

The phenomenon of diffusion in liquids and solids. Osmotic pressure.

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ABSTRACT

Diffusion of liquids, diffusion coefficient of liquids, the phenomenon of diffusion in solids, accelerating the diffusion process by increasing temperature, the role of diffusion in nature and technology, formation of dilute solutions, and the generation and magnitude of osmotic pressure.

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Two liquids in contact diffuse into one another until they are completely mixed. For instance, if a copper sulfate solution is poured onto the bottom of a vessel containing water using a long-stemmed funnel, the initial sharp boundary between the liquids gradually blurs. After several months, they become fully mixed. The diffusion process in liquids is described by Fick's law, which we previously derived for gases:

$$\Delta M = -D \frac{\Delta \rho}{\Delta x} \Delta S \Delta t$$

Here, ΔM is the mass of liquid diffusing through an area ΔS in time Δt in a direction perpendicular to the density change; $\Delta \rho / \Delta x$ is the density gradient; and D is the diffusion coefficient of the liquid.

We take into account that $\Delta M = m \Delta n$ and $\Delta \rho = m \Delta n_0$, where m is the mass of a liquid particle (molecule or atom), Δn is the number of diffused particles, and Δn_0 is the difference in the number of particles per unit volume between the first and second liquids (the difference in molecular concentrations). Then, by dividing both sides of the equation by m , we obtain an expression relating the number of diffused particles to the molecular concentration gradient:

$$\Delta n = -D \frac{\Delta n_0}{\Delta x} \Delta S \Delta t$$

It should be noted that the diffusion coefficient for liquids cannot be calculated using the formula derived for gases, as the nature of thermal motion in liquids differs significantly from that in gases: liquid particles do not move freely over long distances. Consequently, the diffusion coefficient in liquids is hundreds of thousands of times smaller than in gases—specifically, in the range of 10^{-10} to $10^{-9} \text{ m}^2/\text{s}$. Accordingly, diffusion proceeds much more slowly in liquids than in gases. However, when the concentration gradient is large (as is often the case with gases), diffusion can occur quite rapidly in liquids as well, despite the low diffusion coefficient.

Diffusion can also be observed in solids, and Fick's law is applicable in this context. However, diffusion in solids proceeds even more slowly than in liquids; the diffusion coefficient for solids is significantly lower than that for liquids. The diffusion process in solids can be accelerated by raising the temperature. For

instance, at a temperature of 2200°C, a boundary layer 0.3 mm thick—consisting of a mixture of copper and zinc particles—forms between tightly pressed copper and zinc plates after 12 hours. Although the melting temperatures of copper and zinc are well above 220°C (copper melts at 1083°C and zinc at 419°C), the plates become firmly soldered together.

In a solid crystalline body, particles are situated very close to one another and are capable of vibrating near the nodes of the spatial lattice. Therefore, to explain diffusion in crystals, one must assume the existence of "holes"—lattice nodes not occupied by particles—within the crystal lattices. In this scenario, a vibrating particle can move to an adjacent "empty" (vacant) node, another particle moves into the vacated spot, and so on.

The phenomenon of diffusion plays a significant role in both nature and technology. For instance, plant nutrition occurs through diffusion. Soil water surrounding plant roots contains various dissolved substances. Plants immediately absorb the substances that serve as nutrients. Consequently, the concentration of these substances inside the root differs from that outside the root is always lower than the concentration... Due to the concentration gradient at the root surface, a continuous diffusive flow of nutrients from the surrounding soil water to the root system is maintained. At the same time, dissolved substances that are not required by the plant—and thus not assimilated by it—exist at equal concentrations both inside and outside the root. The absence of a concentration gradient halts the flow of these unwanted dissolved substances into the root system.

Diffusion plays a similar role in the nutrition of animals and humans. Through the walls of the stomach and intestines, the body absorbs only those dissolved substances from food that are necessary for the structure of its cells. Consequently, a nutrient concentration gradient is established at the walls of the digestive tract, facilitating the diffusion of these substances into the body.

