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ABSTRACT

A study was conducted to determine if increasing the redundancy of sections in scientific articles where typical readers became bored or confused would have a desirable effect on other readers. Undergraduate journalism students applied R. F. Carter's signalled stopping technique to two different science articles by indicating points where they stopped reading because of confusion, boredom, or special interest. Both articles were then rewritten, giving attention to the feedback provided by the students' stopping behavior. W. Taylor's cloze procedure--a measure of the redundancy of language patterns--confirmed that the revised articles were more redundant than the original versions, although both were approximately the same length. Similarly qualified students then applied the same stopping procedure to the revised articles. Results indicated that changes in redundancy made in response to the feedback of the first group significantly decreased reader confusion. However, reader interest and scores on an objective comprehension/recall test were not increased significantly. These results suggested that feedback from typical readers can help science writers to communicate scientific information to selected audiences more effectively. (Copies of the original and revised essays used in the study are appended.) (JL)

THE MEASUREMENT OF REDUNDANCY AND ITS EFFECTS IN SCIENCE COMMUNICATION

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PURPOSE

> The influence of science and technology on our lives has boomed in the last quarter century, and concern that the average American is getting further and further out of touch with the world he lives in has followed this boom like a shockwave....The expansion of science knowledge in the last few decades has been so tremendous that the specialists can barely keep pace with developments in their own fields--let alone the layman. (Funkhouser, 1969, p. 721)

Few can argue the extent to which scientific advancements and new technologies affect our socio-economic environment. On a personal level, technology reorders our lifestyles at a bewildering rate. If an individual is to maintain any semblance of cognitive equilibrium with his rapidly evolving technological lifestyle, he must begin to understand the undercurrents of scientific change that speed him into an ever more complex world.

Although our involvement in technology is increasing at an exponential rate, our understanding of the scientific factors that shape our lives lags far behind. As this gap between technological reality and understanding widens, the individual's bewilderment with his own lifestyle will surely increase.

This, then, is the crucial role of science communication--to narrow the understanding gap, to lessen the technological shockwave.

According to Grunig (1974), public understanding of science means understanding abstract concepts and codes. Scientists have built up a complex and highly abstracted symbol system to represent relationships between concepts and their attributes. (See Carter, 1977, for a discussion of concept-attribute relationships.) Unfortunately, this symbol system is outside the realm of the average person; the layman is not privy to the code that scientists use to communicate.

Therefore, the communication of science to the general public involves "taking a specialized technical language or environment and translating it, with a minimum loss of meaning, into the speech of an intelligent layman unversed in the particular jargon, and, hopefully, into the speech of the typical men in the street." The major problem facing the science communicator is to find "commonly grounded" symbols to link the scientist and the layman (Kreighbaum, 1967).

Language has been described as a code upon which there is "societal agreement" (Glucksberg and Danks, 1975, pp. 198-201). The key to this code consists of the vocabulary of the language and knowledge of how it is used--its semantic and syntactic aspects. The science writer must learn new concepts, usually expressed in scientific terms, from scientists and find ways to explain these concepts to readers who have no knowledge of either the scientific concept or the terminology used by the scientist to explain it. The science writer's job is, thus, somewhat like that of a cryptographer who wants to send a secret message to someone who does not know the entire key to the cryptosystem that must be used. He must supply some additional information about the key before he can send his message.

The science writer can increase the vocabulary of readers by describing new concepts in words that have already been agreed upon by society and then giving them a label. Preferably, this label should be the correct scientific name for the new concept, or an abbreviation that is easier to repeat and remember.

To "flesh out" a scientific concept, the science writer must relate it to the reader's established symbol base. Typically, science writers use definitions, examples, analogies, and parables to lessen the abstractness of scientific terms. Each of these devices serves to increase redundancy--each amounts to a restatement of the relationship between a concept and its attributes. By expressing these relationships in a number of different ways, the writer reduces the complexity of the concept and increases the chance that the reader will be able to compare the concept with his existing framework of symbols.

Hsia (1977, p. 80) said, "Redundancy is probably the most effective means yet found to reduce equivocation and error in communication." Unfortunately, the writer can only guess <u>where</u> to insert redundancy into his writing, <u>which device</u> will best convey meaning to his readers, and how to structure redundancy into his writing. (The redundancy may be coded in one or several words, a phrase, a clause, or an entire sentence or paragraph.)

How well the writer can guess what his audience needs in the way of redundancy places a limit on the effectiveness of his writing. Funkhouser and Maccoby (1971) analyzed the effect of several textual variables--including examples, analogies, rules, and exceptions to rules--in comparable articles on enzymology written by nine professional science writers. They found that different articles produced significantly different reader effects--such as level of interest, information gain, and enjoyment. The implication was that even professional writers are not fully in control of the effectiveness of their own writing. Were the more effective writers better guessers?

Even the best writer cannot hope to reach every member of his audience. Since people with different backgrounds of knowledge may assume that the same words or expressions mean different things (Palermo, 1978, p. 171), there is not likely to be a specific quantity of redundancy that is ideal for all readers. It should be possible, however, to determine experimentally some guidelines to follow in science writing so that a larger portion of the nonscientific public will read, enjoy, understand and remember what has been written.

Weiner's cybernetics (1948) introduced the notion of feedback: systems do not guess about the states of their partners; they adjust to one another by bouncing information back and forth. Shannon (1950) suggested the use of feedback can also improve the efficiency of communicative systems. Although researchers have adjusted the earlier, "one-way" model of the communication process to include the feedback function, on a practical level it remains the missing link in mass communication.

In general, feedback means any information sent by the recipient of communication back to the originator of that communication. In this experiment, feedback came from students who read preliminary drafts of scientific articles.

This research addressed the following questions:

1) Can feedback from readers help the science writer locate points in an article where redundancy would be most helpful?

2) Does writing in redundancy at "feedback points" increase reader interest and comprehension?

CONCEPTUALIZATION

Some 40 years ago, scientists began serious efforts to understand and improve the communication art (McMillan, 1953). These efforts led to Claude Shannon's classic paper, "The Mathematical Theory of Communication" (1948), but numerous other papers made major contributions to "Information Theory," as this body of statistical mathematics is now called.

Shannon (1948) related the information content of a message to the randomness of its elements--his application of the physical science concept of entropy to communicative systems. The entropy--and, therefore, the information content--of a message is greatest when the probabilities of the occurence of each of its elements are equal. For example, when the next letter in a sequence is equally likely to be any letter.

