



The Meaning of Life

Lin Chao

BioScience, Vol. 50, No. 3. (Mar., 2000), pp. 245-250.

Stable URL:

<http://links.jstor.org/sici?sici=0006-3568%28200003%2950%3A3%3C245%3ATMOL%3E2.0.CO%3B2-0>

BioScience is currently published by American Institute of Biological Sciences.

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at <http://www.jstor.org/about/terms.html>. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Please contact the publisher regarding any further use of this work. Publisher contact information may be obtained at <http://www.jstor.org/journals/aibs.html>.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

The JSTOR Archive is a trusted digital repository providing for long-term preservation and access to leading academic journals and scholarly literature from around the world. The Archive is supported by libraries, scholarly societies, publishers, and foundations. It is an initiative of JSTOR, a not-for-profit organization with a mission to help the scholarly community take advantage of advances in technology. For more information regarding JSTOR, please contact support@jstor.org.

The Meaning of Life

BY LIN CHAO

Biology is unique among the sciences in being perhaps the only field in which there is no general agreement on the object of its study. As beginning biology students quickly learn, adding the suffix “-logy” to most words instantly creates an area of study. However, although most biologists come to appreciate the difference between ichthyology, parasitology, embryology, paleontology, and even malacology, many have difficulties when challenged with defining biology. Biology is the study of life, but what is life? Some people enumerate metabolism, reproduction, homeostasis, genetics, and other characteristics often listed in introductory textbooks, but such checklists only understate the difficulty of defining life. Just walk the halls of any biology department and ask whether viruses are alive.

Attempting to define life evokes a sense of frustration in many biologists. Why define the obvious? Why complicate the simple? In this respect, defining life reminds one of Justice Potter Stewart’s struggle to define pornography in *Jacobellis v. Ohio*, 378 US 184, 197 (1964). Like pornography, life may not present any easy shorthand definition, but most people feel that “they know it when they see it.” Such feelings are not imagined. Consider, for example, taking a group of students to an archeological excavation and asking them to identify human artifacts among the rock debris. Most would be able to recover some artifacts without much training. Based on past experience, they will have formed a mental reference of potential human artifacts. Comparisons to this reference clue the students and provide them with intuition as to what is an artifact. Of all of the possible random shapes that rock debris can achieve, the probability is simply too small that one could be shaped like an arrowhead. Thus, if it looks like an arrowhead, it is likely to be an arrowhead. In this case, it is not life that they discover, but manifestations of the human form of life. Nonetheless, the process could be the same if they were looking for life.

The use of a reference, and the assumption that random forces are highly unlikely to have generated objects that are so similar, is the basis of the first modern definition of life—that of Erwin Schrodinger, who proposed in a 1943 series of lectures that life is negative entropy. Schrodinger later published these ideas as the book *What Is Life?*

(Schrodinger 1967). Interpreted more broadly to include other characteristics of life, such as morphology, and not just entropy changes in chemical reactions, Schrodinger’s definition implies that the characteristic feature of life is its ability to exist in improbable states (Lederberg 1965). Thus, the reference or baseline above which life rises is randomness. Such a definition is useful. It allows for the identification of human artifacts or dinosaur footprints. The similarity between ancient rock striations and modern mineral accretions by cyanobacteria led to the conclusion that stromatolites and life existed 3.5 billion years ago (Schopf 1992). Because microscopic structures on a Martian meteorite resemble terrestrial microbes, it was suggested that microbial life existed on Mars (McKay et al. 1996). In an earlier proposal to identify Martian life, consideration was given to looking for L- and D-amino acids on Mars (Lederberg 1965). Because terrestrial life uses only L-amino acids, the conjecture was that Martian life should also be biased toward one enantiomer or the other, although not necessarily to the L form.

