leasing hormones from the adrenal cortex. The relative immunity to stress damage on the part of the gentled animals may, therefore, have resulted from a decreased ACTH output from the pituitary in response to the same alarming situation that also faced the nongentled animals. If this were the case, it could be expected that a comparison of adrenals from gentled and nongentled rats following stress would show the latter to be heavier, after being stimulated by more ACTH output. Such was indeed the case.

References

1. GREENMAN, M. J., and DUHRING, F. LOUISE. *Breeding and Care of the Albino Rat for Research Purposes.* Philadelphia: Wistar Institute of Anatomy and Biology, (2nd ed.), 1931.
2. SELYE, H. *Annual report on stress.* Montreal: Acta, 1951.

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The Energy Requirements for Bacterial Motility

Harold J. Morowitz[1]

National Bureau of Standards, Washington, D. C.

In light of recent advances on the structure of bacterial flagella (*1, 2*), it is of interest to calculate the energy expended by these "monomolecular muscles" in propelling the organism.

For the case of a small object moving through a viscous medium at low velocity, the force F necessary to balance frictional resistance is given by $F = fv$, where f is the frictional coefficient and v the velocity. If the bacteria under consideration are assumed to be prolate spheroids of equatorial semi-axis b and semi-axis of revolution a, then f, is given (*3*) by

$$f = \frac{6\pi\eta \sqrt[3]{ab^2}(1-\rho^2)^{1/2}}{\rho^{2/3} ln\left[\frac{1+(1-\rho^2)^{1/2}}{\rho}\right]}, \qquad (1)$$

where η is the coefficient of viscosity of the medium surrounding the bacterium and ρ is the ratio of axes, b/a. The energy expended per unit time, P, is given by

$$P = Fv = fv^2, \qquad (2)$$

where f is given by Eq. (1).

This formulation neglects the frictional resistance of the flagella which will be assumed to have the same value of that of the bacterium for order of magnitude calculations. An extension of the more exact hydrodynamical analysis of Taylor (*4*) should lead to a more precise value of P.

For cells of *Bacillus subtilis*, b is 0.5 micron, a is 1 micron (*5*) and v is 10 microns/sec (*6*). The coefficient of viscosity of water at 25° C is approximately 0.009 poise. Substitution of these values in Eq. (2) leads to a value of about 1.1×10^{-11} erg/sec. Doubling this figure to allow for the resistance of the flagella and converting to more convenient units yields a power output in motility of about 14 electron volts/sec. Further assuming that the conversion from chemical to mechanical energy is 25 percent efficient, one finds the total rates of energy expenditure for motility of one organism to be about 56 electron volts/sec.

The analogy between flagella and muscle fibers (1), and the observation that isolated flagella contract in the presence of adenosine triphosphate (2) makes it reasonable to assume that the energy of motility comes from energy rich phosphate bonds. In that case about 150 bonds reacting per sec would supply the necessary energy. Electron micrographs indicate that the organism has about 10 to 20 flagella, and analogous data from the flagella of larger organisms would indicate that each of the flagella flicks about 10 to 20 cps.

As the total number of flagellar flicks per sec, 100–400, is the same order of magnitude as the number of bonds reacting per sec, it is possible to consider each flagellar flick as the result of a small number of discrete chemical events (perhaps one), such as metabolic hydrolysis of energy rich phosphate bonds. In studying bacteria, one reaches a small order of size where a very few reacting molecules exert a large influence.

References

1. ASTBURY, W. T. *Scientific American* **184**, 20 (1951).
2. DE ROBERTIS, E., and FRANCHI, D. M. *Program IXth Meeting, Electron Microscope Soc. America,* 1951.
3. COHN, E. J., and EDSALL, J. T. *Proteins, Amino Acids and Peptides,* 404–406. New York: Reinhold, 1943.
4. TAYLOR, G. *Proc. Royal Soc. (London)* **211A**, 225 (1952).
5. KNAYSI, G. *Elements of Bacterial Cytology.* Ithaca: Comstock Pub. Co., 1951.
6. HEILBRUNN, L. V. *An Outline of General Physiology.* Philadelphia: Saunders, 1943.

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The Induction of Scab Lesions on Aseptic Potato Tubers Cultured *in vitro*[1]

W. G. Barker and O. T. Page

Department of Botany,
Ontario Agricultural College, Guelph, Canada

The production *in vitro* of tubers from etiolated potato shoots has been reported recently (*1*). It was considered that a significant contribution could be made concerning the inception of potato scab lesions by observing the action of a pure culture of a known pathogenic strain of *Streptomyces scabies* (Thaxter) Waks. and Henrici on sterile potato tissue. This would be of particular interest because it has not been possible to demonstrate that *S. scabies* alone could cause scab. In addition, there are reports citing the habitation of normal potato tissue by microorganisms (*2–4,* among others). It is with these considerations that this preliminary report is concerned.

A series of differential media was used in an attempt to isolate microorganisms that might be occurring as "normal" microflora of the cultured potato tissue. In addition, the medium used in culturing the potato tissue (*1*) will support the growth of many organisms. In no case was there a microorganism isolated from cultured potato tissue which appeared

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[1] Present address: National Heart Institute, National Institutes of Health, Bethesda, Md.