In the sugar industry, diffusion is employed to extract sugar from beet pulp.

The process of diffusion plays a crucial role in metallurgy; the cementation of iron and steel products is also based on diffusion. When iron is heated with carbon, carbon diffuses into the iron, forming a surface layer of iron carbide (cementite, Fe_3C). After hardening, the cemented iron object (such as a shaft, transmission axle, or similar component) acquires a hard outer layer while retaining a soft, tough core. A similar process is used when cementing iron with other metals, such as chromium, tungsten, and the like.

The phenomenon of the diffusion of substances through semi-permeable membranes—known as osmosis—is of particular interest, and we will examine it below.

OSMOSIS

When a solid substance is dissolved in a liquid, its molecules distribute themselves uniformly throughout the liquid's volume, forming a medium known as a solution; the liquid is called the solvent, and the solid substance is called the solute. The mass of the solute (m) per unit volume of the solution (V) is defined as the concentration (C) of the solution; thus:

$$C = \frac{m}{V}.$$

Solutions with low concentrations are referred to as weak or dilute solutions.

Let us visualize a weak solution poured into a container; The dimensions of dissolved substance molecules are small relative to the distances between them; consequently, there is virtually no interaction between these molecules. Thus, a dissolved substance in a dilute solution behaves much like an ideal gas, the only difference being that the freedom of movement of the dissolved molecules is restricted by the presence of solvent molecules. Nevertheless, this analogy between an ideal gas and a dissolved substance suggests the possibility of applying ideal gas laws to dissolved substances. Specifically, one can hypothesize that the dissolved substance exerts a partial pressure expressed by the formulas derived from the fundamental equation of the kinetic theory of gases and the Mendeleev-Clapeyron equation:

$$p = \frac{2}{3} n_0 W \quad p = \frac{m}{\mu} \frac{RT}{V}$$

where n_0 is the concentration of dissolved substance molecules (the number of dissolved molecules per unit volume of solution), W is the average kinetic energy of a dissolved molecule, m and μ are the mass and kilomolar mass of the dissolved substance, V and T are the volume and temperature of the solution, and R is the universal gas constant.

To observe this pressure, it is necessary to separate the solution from the pure solvent using a semi-permeable barrier—one that allows solvent molecules to pass through but prevents the passage of dissolved substance molecules. For an aqueous sugar solution, materials such as ox bladder, intestinal tissue, and certain synthetic plastic films can serve as semi-permeable barriers; however, the larger sugar molecules cannot pass through them.

Let us now conduct the following experiment. We pour a dilute aqueous sugar solution into a funnel covered with an ox bladder membrane and place it into a container of pure water, positioning it so that the liquid levels in both the funnel and the container are equal. Observations show that the level of the solution in the funnel gradually rises and eventually stops at a height h above the water level in the container. The reason for this is as follows: the concentration of water molecules in the container exceeds the concentration of water molecules in the funnel by an amount corresponding to the concentration of the sugar molecules. Consequently, more water molecules diffuse from the container into the funnel through the semi-permeable barrier than in the opposite direction, causing the liquid level in the funnel to rise. Sugar molecules cannot pass through the semi-permeable barrier from the funnel into the container. As a result, the concentration of water molecules in the funnel and the container equalizes, while the concentration of sugar molecules remains unequal—specifically, n_0 in the funnel and zero in the container. An excess concentration of sugar molecules generates a partial pressure of the dissolved substance that balances the hydrostatic pressure of the solution column of height h . The phenomenon of solvent diffusion through a semi-permeable barrier separating a solution from the pure solvent is called osmosis; the excess pressure generated in the solution (equal to the partial pressure of the dissolved substance, p) is termed osmotic pressure. Since the pressure exerted by a solution column of height h is ρgh , it is easy to determine the osmotic pressure from this experiment using the following formula:

$$p = \rho gh$$

where ρ is the density of the solution and g is the acceleration due to gravity. Alternatively, osmotic pressure can be calculated using the formulas mentioned earlier. Both calculations yield consistent values for osmotic pressure, leading to the conclusion that the analogy between an ideal gas and a solute in a dilute solution is valid.

