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MICROBIAL STERILIZATION IN ULTRA-HIGH VACUUM AND OUTER SPACE: A KINETIC COMPARISON

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There has been a series of papers [1,2,3] concerned with the survival of microorganisms in ultra-high vacuum and in space. The correlation between microbial die off in ultra-high vacuum and space is not immediately obvious. It is the purpose of this note to call attention to the fact that from a kinetic viewpoint, D values obtained under ultra-high vacuum, 10^{-6} torr, are not appreciably different from those obtained under 10^{-17} torr, pressure of outer space.

Suppose the microorganisms are being sterilized by a first order chemical reaction, i.e., survival is logarithmic. Then the relationship between the D value and the reaction rate constant, k, is given by

$$D = -\ln(0.1)/k. \tag{1}$$

Under the absolute reaction rate theory

$$k = \frac{KT}{h} \exp(-\Delta F^{\ddagger}/RT) \tag{2}$$

where K is Boltzmann's constant, h is Planck's constant, T is the temperature in degrees Kelvin, R is the gas constant and $\Delta F^{\ddagger}$ is the free energy of activation. $\Delta F^{\ddagger}$ may be broken down further as

$$\Delta F^{\ddagger} = \Delta H^{\ddagger} - T\Delta S^{\ddagger} + p\Delta V^{\ddagger} \tag{3}$$

where $\Delta H^{\ddagger}$, $\Delta S^{\ddagger}$, and $\Delta V^{\ddagger}$ are activation enthalpy, entropy, and volume respectively, and where p is pressure [4].

One normally associates a positive $\Delta V^{\ddagger}$ with first order reactions. Furthermore, with $\Delta V^{\ddagger}$ positive, as pressure decreases the reaction rate increases so that from equation 1 we see that the D value decreases. The question we address is how much will D decrease for a fixed value of $\Delta V^{\ddagger}$ as p goes from 10^{-6} to 10^{-17} torr.

Combining equations 2 and 3 we get the relationship for pressures p_1 and p_2.

$$\ln(k_{p_1}/k_{p_2}) = \Delta V^{\ddagger}(p_2-p_1)/RT. \tag{4}$$

If we take pressure in atm, the gas constant will be

$$R = 82.06 \text{ cc atm/mole.}$$

From equations 1 and 4 we find

$$\ln(D_{p_2}/D_{p_1}) = \ln(k_{p_1}/k_{p_2}). \tag{5}$$

The largest $\Delta V^{\ddagger}$ value we have seen was recorded for ribonuclease by Kettman et.al. [5] as 200 cc/mole. To be safe we will use 10000 cc/mole. Suppose we assume that $T = 333^{\circ}K = 60^{\circ}C$. We convert the pressures to atmospheres so that

$$p_1 = 10^{-6} \text{ torr} = (1/7.6) \times 10^{-8} \text{ atm}$$

and

$$p_2 = 10^{-17} \text{ torr} = (1/7.6) \times 10^{-19} \text{ atm.}$$

Using these values in eq. 4 we find that

$$\ln(k_{p_1}/k_{p_2}) = \frac{(10^4 \text{cc/mole})(1/7.6)(10^{-19}-10^{-8})\text{atm}}{(333 \text{ deg})(86.0597 \text{ cc atm/deg mole})}$$

Using orders of magnitude we see that

$$\ln(k_{p_1}/k_{p_2}) = 10^{-10}(10^{-11}-1). \qquad (6)$$

Thus despite the magnitude of the $\Delta V^{\ddagger}$ chosen the right side of equation 6 differs from 0 by less than 10^{-8}. This of course implies that the ratio k_{p_1}/k_{p_2} is so near 1 that in view of equation 5 an experimenter could not distinguish between D values taken at 10^{-6} and 10^{-17} torr if only first order kinetics is involved in the sterilization.

References

1. Davis, N. S., Silverman, G. J., and Keller, W. H.: 1962, Appl. Microbiol. 11, 202.

2. Hotchin, J., Lorenz, P., and Hemennay, C.: 1965, Nature, 206, 442.

3. Portner, D. M., Spiner, D. R., Hoffman, R. K. and Phillips, C. R.: 1961, Science 134, 2047.

4. Glasstone, S., Laidler, K. and Eyring, H: 1941, The Theory of Rate Processes, McGraw-Hill, New York.

5. Kettman, M. S., Nishikawa, A. H., Morita, R. Y. and Becker, R. R.: 1966, Biochem. Biophy. Res. Comm. 22, 262.