One Setup, Three Systems

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Abstract: The system–surroundings concept is one of the most important in thermodynamics. Precisely defining a system is of critical importance to thermodynamic analysis. Even when studying the same problem, different individuals may opt to select different systems; therefore, choosing the correct system requires skill. In order to help students understand the various systems and their differences, a simple distillation setup is used to demonstrate the three thermodynamic systems: open, closed, and isolated.

Thermodynamics is the study of heat or energy flow in chemical reactions. In order to keep track of the energy changes that occur in a chemical reaction it is helpful to think of the reaction or the reaction and its periphery as separate from the world around it [1]. Thus, the first concept that students learn in thermodynamics, both in general chemistry and physical chemistry, is the division of the universe into system and surroundings. The macroscopic part of the universe under study is defined as the system while the rest of the universe is the surroundings. The system–surroundings concept is one of the most important in thermodynamics. Paradoxical differences between two results for the same problem by two experts often occur because they are addressing different systems [2]; therefore, precisely defining a system is critical in thermodynamic analysis.

The choice of system depends on the individual and the problem under investigation. Certain skills are required to define the system. Depending upon how the boundary between the system and the surroundings is drawn (a real or an imaginary boundary) and whether or not matter transfer is also involved, a system can be further subdivided into one of three types: open, closed, or isolated. An open system can exchange energy and matter with its surroundings while a closed system can exchange energy but not matter with its surroundings. An isolated system, however, can exchange neither energy nor matter with its surroundings. Both general chemistry and physical chemistry textbooks [1, 3–6] have some discussion of systems and surroundings; however, there are no illustrations to show the three definitions using an example familiar to students. To help our students understand the various systems and their differences, we have used the distillation apparatus. Although students may not use a distillation setup until organic chemistry, they have seen pictures or drawings of either a simple or fractional distillation apparatus in most general chemistry textbooks [1, 3, 4] and know that it is used for separating mixtures of liquids.

Consider the case where water containing a nonvolatile solute such as sodium chloride is to be purified by distillation. When the salt water is heated to its boiling temperature, the water in the distillation flask goes into the vapor phase and later condenses to liquid, which flows into the receiving flask. Before using this illustration [7], we need to assume the following: (1) Although the receiving flask is open to the air, the liquid water in the receiving flask that escapes into the air is negligible and (2) no heat from the Bunsen burner is lost to the air.

System 1 (Figure 1, red line), which consists of the distillation flask containing salt water, fits the definition of an open system. This is because there is a transfer of matter (water) from the distillation flask (the system) to the receiving flask (the surroundings) as well as the transfer of energy as heat from the Bunsen burner, which is also a part of the surroundings, to the distillation flask.

System 2 (Figure 1, purple line), which consists of the distillation flask, the condenser, the adapter, and the receiving flask, is a closed system. In this case there is only heat exchange between the system and the Bunsen burner in the surroundings; mass transfer occurs within the system as water leaves the distilling flask and enters the receiving flask.

Strictly speaking, there are no real examples of an isolated system except the universe because energy exchange in any real system cannot be absolutely excluded; however, if the energy exchange between a system and the surroundings can be reduced to a negligible amount or the part involving energy exchange is enclosed in the system, then this system can be approximated as an isolated system. For example, System 3 (Figure 1, blue line), which consists of the whole distillation setup (the distillation flask, the condenser, the adapter, the receiving flask, the Bunsen burner, and the methane tank) and the environment of the room where distillation occurs is an isolated system because, based on the above assumptions, neither matter nor energy exchanges with surroundings.

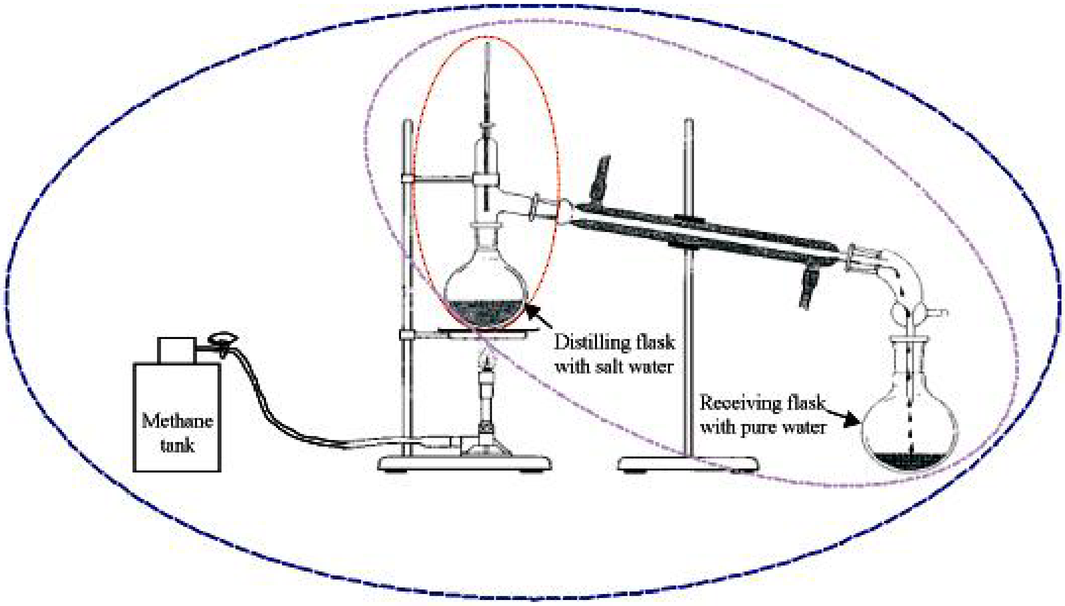

Figure 1. Distillation Apparatus. *System 1* (········) Distitling flask containing salt water (mass transfer between distilling flask and receiving flask) (heat transfer between distilling flask and Bunsen burner). *System 2* (·-·-·-·-) Whole distillation setup except Bunsen burner (no mass transfer) (heat transfer between distilling flask and Bunsen burner). *System 3*(**-----**) Distillation setup plus Bunsen burner (no mass transfer, no heat exchange).

References and Notes

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7. If this concept is to be illustrated with a laboratory demonstration, the instructor should follow laboratory safety procedures as set forth by the institution.