while others are more dependent upon the physiological state existing during the phase of the radiation-sickness syndrome in which death occurs. By day 29 only taurine and urine volumes had returned to preirradiation levels in group I. The relationship of some of these changes to known sequelae of the syndrome are evident: for example, taurine to depressed —SH (*8*) and disrupted cysteine metabolism, histidine to hemopoiesis, phosphate and uric acid to nucleic acid metabolism, and urea and creatinine to tissue damage and starvation. The other amino acid patterns are difficult to understand at present.

The biological action spectrum of ionizing radiation is very broad—the amount required to inactivate enzyme molecules is greater by several orders of magnitude than that required to kill mammals, and this in turn is much greater than that required to inactivate lymphocytes. However, the difference between the amount of radiation that is needed to give mammals either a 100- or 0-percent survival in a given period is very small. At a given dosage in this range the distinction between survival and death is very fine. A group of animals (inbred or not) irradiated with an identical dose probably vary widely at the time in relative sensitivities and recovery potentialities, owing to both genetic heterogeneity and phenotypic variability. Some individuals survive and some die. The metabolic differences among them are detectable within 24 hours after exposure. Indeed, in this case, short-term survivors had the lowest individual preirradiation values of the 12 rats in urine volumes, phosphate, creatinine, urea, and uric acid. Further study may make possible the construction of an index of survival; for example, on day 1, animals surviving only 10 days had the highest phosphate, taurine, creatinine, and alanine, and the lowest urea, aspartic acid, glutamic acid, and histidine. Taurine is especially interesting because of the small individual variability.

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9. Because of the large variance within the groups, the Mann-Whitney "U" test [*Ann. Math. Statist.* 18, 50 (1947)] was used except for the low variance taurine and histidine, where Student's "t" test was employed.

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13 June 1955

Reward Schedules and Behavior Maintained by Intracranial Self-Stimulation

Olds and Milner have demonstrated a rewarding effect produced by electric stimulation of some areas of the brain (*1*). Rats that could electrically stimulate themselves in the septal region and certain other areas each time they pressed a lever (continuous reinforcement) were able to maintain high lever-pressing rates without any other reward. The present study was undertaken to develop, through the use of reward (reinforcement) scheduling techniques, stable, long-term lever-pressing rates sensitive to the effects of relevant variables.

In contrast to the continuous reinforcement procedure in which every lever press produces the reward, the reinforcement may be programmed in such a way that only occasional responses are rewarded. This may be accomplished by means of a variable-interval schedule, in which the lever is primed to deliver the reward on a random time basis, or by means of a fixed-ratio schedule, in which a fixed number of responses is required to produce the reward. Such schedules have been demonstrated to generate characteristic types of behavior when conventional rewards—for example, food or water—are used (*2*).

A pulse-pair generator recently described by Lilly and his coworkers (*3*) served as the electric stimulus source. Stable lever-pressing rates have been maintained by rats and cats on reinforcement schedules over periods as long as 6 months without any change in the stimulus parameters. The stimulus, delivered through chronically implanted electrodes (*4*), had a frequency of 100 cy/sec and a pulse-pair duration of 0.1 msec, with amperage varying from animal to animal. The duration of each train of pulse-pairs was 0.5 sec, regardless of the duration of the lever-press. In the rats, the electrode tips were located in the septal area, while in the cats the caudate nucleus was found to be an effective site of stimulation (*5*).

Figure 1 presents 15-minute cumulative response curves obtained from one cat under two reinforcement schedules. The curves shown are typical of those obtained during the intervening days. On the variable interval schedule the lever was connected to the stimulator at irregular intervals, with a mean of 16 sec, so that only some lever-presses produced the intracranial stimulation. On the fixed-ratio schedule, seven responses were required to produce each electric stimulus. The animals were originally trained on a continuous reinforcement schedule, in which every lever-press resulted in an electric stimulus. Marked differences in the rate of responding were obtained with the two schedules. The fixed-ratio was also characterized by typical pauses following reinforcements, although these are generally obscured in the reduced figure.

