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

(Research Note)

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There has been a series of papers (Davis *et al.*, 1962; Hotchin *et al.*, 1965; Porter *et al.*, 1961) 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 (Glasstone *et al.*, 1941).

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.

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

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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.* (1966) as 200 cc/mole. To be safe we will use 10 000 cc/mole. Suppose we assume that $T = 333\,\text{K} = 60\,°\text{C}$. 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 Equation (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

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

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

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