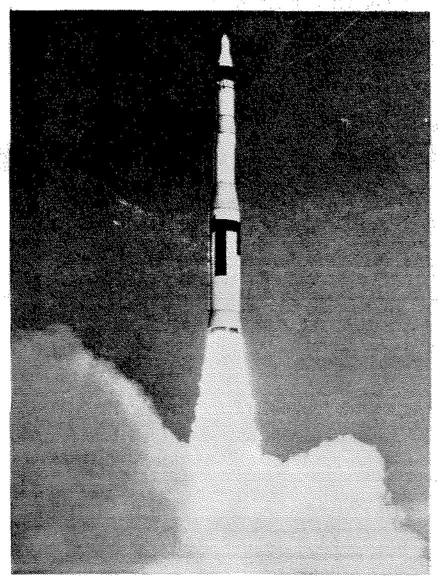
Boeing KC-135 jet tanker-transport is U.S. Air Force's principal aerial refueler. Forty-five C-135 cargo-jet models of KC-135 have been ordered for Military Air Transport Service.



Dyna-Soar manned space glider is shown, in artist's concept, atop Titan ICBM for launching. Design will permit return for conventional landing. Boeing is prime contractor for glider and system.



Boeing gas turbine engines power pumps on U.S. Army tug-fireboat. In other applications, Boeing engines power U.S. Navy boats and generators.

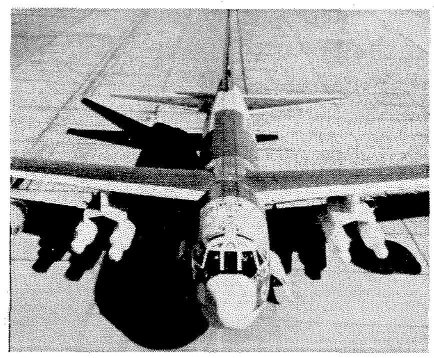


Minuteman, nation's first solid-fuel intercontinental ballistic missile, shown on initial flight—most successful first flight in missile history. Besides holding major Minuteman contract responsibility, *Boeing holds primary developmental, building* and test responsibility for SATURN S-1B booster.

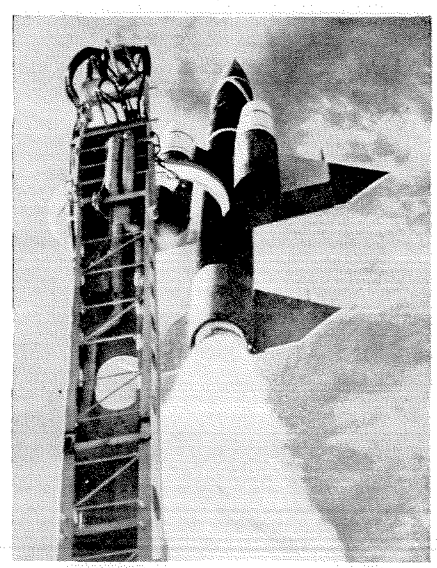
Boeing Scientific Research Laboratories where scientists expand the frontiers of knowledge in research in solid state physics, flight sciences, mathematics, plasma physics and geo-astrophysics.

BOEING

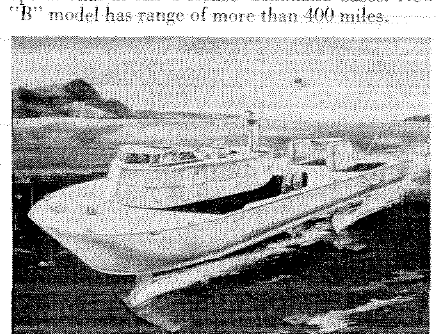
Boeing-Vertol 107 helicopter shown with famous Boeing 707 jetliner, world's most popular airliner. Boeing is world leader in jet transportation.



Boeing B-52H shown carrying mockups of Skybolt air-launch ballistic missiles. B-52s are also jet-fast platforms for Hound Dog guided missiles. They hold 11 world nonstop distance, speed records.



Supersonic Boeing BOMARC, longest-range air defense missile in U. S. Air Force arsenal, is now operational at Air Defense Command bases. New "B" model has range of more than 400 miles.



Drawing of 115-foot hydrofoil craft Boeing is building for U. S. Navy. Riding out of water, craft will "fly" at speeds up to 45 knots on underwater wings.

SOMEONE WITH ZIP

"Well George, I don't know what *I* can do. *I already gave,* but what *you* should do is go see these guys who haven't given and —

"Sixty-four hundred of them? Good grief! Well, what are you going to do in your spare time? Heh, heh.