However, although negative entropy is useful as a broad definition of life, this definition is not secure (Lederberg 1965). It can always be challenged because an abiotic process could have produced the presumed sign of life. A case in point is the 1976 Viking mission to find life on Mars. One of the studies completed on Mars by the mission was the Labeled Release experiment (Levin and Straat 1977). A small drop of solution containing ¹⁴C-labeled nutrients was applied to a sample of Martian soil, and any generation of labeled gas was monitored. For a control, a duplicate soil sample was heated to 160 °C for 3 hours before the addition of the nutrients. In such an experiment, a positive result for life is the generation of labeled gas in the experimental sample but not in the control sample, where any life would have been killed by the heat treatment. Terrestrial soil samples consistently give positive results, and Viking samples on Mars did so as well. Nonetheless, the Viking result is interpreted to be likely an artifact and not a sign of life (McKay et al. 1998). Abiotic factors, such as an inorganic oxidant, are suspected to have produced the labeled gases in the Martian Labeled Release experiments.

The problem with negative entropy is that it is not an exclusive definition. Randomness is an inadequate baseline because, although life is less probable than a random event, not all improbable states are life. Had the Viking mission sampled Martian soil for L- and D-amino acids and found only one enantiomer, the concern would still be

Lin Chao (e-mail: lchao@biomail.ucsd.edu) is a professor in the Department of Biology, University of California—San Diego, La Jolla, CA 92093-0116. © 2000 American Institute of Biological Sciences.

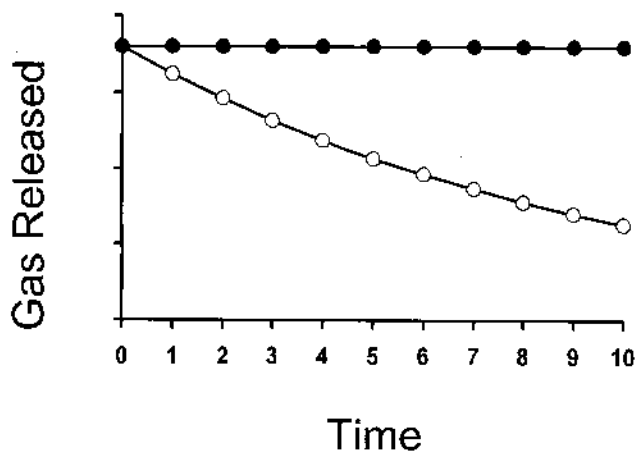


Figure 1. Expected gas release in a serially transferred Labeled Release experiment. If the release were due to the activity of an inorganic oxidant, then the amount of gas should decline exponentially with each transfer as the oxidant, being nonreproductive, is diluted (open circles). If a biotic agent produced the gas, then the amount should not decline because the agent will reproduce and replenish its numbers after each transfer and dilution (solid circles). Units for gas release are arbitrary and are not included because they would be relevant only as a relative scale for comparing the oxidant and a biotic agent within this figure. Units for time are also arbitrary but are included to provide a scale for comparison with Figures 3 and 4.

whether an abiotic source could have produced that pattern. Because the identification of extraterrestrial life is a major scientific milestone, no evidence for Martian life is acceptable until all alternatives are ruled out. In effect, the choice is to be conservative and bias the judgment against false positives. The same bias was evident when critics rejected more recent reports of microbes on a Martian meteorite (Bradley et al. 1997). Abiotic factors—this time natural deposition and bad camera angles—were again implicated. Debates over what constitutes extraterrestrial life may be more critical than debates over what constitutes terrestrial life, but claims of terrestrial life based on the observation of a nonrandom pattern can be equally challenged. For example, despite the fact that they have modern and living counterparts, stromatolites have also been attributed to abiotic factors (Grotzinger and Rothman 1996).

The evaluation of life in all of these examples is technically difficult. However, it may well be that the problem is not the search itself but rather the failure to identify an adequate definition of life. Negative entropy may be useful as a concept of life, but it fails as a useful definition. In this article, I review two alternative definitions—life as reproduction and life as evolution by natural selection—and assess their value by a gedanken, but technically realistic, experiment that reenacts the Viking mission. I argue that

defining life as evolution by natural selection fares the best by being the least likely to yield false positive results. Thus, I propose that evolution by natural selection is the best operational definition of life and that it should be applied in future searches for extraterrestrial life.

