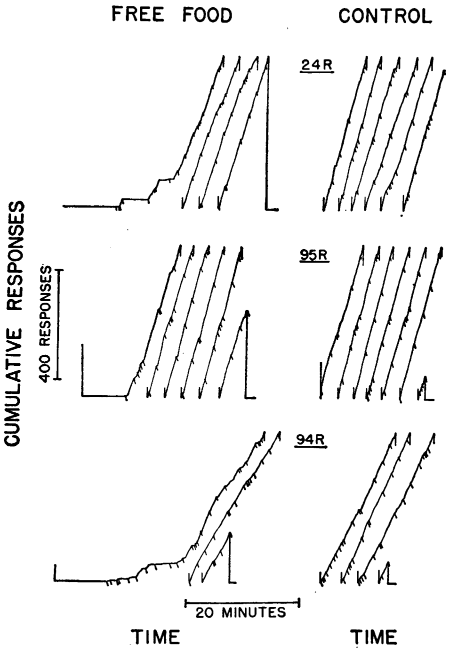

Fig. 1. Cumulative response records showing the second free-food session (24R), the third free-food session (95R), and the last free-food session (94R). Paired control sessions preceded the free-food sessions by one day. Slash marks indicate the presentation of grain in the hopper.

once per minute, a peck to a lighted response disk produced 4 seconds of access to grain in a lighted hopper (see *3*). A session ended when the bird obtained 45 reinforcements. During the first "free food" session, the procedure was identical except that a cup filled with about 240 g of grain was placed in a rear corner of the chamber. Thus, there were now two sources of identical food. The apparatus was turned on (the response disk was lighted, and so forth) only after the bird began to eat the free grain. All birds behaved similarly. They ate the free grain continuously for a few minutes, then turned around and pecked the disk to produce hopper grain. During the next few minutes, the subjects occasionally returned to the cup of free food, but they then ignored the free food, pecked the disk at relatively high frequencies, and ate grain from the hopper until the programed 45 reinforcements were obtained. The cup of free food was about half-filled with grain at the end of each session. After returning to 80 percent of normal weights (about 4 days later), the birds received one control session under the variable-interval schedule alone (no free food), followed the next day by a session with free grain again available. This same sequence was repeated three more times. During the five free-food sessions, subjects 95R, 24R, and 94R responded on the average of 64, 40, and 26 times, respectively, for each reinforcement. The averages during the intervening control sessions were 69, 71, and 47 responses per reinforcement, respectively. Responding during the last free-food session (an average of 42 responses per reinforcement) was approximately the same as during the first free-food session (39 reponses per reinforcement). Figure 1 shows representative cumulative response records of these performances. The birds responded despite an average gain in weight during free-food sessions approximately ten times greater than that during control sessions. Indeed, after some free-food sessions, one bird regurgitated grain in its home cage.

This study differs from previous experiments (*1–4*) in a number of ways. The birds were at 80 percent of their normal weights when sessions began; a variable-interval schedule of reinforcement was used; free-food sessions alternated with control sessions; and the subjects had considerable prior experimental experiences. The individual contributions of each of these, together with the durability of the effect, must be determined. My results indicate, however, that under some conditions animals respond many times to earn one food reward while identical food is freely available.

ALLEN J. NEURINGER
Foundation For Research On The Nervous System, 36 The Fenway, Boston, Massachusetts 02215

References and Notes

1. B. Carder and K. Berkowitz, *Science* **167**, 1273 (1970).
2. G. D. Jensen, *J. Exp. Psychol.* **65**, 451 (1963).
3. A. J. Neuringer, *Science* **166**, 399 (1969).
4. S. B. Stolz and D. F. Lott, *J. Comp. Physiol. Psychol.* **57**, 147 (1964).
5. Supported by PHS research grant MH-15495. I thank M. Miskella, D. Ramsay, and A. Schein. Reprint requests should be sent to the author at Reed College, Portland, Oregon 97202.

30 March 1970

Control of Acidic Mine Drainage

Singer and Stumm (*1*) have established the oxidation of Fe^{2+} as the rate-determining step and propose two means for control of pyrite oxidation—the highly impractical one of excluding oxygen from a mine, and the more likely one of introducing bactericides to reduce the rate by destruction of the biocatalytic organisms presumably present in natural systems.

A third possibility exists—that of reducing the rate of a noncritical step to a very small value. About 1953, Patrick (*2*) found that small quantities of chromate ion were effective in inhibiting the oxidation of pyrite, both in laboratory tests and in the field. The mechanism is probably analogous to that of chromate in inhibiting the corrosion of metals.

Patrick's work was with sodium chromate, which of course leached rapidly from a wet mine face, and hence the effect was not long-lasting. Furthermore, this rapid leaching would cause significant if temporary pollution of the mine effluent. The amount of chromate necessary to afford virtually complete inhibition of iron in waters with a chloride concentration of 10 ppm is 100 ppm (*3*), but corrosion is reduced by 90 percent or more in systems where 5 ppm is maintained (*4*). Such concentrations can be readily attained on the mine face by the use of a slightly soluble chromate, such as calcium or strontium chromate, dispersed in an adherent, hydrophilic coating, such as a polyvinyl acetate. Although chromate is photochemically reduced in such systems, they should be stable inside a mine.

Some of the oxidation of pyrite in mines results from the percolation of oxidizing groundwaters through fracture zones, but much occurs at the mine face, where both oxygen and bacteria have free access, and it is this that chromates may be helpful in controlling. Only a small amount of chromate should appear in the mine effluent, and this will probably be reduced and precipitated not far below the effluent point.

In accord with Singer and Stumm (*1*), it is important to note that chromate is an effective biocide, having a low killing concentration for wood-destroying fungi (*5*).

WINSLOW H. HARTFORD
1413 Redcoat Drive, Charlotte, North Carolina 28211

References

1. P. C. Singer and W. Stumm, *Science* **167**, 1121 (1970).
2. W. A. Patrick, unpublished data (1953).
3. M. Darrin, *Ind. Eng. Chem.* **38**, 368 (1946).
4. W. B. Lauder, thesis, Johns Hopkins University (1949).
5. E. Bateman and R. H. Baechler, *Proc. Amer. Wood Preserv. Ass.* **33**, 91 (1937).

2 March 1970; revised 14 May 1970

Control of Acidic Mine Drainage

Winslow H. Hartford

Science **169** (3944), 504.
DOI: 10.1126/science.169.3944.504

Science (print ISSN 0036-8075; online ISSN 1095-9203) is published by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005. The title *Science* is a registered trademark of AAAS.