When the probabilities of the occurence of certain elements are not equal--that is, certain elements are more likely to follow certain elements--entropy is reduced. Redundant elements are those that are contingent on their predecessors and can be predicted by the context of the message. Redundancy, which is inversely related to entropy, is a measure of the organization or patterning of message elements. In general, redundancy is any information not required for complete and correct understanding of any message.

Shannon's 1948 paper is closely related to his paper "A Mathematical Theory of Cryptography," which he published as a confidential report in 1945. This wartime work has since been published in revised form as "Communication Theory of Secrecy Systems" (Shannon, 1949). In a secrecy system, as described by Shannon, both the sender and the receiver of a message have a source of key information. Without this information, the sender could not encipher (encode) a message, and the receiver could not decipher (decode) it. That all types of communication systems have something similar to this "key information" was brought out by Fano (1949) when he said, "The receiver is conscious of all possible choices, as is, of course, the transmitter (that is, the individual or the machine that is supplying the information)."

Figures 1 and 2 show how closely the science writer's communication system resembles that of Shannon's general secrecy system. In Fig. 1, the key tells the encipherer (encoder) precisely how each message from the source should be rewritten to form the cryptogram or message to be transmitted. The same key is available for the decipherer (decoder), but the enemy cryptanalyst does not have access to it. Thus, the decipherer can decode the message, but the enemy cannot.

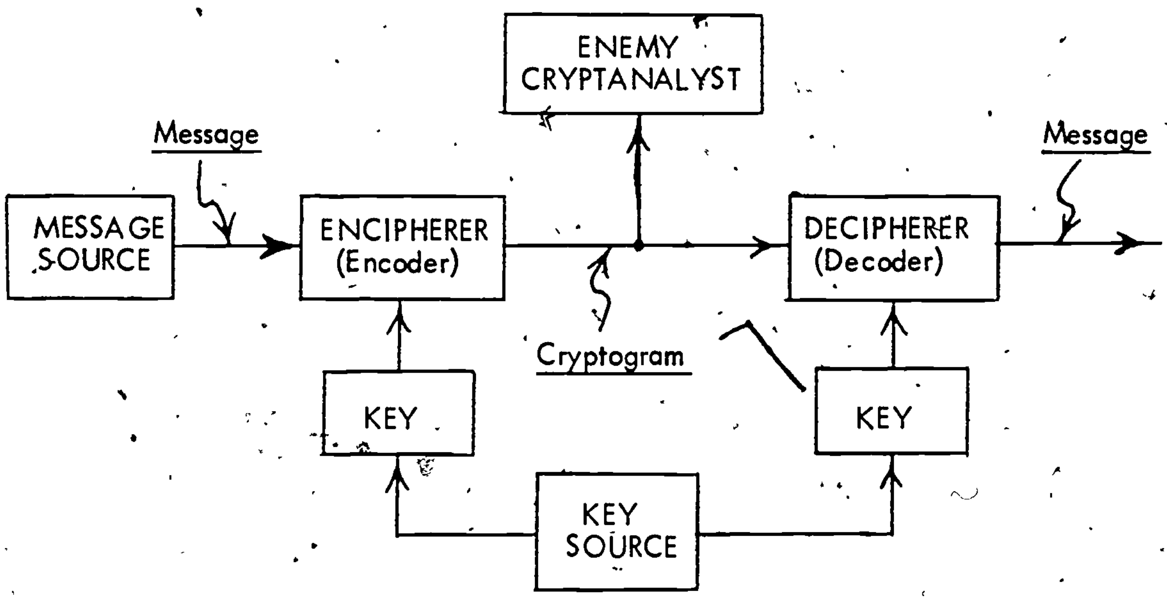

Fig. 1 Shannon's Schematic of a General Secrecy System

In Fig. 2, the science writer as the "encoder" rewrites a concept obtained from a scientist (his message source) by using a portion of his vocabulary and general knowledge. The lay reader uses his own vocabulary and general knowledge to interpret (decode) what he receives. If the science writer's evaluation of the vocabulary and knowledge of the reader is correct, or "congruent" to it (Grunig, 1980, p. 200), then communication can be successful. If the writer overestimates the reader's capability, the communication will be unsuccessful, because the reader then faces the same problem that the enemy cryptanalyst faced in the secrecy system. He cannot decipher (decode) the message because he does not have the proper "key."

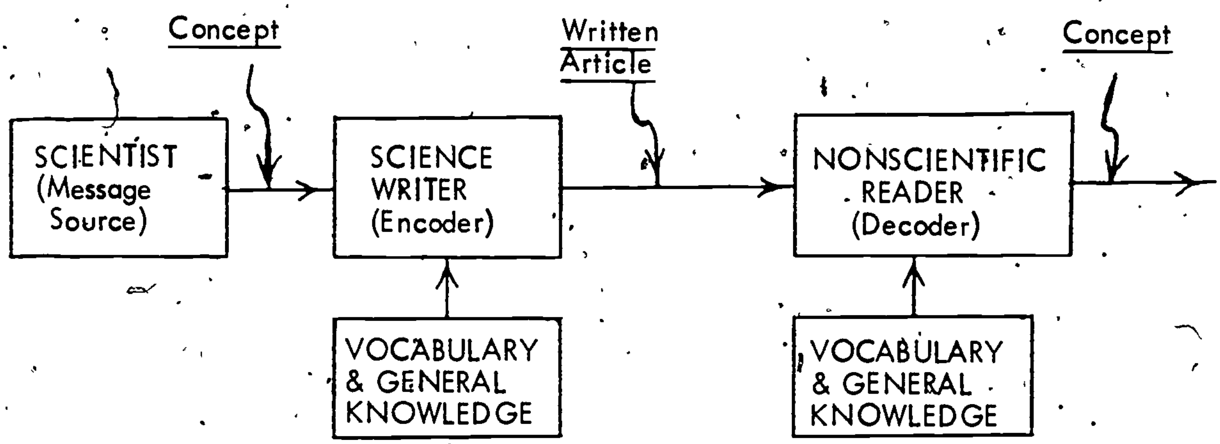

Fig. 2 Schematic of Science Writer's Communication System

Researchers do not agree about what should, or can, be done with the mathematical theory of communication. Weaver (1949, p. 114) said it "is general enough that it can be applied to written language, musical notes, spoken words, music, pictures and many other communication signals." But Severin and Tankard (1979, p. 48) said that it cannot be applied to human communication. According to Schramm (1955, p. 713) information theory cannot be applied to human communication since its formulas are based on probabilities, and learning alters these probabilities. However, if the effect of learning on the probabilities can be measured, then perhaps information theory can be applied to human communication.