The operational test

An operational definition requires a defining test. Let that test be a reenactment of the Labeled Release experiments of the Viking mission. These experiments showed that if Martian soil is mixed with a solution containing labeled nutrients, labeled gases are released. The release of gases resembles the behavior of life-bearing terrestrial samples. However, as indicated above, this positive result is necessary, but not sufficient, to reveal the presence of life. Although it reproduces an improbable event and satisfies Schrodinger's negative entropy definition of life, the result suffers from the danger of false positives. Thus, the criterion is set. Are there definitions of life that fare better and yield fewer false positives?

Life is reproduction

Reproduction is perhaps the most popular definition of life. Three current introductory textbooks (Purves et al. 1998, Campbell et al. 1999, Solomon et al. 1999) list it as one of the major features of life. However, how well does it fare when used as the definition of life in a new Labeled Release experiment on Mars?

It is easy to incorporate the definition of life as reproduction into a new Labeled Release experiment. In the original experiments, a solution of labeled nutrients was added to a soil sample. For the present task, consider the converse experiment: adding a soil sample to a flask containing the nutrient solution. If the causative agent were in the soil, labeled gases would have been emitted just as in the original experiment, and equivalent results would have been obtained.

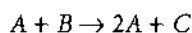
The first design was technically simpler and made no difference in the original Viking mission, but the converse approach is needed for the new Labeled Release experiment. To illustrate why, suppose that the labeled gases emitted in the original Labeled Release experiments on Mars were indeed due to inorganic oxidants in the Martian soil sample. Imagine, then, that after the gases are emitted, a small aliquot of the solution, which now contains Martian soil, is transferred to a new flask containing fresh solution. No new Martian soil is added to the new flask; the only soil that can be added has to come in the aliquot from the first flask. If the addition is done correctly, the amount of inorganic oxidants in the second flask will be less than in the first. Because an inorganic oxidant cannot reproduce, less gas will be emitted in the second flask. If the source of the gas is inorganic, the amount of gas emitted in each successive flask should decline exponentially as the transfer process is repeated (Figure 1). By contrast, a microbe under an equivalent treatment will be

able to make up for the dilution by reproducing. As a result, the same amount of gas will be generated in the successive flasks (Figure 1). This latter outcome (measured as the number of cells generated and not the amount of gas released) is in fact observed daily as microbiologists serially transfer cultures of bacteria in the laboratory (Atwood et al. 1951, Chao and Levin 1981).

Thus, life as reproduction improves on Schrodinger's definition of life by excluding non-reproducing abiotic agents. The required modification to the original Labeled Release experiments is slight. It is necessary only that gas release be monitored over time as the soil samples are cultured and serially transferred. However, this definition of life is also not immune to false positives. By depending on reproduction as the criterion, it can be fooled by abiotic autocatalytic systems.

Autocatalytic reactions

Autocatalysis requires that a given factor be able to convert substrate(s) or precursor(s) into a new factor of the same type. Thus, if *A* is the factor and *B* is the substrate(s), the reaction



is autocatalytic (*C* is a byproduct[s] that may or may not be generated). In relation to the Labeled Release experiments, *A* corresponds to a putative abiotic agent, *B* to the nutrient(s), and *C* to the labeled gas that is released. Because *A* is now able to increase in number, gas will be released in the new flask, so long as some *A* is passaged during serial transfer. Autocatalysis satisfies the serial transfer criterion because it mimics biological reproduction.

