Pfeffer Cell Apparatus [1]

By: Parker, Sara Keywords: Wilhelm Pfeffer [2] osmotic pressure [3] osmosis [4] plant cells [5]

The *Pfeffer Zelle* (*Pfeffer Cell Apparatus*), invented by Wilhelm Pfeffer [6] in 1877, measured the minimum pressure needed to prevent a pure solvent from passing into a solution across a semi-permeable membrane, called osmotic pressure. The apparatus provided Pfeffer with a way to quantitatively measure osmotic pressure. Pfeffer devised the apparatus in the 1870s at the University of Basel [7] in Basel, Switzerland, and he described the *Pfeffer Cell Apparatus* in his 1877 book *Osmotische Untersuchungen: Studien Zur Zellmechanik* (*Osmotic Investigations: Studies on Cell Mechanics*). Pfeffer relied on nineteenth century experiments of Moritz Traube in Germany, who constructed artificial copper ferrocyanide membranes to study osmosis. The apparatus enabled Pfeffer to study osmosis and osmotic pressure as plants grow, and later researchers used it to explain how plants develop.

Pfeffer spent his post-doctoral years in the laboratories of several botanists including Nathanael Pringsheim in Berlin, Germany, who studied reproduction in plants, and Julius von Sachs in Leipzig [8], Germany, who studied plant physiology. Both men encouraged Pfeffer to study plant physiology rather than chemistry. In the late 1860s and early 1870s, at the University of Marburg in Marburg, Germany, Pfeffer studied different stimulants that affect plants including light and temperature. Pringsheim and Sachs introduced him to the research problems in botany that led Pfeffer to study osmotics, which concerns anything relating to osmosis or the passage of water through a membrane, in plant membranes.

In 1872, Pfeffer began to conduct experiments on osmotic pressure. According to Gordon R. Kepner and Eduard J. Stadelmann, the 1985 translators of Pfeffer's *Osmotic Investigations* into English, Pfeffer experimented on various stimulants and the cause of the pressure exerted by the cell wall on the cell as it forces water to leave the cell, or hydrostatic pressure. In 1873, Pfeffer began his first professorial appointment at the University of Bonn [9] in Bonn, Germany, where he continued researching aspects of osmotic phenomena.

The theory of osmosis describes the spontaneous movement of solvent molecules, such as water, through a semi-permeable membrane from lower to higher concentration of solute to equalize the concentration of solute on both sides of the membrane. By the mid-nineteenth century, the theory of osmosis was over one hundred years old. Tests on how osmosis operates had been repeated numerous times using organic and inorganic materials. Most of those experiments used the osmometer apparatus created by René Henri Dutrochet, who researched osmosis and diffusion in France in the early 1800s.

The osmometer was an inverted funnel with the mouth covered by a diaphragm [10], or membrane, which was filled with a solution and placed in a water bath. Scientists observed that water flowed through the membrane from the lower concentration of solute outside the funnel to the higher concentration of solute inside the funnel. The changing fluid level in the stem of the funnel measured the osmotic pressure of the solution.

By the late 1860s, after several basic experiments on osmosis, Friedrich Wilhelm Ostwald [11], who studied the physical chemistry of chemical equilibrium and reactivity at the University of Leipzig [12] in Leipzig [8], Germany, concluded that osmotic phenomena depended on the nature of the membrane. Ostwald and other physicists and chemists argued that physiologists should study osmotic phenomena but few did until Pfeffer's work.

When Pfeffer began his experiments, he started with a technique published by Traube in 1867. Traube worked out the conditions for forming artificial membranes using, a solution of copper sulfate and crystals or a solution of potassium ferrocyanide. Traube dropped crystals of potassium ferrocyanide into a solution of copper sulfate a film of copper-ferrocyanide formed, or precipitated at the boundary between the crystals and the solution. Traube called those films "cells" because they expanded and budded like the plasma membranes of living cells. Water from the copper sulfate solution could pass through the precipitated film or membrane and dissolve the crystals of potassium ferrocyanide. There is no further passage of the copper sulfate or the potassium ferrocyanide molecules from one side of the membrane to the other and the cell would burst when too much water enter the cell.

Pfeffer could not measure the pressures that developed across a Traube membrane, as the membrane would break with any excess pressure. Pfeffer overcame those difficulties with his apparatus by precipitating the membrane in the walls of a porous porcelain cell, which provided the mechanical support needed to resist pressures reaching several times the atmospheric pressure at sea level, called atmospheres. Pfeffer used porcelain cells that were the unglazed type found in electric batteries. Each cell was approximately forty-six millimeters (1.8 inches) high, sixteen millimeters (0.63 inches) in diameter, and one and a quarter to two millimeters (approximately 0.079 inches) thick.

