Short Communications

Bacteria and their flagella

Flagella are difficult to observe on living bacteria for they have extremely small diameters[1]. Under an electron microscope, however, they appear to be made up of very fine filaments of macromolecular dimensions which are twisted together in rope-like structures[2–4]. How flagella are utilized by bacteria has been debated over the years since they were first seen on fixed and stained preparations. Flagella generally are found on motile bacterial cells and when cells are in motion the flagella, when seen, also appear to be in motion. The circumstantial evidence is strong for the belief that flagella are organs of locomotion[1,5]. On the other hand, there is some indication that they reduce the forward speed because of viscous drag[6].

It has been difficult to conceive the ultrafine flagellar filaments themselves to be sufficiently complex in structure to support metabolic or other processes for producing energy-rich molecules and at the same time to convert the released energy to kinetic energy of locomotion. Some investigators have suggested that the source of energy is not the flagellum but the bacterial cell itself. It is assumed that the bacterium rather leisurely snaps the flagellum as a whip, or coils and uncoils it at different rates, thus propelling itself forward.

Unfortunately, this suggestion also meets with difficulties. Because of viscous drag the flagellum would be unable to support a wave, certainly not one of uniform amplitude[11]. The base end would need to continually execute to and fro displacements equal to the amplitude of the undulations on the flagellum and even then the motion would be damped out so rapidly that there would be no apparent waveform. A piece of flagellum with an initial speed of 30 μ/sec in water, for example, would come to rest within a distance of less than 1 mμ.

A third group of investigators under the leadership of PIJPER have suggested that bacterial locomotion is accomplished by the sinuous movements of the bacterium itself and that the flagella are really trails of materials sloughed off a slime layer[7]. In other words, the flagella serve neither as organs nor as propellers for locomotion; they are simply inactive appendages. As pointed out by HOUWINK AND VAN ITERSON[5], however, the electron-microscopic observations suggest that the high degree of uniformity in cross-section and the attachment of the flagellum to the cell are not consistent with this picture.

In this note we suggest that some means of stabilization is needed by a bacterium if it is to undergo long range translatory motions and that flagella may well serve as such stabilizers.

Translational Brownian motion commonly is observed among bacteria, for they are small enough to reveal the effects of fluctuations in the impacts of molecules of the growth medium. In essence, the bacteria are large "molecules" in thermal agitation. Perhaps not so well known is the phenomenon of rotational Brownian motion. An equation for the mean-square angle of rotation for a spherical particle was derived by EINSTEIN[8] and experimentally verified by PERRIN[9]. A similar equation may be

deduced for the rotation of a small cylinder about a transverse axis through its center. It is $\overline{\theta^2} = 24\,kTt/\pi\eta l^3$, where k is the Boltzmann constant, T is the absolute temperature, η is the coefficient of viscosity of the medium, l is the length of the cylinder, and t is the time interval between observations of the angle θ through which the sphere rotates. It must be understood that $\overline{\theta^2}$ represents the resultant mean-square angular displacement due to a very large number of nudges from impacts of the substrate molecules. In all observations on rotational Brownian motion, however, the projection of the angle on a fixed plane is measured, so that the foregoing equation should be divided by 3 in applying it to experimental data.

Consider a rod-like bacterium 1.5 μ long and 0.5 μ in diameter in a medium at a temperature of 27°. Set η equal to 1 cpoise, t to 1 sec and k to $1.38 \cdot 10^{-16}$ erg/°. Then the ratio of the mean-square angle of rotation about a transverse axis to the time interval for observations equals $24 \times 1.38 \times 10^{-16} \times 300 \times 0.01 \times (1.5)^3 \times 10^{-12}$ or 9.3 radians^2 sec. On the average, therefore, the bacterium would rotate through approximately 175°, almost a complete about face, during a 1-sec time interval. Thus locomotion in a given direction long enough to measure the speed, or even to allow the bacterium to go anywhere, is practically impossible unless provision is made to reduce the effects of rotational Brownian motion. A flagellum or flagellar tress several tens of μ long would prevent undue rotations; in effect, it would act as a stabilizer for the bacterium. If the over-all length is increased by a factor of 10 the root-mean-square angle is reduced by a factor of 1/30. REICHERT's observations that, by and large, small bacteria have longer flagella than large bacteria[10] support this hypothesis.

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Received March 28th, 1960

Biochim. Biophys. Acta, 42 (1960) 344–345

Masked condition of ionic residues in collagen

Physico-chemical studies on collagen have emphasized the importance of hydrogen bonds in the structure. However, the state of the ionized residues in this protein is still obscure, although there is evidence from electron microscopy that they may have a special orientation in the fibril[1]. Also, analysis of titration curves reveals unusual behavior in that there is slight reactivity over the range pH 6–10, and a low alkali-neutralizing capacity compared to the content of basic amino acids[2]. This and other evidence mentioned by GUSTAVSON suggests the existence of salt-like