Many autocatalytic systems exist that are clearly not life. Many synthetic peptides and oligonucleotides are autocatalytic (Wilson 1998). For example, a 32-amino acid peptide with a structure based on a yeast transcription factor autocatalyzes its own synthesis by joining a 15-amino acid and a 17-amino acid fragment (Lee et al. 1996). Although the 32-amino acid peptide is of biotic origin, it is itself not life. A purely physical system of autocatalysis is the Oregonator mechanism for the Belovsov-Zhabotinskii reaction (Field and Noyes 1974), in which a molecule of bromous acid reacts with a bromate ion (along with other reagents) to generate two molecules of bromous acid. For an evolutionary biologist, the most illustrative autocatalytic but abiotic system is fire (Maynard Smith 1986). Like life, fires can give rise to fires. Every time a torchbearer lights a new torch, fire is effectively being serially transferred. But fire is clearly not life, which then takes us to the last definition of life.

Life is evolution by natural selection

Unlike life, fires lack heredity. In other words, fires lack the ability to acquire the characteristics of their "ancestors." For example, although fires vary in color, temperature, and size, their characteristics at any instant depend only

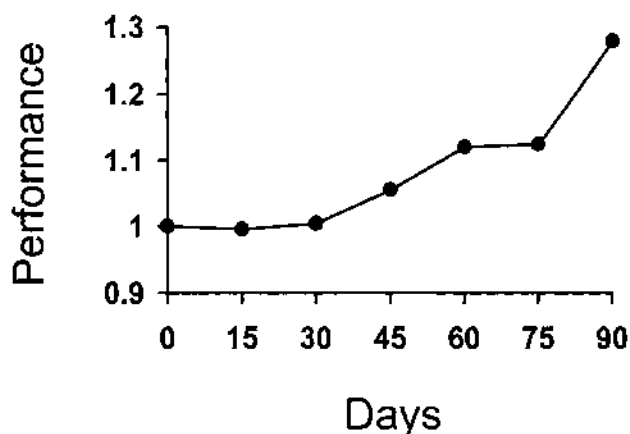


Figure 2. Observed mean performance of the bacterium *Escherichia coli* in long-term serial transfer. Performance, which is shown relative to that at the start of the experiment, corresponds to the ability of a bacterial population to reproduce and survive within a flask. The increase in performance is the result of evolutionary changes in the population. These results show the characteristic increase after approximately 30 days, which is approximately the time needed for novel beneficial mutations to appear and become the majority genotype in the population. An increase in mean performance is detectable only after beneficial mutations have become sufficiently common. Figure adapted from Lenski et al. (1991).

on their environment. A hot fire is hot because of its current supply of oxygen and fuel, not because the "ancestor" flame of the match that started it was hot. Thus, like does not beget like, and fires do not evolve by natural selection. Similarly, current autocatalytic systems of peptides and oligonucleotides still lack heredity and are thus also unable to evolve. Is life, then, evolution by natural selection? How well does such a definition fare when challenged with a mission to Mars?

A brief survey of three recent biology textbooks also finds a consistent description of evolution by natural selection as one of the major characteristics of life (Purves et al. 1998, Campbell et al. 1999, Solomon et al. 1999). The first formal use of this feature of life as a defining characteristic was most likely by Hermann J. Muller (1966). It is again easy to incorporate this definition into a Labeled Release experiment. As Atwood et al. (1951) first demonstrated, if a population of bacteria is serially transferred for many hundreds of generations, the bacteria will evolve and become better adapted to the laboratory culture. The time course of adaptation can be monitored by measuring population parameters such as total density, growth rate, and lag time within a flask. The routine outcome, as illustrated by the more recent results of Lenski et al. (1991), is that fitness or total performance (the compounded effect of total density, growth rate, and lag time) evolves to higher values after approximately 30 days (Figure 2).

