of renal tubular function will help in understanding the physiology of vitamin D. The experiments reported suggest an interrelationship of the metabolism of the polycarboxylic acids and specific renal tubular functions.

References and Notes

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1. R. W. Berliner, T. J. Kennedy, and J. G. Hilton, *Proc. Soc. Exptl. Biol. Med.* **75**, 791 (1950).
2. H. E. Harrison and H. C. Harrison, *J. Clin. Invest.* **20**, 47 (1941).
3. C. H. Fiske and Y. Subbarow, *J. Biol. Chem.* **66**, 375 (1925).
4. B. Kramer and F. F. Tisdall, *ibid.* **47**, 475 (1921).
5. S. Natelson, J. B. Pincus, and J. K. Lugovoy, *ibid.* **175**, 745 (1948).
6. W. Troll and R. K. Cannan, *ibid.* **200**, 803 (1953).
7. N. A. Nelson, *ibid.* **153**, 375 (1944).
8. K. H. Beyer *et al.*, *Am. J. Physiol.* **151**, 202 (1947).
9. G. Fanconi, *Jahrb. Kinderheilk.* **147**, 299 (1936).
10. D. J. McCune, H. H. Mason, and H. T. Clarke, *Am. J. Diseases Children* **65**, 81 (1943).

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Influence of Hydrogen Ion Concentration on Radiation Effects

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When ionizing radiation acts on chemical or biological systems by "indirect effect," that is, through the medium of free radicals, the changes are very often oxidations or reductions. It is commonly supposed that the majority of radiobiological changes are oxidative, because the presence of oxygen during irradiation enhances the effects (*1, 2*). Evidence was presented earlier by one of us (*3–5*) that the inactivation of phages S13 and T3 by indirect action of radiation is due to reduction, so that oxygen in the suspension protects the phage, whereas removing oxygen and bubbling hydrogen during irradiation enhances "immediate" radiation effects (*6*). More recently, Bachofer and Pottinger (*7*) found a protective effect of oxygen on T1, and it may be that all phages are sensitive, in the free state, to inactivation by reducing agents.

We have shown (*6*) that, under electron or x-irradiation, the mechanisms of hydrogen peroxide formation in water and immediate phage inactivation in aqueous suspensions can to some extent be regarded as complementary. Under a wide variety of gas treatments, the inactivation of phage proceeded fastest when the hydrogen peroxide formed was least, and vice versa. We showed that the likely reactions leading to formation of hydrogen peroxide and phage inactivation could be fitted into a simple theory of radical formation and reaction. This theory would lead to a dependence on hydrogen ion concentration of the yield for both oxidative and reductive changes, and we are now able to show that in this respect, too, phage inactivation and hydrogen peroxide formation proceed in complementary fashion.

The *p*H dependence of these reactions arises from the step

$$HO_2 \rightleftharpoons H^+ + O_2^-,$$

reductive changes being due to the radical ion O_2^-, so that oxidation yields are increased, and reduction yields decreased, in more acid solutions. However, the extent of reaction with O_2^- will depend on *p*H only in the presence of oxygen, since the formation of the HO_2 radical is a preliminary step. As is shown by Fig. 1a, phage is protected against inactivation in acid

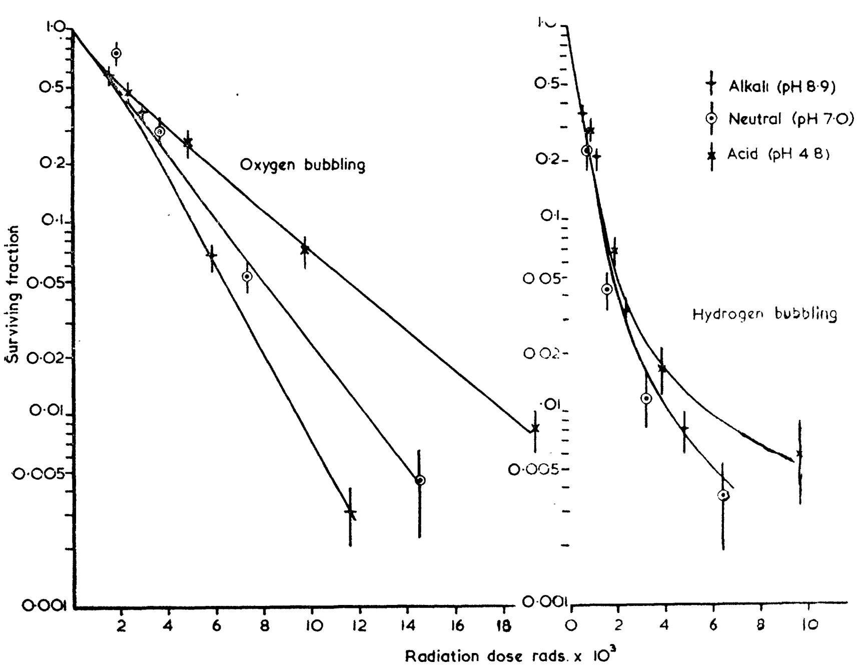

Fig. 1. Survival curves of bacteriophage S13, x-irradiated under (*a*, left) oxygen, (*b*, right) hydrogen bubbling, at three hydrogen ion concentrations.

