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OSMOSIS AND MICROGRAVITY

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It is demonstrated that in the absence of buoyancy driven convection, as in microgravity, the osmotic process is modified considerably.

It is well known that buoyancy driven convection processes may be modified in the microgravity environment of Low Earth Orbit. Such modifications will extend over a wide range of phenomena including materials processing (such as crystal growth and electrophoresis) and biological processes (such as osmosis). In the microgravity environment, convection driven processes are sufficiently suppressed as to approach diffusion limited conditions. This report demonstrates a modification of the osmotic process with a simple laboratory experiment.

The phenomenon of osmosis may be illustrated by sealing a semipermeable membrane over the end of an inverted thistle-tube that is partially filled with a hypertonic solution (*e.g.*, sucrose/water) and placed into a beaker of water. In the ensuing osmotic process, water flows through the membrane to the solution side. The increasing volume is observed as a rising level within the thistle-tube, which proceeds until the hydrostatic pressure reaches equilibrium with the osmotic pressure, and water flows out of the solution at the same rate as the inward flow caused by osmosis. Thermodynamically the osmotic process arises from the difference in chemical potential of the solutions on either side of the membrane. The chemical potential of the pure water is greater than that in the solution, and the water flows from a region of higher chemical potential to that of lower chemical potential. In the experimental configuration described, with no other forces present it might be expected that when sufficient water passes through the membrane, a water layer would form on the solution side of the membrane; the chemical potential would then be the same on both sides of the membrane, and the osmotic process would stop. In the presence of gravity however, this idealized model fails. Water passing upward through the membrane into the more dense solution generates buoyancy driven convection, which continuously presents fresh hypertonic solution to the membrane and allows osmosis to continue. In the absence of buoyancy driven convection (such as in microgravity), osmotically driven processes should be modified considerably.

The study presented here compares the rates of transport through a semipermeable membrane of an osmotic experiment performed in the "normal" orientation (*i.e.*, hypertonic solution located above the

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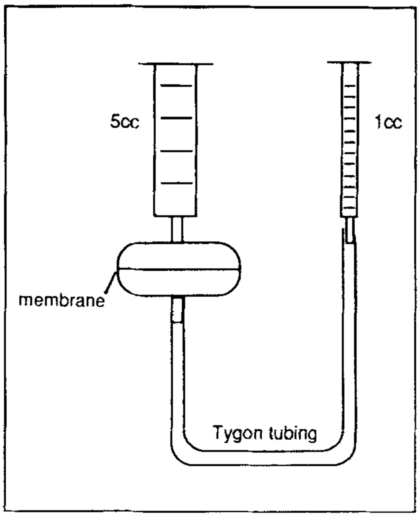

Figure 1. Experimental apparatus. "Normal" with sucrose solution above the membrane. "Inverted" with sucrose solution below the membrane.

membrane) with an "inverted" experiment, where the hypertonic solution is located below the membrane. In this inverted orientation, the gravitational force tends to inhibit the buoyancy driven convection, as the less dense water enters the more dense solution from the top. Thus, the study compares the kinetics of the osmotic process with and without the presence of buoyancy driven convection.

The experimental apparatus shown in Figure 1 was constructed using Nuclepore 25mm membrane holders, Tygon tubing, and 1cc and 5cc syringes. Two identical units were used to simultaneously run the "normal" and "inverted" cases. Solutions of pure cane sugar (sucrose) were prepared immediately before each experiment in the following manner: the appropriate amount of sugar was weighed, dissolved in approximately one half the final volume of deionized water, the pH adjusted to approximately 9.5 to prevent hydrolysis, the solutions degassed under vacuum for about 30 minutes, and finally diluted to the appropriate volume using degassed, deionized water. The semipermeable membrane used in all experiments was a commercially available reverse osmosis membrane. A fresh membrane was used for each experiment. Great care was taken to ensure that all bubbles were eliminated from the membrane holder prior to the start of an experiment, and that no leaks were present in the membrane itself. The initial volumes were 2.5cc on each side of the membrane, and the relative syringe positions were adjusted so the heads were even at the start of a run. All data were taken from the 1cc syringe which had divisions at .01cc intervals. Three solution concentrations were studied; 127, 333, and 569 mM, as determined by specific gravity measurements.

Figure 2 shows the results obtained for the three concentrations studied, for both the "normal" and "inverted" solution orientations. The data have been normalized to the initial volume on the solution side of the membrane and are shown as percent increase in volume. For each concentration, the