Shannon's theory dealt with relatively simple communication systems that contained a transmitter and a receiver. He was concerned with the accuracy with which mindless electronic components could encode and decode the discreet symbols that make up a message. He was not concerned with the meaning carried by the symbols.

Human communication is more than transmitting and receiving messages--more than a mere encoding and decoding of a linear string of symbols. Any study of human communication must concern itself with the meaning of a complex of interrelated symbols. To get at the meaning of symbols one must go beyond Shannon's formal theory and take a look at the relationship between entropy, redundancy, and meaning.

If a concept is taken as a system of relationships between objects and attributes, symbols gain meaning as expressions of these relationships. Total entropy gives no hint of a systematic pattern of relationships on which to base a concept. A certain amount of redundancy is necessary to organize the essential information of a message.

To organize a concept, object-attribute relationships are categorized and redundant elements are recognized as logical associations. Once these relationships are understood, the concept is abstracted from its redundant elements.

As a scientific discipline develops, symbols are generated to represent concept systems of object-attribute relationships. Concepts subsume other concepts, and increasing amounts of redundancy are coded into the symbols. Scientific terms are powerful because they are highly abstract symbols--they carry a wealth of implicit meaning for those who are initiated into the symbol system. Symbols have meaning because of layer upon layer of relationships.

In terms of probability, symbols gain meaning through their conceptual context. A symbol's meaning is influenced by other symbols it is most frequently associated with. To the biochemist, the term DNA has meaning because he knows it is intimately related to such terms as RNA, m-RNA, transcription, ribosome, and protein synthesis. The term DNA means less to the layman because he doesn't know which other terms it is likely to be associated with.

Samson (1951, pp. 8-9) considered experience as an essential parameter in his development of "the fundamental natural concepts of information theory". He introduced the term "surprisal" as a measure of the subjective feeling that an individual has upon receiving a message. This measure of "surprise" corresponds closely to the uncertainty or entropy of a digital message. If a message surprises the receiver, then it may be assumed that he did not expect or anticipate receiving what the message contained. According to this view, the perceived entropy of a message is relative to the experience of the receiver.

When the lay reader comes across a scientific symbol that is not present in his existing language keys he is faced with uncertainty about its meaning. Since the symbol suggests no pattern, he cannot relate it to his existing object-attribute systems. In the face of an unfamiliar word, the lay reader might pause to consider what it means.

Carter (1974) views human behavior as movement through an environment. To change the direction of movement (i.e. to initiate a new behavior) the individual must first stop the movement he is engaged in. This is analogous to the switching of a cybernetic control mechanism "upon the observation of a discrepancy from a given standard" (Carter, et al, 1973).

According to Carter's hypothesis, cognitive discrepancies are a major cause for stopping. Interpreting Carter's notion of stopping, Grunig (1974) stated, "The reader of an article about science would be stopped if he encountered a concept which he could not include within his existing codes..." In other words, when he comes upon the unfamiliar scientific concept, the reader would go through this sequence of behavioral events:

READ....STOP....THINK....STOP....READ

> "One thing at a time" implies that the receiver must halt an incoming message, in some functional sense, if he is about to do something besides attend to it. We can make use of the evidence afforded us by such information. (Carter, et al, 1973)

A record of a reader's stopping behavior while reading an article about science might accurately pinpoint the concepts that are not included in his language keys. These could be the precise points at which the science writer might revise his work to include redundancy.

In this sense, Carter's signalled stopping technique can be used as a tool to pinpoint parts of a message that contain a high degree of entropy--from the reader's point of view. Similarly, the cloze procedure (Taylor, 1953, ~~1956~~ 1957) provides an overall measure of the relative entropy-redundancy of a message.

Taylor's major hypothesis is that meaning is related to patterns established by language. If the reader can close gaps in language patterns this indicates that he understands the meaning of symbols. He can fill in the gaps because he recognizes redundant patterns that allow him to place concepts in a relevant object-attribute system. Cloze procedure provides a tool for comparing the language keys of the science writer and the reader. "Cloze procedure takes a measure of the likeness between the pattern a writer has used and the pattern the reader is anticipating while he is reading" (Taylor, 1953).

In this research, Carter's stopping procedure was used to indicate points in science articles where the readers became confused, bored or especially interested. This information was then used as feedback to indicate how the articles could be rewritten to improve reader interest and comprehension. Emphasis was placed on finding ways to make redundancy increase the reader's science vocabulary so that what was previously incomprehensible would become understandable. This vocabulary, or knowledge of expressions used, corresponds to the key used to encode and decode messages in a secrecy system. Taylor's cloze procedure was used to measure the redundancy of the original and revised versions of the articles.

The hypotheses were:

1) Cloze scores will be higher for subjects who read a science article rewritten to include redundancy at points indicated by reader's stopping behavior than those who read the original article.

2) The number of stops due to confusion will be smaller for the revised articles.

3) The number of stops due to boredom will be smaller for the revised articles.

4) The number of stops due to special interest will be larger for the revised articles.

5) Scores on comprehension/recall tests will be higher for the revised articles.

6) Readers will rate the revised articles more interesting than the original articles.

METHOD

Dr. Cyril Ponnamperuma, an authority on chemical evolution and advocate of wider dissemination of science information, provided the researchers with several papers intended for a nonscientific audience. From these, excerpts were drawn to make two articles--each approximately 1,300 words long. One article was entitled "Is There Life on Mars?", the other, "The Emergence of Life." No editing was done on the excerpts that composed the articles.

A multiple-choice test consisting of 14 comprehension and recall questions was made for each of the articles. Also included in each test was a question that rated reader interest in the article.

Cloze tests were prepared for each article using a sampling procedure adapted fromTaylor (1957). First, each article was counted out into 50-word blocks. The first 50-word block, plus every third 50-word block were included in the sample. The sentences falling nearest to the beginning and end of each sample block were included in their entirety. This resulted in a total sample equal to about one-third of the original articles.

Beginning with the first word in each sample block, every seventh word was deleted and replaced with a blank of standard size. This procedure produced a total of 63 blanks for the "Mars" article and 64 blanks for the "Emergence" article.

Journalism students were assigned to one of four groups and were tested according to the following schedule:

GROUP 1: "Emergence of Life"--stopping test, comprehension/recall test
GROUP 2: "Emergence of Life"--cloze test
GROUP 3: "Is There Life on Mars?"--Stopping test, comprehension/recall test
GROUP 4: "Is There Life on Mars?"--cloze test.

Subjects performing the cloze test were instructed to read the mutilated sample passages and to fill the blanks with the words they thought were missing.