suspension under oxygen bubbling, whereas in alkaline suspension radiation effects are enhanced. Under hydrogen bubbling there is much less pH dependence (Fig. 1b). These facts would appear to support the hypothesis that O_2^- radical ions are inactivating agents for phage. The pH dependence under hydrogen bubbling may arise from the reaction proposed by Weiss (*8*),

$$H + H^+ \rightleftarrows H_2^+.$$

The effects of pH variation on formation and decomposition of H_2O_2 were reported previously by Ebert and Boag (*9*). As Fig. 2 shows, the equilibrium

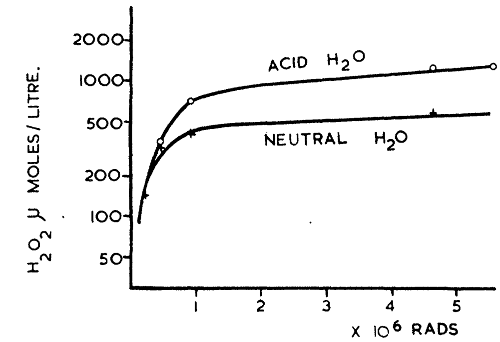

Fig. 2. Formation of H_2O_2 by electron irradiation under oxygen bubbling, at two hydrogen ion concentrations.

yield of H_2O_2 under oxygen bubbling was higher in more acid solution, indicating that the back reaction (decomposition of H_2O_2) became equal to the forward reaction (formation of H_2O_2) earlier, in more alkaline solution. The formation of H_2O_2 under nitrogen bubbling could not be followed by the methods used, because the yields were not measurable. The effect of varying the pH was therefore studied by means of decomposition reactions, and, as is shown by Fig. 3, these were very much slower in more acid solution.

Although the dependence of radiation effects on pH is well established in radiation chemistry and is to be predicted from theories of radical reactions (*10*), only a few biological systems appear to have been studied

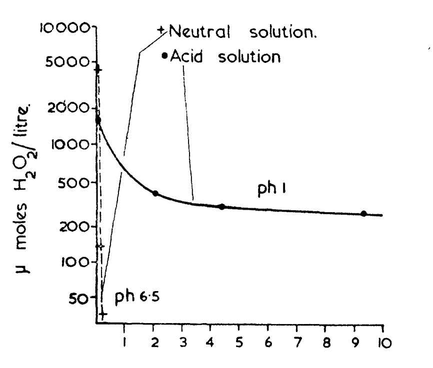

Fig. 3. Decomposition of H_2O_2 by electron irradiation under nitrogen bubbling, at two hydrogen ion concentrations.

from this point of view (*11–13*). The nonuniform distribution, within the cell, of metabolites, enzymes, and colloidal matter probably involves local and temporal variations in pH and in the concentration of dissolved substances. If radiation-produced radicals are responsible for some effects in the living cell, then a complicated pattern of radiosensitivity is to be expected on these grounds alone.

References

1. L. H. Gray, *Brit. J. Radiol.* **26**, 609 (1953).
2. L. H. Gray *et al., ibid.* **26**, 638 (1953).
3. T. Alper, "Radiation chemistry," *Discussions Faraday Soc.* No. 12, (1952), p. 234.
4. ———, VI International Microbiology Congress, Rome, Riassunti delle Comunicazioni, No. 528 (1953), vol. II, p. 181.
5. ———, *Brit. J. Radiol.* **27**, 50 (symposium 1952) (1954).
6. M. Ebert and T. Alper, *Nature* **173**, 987 (1954).
7. C. S. Bachofer and M. A. Pottinger, *Science* **119**, 378 (1954).
8. J. Weiss, *Nature* **165**, 728 (1950).
9. M. Ebert and J. W. Boag, "Radiation chemistry," *Discussions Faraday Soc.* No. 12 (1952), p. 189.
10. H. A. Dewhurst, A. H. Samuel, and J. L. Magee, *Radiation Research* **1**, 62 (1954).
11. R. E. Zirkle, *Am. J. Roentgenol. Radium Therapy Nuclear Med.* **35**, 230 (1936).
12. ———, *J. Cellular Comp. Physiol.* **16**, 301 (1940).
13. ———, *ibid.* **17**, 65 (1941).

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Theoretical Rate of Fat Formation by Yeasts

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Synthesis of fat by microorganisms has interested a number of investigators since the early work of Lindner (*1*). We recently reported on some studies concerning the effect of several cultural conditions on fat formation by *Rhodotorula gracilis* (*2*). In this work the fat content of the yeast was expressed as a weight ratio of fat to nonfat dry yeast. When this fat ratio was plotted against time, the curve was a straight line after an initial lag period. This indicated that the cells produced an equal quantity of fat during like intervals of time. Thus the fat was produced at a constant rate which was represented by the slope of the linear portion of the curve. We have termed this slope the *fat rate*; it is expressed in grams of fat per 100 g nonfat dry yeast per hour. It was of interest to compare experimental fat rates with the maximum rate theoretically possible. Such a comparison would indicate whether a larger rate of fattening could be obtained as a result of further investigations on this problem.

The relationship between the energy required for growth of the yeast and that required for synthesis of fat was the basis used in deriving a theoretical fat rate. Thus, a given rate of growth is evidence of a definite rate of energy utilization. If this energy were applied solely to the formation of fat, then a corresponding rate of fattening would be obtained. This theoretical fat rate was derived as follows.