"These guys just don't think it's important to give to the Fund and they prob'ly won't give a *nickel* until —

"I *know* you aren't looking for nickels — I only meant they won't give if they don't think it's important, and that's *your* job — to see that they know.

"Sure you've been working hard! Wasn't I there when you had your fit — I mean nervous breakdown?

"Whatcha need is something flashy — like maybe matchbook advertising — or how about a blimp with 'Give to Caltech' on a banner — or, I've got it! Instead of a regular dull letter, send these guys a sheet of paper — maybe green — and put a bunch of words on it like *Participate, 'lumni Fund,* an' —

"Oh, you did, huh? Well, you've got to get some life into this thing. You need someone with *zip!* Boy! When I raised that money for the Campfire Girls I just sat down at the desk and dictated a letter to —

"What? Oh, no. I just meant that . . . no, I don't have ti — But . . . but . . . Nolte can do it . . . no . . . well . . . if you don't think it would upset him . . . alright. 'Bye.

"Miss Johnson? . . . Yes, *now* please. This is a draft, double space. Ready?

"Dear 'lumnus: Be the first one in your block to make your gift to the 1961-62 'lumni Fund. Awaken! For a limited time only, each and every 'lumnus who gives will receive absolutely free of charge . . ."

THE 1961-62 CALTECH ALUMNI ENDOWMENT FUND ENDS SOON

One of a series*

Interview with General Electric's

Charles F. Savage

Consultant—Engineering Professional Relations

How Professional Societies Help Develop Young Engineers

Q. Mr. Savage, should young engineers join professional engineering societies?

A. By all means. Once engineers have graduated from college they are immediately "on the outside looking in," so to speak, of a new social circle to which they must earn their right to belong. Joining a professional or technical society represents a good entree.

Q. How do these societies help young engineers?

A. The members of these societies—mature, knowledgeable men—have an obligation to instruct those who follow after them. Engineers and scientists—as professional people—are custodians of a specialized body or fund of knowledge to which they have three definite responsibilities. The first is to *generate* new knowledge and add to this total fund. The second is to *utilize* this fund of knowledge in service to society. The third is to *teach* this knowledge to others, including young engineers.

Q. Specifically, what benefits accrue from belonging to these groups?

A. There are many. For the young engineer, affiliation serves the practical purpose of exposing his work to appraisal by other scientists and engineers. Most important, however, technical societies enable young engineers to learn of work crucial to their own. These organizations are a prime source of ideas—meeting colleagues and talking with them, reading reports, attending meetings and lectures. And, for the young engineer, recognition of his accomplishments by associates and organizations generally heads the list of his aspirations. He derives satisfaction from knowing that he has been identified in his field.

Q. What contribution is the young engineer expected to make as an active member of technical and professional societies?

A. First of all, he should become active in helping promote the objectives of a society by preparing and presenting timely, well-conceived technical papers. He should also become active in organizational administration. This is self-development at work, for such efforts can enhance the personal stature and reputation of the individual. And, I might add that professional development is a continuous process, starting prior to entering college and progressing beyond retirement. Professional aspirations may change but learning covers a person's entire life span. And, of course, there are dues to be paid. The amount is graduated in terms of professional stature gained and should always be considered as a personal investment in his future.

Q. How do you go about joining professional groups?

A. While still in school, join student chapters of societies right on campus. Once an engineer is out working in industry, he should contact local chapters of technical and professional societies, or find out about them from fellow engineers.

Q. Does General Electric encourage participation in technical and professional societies?

A. It certainly does. General Electric progress is built upon creative ideas and innovations. The Company goes to great lengths to establish a climate and incentive to yield these results. One way to get ideas is to encourage employees to join professional societies. Why? Because General Electric shares in recognition accorded any of its individual employees, as well as the common pool of knowledge that these engineers build up. It can't help but profit by encouraging such association, which sparks and stimulates contributions.

Right now, sizeable numbers of General Electric employees, at all levels in the Company, belong to engineering societies, hold responsible offices, serve on working committees and handle important assignments. Many are recognized for their outstanding contributions by honor and medal awards.

These general observations emphasize that General Electric does encourage participation. In indication of the importance of this view, the Company usually defrays a portion of the expense accrued by the men involved in supporting the activities of these various organizations. Remember, our goal is to see every man advance to the full limit of his capabilities. Encouraging him to join Professional Societies is one way to help him do so.

Mr. Savage has copies of the booklet "Your First 5 Years" published by the Engineers' Council for Professional Development which you may have for the asking. Simply write to Mr. C. F. Savage, Section 959-12, General Electric Co., Schenectady 5, N. Y.

*LOOK FOR *other interviews discussing:* Salary • Why Companies have Training Programs • How to Get the Job You Want.

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