Subjects performing the stopping test were instructed to place a slash mark wherever they paused or stopped while reading the articles. They were asked to key each stopping point with a letter that explained their reasons for stopping: C--if they stopped because they were confused, B--if they stopped because they were bored, or I-- if they stopped because they found something interesting that they wanted to think about. Also, after finishing the article, they were to go back to each point they were confused and briefly explain how the author might improve their understanding at that point.

After finishing the stopping test and returning the article to a researcher, each subject completed the multiple-choice comprehension/recall test.

After the first battery of tests were completed, the researchers revised and edited the articles. Responses from the stopping tests served as feedback to indicate points where redundancy--in the form of definitions, explanations, analogies, etc.--should be written into the articles.

The articles were prepared for the cloze test following the procedure outlined above. A total of 62 blanks were used for the "Mars" article and 64 blanks for the "Emergence" article.

The same comprehension/recall test used for the original articles were used for the revised articles.

To control for possible learning effects, the testing schedule was shifted. Each group of subjects worked on a different article than they had in the previous battery of tests, and each performed a different test. Their schedule was as follows:

GROUP 1: "Is There Life on Mars?"--cloze test

GROUP 2: "Is There Life on Mars?"--stopping test, comprehension/recall test

GROUP 3: "The Emergence of Life"--cloze test

GROUP 4: "The Emergence of Life"--stopping test, comprehension/recall test

RESULTS

Differences in cloze scores indicate that the revised articles were more redundant than the original articles. The researchers apparently did achieve the goal of writing more redundancy into the revised versions of each article. The mean number of correct responses increased from 24.5 to 28.7 for "The Emergence of Life" and from 19.4 to 24.4 for "Is There Life on Mars?".

One-tailed values were computed. There were significant differences between mean cloze scores for the original and revised forms of both articles, (Table 1). This offered support for hypothesis 1.

TABLE 1: T-test results for cloze tests:

	NUMBER OF CASES	MEAN	STANDARD DEVIATION	T VALUE	1-TAILED PROBABILITY
"The Emergence of Life"					
Original Version	30	24.500	5.043	-2.10	0.022
Revised Version	24	28.708	8.725		
"Is There Life on Mars?"					
Original Version	28	19.357	7.176	-2.73	0.005
Revised Version	27	24.407	6.530		

There was a shift in stopping behavior between the original and revised versions of both articles. The mean number of stops due to confusion dropped markedly for the revised versions of both articles. The mean number of stops due to boredom dropped slightly, while the mean number of stops due to interest rose slightly in the revised versions.

One-tailed T values were computed to test the significance of the observed differences in stopping behavior (Table 2).

TABLE 2: T-test results for stopping behavior.

		NUMBER OF CASES	MEAN	STANDARD DEVIATION	T-VALUE	1-TAILED PROBABILITY
"The Emergence of Life"						
CONFUSED	Original Version	29	10.931	7.620	5.36	0.00
	Revised Version	23	2.652	2.979		
BORED	Original Version	29	3.448	4.702	1.73	0.046
	Revised Version	23	1.739	2.220		
INTERESTED	Original Version	29	1.655	2.058	-1.00	0.164
	Revised Version	23	3.130	6.838		
"Is There Life on Mars?"						
CONFUSED	Original Version	30	6.800	4.213	3.61	0.001
	Revised Version	24	3.333	2.823		
BORED	Original Version	30	2.733	3.016	0.76	0.226
	Revised Version	24	2.167	2.461		
INTERESTED	Original Version	30	2.567	2.344	-0.20	0.421
	Revised Version	24	2.750	3.948		

For "The Emergence of Life", the drop in the mean number of stops due to confusion (from 10.9 in the original version to 2.7 in the revised version) was significant at the p=0.000 level. The drop in the mean number of stops due to boredom (from 3.4 to 1.7) was significant at the p=0.046 level. The change in the mean number of stops due to interest was not significant. These results support hypotheses 2 and 3, but not 4.

For "Is There Life on Mars?", the drop in the mean number of stops due to confusion (from 6.8 in the original article to 3.3 in the revised article) was significant at the p=0.001 level. Changes in the mean number of stops due to boredom and interest were not significant. These results support only hypothesis 2.

The mean scores on the comprehension/recall test were the same for the original and revised versions of the "Mars" article, while the mean score on the revised version of the "Emergence" article was slightly lower than that of the original. T-tests showed no significant differences in comprehension/recall scores for the original and revised versions of both articles (Table 3). Thus, hypothesis 5 was not supported.

TABLE 3: T-test results for the comprehension/recall test.

	NUMBER OF CASES	MEAN	STANDARD DEVIATION	T-VALUE	1-TAILED PROBABILITY
"The Emergence of Life"					
Original Version	29	10.310	2.436	0.78	0.222
Revised Version	23	9.696	3.267		
"Is There Life on Mars?"					
Original Version	30	9.100	2.155	-0.06	0.478
Revised Version	23	9.130	1.740		

The revised versions of both articles were rated as interesting by more subjects than were the original versions. Of the subjects who read the revised version of the "Emergence" article, 65.2 percent rated it as "somewhat interesting" or "very interesting," and 51.9 percent of those who read the original article gave it these ratings. Of those who read the revised version of the "Mars" article, 65.2 percent rated it as "somewhat interesting" or "very intetesting," and 56.7 percent of those who read the original version gave it these ratings.

The article ratings were assembled in contingency tables and chi-squares were computed to test the significance of the observed differences. (Table 4). The chi-squares comparing ratings between the original and revised versions were not significant at the $p \leq 0.05$ level. Hypothesis 6 was not supported.

TABLE 4: Chi square results for ratings of original and revised versions of "The Emergence of Life" and "Is There Life on Mars?"

	ARTICLE RATINGS			
	Very Interesting	Somewhat Interesting	Somewhat Boring	Very Boring
"The Emergence of Life"				
Original Version	1	13	9	4
Revised Version	2	13	6	2

Chi square = 1.29
For 3 degrees of freedom, probability = 0.74

	ARTICLE RATINGS			
	Very Interesting	Somewhat Interesting	Somewhat Boring	Very Boring
"Is There Life on Mars?"				
Original Version	2	15	7	6
Revised Version	4	11	5	3

Chi square = 1.72
For 3 degrees of freedom, probability = 0.64

CONCLUSION

The results of this research indicate that increasing redundancy in science articles at points where typical readers become confused and choosing different forms of redundancy where they become bored can have a desirable effect on other readers.