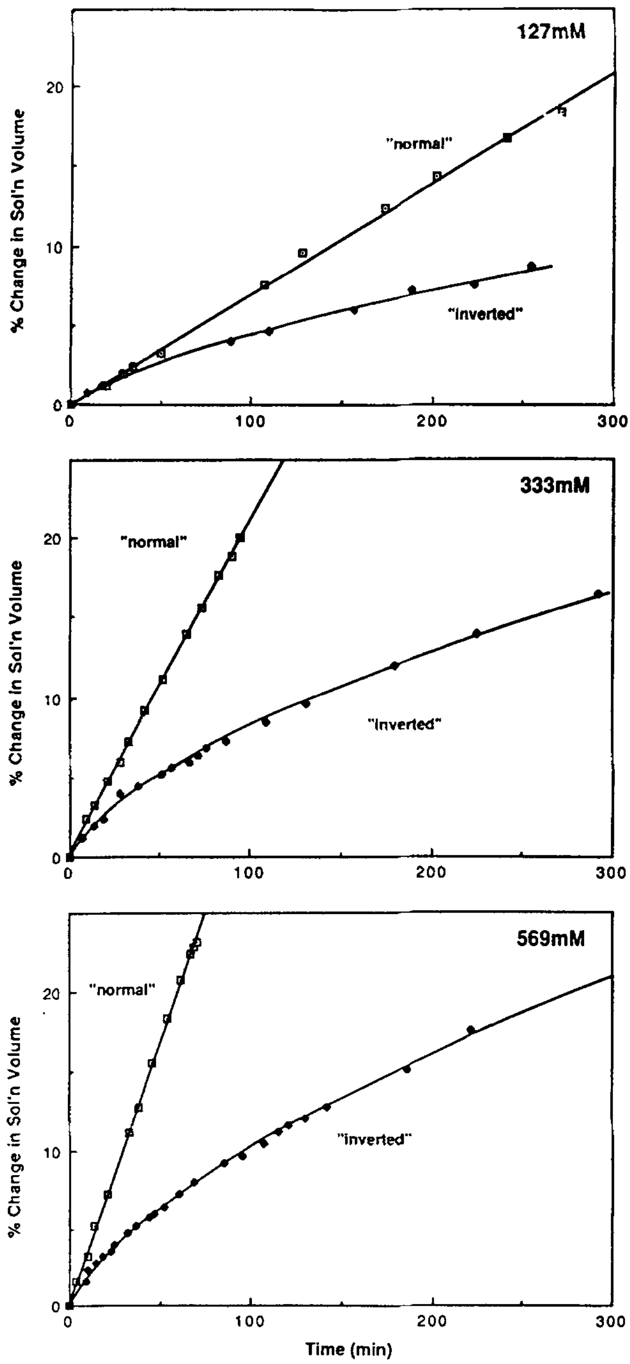

Figure 2. Rates of water transport through the membrane.

transport kinetics for the "normal" and "inverted" orientations are clearly dissimilar, even though the osmotic potential across the membrane is the same in each case. The similarity in shape of each set of curves serves as an internal check on the experimental procedure.

In the "normal" orientation, it is assumed that the osmotic process is proceeding via buoyancy driven convection generated by gravity. Since the "normal" rates depicted in Figure 2 are constant, the kinetics are not yet affected by dilution of the hypertonic solution. In the "inverted" configuration with the same degree of dilution, the kinetics are different. In an idealized model, with water passing downward onto the more dense solution, the gravitational force should act to inhibit buoyancy driven convection, and a water layer should form against the membrane and inhibit the osmotic process. In this case, it appears that gravity is enhancing the formation of a density gradient within the hypertonic solution, which has the effect of lowering the effective concentration gradient across the membrane and thereby modifying the osmotic potential and kinetics of the osmotic process. That osmosis continues, albeit at a substantially slower rate, is evidence for the presence of other forces (*e.g.*, diffusion). An empirical fit of the data for the rate of volume change with time in the 1cc syringe yields rate equations of the form $dV/dt=kV^{-n}$, where each concentration has a different n and k ($n<1$, k=constant). The correlation coefficients are ≥ 0.99 for all three cases, including data taken out to 400 minutes for the two higher concentrations. With this fit, the mass flow rate through the membrane approaches zero asymptotically. Thus, even without dilution, it appears that in an osmotic process limited by diffusion (assuming that is indeed the limiting operational mechanism in the "inverted" case), the final hydrostatic pressure (*i.e.*, equilibrium) may not be reached in a finite time.

Although the present work does not duplicate exactly the conditions of microgravity, it does illustrate the osmotic consequences for biological and physical systems operating in the absence of gravity. The results of a biological experiment which has been performed in space are worth noting here. One of us (H.A.P) was associated, as the industry scientist, with a NASA Shuttle Student Involvement Project[1]. Cells from roots of corn seedlings germinated in microgravity were "fixed" on orbit in preparation for electron micrography (performed on the ground). Ground control seedlings were packaged and fixed in a procedure identical to that of the flight experiment, the only difference being the presence or absence of gravity. The flight cell micrographs indicated substantial plasmolysis and the ground controls showed no plasmolysis. Furthermore, the average root length of the flight seedlings was 71% of the ground control average, from which it can be concluded that gravity plays a significant role in the corn seedling growth process. Cellular plasmolysis generally results from cells being immersed in a hypertonic solution, with the resulting loss of intracellular water causing the cell membrane to pull away from the more rigid cell wall. The present study has shown that osmotic effects should in general be moderated in the absence of gravity, as in the "inverted" experiment discussed above. The observed plasmolysis in the flight specimens can be made consistent with the present results if it is assumed that buoyancy driven convection is present within the cell. If this is an untenable assumption, then the present results are contrary to expectation and further speculation is not useful at this time, but the effects of microgravity cannot be eliminated from consideration.

REFERENCE

1. S. Amberg, Statoliths in Corn Seed Root Caps, SE82-03-001 (Shuttle 51D, 1985).