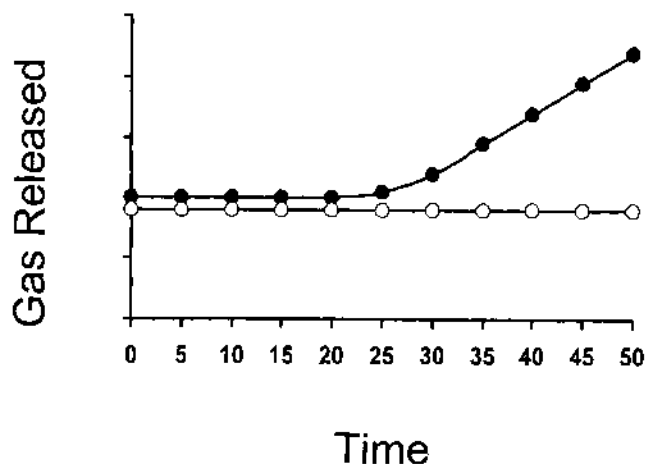


Figure 3. Expected changes in gas release in a long-term, serially transferred Labeled Release experiment. If the release were by an agent capable of reproducing but incapable of evolving by natural selection, then the amount of gas produced within each flask should remain constant with time (open circles). If the agent were able to reproduce and evolve, then the amount of gas could increase with time (solid circles). However, any increase would be expected to take place only after a time period of no change (see Figure 2)—that is, after a period longer than that in Figure 1. One line is arbitrarily drawn to start above the other to avoid overlapping the symbols. As in Figure 1, the units for gas release are arbitrary and omitted. The units for time, which are also arbitrary, are included for comparison with Figures 1 and 4.

Thus, the definition of life as evolution by natural selection predicts that Martian life should behave in the same manner as bacteria if the Labeled Release experiments were serially transferred for a large number of generations. The number of generations would have to exceed the number used in the life-as-reproduction experiments (see Figure 1) to allow for evolution. Total density, growth rate, and lag time of the Martian life could potentially be measured by following turbidity within a flask, but monitoring the release of labeled gases could also suffice. If evolution is occurring, the total amount of gas released per flask could increase with time (Figure 3). Alternatively, if finer time-scale measurements are possible, then the lag time to the first detection of released gas within a flask could also serve as an indication of evolution. However, lag time is expected to decrease, not increase, with time (Figure 4).

Because evolution is unpredictable, life may not always respond as anticipated by Figures 3 and 4. Instead of increasing the amount of gas released or decreasing the lag time, Martian life could evolve a different response and give a false negative. The possibility of false negatives is minimized if additional responses, such as the rate of exponential increase in gas release (see Figure 4), are monitored. However, if a Labeled Release experiment produces results such as Figures 3 and 4, the conclusion would be

that Martian soils contain life. But are false positives less likely when evolution by natural selection is used as the definition of life?

False positives and false negatives

Choosing whether it is better to risk false positives or false negatives is not necessarily an objective process. If the issue is a new and tasty but potentially harmful artificial sweetener, extremely wary consumers might want to bias their judgment against false negatives during safety testing. That is, they may prefer to lose a good sweetener than to mistakenly accept as safe one with harmful side effects. However, the company marketing the sweetener may feel otherwise. The company has more to lose with a false negative and may want a more even balance between the likelihood of false negatives and false positives. A less scrupulous company may want to bias the judgment against false positives. Consumers who are more concerned with preventing weight gain than with ensuring their health may likewise want a bias against false positives.

Because I have cast the test of the three definitions of life in the contentious arena of extraterrestrial life, it is understandable that most critics and judges have chosen to evaluate the data with an extreme bias against false positives and, hence, a necessarily high acceptance of false negatives. Such a bias against false positives is best summarized by Carl Sagan's edict (www.pbs.org/wgbh/nova/aliens/carlsagan.html) that "extraordinary claims require extraordinary evidence." However, this bias would probably be warranted even if the judgment did not concern extraterrestrial life. Drawing the line demarcating terrestrial life and non-life is also sufficiently contentious that one would want to avoid false positives. Thus, the first two definitions of life—as negative entropy and reproduction—fail the test because they produce too many false positives. That is, there are too many examples of obvious non-life that could satisfy either definition.

By contrast, the third definition of life—as evolution by natural selection—does not yield a high rate of false positives. No known abiotic agent could ever give patterns similar or analogous to those in Figures 3 and 4. Based on our knowledge of terrestrial chemistry and biology, the ability to change and improve in the manner predicted in the figures can be the result only of evolution by natural selection. And, on Earth, evolution by natural selection is the exclusive characteristic of life. On this basis, false positives are not possible if the definition of life is evolution by natural selection.