Knowledge of points in an article where readers are not satisfied, gives the science writer a second chance to estimate his or her readers' "language keys" or vocabulary.

Communicating science information to journalism students, as attempted in this experiment, exemplifies the problems faced by science writers for the mass media. The sample of students, as well as the typical mass media audience, comprise readers who have little or no interest or schooling in science, as well as a few who have considerable interest but little schooling.

Although it may be fairly easy to describe science concepts in a way that does not patently confuse, it is harder to present them in a way that stimulates interest. It is still harder to do both simultaneously, because changes in redundancy can both decrease the confusion of some readers and decrease the interest of others. It is perhaps because of this effect that the changes in redundancy made in this experiment decreased confusion significantly but did not increase interest significantly.

The results indicate that it is difficult to increase comprehension test scores beyond a certain point. Whether this limitation is due to the way articles are rewritten or the nature of the test used is difficult to determine.

Statistical analyses of the data obtained in this experiment imply that use of Carter's stopping technique (Carter et al, 1974) can provide useful feedback to the science writer. For best results, the technique should be applied to a sample of readers typical of those with whom the writer wishes to communicate. If the science writer wishes to reach readers with widely varying backgrounds he may have to write several articles using different levels of redundancy.

The feedback provided by Carter's stopping technique can help tell the science writer in what "language" he or she should present science concepts if they are to be understood and appreciated by selected audiences.

Comparing the stopping behavior of representative audiences with that of science writers, editors, and scientists could show just how well the gatekeepers of science information perceive the language ability of their readers. Coorientation studies using Carter's stopping technique might help in this effort and shed new light on the feedback function.

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APPENDIX

Original and revised versions of the two science articles

The "big bang" is presumed to have occurred 13 billion years ago. About 8 billion years later, when the solar system was being formed, the highly reactive elements existed as methane, ammonia, and water. 4.5 billion years ago, when the planet earth was being born from the primitive dust cloud, the rudimentary molecules which were the forerunners of the complex biological polymers were perhaps already in existence.

In this scheme of things, life is only a special and very complicated form of the motion of matter. It arose as a new property of matter which it had not possessed earlier, and which only occurred at a particular period in the existence of our planet and resulted from its orderly development. The origin of life was not an occurrence ascribed to some definite place and time; it was a gradual process operating upon the earth over a long period of time. a process of unfolding which consumed millions of years. One might think of the evolutionary process passing through three distinct chemical phases--from inorganic chemistry, to organic chemistry, to biological chemistry.

A starting point for any discussion on the origin of life must be a consideration of the cosmic distribution of elements. Astronomical spectroscopy reveals that with surprising uniformity the most abundant elements in our galaxy are, in order of rank, hydrogen, helium, oxygen, nitrogen and carbon. Hydrogen, oxygen, nitrogen, and carbon are indeed the basic constituents of living systems.

Because of its high rate of escape, most of the free hydrogen must have been lost and the principal constituents of the atmosphere must have been water vapor, ammonia, and methane. It is this atmosphere of water vapor, methane, ammonia, and small amounts of hydrogen which will be considered in this discussion as the

Original Version

THE EMERGENCE OF LIFE

"How did life begin?" is a question which has been asked ever since the dawn of recorded time. The naturalist, aware of the awe-inspiring cosmological discoveries and the triumph of biological evolution, cannot help the belief that life evolved inevitably from the non-living. The humanist, filled with traditional learning, is indignant that a problem so transcendentally profound should be regarded as belonging to the realm of the natural sciences and subject to judgments arrived at by laboratory manipulations. The experimental scientist, however, with a happy optimism, expects his current investigations to produce the key to unlock the door to this profound mystery.

Recent biochemical discoveries have underlined the remarkable unity of living matter. In all living organisms, from the smallest microbe to the largest mammal, there are two basic molecules. Their interaction appears to result in that unique property of matter which is generally defined by the word "life". These two molecules are the nucleic acid and protein. While each one of these molecules is complex in form, the units comprising them are few in number. The nucleic acid molecule consists of nucleotides strung together like beads along a chain. In the protein molecule, twenty amino acids link up with one another to give the macromolecule. A study of the composition of living matter thus leads us to the inescapable conclusion that all living organisms must have had some common chemical origin. A form of evolution purely chemical in nature must of necessity have preceded biological evolution.

In the first stage of chemical evolution, the catastrophic events associated with the origin of the universe gave rise to the elements of the periodic table.

primitive atmoshpere of the earth.

The energies available for the synthesis of organic compounds under primitive earth conditions are ultraviolet light from the sun, electric discharges, ionizing radiation, and heat. While it is evident that sunlight is the principal source of energy, only a small fraction of this was in the wavelength below 2000 Å, which could have been absorbed by the methane, ammonia, and water. However, the photodissociation products of these molecules could absorb energy of higher wavelengths. Next in importance as a source of energy are electric discharges such as lightning and corona discharges from pointed objects. These occur close to the earth's surface, and hence, would more efficiently transfer the reaction products to the primitive oceans. A certain amount of energy was also available from disintegration of radioactive uranium, thorium, and potassium. While some of this energy may have been expended on the solid material such as rocks, a certain proportion of it was available in the oceans and the atmosphere. Heat from volcanoes was another from of energy that may have been effective. But in comparison to the energy from the sun and electric discharges this was only a small proportion and perhaps not too widely distributed, so that its effect may be considered to have been only local--such as on the sides of volcanoes.

Most of these forms of energy have been used in the laboratory for the synthesis of organic molecules. Simulation experiments have been devised to study the effect of ionizing radiation, electric discharges, heat, and ultraviolet light on the presumed early atmosphere of the earth. The analysis of the end products has often yielded, most surprisingly, the very compounds which we consider today as important for living systems.

In addition to the synthetic experiments just described, another approach has been to study chemical evolution by examining sediments, meteorites, interstellar space, and lunar samples for evidence of life or the organic compounds which may have preceded its genesis.

Although meteorites have been analyzed for the presence of organic compounds for over a century, the source of the polymeric organic matter detected in carbonaceous chondrites has not been clear. In previous studies, the possibility that the meteorites examined had been contaminated with terrestrial biomolecules before being analyzed could never be excluded with certainty. However, amino acids believed to be indigenous to the Murchison and Murray meteorites. have recently been detected. Using the analytical techniques of ion-exchange chromatography, gas chromatography, and gas chromatography combined with mass spectrometry, the presence of a host of amino acids have been identified.

Several lines of evidence support an extraterrestrial origin for these amino acids. The right-handed and left-handed forms of the amino acids are almost equally abundant. Terrestrial biological contamination would have resulted in a predominance of those amino acids commonly found in protein which are generally left-handed in configuration. A random abiotic synthesis is indicated by the presence of several non-protein amino acids.