Pfeffer discusses and illustrates the Pfeffer apparatus, which contains the porcelain cell, in his book *Osmotic Investigations*. The apparatus consisted of the porcelain cell with a membrane, a connecting piece fused to the porcelain cell, and a narrow closing piece fused to the connecting piece. Together those components were five inches in length. The apparatus also included a manometer, a device used to measure pressure, that was approximately ten inches long and that was attached the other components. A glass ring covered the connection between the porcelain cell and the connecting piece with the manometer on the side. The connecting piece fastened into the porcelain cell and the closing piece attached to the other end of the connecting piece with sealing wax. The glass ring was only necessary in experiments at higher temperatures in which the sealing wax softened. At higher temperatures pitch, a residue created by the distillation of organic materials such as tar, helped to hold the inserted pieces firmly together.

In *Osmotic Investigations* Pfeffer gives a general account of the preparation of the porcelain cell and then a detailed explanation of the preparation of the porcelain cell before precipitation of the membrane. Pfeffer detailed the production of the cell because in previous experiments performed by Traube the membrane tore under pressure. Pfeffer prepared the membrane so that it was sturdier than Traube's membranes under pressure, which was a feature that enabled Pfeffer to measure the amount of osmotic pressure accurately. Pfeffer's membrane was thicker and more resistant, which helped it counteract greater pressures.

In the general description, the porcelain cell was treated with water then placed in a dilute solution of copper sulfate. Either immediately or after some time, Pfeffer introduced the interior of the cell to a solution of potassium ferrocyanide. After some time, a membrane of copper ferrocyanide formed in the porcelain cell.

In the detailed description, Pfeffer further describes the preparation of the porcelain cell. He treated the porcelain cell with dilute potassium hydroxide, then with three percent hydrochloric acid, washed the porcelain cell with water, and dried it. Then he saturated the porcelain cell with water by repeated evacuation with an air- pump and placed the cell in a solution containing three percent copper sulfate that filled the interior of the cell for twenty-four to forty-eight hours. He rinsed the cell with water and dried with strips of filter paper and poured a solution of potassium ferrocyanide into the interior of the cell and reintroduced the cell into the solution of copper sulfate. After Pfeffer closed the apparatus the cell needed to be undisturbed for another twenty-four to forty-eight hours while the membrane formed. A certain excess of pressure of the contents of the cell gradually manifested itself because the potassium ferrocyanide has a higher osmotic pressure than the copper sulfate solution. After closing, the apparatus the two solutions reacted and a membrane of copper ferrocyanide formed either in the wall or on the surface of the porcelain cell by precipitation.

After the twenty-four to forty-eight hours, Pheffer opened the apparatus and slowly introduced a solution of three percent potassium ferrocyanide containing one and a half percent potassium nitrate solution. The solution showed an excess of osmotic pressure of three atmospheres, to test the integrity of the membrane. Pfeffer encouraged other researchers to increase the pressure slowly and to maintain the lower pressure for a specific length of time to enable the membrane to stretch over small depressions on the inner surface of the porcelain disk to prevent the membrane from tearing.

Using the constructed apparatus, Pfeffer filled the cell and connecting pieces with sucrose, or sugar, solutions. The apparatus was then placed into a water bath. Water moved from the bath into the cell, which created pressure within the cell that Pfeffer measured with the monometer. Pfeffer calibrated his apparatus with different concentrations of sucrose and found that the movement of water would stop once the pressure was great enough in the side containing the more concentrated sugar solution. Semipermeable membranes have the properties of preventing certain substances to pass through to equalize concentrations on both sides of the membrane, called osmosis, but preventing others from passing through, called filtration. He measured the pressure resulting from a state of equilibrium between the movement of the water and the filtration of dissolved molecules, called osmotic pressure.

The Pfeffer apparatus provided accurate measurements of the osmotic pressure that an impermeable solute produced across a copper ferrocyanide membrane. The apparatus also showed that osmotic pressure is proportional to concentration and temperature. However, those results were relatively unknown until Jacobus Van't Hoff provided his theory on osmotic pressure in the early 1880s. Van't Hoff studied physical chemistry at several different universities in France, Germany, and at the University of Amsterdam from1878 to 1896. He used Pfeffer's osmotic pressure measurements to devise his formulas for the osmotic pressure equation. Van't Hoff showed that the osmotic pressure of a solution inside a vessel in a pure solvent is directly proportional to the concentration of the solute and inversely proportional to the volume of the solution.

Although Van't Hoff brought renewed attention to Pfeffer and osmotic pressure, historians argued that Pfeffer's theories remained obscure. Kepner and Stadelmann the 1984 translators of *Osmotic Investigations* argued that due to Pfeffer's abstract and unclear writing style other scientists could not build upon his research. Kepner and Stadelmann explain that Pfeffer's ideas are often speculative and abstract, which would have made further experiments difficult for other scientists to perform. Few scientists used Pfeffer's tools and methods to study osmosis until the twentieth century.

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