The curves of Fig. 1 are similar to those obtained with food or water reinforcement. However, the low ratios and short mean intervals at which responding could be maintained suggest comparison with small amounts of reinforcement (*6*). On the assumption that stimulus intensity may be analogous to "amount" of reinforcement, amperage was varied during an hour-long session for one cat that was producing an irregular curve on a fixed-ratio schedule of 8:1. At the start of the session the stimulus was presented at a lower amperage than was usual for this cat. Figure 2, depicting the complete record for one 60-minute session, suggests that an increase in electric stimulus intensity may act in a manner similar to an increase in the amount of reinforcement.

In addition to producing stable behavior sensitive to other variables, such as electric stimulus parameters, intermittent reward schedules also have the advantage of minimizing the influence of gross motor effects of the stimulus on the response rate. Such schedules have proved useful in studying the effects of other motivating conditions, for example,

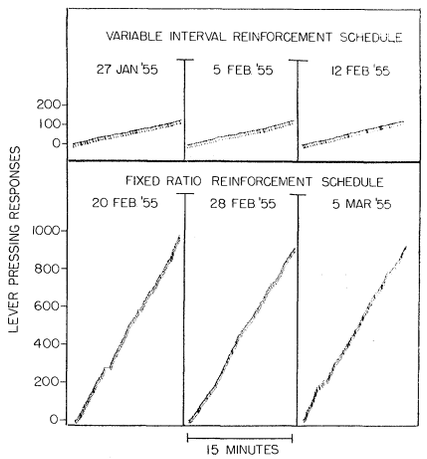

Fig. 1. Fifteen-minute cumulative lever-pressing curves for fixed ratio (7:1) and variable interval (mean of 16 sec) intracranial electric stimulation reward (cat E-5). Oblique "pips" indicate reinforcements.

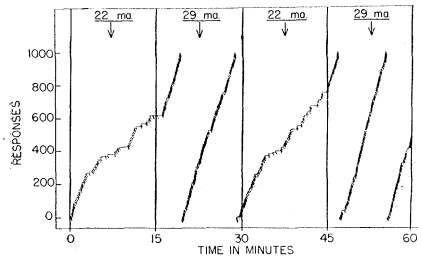

Fig. 2. A 60-minute session under fixed-ratio (8:1) during which the electric stimulus current was varied in alternate 15-minute periods (cat E-5, 7 Mar. 1955).

food and water deprivation, and conditioned "anxiety" states, on behavior controlled by brain stimulation. Reports of these investigations are now in preparation.

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21 June 1955

Proton Affinity of Phosphine in the Phosphonium Halides

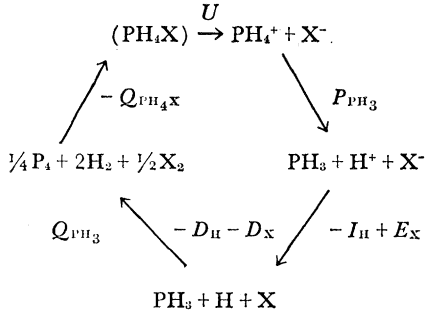
It has been pointed out by Grimm (*1*) that it is possible to calculate the proton affinity of ammonia, P_{NH_3}, if the crystal energies of the ammonium halides and the electron affinities of the halogens are known. Using this method, Sherman (*2*) has calculated the proton affinity of ammonia in the ammonium halides and found it to be 221.0, 209.0, 208.6, and 202.7 kcal in NH_4F, NH_4Cl, NH_4Br, and NH_4I, respectively. An average value of 206.8 kcal was adopted. Similar calculations were made for the proton affinity of water, the calculated value being 182 kcal.

