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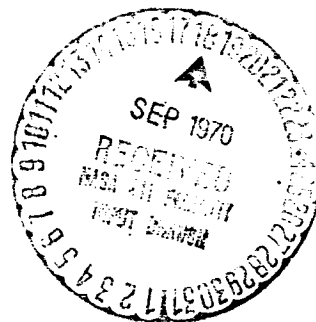
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MICROBIAL STERILIZATION IN ULTRA-HIGH VACUUM
AND OUTER SPACE: A KINETIC COMPARISON

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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

$$D = -\ln(0.1)/k. \quad (1)$$

Under the absolute reaction rate theory

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

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

$$\Delta F^\ddagger = \Delta H^\ddagger - T\Delta S^\ddagger + p\Delta V^\ddagger \quad (3)$$

where ΔH^\ddagger , ΔS^\ddagger , and ΔV^\ddagger are activation enthalpy, entropy, and volume respectively, and where p is pressure [4].

One normally associates a positive ΔV^\ddagger with first order reactions. Furthermore, with ΔV^\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 ΔV^\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 .

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

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

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

The largest ΔV^\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 $T = 333^\circ\text{K} = 60^\circ\text{C}$. 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

$$\ln(k_{p_1}/k_{p_2}) = \frac{(10^4 \text{ cc/mole})(1/7.6)(10^{-19} - 10^{-3}) \text{ atm}}{(333 \text{ deg})(86.0597 \text{ cc atm/deg mole})}$$

Using orders of magnitude we see that

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

Thus despite the magnitude of the ΔV^\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.

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