To gain an idea of the magnitude of osmotic pressure, let us calculate—using the formula—the osmotic pressure of an aqueous solution of cane sugar ($C_{12}H_{22}O_{11}$) at a temperature of 27°C , assuming a concentration of 0.034 kg of sugar per liter of water. Based on the chemical formula of sugar, the mass of a kilomole of sugar is 342 kg/kmol; thus:

$$p = \frac{m}{\mu} \frac{RT}{V} = \frac{0,034 \cdot 82 \cdot 300}{342 \cdot 1} = 2,46 \text{ (atm)}.$$

Osmotic pressure is clearly evident in the following well-known phenomenon. If dried fruits are placed in water without rupturing their skin (membrane), they quickly swell into a spherical shape; this indicates the presence of excess internal pressure. This excess pressure is osmotic pressure. Water molecules can pass through the fruit's skin, whereas the sugar molecules inside cannot. Water diffuses into the fruit, forming an aqueous sugar solution. As with the aforementioned sugar solution, osmotic pressure develops within this solution, causing the fruit's skin to swell. Incorporating the solution concentration, C , into the formula yields the following:

$$p = \frac{CRT}{\mu}$$

This leads to the following conclusion:

Osmotic pressure is directly proportional to the solution's concentration and temperature, and inversely proportional to the molecular weight of the dissolved substance.

This law was established in 1987 by the Dutch chemist van 't Hoff. It should be noted that, according to van 't Hoff's law, osmotic pressure is independent of the solvent's properties.

Van 't Hoff's law holds true precisely only for dilute solutions in which the dissolved substance does not undergo dissociation. For dissociated solutions (i.e., electrolytes), osmotic pressure is significantly higher than predicted by van't Hoff's law. This is because dissociation increases the number of solute particles (a single molecule can yield two ions), thereby raising the osmotic pressure in accordance with the formula.

The phenomenon of osmosis plays a vital role in the lives of plants and living organisms. Living cell membranes act as semi-permeable barriers; they allow water molecules to pass through but block the complex organic molecules generated within the cell during its metabolic processes. Consequently, a solution forms inside the cell, generating osmotic pressure that causes the cell to swell and become elastic, much like an inflated rubber ball. Plant and animal tissues composed of such cells exhibit high elasticity and an enhanced ability to maintain their shape. In biology, this osmosis-related phenomenon is known as cell turgor.

Osmotic pressure can be extremely high in plant cells surrounded by water. For instance, the osmotic pressure in a carrot can reach several atmospheres. If a body cell is in contact with an aqueous solution containing a high concentration of a substance that cannot pass through the cell membrane, water moves from the cell into that solution. This results in a phenomenon known as the "osmotic withdrawal" of water from the cell. It is this phenomenon that causes the sensation of thirst after consuming sweet foods.

Living organisms maintain a constant osmotic pressure within their cells (a process known as osmoregulation) through physiological processes such as nutrition, excretion, respiration, and others.

References

1. R.I. Grabovsky, *Course of Physics*, 1973.
2. *Physics*: Textbook for specialized secondary educational institutions, L.S. Zhdanov, 1979.
3. Tsvetkov V.N., *Rigid-Chain Polymer Molecules*, Leningrad: Nauka, 1986.
4. Klenin V.I., *Thermodynamics of Systems with Flexible-Chain Polymers*, Saratov: Saratov State University, 1995.
5. *General Physics Course*, Part 1, I.V. Savelyev, 1979.

Websites used

1. [http:// www.Ilmiy.uz](http://www.Ilmiy.uz);
2. [http:// www.IIAU Digital library.uz](http://www.IIAU Digital library.uz);
3. [http:// www.Ziyo.uz](http://www.Ziyo.uz);
4. [http:// www.TDPU.uz](http://www.TDPU.uz);