In thermodynamics, it is imperative to define a system and its surroundings because that concept becomes the basis for many types of descriptions and calculations.

**Introduction**

A primary goal of the study of thermochemistry is to determine the quantity of heat exchanged between a system and its surroundings. The *system* is the part of the universe being studied, while the *surroundings* are the rest of the universe that interacts with the system. A system and its surroundings can be as large as the rain forests in South America or as small as the contents of a beaker in a chemistry laboratory. The type of system one is dealing with can have very important implications in chemistry because the type of system dictates certain conditions and laws of thermodynamics associated with that system.

**Open System**

An *open system* is a system that freely exchanges *energy* and *matter* with its surroundings. For instance, when you are boiling soup in an open saucepan on a stove, energy and matter are being transferred to the surroundings through steam. The saucepan is an open system because it allows for the transfer of matter (for example adding spices in the saucepan) and for the transfer of energy (for example heating the saucepan and allowing steam to leave the saucepan).

Let us examine how matter and energy are exchanged in an open system. Matter can be exchanged rather easily: by adding matter (i.e. spices) or removing matter (i.e tasting what is being cooked). Energy exchange is a little bit more complicated than matter exchange. There are a couple of ways energy can be exchanged: through heat and through work (a more in-depth discussion of heat and work has been included below). Energy induced through heat can be demonstrated by bringing the system close to an object that dissipates heat (i.e. Bunsen burner, stove, etc.). By doing so, one is able to change the temperature of the system and therefore, induce energy through heat. Another way to increase the energy is through work. An example of inducing work is by taking a stirrer and then mixing the coffee in the cup with the stirrer. By mixing coffee, work is done as the coffee is being moved against a force.

Note: the blue diagram depicting the transfer of energy and matter is showing how energy and matter can enter the system **AND** leave the system. Do not be fooled by the one way arrows.
Closed System

Putting a lid on the saucepan makes the saucepan a closed system. A closed system is a system that exchanges only energy with its surroundings, not matter. By putting a lid on the saucepan, matter can no longer transfer because the lid prevents matter from entering the saucepan and leaving the saucepan. Still, the saucepan allows energy transfer. Imagine putting the saucepan on a stove and heating it. The saucepan allows energy transfer as the saucepan heats up and heats the contents inside it. For example, when a lid is put a beaker, it becomes a closed system. Next, when the contents in the beaker are boiled, the sides of the beaker will start getting foggy and misty. This fog and mist is the steam which covers the sides of the container because it cannot escape the beaker due to the lid. The fact that the beaker is able to produce this steam means that the beaker allows for energy transfer. Thus, even though a closed system cannot allow matter transfer, it can still allow energy transfer.

The methods of energy transfer in a closed system are the same as those described for an open system above.

Note, the blue diagram is showing how energy can enter the system AND leave the system. Do not be fooled by the one-way arrows.
Isolated System

Now let's examine the type of system you have if you substituted a thermos for the saucepan. A thermos is used to keep things either cold or hot. Thus, a thermos does not allow for energy transfer. Additionally, the thermos, like any other closed container, does not allow matter transfer because it has a lid that does not allow anything to enter or leave the container. As a result, the thermos is what we call an isolated system. An isolated system does not exchange energy or matter with its surroundings. For example, if soup is poured into an insulated container (as seen below) and closed, there is no exchange of heat or matter. The fact that, in reality, a thermos is not perfect in keeping things warm/cold illustrates the difficulty in creating an truly isolated system. In fact, there are a few, if any, systems that exist in this world that are completely isolated systems.
Energy, Heat, and Work

In defining a system and its surroundings, words like energy and matter are used very often. As a result, one’s understanding of a system and its surroundings can increase by understanding energy and matter. Energy is the ability to do work. Work is when an object moves against a force and is defined by the following equation:

\[ W = FD \]

with

- \( W \) representing work,
- \( F \) representing force, and
- \( D \) representing distance.

It can be as simple as picking up a tennis ball or as complicated as pushing a car. When you are moving an object against a force (i.e. gravity), you are doing work on that object.

