data on XeF_6 of the Argonne Laboratory, the Ford Laboratory, G. Cady's laboratory, and our own laboratory (RITU) are included in Fig. 2 (*4*).

The vapor-pressure equation for solid KrF_4 is

$$\log_{10} p_{mm} = 8.531 - 1930/T$$

(T in degrees Kelvin); $\Delta H_{subl.} = 8840$ ($\pm \sim 300$) cal/mole. The curve is practically parallel to the vapor-pressure curve for XeF_6. The extrapolated sublimation temperature (at pressure of 1.00 atm) is approximately 70°C.

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References and Notes

1. H. H. Claassen, H. Selig, J. G. Malm, *J. Am. Chem. Soc.* **84**, 3593 (1962); C. L. Chernick *et al.*, *Science* **138**, 136 (1962).
2. P. R. Fields, L. Stein, M. H. Zirin, *J. Am. Chem. Soc.* **84**, 4164 (1962).
3. J. L. Weeks, C. L. Chernick, M. S. Matheson, *ibid.* **84**, 4613 (1962).
4. N. Bartlett, *Chem. Eng. News* **1963**, 36 (4 Feb. 1963).
5. A. D. Kirshenbaum and A. V. Grosse, *J. Am. Chem. Soc.* **81**, 1277 (1959); ——— and J. G. Aston, *ibid.* **81**, 6398 (1959).
6. A. V. Grosse, A. G. Streng, A. D. Kirshenbaum, *ibid.* **83**, 1004 (1961).
7. A. D. Kirshenbaum, L. V. Streng, A. G. Streng, A. V. Grosse, *ibid.* **85**, 360 (1963).
8. This work was supported by the Office of Naval Research [Project Nonr 3085(01)].
9. These figures are given for purposes of orientation only; actually, deposit of CuF_2 on the surface of the vessel is likely to catalyze the decomposition. A study of thermal decomposition in a chemically completely inert vessel will have to be made at some future time.

13 February 1963

Conditioning of a Free Operant Response in Planaria

Abstract. *The response of breaking a photoelectric cell beam was automatically recorded and reinforced. Termination of an intense light was the reinforcement in an escape conditioning situation. The rate of response for the experimental subjects was significantly different from that of controls matched for equivalent changes in light intensity.*

Studies of learning in simple organisms have been concerned with the habituation of a response, classical (Pavlovian) conditioning, and maze behavior. No studies of free operant conditioning (*1*) for species in any phylum from Protozoa to Annelida have been reported. Recent experiments on learning in planaria have dealt with classical conditioning, first studied by Thompson and McConnell (*2*), and maze learning, such as the studies of Best and Rubinstein (*3*).

This report describes experiments in which a free operant response was recorded continuously for periods as long as 165 hours. The response measured was that of the planarian's passage through a narrow beam of light directed at a photoelectric cell, and the reinforcement was the termination of an intense light. The technique is entirely objective since responses are recorded and reinforced automatically.

The apparatus consisted of a small, clear Plexiglas chamber, a light bulb (providing the reinforcing stimulus), a photosensitive diode and light beam, and ordinary control equipment used for operant conditioning experiments. The chamber was designed so that subjects would have a reasonably high operant level without excessively restricting their motion and so that they could be maintained for long periods of time. It was cylindrical, with a depth of 1.27 cm and a diameter of 1.90 cm, and was filled with aged tap water. A narrow beam of light, 3.2 mm in diameter, from a 7-watt clear bulb passed up through the bottom of the chamber, through a small rectangular block of Plexiglas projecting from the chamber wall, and into a fine cylindrical opening leading to the photocell. The subject passed under the projecting block, which was 1.5 mm above the chamber bottom, and interrupted the beam. A 60-watt frosted bulb, 12.7 cm above the chamber, provided the aversive stimulus. The temperature of the water, regulated by a stream of cool air, was between 16° and 18°C.