It is always possible that somehow, whether on this planet or another, an abiotic factor with properties totally unknown to us will be able to generate a pattern indicative of evolution of natural selection. However, if such a factor exists, the burden should be to explain why it is abiotic. Why not call it life? If it can evolve by natural selection, then—no matter how unlike life it is and regardless of whether it is extraterrestrial or not—it should have the

potential to change, to evolve, and to become any form of life. It is for this same reason that viruses are life. The fact that viruses require a living cell to reproduce is irrelevant to deciding whether they are life. In fact, humans themselves could not reproduce if they could not consume living cells. In any case, the definition of life as evolution by natural selection is at least less vulnerable to false positives than any other definition. Thus, it fares best in a challenge to search for extraterrestrial life.

Introductory biology textbooks still define life as a checklist of characteristics (Purves et al. 1998, Campbell et al. 1999, Solomon et al. 1999). The three characteristics I have considered in this article—nonrandomness, reproduction, and evolution—are included, but the use of a checklist differs from the approach I have presented of using a single operational definition. The use of a single definition is motivated in part because the decision of whether Martian life exists requires an all-or-none outcome. But a single definition may be actually more appropriate than a checklist because it is more accurate. For example, textbooks often list homeostasis as a characteristic of life. Although homeostasis may in fact be as fundamental to life as evolution, the two are not equivalent. Homeostasis is the product of evolution, but evolution is not the product of homeostasis. The same is true for any other characteristic of life. Evolution is the only characteristic of life that explains the rest (Dobzhansky 1973). Evolution unifies biology.

Although the modifications to the original Labeled Release experiment were presented here simply to demonstrate a point, there is no reason why they could not be carried out in future missions to Mars. They are simple and in fact could probably have been included in the original Viking mission. Indeed, in hindsight, the original Viking mission may have been as limited by definitions as it was by technical constraints. A better definition of life could have yielded better experiments. However, because current plans may call for Martian soil to be retrieved for analysis on Earth, deploying a modified Labeled Release experiment on Mars may not be necessary. Analyzing the samples on Earth relieves many of the technical constraints and makes it possible to analyze the samples by a much larger battery of tests. However, it may be that the most revealing test of all will still be an evolutionary experiment. After all, what would make a bigger stir? No nucleic acids, but a suspicious sample that evolves? Or Martian nucleic acids that cannot evolve? Which is less likely to be a false positive?

Acknowledgments

I thank Mark Lonergan (University of Oregon), Cecilia Dahlberg (University of California, San Diego), Rebecca Chasan, four anonymous reviewers, and my students for helpful discussions and feedback. The ideas in this essay were first developed as the introductory lecture for my Evolution class (Zoology 440, University of Maryland,

