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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

\[ D = -\ln(0.1)/k. \]  

(1)

Under the absolute reaction rate theory

\[ k = \frac{kT}{h} \exp\left(-\frac{\Delta F^\ddagger}{RT}\right) \]  

(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

\[ \Delta F^\ddagger = \Delta H^\ddagger - T\Delta S^\ddagger + p\Delta V^\ddagger \]  

(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 $p_2$.

$$\ln\left(\frac{k_{p_1}}{k_{p_2}}\right) = \frac{\Delta V^\ddagger(p_2-p_1)}{RT}.$$  \hspace{1cm} (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

$$\ln\left(\frac{D_{p_2}}{D_{p_1}}\right) = \ln\left(\frac{k_{p_2}}{k_{p_1}}\right).$$  \hspace{1cm} (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

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

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

Using these values in eq. 4 we find that

\[ \ln\left(\frac{k_{p_1}}{k_{p_2}}\right) = \frac{(10^4 \text{ cc/mole})(1/7.6)(10^{-19} - 10^{-9})\text{ atm}}{(333 \text{ deg})(86.0597 \text{ cc atm/deg mole})} \]

Using orders of magnitude we see that

\[ \ln\left(\frac{k_{p_1}}{k_{p_2}}\right) = 10^{-10}(10^{-11} - 1). \]  \( (6) \)

Thus despite the magnitude of the \( \Delta V \) chosen the right side of equation 6 differs from 0 by less than \( 10^{-8} \). This of course implies that the ratio \( \frac{k_{p_1}}{k_{p_2}} \) 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