All subjects were maintained in a large covered jar filled with aged tap water at 18°C and were fed live tubifex worms every 2 to 3 days. A pipette with a large opening was used to transfer the planarians to the chamber. Aged tap water in the chamber was changed every 9 hours for the duration of the experiment. Responses were recorded continuously for periods which averaged about 70 hours. Subjects were removed from the chamber after the procedure of extinction and reconditioning, or because of equipment failure or an accident to the subject. The small light which was trained on the photocell remained on continuously for all procedures, and responses were recorded with the stimulus light on and off.

The subjects were 22 adult *cura foremani*. For the eight experimental subjects, reinforcement was the

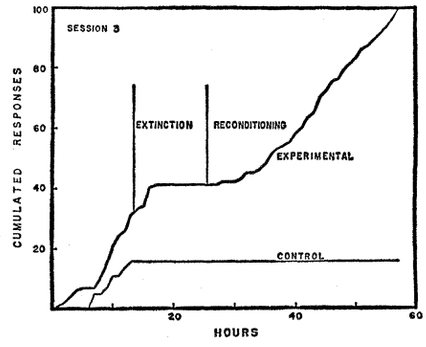

Fig. 1. Cumulated responses as a function of time in hours from the beginning of the experiment. Data for the experimental and matched control subjects are shown. The period for which the extinction procedure was followed is marked on the experimental curve.

termination of the light for 15 minutes. Eight subjects (matched controls) were each paired with an experimental animal. Six additional subjects were run with the procedures of light on continuously, light off continuously, and alternating 15-minute periods of light on and light off.

The matched control and experimental subjects were placed in adjacent chambers illuminated by the same stimulus light. As indicated by the data for the continuous-light-on and the continuous-light-off subjects, the general activity of *C. foremani* is greatly affected by differences in light intensity apart from any reinforcement contingency. To control for such changes in general activity, the matched control subject was exposed to the same changes in illumination as the experimental subject, but it did not bring about the changes by responding. These subjects

Table 1. Percentage half-hour intervals with response rates of one to two responses per half hour. Results for experimental and matched control subjects are shown. Additional data for subjects with alternating 15 minutes light and 15 minutes dark (ALD), continuous darkness (CD), and continuous light (CL) are listed.

Session	Total time (hr)	Percentage intervals	
		Exptl.	Control
01	52	64	16
02	79	34	07
03	58	66	05
04	16	46	14
05	107	29	13
06	165	25	09
07	31	26	16
08	68	36	12
ALD	72		19
			12
CD	62		09
			12
CL	73		15
			09

also served to control for possible variations in response rate due to changes in the chemical environment or the temperature and depth of the water.

The effects of the conditioning procedure are illustrated in Table 1, which compares the response rates for the experimental and control subjects. With 15 minutes' light termination, one would expect a conditioned subject to respond at a rate near one response per 15 minutes. Since the data were evaluated by counting the number of responses per half hour, the percentage of half-hour intervals in which the response rate was one to two responses per half hour is compared. All eight experimental subjects had higher percentages than the matched control subjects. The probability of this result occurring by chance is 0.004 by the randomization test for matched pairs. Another measure of conditioning was median latencies of response (time interval between the onset of the stimulus light and the next response) computed for successive 6-hour intervals. The experimental subject of session I was particularly striking in this regard, showing a monotonic decrease from 30 minutes for the first interval to 3 minutes for the seventh.

Only the reinforced subjects produced steady, spaced behavior. The response pattern of the control subjects generally consisted of a burst of rapid responding (as high as 62 per half hour) during the long latencies of the experimental animals and a depression of responding when the experimental subjects had short latencies. Occasional observations of the subjects indicated that after a brief period of exploratory behavior, the motion of the control subjects consisted of a repeated circling of the chamber wall. The experimental subjects at first showed similar behavior, but after 20 or 30 hours would occasionally move directly towards the photocell beam. After a period of steady responding, usually about 50 to 60 hours from the beginning of the experiment, some of the reinforced subjects became "lethargic" in their motion and showed a decrease in response rate. When removed from the chamber (but not simply when the water was changed) the subjects resumed their usual rate of movement. Best and Rubinstein (*3*) noted a similar effect for a conditioned subject in a maze: "There is, in Planaria, some process that, following the phase of rejection of the reinforced alternative, leads to a lethargic state which is not a simple fatigue or injury state."