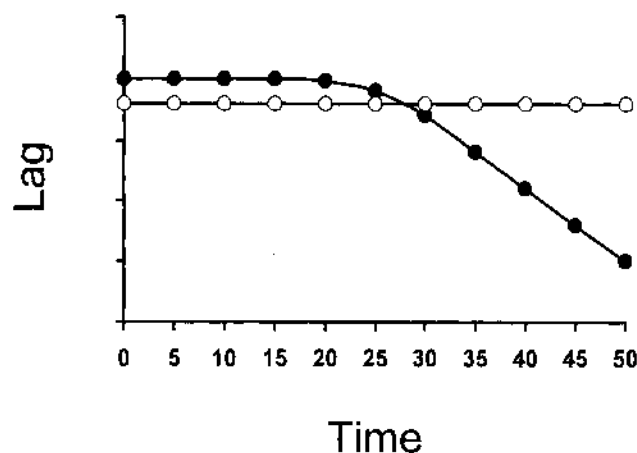


Figure 4. Other evolutionary changes in a long-term, serially transferred Labeled Release experiment. Because increased performance may evolve in a variety of ways, other variables in the experiment could show changes with time. For example, gas release within an experimental flask is expected to follow a distinct pattern (Levin 1972). Release is expected to start after a lag period (time); once initiated, the release should increase through an exponential phase; after the nutrients (or reagents) are exhausted, the release should level off at a maximum value. Figure 3 shows how the maximum value in successive flasks would increase if evolution occurred. The rate of increase during the exponential phase could likewise increase with evolution. Lag time would be expected to decrease if evolutionary changes occurred (solid circles). A shorter lag time results in better performance by providing a head start. An agent capable of reproduction but incapable of evolution should not change its lag time (open circles). One line is arbitrarily drawn to start above the other to avoid overlapping the symbols. Units for lag time are arbitrary and are omitted; units for time are arbitrary but are included for comparison.

College Park, MD) and later presented as a public lecture at American University (CAS Dean's Colloquium, 5 March 1998).

References cited

- Atwood KC, Schneider LK, Ryan FJ. 1951. Selective mechanisms in bacteria. *Cold Spring Harbor Symposia on Quantitative Biology* 16: 345–354.
- Bradley JB, Harvey RP, McSween HY Jr. 1997. No 'nanofossils' in martian meteorite. *Nature* 390: 454.
- Campbell NA, Reece JB, Mitchell LG. 1999. *Biology*, 5th ed. Menlo Park (CA): Addison Wesley Longman.
- Chao L, Levin BR. 1981. Structured habitats and the evolution of antimicrobial toxins in bacteria. *Proceedings of the National Academy of Sciences of the United States of America* 78: 6324–6328.
- Dobzhansky T. 1973. Nothing in biology makes sense, except in the light of evolution. *American Biology Teacher* 35: 125–129.
- Field RJ, Noyes RM. 1974. Oscillations in chemical systems. IV. Limit cycle behavior in a model of a real chemical reaction. *Journal of Chemical Physics* 60: 1877–1884.
- Grotzinger JP, Rothman DH. 1996. An abiotic model for stromatolite morphogenesis. *Nature* 383: 423–425.

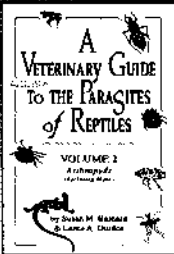
NEW TITLES AVAILABLE FROM KRIEGER



UNDER SOUTHERN SEAS:
The ecology of Australia's rocky reefs
edited by Neil Andrew
256 pp. ISBN 1-57524-141-2 \$49.50



SEA SNAKES, 2nd Ed.
by Harold Heatwole
166 pp. ISBN 1-57524-116-1 Paper \$29.50



A VETERINARY GUIDE TO THE PARASITES OF REPTILES - VOL 2: Arthropods (excluding Mites)
by Susan M. Barnard & Lance A. Dirden
298 pp. ISBN 0-89464-908-6 \$46.50



THE KOALA:
Natural History, Conservation, Management
by Roger Martin & Kathrine Handasyde
144 pp. ISBN 1-57524-136-6 Paper \$28.50

To place your order and obtain shipping costs call
1-800-724-0025
or e-mail us at: info@krieger-publishing.com



KRIEGER PUBLISHING COMPANY
P.O. Box 9542 • Melbourne, FL 32903-9542
(321) 724-9542 • FAX (321) 951-3671
www.krieger-publishing.com

Lederberg J. 1965. Signs of life. *Nature* 207: 9-13.

Lee DH, Granja JR, Martinez JA, Severin K, Ghadiri MR. 1996. A self-replicating peptide. *Nature* 382: 525-528.

Lenski RE, Rose MR, Simpson SC, Tadler SC. 1991. Long-term experimental evolution in *Escherichia coli*. I. Adaptation and divergence during 2,000 generations. *American Naturalist* 138: 1315-1341.

Levin GV. 1972. Detection of metabolically produced labeled gas: The Viking Mars Lander. *Icarus* 16: 153-166.

Levin GV, Straat PA. 1977. Recent results from the Viking Labeled Release Experiment on Mars. *Journal of Geophysical Research* 82: 4663-4667.