Experimental evidence indicates that phosphine is a weaker base than ammonia. The absence of a series of phosphonium salts comparable in stability to the ammonium salts is evidence for the decreased basicity. At room temperature PH_4I is a solid (sublimation point 62°C), while the bromide and chloride are dissociated gases. Since the proton affinity of a molecule is a measure of basicity, it was of interest to calculate this value for phosphine.

The proton affinity of phosphine, P_{PH_3}, is defined as the energy change for the reaction

$$PH_4^+ \rightarrow PH_3 + H^+$$

This energy change can be calculated indirectly by use of the familiar Born-Haber cycle. This cycle is represented as



The proton affinity at 0°K is given by the relation

$$P_{PH_3} = U + Q_{PH_4X} - Q_{PH_3} + D_H + I_H + D_X - E_X - 5/2RT,$$

where U is the lattice energy of the PH_4X (X representing chlorine, bromine, or iodine) Q_{PH_4X} is the heat of formation of PH_4X, Q_{PH_3} is the heat of formation of phosphine, D_H is the heat of dissociation of hydrogen, I_H is the ionization potential of hydrogen, D_X is the heat of dissociation of the halogen molecule, E_X is the electron affinity of the halogen, and RT is the gas constant, 1.987 cal deg^{-1} $mole^{-1}$, times the temperature, 298.1°K.

Table 1 gives the thermal data required to calculate the proton affinity of phosphine in PH_4I, PH_4Br, and PH_4Cl. Because of the unreliability of many of the data, the calculated proton affinities are accurate only to about ± 5 percent in PH_4I and about ± 10 percent in the other two halides. The error is of this magnitude because the crystal lattice of PH_4I is the only one known with accuracy (*3*). Similar structures have been assumed for the other two halides. Thus, the PH_4I value for the proton affinity would be the most reliable.

Recent electron affinity values for the halogens E_X (*4*) are lower by about 5 to 7 percent than the values used by Sherman (*2*). This would give a higher proton affinity for ammonia by about 2 to 5 percent. Thus, the new values would be in the range from 226 to 210 kcal. However, even with this revision, the proton affinity of phosphine is of the same order of magnitude as that of ammonia.

Table 1. Proton affinity of phosphine at 0°K

Quantity	PH_4I	PH_4Br	PH_4Cl
U*	131.5†	130.3	132.2
$-Q_{PH_4X}$ (*5*)	15.8	29.5	42.5‡
Q_{PH_3}	2.21	2.21	2.21
$-D_H$	52.1	52.1	52.1
$-I_H$	311.9	311.9	311.9
$-D_X$	25.5	26.7	28.9
E_X (*4*)	74.6 (*6*)	81.5	86.5
$5/2RT$	1.5	1.5	1.5
$-P_{PH_3}$	200 ± 10	209 ± 21	217 ± 22

* Assume a CsCl lattice, densities of PH_4Br and PH_4Cl estimated at 1.94 and 1.27 g/cm³, respectively.
† All values in kilocalories.
‡ Estimated from the Q_{PH_4Cl} in the gas phase.

The low value for the proton affinity of water would indicate that the H_3O^+ is less stable than the PH_4^+. The reverse seems to be true because the phosphonium halides, unlike the ammonium halides, are readily hydrolyzed by water according to the equation

$$PH_4X + H_2O \rightarrow PH_3 + H_3O^+ + X^-$$

Apparently other factors must enter in, because this result is not what would be predicted according to the calculated proton affinities of water and phosphine.

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15 March 1955

Ecology and the Population Problem

In commenting on the problem of providing space and food for the growing human population, A. M. Woodbury implies [*Science* **122**, 200 (1955)] that this problem is sufficiently critical in the United States to reduce such questions as those concerning the preservation of our national parks and monuments and recreation areas to the status of "minor matters." Woodbury is my former teacher and companion in fieldwork, and he is the man most directly responsible for my initial decision to become an ecologist; hence, there is no one to whom I would