Taken together, the results obtained in studies of the Murchison and Murray meteorites strongly suggest that extraterrestrial chemical evolution has taken place - and may be continuing.

Observations by many groups of radioastronomers during the last three years have revealed the presence of serveral organic molecules in the intergalactic regions examined. To date, the molecules discovered include water, ammonia, formaldehyde, hydrogen cyanide. Molecules such as these are now considered to be widely distributed throughout interstellar space. The nature of the complex molecules observed indicates that they are all steps in a widely occurring evolutionary sequence which spans the formation of atoms during the birth of a star to the synthesis of biologically significant molecules leading to life.

There is no reason to doubt that we shall rediscover, one by one, the physical and chemical conditions which once determined and directed the course of chemical evolution. We may even reproduce the intermediate steps in the laboratory. Looking back upon the biochemical understanding gained during the span of one human generation, we have the right to be quite optimistic.

Revised Version

THE EMERGENCE OF LIFE

"How did life begin?" is a question which has been asked since the dawn of recorded time. The naturalist believes that life must have evolved from nonliving material and the experimental scientist is busy trying to recreate the early chemical steps that may have lead to the formation of life. However, the humanist is indignant that such a profound philosophical problem should be regarded as belonging to the realm of science.

Recent discoveries in biochemistry have emphasized the remarkable unity of life on Earth. In every living organism, ranging from the smallest microbe to the largest whale, we find two basic molecules: protein and nucleic acid. While each of these molecules is complex, each is composed of several relatively simple units. The protein molecule is made of amino acids strung together like beads on a string; the nucleic acid molecule is made of repeating units of nucleotides. The fact that the basic chemical makeup of all living things is so similar leads to the inescapable conclusion that all life must have shared a common chemical origin.

The interaction of protein and nucleic acid appears to result in that unique property of matter called "life". To the biochemist, life is only a special and very complicated form of the motion of matter.

The emergence of life from nonliving matter was a gradual process that unfolded over a period of millions of years. One might consider this slow evolutionary process as passing through three distinct chemical stages--from inorganic chemistry (the formation of elements and simple compounds), to organic chemistry (the formation of complex compounds based on carbon), to biological chemistry (the formation of living organisms).

The first stage of chemical evolution began with the "big bang"--the catostrophic explosion which scientists believe gave birth to the universe some 12 billion years ago. The "big bang" created the basic elements which are the building blocks of all matter.

Spectroscopy--a method of analysing the light coming from stars--has shown that the most abundant elements in our galaxy, in order of rank, are hydrogen, helium, oxygen, nitrogen, and carbon. With the exception of helium, all of these elements are essential components of living organisms.

By the time the Earth was formed about four an a half billion years ago, hydrogen had already combined with oxygen, nitrogen, and carbon to form several simple compounds, including: methane (hydrogen plus carbon), ammonia (hydrogen plus nitrogen), and water (hydrogen plus oxygen). Since most of the uncombined hydrogen escaped into space, scientist believe that the atmosphere of the primitive Earth consisted mainly of methane, ammonia, and water vapor, with only a small ammount of "free" hydrogen.

During the next stage of chemical evolution the simple, inorganic molecules present in the primitive atmosphere combined to form organic compounds--complex molecules which have a chain of carbon atoms as a backbone. This synthesis (building up) of organic compounds required energy. On the primitive Earth, several sources of this energy were ultraviolet light from the sun, electric discharges, radiation, and heat.

Although the sun was the major energy source, only a small portion of sunlight was of the ultraviolet wavelenghts that could have "excited" methane, ammonia, and water molecules to react with one another. However, the action of sunlight also caused these molecules to break down into other particles which, in turn, could be excited by other wavelengths of light.

Electrical discharges from lightning, or sparks that were created when lightning struck a pointed object, were the second most important source of energy. Since this energy occurred close to the Earth's surface, the organic products that were formed could easily pass into the primitive oceans, where synthesis could continue.

The decay of uranium, thorium, and potassium provided radiation which could break the compounds of the primitve atmosphere into ions (charged particles which react quite readily). Volcanoes were probably a relatively minor source of energy, since their heat only reached a small area surrounding them.

Biochemists have already simulated the chemical reactions that might have occurred during the early stages of evolution. In these experiments, mixtures of methane, ammonia, water, and hydrogen gases representing the primitive atmosphere are exposed to ultraviolet light, electrical sparks, radiation, and heat. Amazingly, these experiments have produced several organic molecules--including amino acids--which are important building blocks of living organisms.

Meteorites have been tested for the presence of organic material for over a century. Organic molecules have been detected in some carbonaceous chondrites--a type of stoney meteorite containing carbon. However, scientists were never certain whether these molecules actually had been formed in space or had merely been picked up after the meteorite had fallen to Earth. It was possible that the meteorites had been contaminated with molecules that had been formed on Earth.

Recently, scientists using chromatography and mass spectrometry--two methods of separating and analysing the compounds present in a mixture--have identified a host of amino acids in meteorite samples. There is fairly strong evidence that these amino acids were formed in space.

Each type of amino acid occurs in two slightly different forms, called isomers. Oddly enough, the proteins produced by living organisms are almost exclusively made up of only one isomer of each amino acid. If the meteorite samples had been contaminated with amino acids formed by Earth organisms, we would expect to find a predominance of the isomers commonly found in proteins. However, both isomers of each amino acid were found in nearly equal proportions in the meteorite samples. Also, the meteorites contained several amino acids not usually found in proteins. This suggests that they were formed by some random process, not by Earth organisms.

Radioastronomers, who study radio waves that reach the Earth from space, have found that some biologically important molecules exist in the vast expanses of space. Scientist now believe that molecules such as water, ammonia, formaldehyde, and hydrogen cyanide are widely distributed throughout interstellar space. The compounds found so far span several of the early steps of chemical evolution--from the formation of elements during the birth of a star to the synthesis of organic molecules important for life.

Taken together, the evidence form meteorites and radioastronomy suggests that chemical evolution has taken place outside the Earth--and may be continuing. The sequence of chemical events that led to the formation of life on Earth appears to be a natural and universal property of matter.

Looking back on the biochemical understanding we have gained in the span of one generation, we have a right to be optimistic. There is little reason to doubt that one day we will be able to reconstruct the entire course of chemical evolution that lead to the emergence of life.

Original Version

IS THERE LIFE ON MARS?

