destroyed. No regeneration took place during the period of the experiments. Stress induced by the cautery was short-lived; the animals began to feed after several hours. After a period of 1 week, the three experimental animals were given 408 trials in which they compiled 197 correct scores (48.3 percent). Training was attempted with the naive fish but was not successful after 32 trials. With these same fish, 114 more tests produced 50 correct scores (43.9 percent). Thus, these tests demonstrated that the fish deprived of their olfactory sense have no ability to discriminate between two other fish.

We then tested the slime of the original donor fishes rather than their ambient water. An experimenter (with rubber gloves) gently lifted the donor fish out of its aquarium by means of a nylon net and wiped the fish's dorsal surface lightly with a piece of wet cheesecloth. The cloth was then placed in a 50-ml vial filled with water in which no fish had resided. The remainder of the experiment proceeded as previously described.

In 32 such trials, one of seven test fish made two errors to a negative stimulus. In the remaining 30 correct performances, we noted that the responses were less intense to the neutral water enriched by the donor slime than to the donor water itself. The lessened intensities of reaction to mucus in water where no fish had resided might be ascribed to a concentration of mucus, to the lack of certain fecal residues, or to the absence of urine (which freshwater fish excrete copiously), or to all of these factors. Stress products have been reported in fish urine (*10*).

Behavior observations had suggested to us that stress influenced chemosensory recognition. Several pairs each of a dominant and a submissive bullhead were made to share 190-liter aquariums. When the dominant fish was removed from such an aquarium, isolated overnight, and returned the next day, the submissive fish did not attack it as it would have attacked a stranger. However, when the dominant fish was returned after having experienced a losing encounter with another bullhead, the originally submissive one immediately attacked it.

To test more rigorously the effects of stress, six donor fish were subjected to mild electric shocks at regular intervals for several hours. After this gentle-to-moderate stress, the donors were recognized by the test fish correctly and without fail. To introduce a variation in stress, donors were made to fight with larger, neutral fish. They lost the fights and, as a result, were altered chemically in such a manner that the test fish did not discriminate between them. These experiments corroborated our observations that natural stress altered the pheromone system, but we have not yet resolved whether the changed chemical nature of a stressed fish is due to its altered slime or to other substances, perhaps in the urine.

In nature, bullheads do not live in 19-liter aquariums; therefore, one might suspect that the demonstrated olfactory capacity for distinguishing between other fish is not important in their lives in lakes and ponds. Only field studies, difficult to devise and execute, primarily because of the highly nocturnal habits of bullheads, should tell us whether or not individual intraspecific recognition is important in nature, as it is suspected to be for many animals (*4*).

An attempt was made to approach natural conditions in large aquariums of up to 7600 liters where bullheads were observed. Whether their vision was intact or not, they reacted to the introduction of small amounts of water from the aquariums of other bullheads. Subsequent observations and experiments in which opaque barriers were raised between previously separated animals suggested that pheromones had a part in their behavior. Interactions of a bullhead with others all pointed to reliance on individual chemosensory recognition and to the existence and importance of a complex chemical communication system outside the breeding season.

JOHN H. TODD, JELLE ATEMA
JOHN E. BARDACH
School of Natural Resources, University of Michigan, Ann Arbor

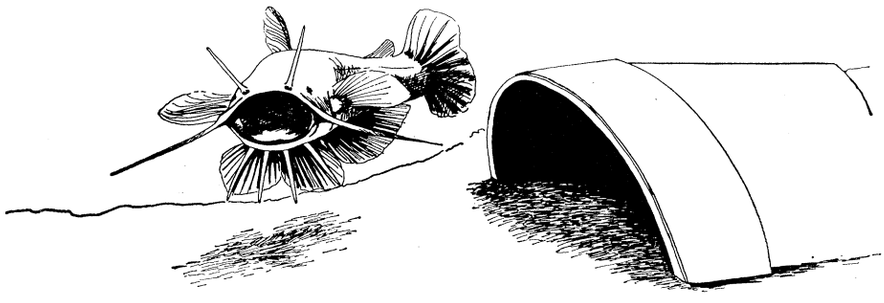

Fig. 1. Blind bullhead attacking the odor of its negative donor immediately before fleeing into the pot. [Drawing from a photograph]

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++−−−+−−++−−+++−++−−−.
This sequence was repeated.
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11. We thank Dr. R. Davis, Mental Health Research Institute, University of Michigan, for assistance in devising the discrimination experiments, and Dr. W. McLarney, of the Department of Wildlife and Fisheries, for his aid. Supported by PHS grant NB04687.

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Primitive Microfossils or Not?

There is increasing interest in possible organic remains in the early Precambrian strata of the earth, and even in celestial material. A variety of minute forms have been shown by Barghoorn and Tyler (*1*) and others to have such distinctive morphology, as well as composition preserved within rocks of such low permeability (after lithifaction) as flint, that there seems little doubt that they are the remains of life some 2 billion or more years ago.