Maynard Smith J. 1986. *The Problems of Biology*. Oxford: Oxford University Press.

McKay DS, Gibson EK, Thomas-Keprta KL, Vali H, Romanek CS, Clemett SJ, Chillier XDF, Maechling CR, Zare RN. 1996. Search for past life on Mars: Possible relic biogenic activity in Martian meteorite ALH84001. *Science* 273: 924-930.

McKay CR, et al. 1998. The Mars Oxidant experiment (MOx) for Mars '96. *Planet. Space Science* 46: 769-777.

Muller HJ. 1966. The gene material as the initiator and the organizing basis of life. *American Naturalist* 100: 493-517.

Purves WK, Orians GH, Heller HC, Sadava D. 1998. *Life*. 5th ed. Sunderland (MA): Sinauer Associates.

Schopf JW. 1992. The oldest fossils and what they mean. Pages 29-63 in Schopf JW, ed. *Major Events in the History of Life*. Boston: Jones and Bartlett Publishers.

Schrodinger E. 1967. *What Is Life?* Cambridge (UK): The University Press.

Solomon EP, Berg LR, Martin DW. 1999. *Biology*. 5th ed. Fort Worth (TX): Saunders College Publishing.

Wilson EK. 1998. Go forth and multiply. *Chemical and Engineering News* 76: 40-44.

LINKED CITATIONS

- Page 1 of 2 -



You have printed the following article:

The Meaning of Life

Lin Chao

BioScience, Vol. 50, No. 3. (Mar., 2000), pp. 245-250.

Stable URL:

<http://links.jstor.org/sici?sici=0006-3568%28200003%2950%3A3%3C245%3ATMOL%3E2.0.CO%3B2-0>

This article references the following linked citations. If you are trying to access articles from an off-campus location, you may be required to first logon via your library web site to access JSTOR. Please visit your library's website or contact a librarian to learn about options for remote access to JSTOR.

References cited

Structured Habitats and the Evolution of Anticompetitor Toxins in Bacteria

Lin Chao; Bruce R. Levin

Proceedings of the National Academy of Sciences of the United States of America, Vol. 78, No. 10, [Part 2: Biological Sciences]. (Oct., 1981), pp. 6324-6328.

Stable URL:

<http://links.jstor.org/sici?sici=0027-8424%28198110%2978%3A10%3C6324%3ASHATEO%3E2.0.CO%3B2-A>

Long-Term Experimental Evolution in *Escherichia coli*. I. Adaptation and Divergence During 2,000 Generations

Richard E. Lenski; Michael R. Rose; Suzanne C. Simpson; Scott C. Tadler

The American Naturalist, Vol. 138, No. 6. (Dec., 1991), pp. 1315-1341.

Stable URL:

<http://links.jstor.org/sici?sici=0003-0147%28199112%29138%3A6%3C1315%3ALEEIEC%3E2.0.CO%3B2-2>

Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001

David S. McKay; Everett K. Gibson Jr.; Kathie L. Thomas-Keppta; Hojatollah Vali; Christopher S. Romanek; Simon J. Clemett; Xavier D. F. Chillier; Claude R. Maechling; Richard N. Zare

Science, New Series, Vol. 273, No. 5277. (Aug. 16, 1996), pp. 924-930.

Stable URL:

<http://links.jstor.org/sici?sici=0036-8075%2819960816%293%3A273%3A5277%3C924%3ASFLOM%3E2.0.CO%3B2-V>

<http://www.jstor.org>

LINKED CITATIONS

- Page 2 of 2 -



The Gene Material as the Initiator and the Organizing Basis of Life

H. J. Muller

The American Naturalist, Vol. 100, No. 915, Special One Hundredth Anniversary Year Issue. (Sep. - Oct., 1966), pp. 493-517.

Stable URL:

<http://links.jstor.org/sici?sici=0003-0147%28196609%2F10%29100%3A915%3C493%3ATGMATI%3E2.0.CO%3B2-R>