In an authoritative document, the National Academy of Sciences has set down the search for extraterrestrial life as the prime goal of space biology. "It is not since Darwin and, before him, Copernicus, that science has had the opportunity for so great an impact on man's understanding of man. The scientific question at stake in exobiology is the most exciting, the most challenging, and profound issue, not only of this century, but of the entire naturalistic movement that has characterized the history of western thought for over 300 years. If there is life on Mars and if we can demonstrate its independent origin, then we shall have an enlightening answer to the question of the improbability and uniqueness in the origin of life. Arising twice in a single planetary system, it must surely occur abundantly elsewhere in the staggering number of comparable planetary systems."

Our effort to land an instrument or eventually a scientist astronaut, on a neighboring planet is primarily directed to the planet Mars. The possibility of life on Mars has often been raised. The canal-like structures on Mars and the seasonal wave of darkening across the planet have led many to believe that there must be some form of life on Mars. Some have suggested the existence of highly intelligent beings who, by incredible feats of engineering, have saved for themselves the depleting water supply on the planet by building mammoth canals crisscrossing the planet. All these speculations have fired the imagination of the planetary scientist and have made him determined to find out the answer to the question, "Is there life on Mars?"

When we leave speculation aside and consider the actual conditions that exist on Mars today, we must very likely exclude the existence of advanced forms of life;

however, the physical conditions are such that low forms of life, such as microorganisms, could survive on the planet. The atmosphere of Mars is made up largely of carbon dioxide with a trace of water. There must be a high ultraviolet flux which reaches the surface of Mars, since the Martian atmosphere does not appear to have a built in protection from ultraviolet light as our own earth. With this high incidence of ultraviolet radiation, Martian organisms would have to protect themselves by burrowing into the surface; or they may have involved a mechanism compatible with the existence of a high ultraviolet flux.

Temperature measurements have shown that the polar caps of Mars consist of ice. They wax and wane with the seasons. In the summer, the pole cap recedes about 35 kilometers per day. As one pole cap recedes, the other is under a cloud. A dark band has been observed to follow the receding pole cap. It is this dark band which has led many to speculate on the existence of vegetation. The wave of darkening proceeds from pole to equator at the rate of about 35 kilometers per day during the spring and summer. The average temperature of Mars is considerably lower than that on the earth; however, the extremes may not be incompatible with life. The highest temperature observed during the day near the equator is about -40 degrees centigrade. The night temperatures go well below zero, to about -85 degrees.

The atmospherio pressure on Mars was long disputed. The recent data confirms the low estimate that it is only 1/100 that of the earth. While this low pressure may not in itself be a factor which affects the survival of microorganisms, it might have an effect on the availability of water. The amount of water present on Mars is about 1/1000 of that found in the earth's atmosphere. This does not preclude the existence of micro environments in which above average accumulations of water may accur.

This survey of the physical parameters of Mars indicate for us that, although the conditions are rigorous as compared to the earth, they are within the range in which microorganisms can survive. Indeed, laboratory experiments in which these conditions have been simulated have shown that some earth microorganisms can survive and even multiply under such conditions. Furthermore, if we consider planetary evolution, on account of the smallness of the planet Mars, the processes of chemical evolution many have proceeded very rapidly. Life may have evolved and disappeared. Visitors to Mars may be greeted by relics or fossils of a once thriving biosphere.

Viking I and II continue the exploration of the martian surface. Each of the twelve investigations abroad the Viking orbiters and landers could directly, or indirectly, relate to the search for life. The most pertinent data should come from the experiments designed to search for organic molecules and microorganisms.

In the molecular-analysis experiment, two samples of Martian soil were heated to 500 C to pyrolyze any organic molecules. The vaporized material was led into a high-efficiency gas chromatography column connected to a fastscanning mass spectrometer. The first results indicated that organic material in the Mars sample was less than 1 part per million. Subsequently, this figure was further refined to less than 10 parts per billion.

In the face of such a result it may seem almost superfluous to conduct a further search for life based on carbon. However, the biologist might suggest a scenario in which wind or dust carries spores or microorganisms to the Chryse desert, there to burst into life at the magic touch of an external stimulus. While the technique of gas chromatography combined with mass spectrometry has lower limit of detection of 10^6 organisms, the biology experiments may detect a single organism by amplification of its activity.

The Viking lander carries three biology experiments: gas-exchange (GEX), labelled release (LR), and pyrolytic release (PR). Here we see a spectrum of approaches, from nothing extraneous added to the soil sample except water vapor, to water and organic substances present to stimulate metabolic activity.

In the GEX experiment, a cubic-centimeter sample of soil is transferred to an incubation chamber and wetted with a mixture of organic compounds in the presence of the ambient Martian atmosphere. At various times, this atmosphere is sampled for analysis by gas chromatography. Changes in the composition of the gas above the soil imply biological activity.

The LR experiment consists of a chamber in which a sample of Martian soil can be wetted with a nutrient containing glycine, alanine, lactate, formate, and glycollate--a soup considered palatable to terrestrial microorganisms. Each carbon atom is radioactively labelled. The release of a volatile radioactive-carbon product indicates biological activity.

The PR experiment tests photosynthetic activity of organisms, by fixation of radioactive carbon dioxide and carbon monoxide into organic compounds. It incubates a soil sample in light under the native Martian atmosphere, spiked with radioactive tracer gas. After incubation, the unreacted gas is flushed from the chamber, the sample pyrolyzed at 625 C, and the organic compounds trapped onto a firebrick column containing copper oxide. When this column is heated to 700 C, the organic material is oxidized and released as radioactive CO_2. A carbon-14 detector monitors the effluent. Should any of the tests produce a positive signal, the experiment is repeated using sterilized Martian soil as a control, after heating the soil sample to 160 C for 3 hours.

All three experiments produced positive results. Control experiments showed that the sterilization procedure inactivates the soil.

But a number of difficulties have been encountered. For example, in GEX the significant change was observed only in the 0_2 level and not in that of the other gases. Furthermore, the 0_2 level rose sharply and remained level, a situation unlikely in the case of microbial activity. In the LR, there was an abrupt climb in the release of readioactivity, but that soon levelled off. The positive result from the PR experiment, however, appears to resemble terrestrial biological activity.

In the absence of organic carbon, as reported by the GC-MS analysis, it seems reasonable to postulate surface chemical reactions of an inorganic nature to account for all these results. The presence of superoxides of metals can indeed be a plausible explanation of the data observed.