More recently, microscopic forms from meteorites which may suggest comparable remains of primitive life have been found, and perhaps soon similar forms from the moon may be discovered. Some of these, which can be demonstrated not to result from contamination, seem to show a morphology so similar to the preservable remains of simple forms of life known to the microbiologist (or to the organ taxa of the palynologist) that they have

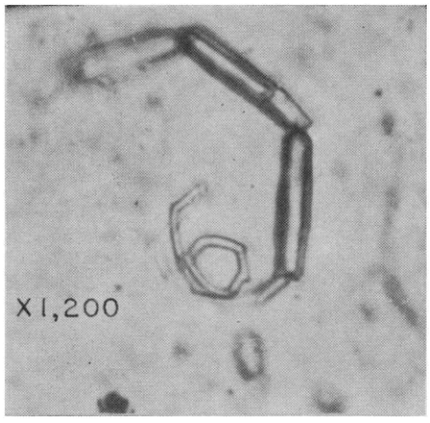

Fig. 1. Trichite in volcanic glass [from Ross (*2*)].

received generic assignments and species names.

However, the petrologist can show many inorganic structures that, with respect to morphology but not considering composition, are replicas of such simple organic remains. Minute vesicles, partially filled with a zeolite in palagonite (altered basalt), may have globular bodies with two or more walls; two or more of the bodies may be combined as "budding forms" or other interesting shapes. These are commonly separated with the disintegration of the matrix material.

One of the various forms of crystal trichites formed within a glassy igneous rock, illustrated in a paper by C. S. Ross (*2*), is reproduced here (Fig. 1). Another (No. 1) on the same plate, but not reproduced here, is perhaps a more striking example. With an expectable alteration of the volcanic glass to a clay mineral, and with the augite of the trichite "weathered" to some iron hydroxide mixture, such forms might seem identifiable to some microbiologist. Perhaps *Trichites trichiformis* is an appropriate name for this interesting form. However, I wish to leave this a *nomen nudum*, assigned to neither the plant nor animal kingdom.

M. N. BRAMLETTE
Scripps Institution of Oceanography, La Jolla, California 92037

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11 September 1967

Planetary Magnetic Fields and Rotation

In their presentation of the results of the particle-detector experiment on Mariner IV, Van Allen *et al.* (*1*) mention the possibility of testing the Blackett hypothesis (*2*), which states that planetary as well as stellar magnetic fields might be due to a hitherto unknown property of matter by which every rotating mass has associated with it a magnetic dipole moment. Blackett was led to this hypothesis from the observation that for both the earth and the sun the relationship between magnetic moment P and angular momentum U can be expressed in terms of the two fundamental constants G and c as

$$P = \beta \frac{G^{1/2}}{c} U \qquad (1)$$

where β is of order unity. However, in addition to the results from Mariner IV, which indicate that Eq. 1 is not valid for Mars (*1*, *3*), there is much other evidence that this equation does not describe a general property of rotating matter. Blackett himself carried out experiments in which he attempted to detect a possible magnetic field due to a mass of gold rotating with the earth; his results were negative (*4*). Experiments by Runcorn *et al.* in deep mines showed that the magnetic field of the earth is due to sources deeper in the earth and not dependent on the distributed mass of the earth (*5*). Finally, the magnetic dipole moment of the sun is now believed to be one (*6*) or two (*7*) orders of magnitude smaller than the value which first led Blackett to postulate Eq. 1.

Nevertheless, a fact which seems so far to have escaped notice is that interpretation of the nonthermal radio emission from Jupiter as being due to the motion of charged particles trapped in a planetary magnetic field (*8*) leads to an absolute value of the magnetic moment (*9–12*) that is entirely consistent with Eq. 1. The angular momentum of Jupiter is approximately 8×10^4 that of the earth, and the recent estimates of the magnetic moment of Jupiter lie in the range 3.5×10^4 to 1.25×10^5 that of the earth. The estimates of Chang and Davis (*9*) and Berge (*10*) are based on interpretation of the decimeter emission as synchrotron radiation from electrons trapped in radiation belts. The estimate of Warwick (*11*) is based on the interpretation of the decameter bursts as Cerenkov radiation from electrons precipitated into the upper ionosphere from the radiation belts, and that of Ellis and McCulloch (*12*) is based on the interpretation of the decameter bursts as Doppler-shifted cyclotron radiation. Thus, while the hypothesis that the magnetic fields of massive rotating bodies may be due simply to a hitherto unknown property of masses in rotation is certainly not true in general, Eq. 1 is valid, over a range of five orders of magnitude, for the two planets known to have magnetic fields.

ROBERT T. BROWN
Department of Space Science, Rice University, Houston, Texas

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30 June 1967

Although Brown properly cites prior evidence against the validity of the Blackett hypothesis, I continue to feel that our determination of an upper limit to the magnetic moment of Mars has a certain cogency in an astronomical context. The test on Mars is one which I have aspired to make since I first heard Professor Blackett lecture on this subject some 20 years ago.

In the face of all the negative evidence concerning the validity of the Blackett hypothesis, Brown's suggestion that it may apply to Earth and Jupiter seems untenable.

J. A. VAN ALLEN
Department of Physics and Astronomy, University of Iowa, Iowa City

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