There are many different types of energy, but the two that will be discussed in this section are potential energy and kinetic energy. Potential energy is “stored energy,” energy that contains the potential to do work when released. Any object that is stationary contains potential energy. For example, if someone is standing in a baseball field holding a ball in their hand, the ball has potential energy. Note that the ball is stationary. Kinetic energy on the other hand, is known as the energy created by movement. Now imagine that someone is still holding that same baseball in their hand. By throwing the baseball, potential energy is transformed to kinetic energy, because the ball is now moving and is not stationary anymore. Below is a visual of kinetic and potential energy:

Initially, when the ball is stationary and not moving, it has potential energy. When it moves towards the baseball bat and when the bat hits the baseball, the baseball it has kinetic energy because the ball is moving the entire time.
Besides potential energy and kinetic energy, energy is also characterized by heat \((q)\). Heat is an extensive property and results from a temperature difference due to the transfer of thermal energy. In our day-to-day language, we use heat and temperature interchangeably. When the word "heat" is used, what comes to mind is usually the following:

Normally, people associate heat with temperature but in chemistry, both those terms have very specific definitions. Temperature is a measure of the average kinetic energy of an object. Heat, on the other hand, describes the transfer of temperature and not temperature itself. They are two different terms. To reinforce, temperature refers to the average kinetic energy of an object whereas heat refers to the transfer of energy.

**Applications**

Systems and surroundings have many practical applications in chemistry as well as in our own day-to-day lives. Without even knowing, we interact with thousands of closed and open systems everyday. For example, when packing lunch, food is normally placed in some sort of closed container (so that things don't enter or leave the container). Anything can be defined as a system, and and everything else would then be the surroundings.

In reality, the type of system one is dealing with has many implications regarding the assumptions and calculations one is allowed in chemistry. Furthermore, based on systems and surroundings, scientists have come up with a couple of laws known as laws of thermodynamics. The first and second law of thermodynamics, briefly stated, are:

1. The internal energy of an isolated system stays constant.
2. The entropy of an isolated system tends to increase.

The first law is based upon the definition of an isolated system. Internal energy is a sum of a system's heat and work. As discussed earlier, heat and work are forms of energy. An isolated system is by definition a system that does not allow energy transfer. Thus, it makes sense to say that the internal energy of an isolated system stays constant because it does not change at all.

The second law of thermodynamics, increasing entropy of an isolated system, asks for basic understanding of entropy. Entropy is the disorder within a system. For example, a solid has no disorder (atoms are packed into a cube and cannot move) whereas a gas has more disorder (atoms bouncing all over the place). Thus, this law states that the entropy of an isolated system tends to increase (i.e. a chemical reaction taking place in an isolated system will never have a liquid becoming a solid because that is a decrease in entropy).

**Analogies & Examples**

The topic of a system and surroundings, just like other topics in chemistry, is one that can be well understood through reading and visualizing examples. An open system is one that allows energy and matter exchange. When deciding whether or not something is an open system, one must determine whether or not the system allows matter and energy transfer. If it does, then it is an open system. If it does not, then it is either a closed system or an isolated system. If the system allows neither energy or matter transfer, then it is an isolated system. However, if it allows only energy transfer, it is a closed system. The videos below provide additional examples of closed, open, and isolated systems. (These videos are available for download at the bottom of the page where it says "Files."
Closed System Video

Media, iframe, embed and object tags are not supported inside of a PDF.
Isolated System Video

Media, iframe, embed and object tags are not supported inside of a PDF.
Practice Problems

1. Which type of thermodynamic system is an ocean? an aquarium? a pizza delivery bag? a greenhouse?
2. A closed system contains 2g of ice. Another 2g of ice are added to the system. What is the final mass of the system?
3. An isolated system has an initial temperature of 30°C. It is then placed on top of a bunsen burner for an hour. What is the final temperature?
4. What type of energy does a stationary pencil contain? falling pencil?
5. What do the first and second laws of thermodynamics have to do with systems?

Answers to Practice Problems

1. ocean: open, aquarium: closed, a pizza delivery bag: isolated, a greenhouse: closed.
2. The final mass will be 2g. Remember, a closed system does not allow for mass exchange.
3. The final temperature will be 30°C. Remember, an isolated system does not allow energy transfer.
4. A stationary pencil has potential energy and a falling pencil has kinetic energy.
5. The first law of thermodynamics is based on an isolated system because the first law of thermodynamics says that the internal energy of an isolated system stays constant. This can only be said for an isolated system because it is the only system that does not allow energy transfer. The second law of thermodynamics states that the entropy of an isolated system increases.

References


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