Before the dawn of the twenty-first century, manned exploration of the solar system may tell us whether we are alone in our universe. Radio telescopes scanning the distant galaxies for intelligible messages may reveal the presence of our more remote neighbors. Laboratory experiments will endeavor to retrace the path of chemical evolution and may support our belief in the existence of extraterrestrial life.

Revised Version

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IS THERE LIFE ON MARS?

The National Academy of Sciences has said the prime task of space biology is the search for life outside the earth and its atmosphere.

Space biology provides the greatest opportunity for scientists to study how life began since Copernicus and Darwin started the naturalistic movement over 300 years ago. The naturalistic movement tries to explain all phenomena in terms of scientific laws.

Our efforts to land an instrument, or eventually a scientist astronaut, on a planet is primarily directed to the planet Mars. If we can find life on Mars and show that it has arisen independently of life on earth, we can conclude that life must have arisen in many other places. There is a staggering number of planetary systems comparable to our own.

The possibility of life on Mars has often been raised. The canal-like structures on Mars and the seasonal wave of darkening that moves across the planet have led many to believe there must be life on Mars. Some have suggested the existence of highly intelligent beings who, by incredible feats of engineering, have saved a vanishing water supply by building mammoth canals crisscrossing the planet. These speculations have fired the imagination of the planetary scientist and have made him determined to answer the question, "Is there life on Mars?"

The physical conditions on Mars are such that advanced forms of life are not likely to exist. However, low forms of life, such as microorganisms, could survive. A high level of ultraviolet energy must reach the surface of Mars, because the Martian atmosphere has no built-in protection from ultraviolet light. It is made up largely of carbon dioxide and contains only a trace of water. To survive, Martian organisms would have to protect themselves by burrowing into the surface or by evolving a mechanism to allow them to withstand the high level of ultraviolet energy.

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Temperature measurements have shown that the polar regions of Mars are covered with ice. The areas covered increase and decrease with the seasons. As one pole cap recedes, the other becomes covered by a cloud. Scientists have observed a dark band following the receding ice cap. It is this dark band that has led many to speculate on the existence of vegetation. The wave of darkening travels about 35 kilometers per day during the spring and summer. Although the average temperature of Mars is considerably lower than that on the earth, the extremes may not be incompatible with life. The highest temperature observed during the day near the equotor is about -40 degrees Celsiur (also equal to -40 degrees Fahrenheit). Night temperatures go down to about -85 degrees Celsius (-121 degrees Fahrenheit).

For a long time, scientists have argued about what the atmospheric pressure on Mars might be. Recent data indicate that it is only 1/100 of that on earth. While this low pressure may not directly affect the survival of microorganisms, it might affect the availability of water, which is necessary for life. The atmosphere of Mars has only about 1/1000 as much water as that of the earth. Very tiny or "micro" environments containing above average accumulations of water could still exist, however.

In summary, a survey of the environment on Mars indicates that although conditions are more rigorous than those on the earth, they are within the range in which microorganisms can survive. Indeed, laboratory experiments have shown that microorganisms can survive and even multiply in environments where conditions found on Mars are simulated. Furthermore, the smallness of Mars might have accelerated the processes of chemical evolution that lead to life. Thus, if such planetary evolution took place, we might expect visitors to Mars to find fossils of a planet once thriving with life.

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Each of the 12 investigations aboard Viking I and II orbiters and landers were designed to help in the search for life. The most pertinent data should come from the experiments designed to search for organic molecules and microorganisms.

In the molecular analysis experiment, two samples of Martian soil were heated to 500 degrees Celsius to pyrolyze (break apart) any organic molecules. The material was then analyzed to determine its components by a gas chromatograph, which separates elements, and a mass spectrometer, which labels them. The first results indicated that the soil sample contained less than one part per million of organic material. Later results showed that the sample contained only 10 parts per billion (only 1/100 as much organic material as the earlier results had shown).

These results seemed to indicate that no further search should be made for life based on carbon. However, biologists suggested a scenario in which wind might carry spores or microorganisms to more suitable environments where they might burst into life. Scientists also suggested more sensitive measuring methods. The technique of gas chromatography combined with mass spectrometry cannot detect life unless at least one million (10^6) organisms are present. Biology experiments, on the other hand, can detect a single organism, because each organism's activity is greatly amplified.

The Viking lander carried three biology experiments, called the gas-exchange, the labelled-release and the pyrolytic-release experiments. They included a variety of ways to test for life.

In the gas-exchange experiment, a sample of soil was transferred to an incubation chamber and wetted with a mixture of organic compounds in the presence of the normal Martian atmosphere. At various times, the chamber's atmosphere was sampled and analyzed. Changes in the composition of the gas above the soil would imply the presence of biological activity.

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A similar chamber was used in the labelled-release experiment, but the Martian soil sample was wetted with a soup considered palatable to terrestrial microorganisms. This soup contained glycine, alanine, lactate, formate and glycollate — a combination of amino acids and organic salts. Each carbon atom in the soup was radioactively labelled; so the release of a gaseous radioactive product would indicate that biological activity had occurred.

The pyrolytic-release experiment first gave any organic material in the sample a chance to perform protosynthesis, which is common in earth plants. This was done by supplying light to the chamber's Martian atmosphere. To detect the presence of any photosynthetic activity, radioactive tracer gas was added and the sample checked to see if any radioactive carbon dioxide or carbon monoxide were released when the sample was heated. It was the expected release of compounds during heating or "pyrolyzation" that gave this experiment its name.

All three experiments produced positive results, suggesting the presence of metabolic activity or some form of life in the Martian soil sample.

Each experiment was repeated using a sample of Martian soil that had been sterilized to kill any living organisms present. None of these "control" experiments produced any indication of metabolic activity.

The positive results, however, did not prove that life exists on Mars. For example, in the gas-exchange experiment, the significant change was observed only in the oxygen level and not in that of other gases. Furthermore, the oxygen level rose sharply and remained level, a situation unlikely if the change had been caused by the action of microorganisms.

In the labelled-release experiment, radioactivity climbed abruptly but soon leveled off. If biological action had been present, the radioactivity should have

- more -

climbed more slowly and continued longer.

Although the positive results of the pyrolytic-release experiment appeared to resemble biological activity, they could very likely have been produced by inorganic chemical reactions. The presence of highly reactive superoxides of metals has been suggested as one explanation for the observed chemical activity.

Before the dawn of the twenty-first century, manned exploration of the solar system may tell us whether we are alone in our universe. Radio telescopes scanning the distant galaxies for intelligible messages may reveal the presence of remote neighbors. Laboratory experiments will continue trying to retrace the path of chemical evolution and may support our belief in the existence of extraterrestrial life.

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