After the response rate stabilized, the experimental subject of session 3 (Fig. 1) was exposed to a modified extinction procedure. The planarian (together with its matched control subject) was presented, independently of the response, with 15 minutes of darkness alternated with 7.5 minutes of light. The 7.5-minute period was the maximum latency of response for the last six trials of conditioning.

As discussed above, the basis for this procedure was to control for changes in general activity due to differences in illumination. Accidental reinforcement was avoided in this procedure by programming a 1.0-minute delay of light termination if a response occurred in the last minute of the light-on period. The response rate greatly decreased in extinction and increased again with reconditioning.

All of the six additional subjects had a lower percentage of response rates at one to two responses per ½ hour than the lowest reinforced subject. The two subjects with continuous light for 72 hours produced high rates of response between periods of inactivity. A similar pattern of response was produced by subjects having the light off continuously for 62 hours except that the rates were about one-tenth as high. Most similar to the experimental subjects' performance were the performances of subjects exposed to alternating 15-minute periods of darkness and light. They began with high rates which gradually decreased and became more distributed, but were not as steady as the experimental subjects. The results provide further evidence that the response rate for the experimental subjects was dependent upon the reinforcement contingency (*4*).

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References and Notes

1. In free operant conditioning, a subject may at any time and repeatedly emit a specified response which leads to a reward or the termination of an aversive condition (for example, pressing a lever for a food reward).
2. R. Thompson and J. McConnell, *J. Comp. Physiol. Psychol.* **48**, 65 (1955).
3. J. Best and I. Rubinstein, *ibid.* **55**, 560 (1962).
4. This report is based on a master's thesis submitted to the department of psychology of the University of Maryland in 1963. The research was conducted in the laboratory of psychopharmacology under the supervision of Dr. Lewis R. Gollub. Supported in part by research grant MY-1604 from the National Institutes of Health and research grant NsG-189 from the National Aeronautics and Space Administration. The advice and encouragement of Dr. Travis I. Thompson are gratefully acknowledged.

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Enzyme Changes in Flight Muscle Correlated with Aging and Flight Ability in the Male Housefly

Abstract. *Magnesium-activated adenosine triphosphatase activity in the giant mitochondria (sarcosomes) of the flight muscle of aging male houseflies decreases concomitantly with failure in flight as reflected in the loss of wings during the second week of adult life. Preceding the loss of wings, however, there is a rapid decline in the activity of an α-glycerophosphate dehydrogenase which is located in the extramitochondrial fraction and is dependent on nicotinamide adenine dinucleotide.*

Earlier reports (*1*, *2*) have shown that the male housefly, *Musca domestica* L., not only has a much shorter life span than the female, but during the second week of adult life exhibits an abrading, and ultimately total loss, of both wings. A marked decline in activity of total body acid, sodium β-glycerophosphatase, and thoracic magnesium-activated adenosine triphosphatase (ATPase) accompanied these gross structural and functional manifestations of senescence (*1*). There is also a time-dependent reciprocal relationship between this failure in ATPase and a sixfold accumulation of total thoracic adenosine triphosphate (ATP) (*3*). By use of differential centrifugation and solubility to separate the various muscle components, particularly the giant mitochondria (sarcosomes) (*4*), it was possible to establish the biochemical mechanisms linked to alterations in flight ability of the aging male housefly and to locate within the flight muscle itself the actual sites of these mechanisms.

Houseflies (strain NAIDM) (*5*) were bred on a regularized 14-day cycle from generation to generation. The larvae were maintained on a standardized artificial laboratory medium, and the adults were reared in screened cages on cane sugar, water, and powdered whole milk. Conditions of constant lighting, temperature (26.7°C), and relative humidity (50 percent) were carefully controlled. All flies were examined, separated by sex, and counted under continuous CO_2 anesthesia. The sarcosomes were isolated in an ice-cold (*6*) isotonic 0.9 percent KCl solution (*7*). The Mg-activated ATPase activity was determined at 37°C for this mitochondrial fraction in