In the name of God

Technical English Language

for Materials Engineering and Metallurgy

Lesson 2: Thermodynamics of Materials

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1. Introduction to thermodynamics

Thermodynamics is a science and, more importantly, an engineering tool used to describe processes that involve changes in temperature, transformation of energy, and the relationships between heat and work. It is used to describe the performance of propulsion systems, power generation systems, refrigerators, fluid flow, combustion, and many other phenomena.

In physics, thermodynamics is the study of energy conversion between heat and mechanical work, and subsequently the macroscopic variables such as temperature, volume and pressure. Its progenitor, based on statistical predictions of the collective motion of particles and is the field of statistical thermodynamics (or statistical mechanics), a branch of statistical physics. Historically, thermodynamics developed out of need to increase the efficiency of early steam engines.

The usage of thermodynamics describes how systems respond to changes in their surroundings. This can be applied to a wide variety of topics in science and engineering, such as engines, phase transitions, chemical reactions, transport phenomena, and even black holes. The results of thermodynamics are essential for other fields of physics and for chemistry, chemical engineering, aerospace engineering, mechanical engineering, cell biology, biomedical engineering, materials science, and economics.

2. Thermodynamic laws

The present text is focused on classical thermodynamics, which is focused on systems in thermodynamic equilibrium. It is wise to distinguish classical thermodynamics from non-equilibrium thermodynamics, which is concerned with systems that are not in thermodynamic equilibrium. In thermodynamics, there are four laws that do not depend on the details of the systems under study or how they interact. These four laws are:

- ✓ ***Zeroth law of thermodynamics***

  If two thermodynamic systems are separately in thermal equilibrium with a third, they are also in thermal equilibrium with each other. If we grant that all systems are in thermal equilibrium with themselves, the Zeroth law implies that thermal equilibrium is an equivalence relation on the set of thermodynamic systems. This law is tacitly assumed in every measurement of temperature. Thus, if we want to know if two bodies are at the same temperature, it is not necessary to bring them into contact and to watch whether their observable properties change with time. This law was considered so obvious, hence the designation Zeroth, rather than Fourth. In short, if the heat energy of material A is equal to the heat energy of material B, and B is equal to the heat energy of material C, then A and C must also be equal.

- ***First law of thermodynamics***

The change in the internal energy of a closed thermodynamic system is equal to the sum of the amount of heat energy supplied to or removed from the system and the work done on or by the system. In short, we can say, "In an isolated system the heat is constant".

- ***Second law of thermodynamics***

The total entropy of any isolated thermodynamic system always increases over time, approaching a maximum value or we can say, "In an isolated system, the entropy never decreases". Another way to phrase this: Heat cannot spontaneously flow from a colder location to a hotter area - work is required to achieve this.

- ***Third law of thermodynamics***

As a system asymptotically approaches absolute zero of temperature, all processes virtually cease and the entropy of the system asymptotically approaches a minimum value. Also in other expression: "the entropy of all systems and of all states of a system is zero at absolute zero". On the other hand, equivalently "it is impossible to reach the absolute zero of temperature by any finite number of processes". Absolute zero, at which all activity would stop if it were possible to happen, is -273.15 °C (degrees Celsius), or -459.67 °F (degrees Fahrenheit) or 0 K (Kelvin).

➢ *Entropy*

Entropy is a measure of how organized or disorganized a system of atoms or molecules. It is measured in Joules of energy per degree Kelvin. Entropy is an important part of the second law of thermodynamics. There are two related definitions of entropy: the thermodynamic definition and the statistical mechanics definition. The thermodynamic definition was developed in the early 1850s by Rudolf Clausius and essentially describes how to measure the entropy of an isolated system in thermodynamic equilibrium. Importantly, it does not refer to the microscopic nature of matter. Ludwig Boltzman developed the statistical definition in the 1870s by analyzing the statistical behavior of the microscopic components of the system. Boltzmann went on to show that this definition of entropy was equivalent to the thermodynamic entropy to within a constant number that has since been known as Boltzmann's constant. In summary, the thermodynamic definition of entropy is the fundamental definition of entropy, while the statistical definition of entropy extends the concept, providing an explanation and a deeper understanding of its nature. The entropy change of a system at temperature T absorbing an infinitesimal amount of heat δq in a reversible way is given by $\delta q/T$.

3. Thermodynamic systems

An important concept in thermodynamics is the "system". Everything in the universe except the system is known as surroundings. A system is the region of the universe under study. A system is separated from the remainder of the universe by a boundary which may be imaginary or not, but which by convention delimits a finite volume. The possible exchanges of work, heat, or matter between the system and the surroundings take place across this boundary. Boundaries are of four types: fixed, moveable, real, and imaginary.

In thermodynamics, a thermodynamic system is said to be in thermodynamic equilibrium when it is in thermal equilibrium, mechanical equilibrium, and chemical equilibrium. Classical thermodynamics deals with dynamic equilibrium states. The local state of a system at thermodynamic equilibrium is determined by the values of its intensive parameters, as pressure, temperature, etc. Specifically, thermodynamic equilibrium is characterized by the minimum of a thermodynamic potential, such as the Helmholtz free energy, *i.e.* systems at constant temperature and volume:

$$A = U - TS;$$

Or as the Gibbs free energy, i.e. systems at constant pressure and temperature:

$$G = H - TS$$

For closed systems, boundaries are real while for open system boundaries are often imaginary. There are five dominant classes of systems:

- Isolated Systems: matter and energy may not cross the boundary;
- Adiabatic Systems: heat must not cross the boundary;
- Diathermic Systems: heat may cross boundary;
- Closed Systems: matter may not cross the boundary;
- Open Systems: heat, work, and matter may cross the boundary.

➢ *Enthalpy*

In thermodynamics and molecular chemistry, enthalpy (denoted as H or specific enthalpy denoted as h) is a thermodynamic property of a thermodynamic system. It can be used to calculate the heat transfer during a quasistatic process, taking place in a closed thermodynamic system under constant pressure (isobaric process). Change in enthalpy ΔH is frequently a more useful value than H itself. For quasistatic processes under constant pressure, ΔH is equal to the change in the internal energy of the system, plus the work that the system has done on its surroundings. This means that the change in enthalpy under such conditions is the heat absorbed by a chemical reaction.

- *Choose the correct terms for the following definitions.*

1. Classical thermodynamics ………………………..…... is a branch of physics that studied heat and work and their relation to the collision and interaction of particles in large near-equilibrium systems.

2. Heat capacity …………….. is a measurable physical quantity that characterizes the amount of heat that is required to change a body's temperature by a given amount (usually denoted by *C*).

3. Helmholtz free energy ………………………. is a thermodynamic potential which measures the useful work obtainable from a closed thermodynamic system at a constant temperature and volume.

4. Intensity property ………………….. is a physical property of a system that does not depend on the system size or the amount of material in the system (≠ extensive property).

5. Statistical thermodynamics ……….......................... is the application of probability theory to study the thermodynamic behavior of systems of a large number of particles.

6. Adiabatic ……………… cooling occurs when the pressure of a system is decreased as it dose work on its surroundings.

7. The dewpoint ……………..…. is the temperature to which a given parcel of air must be cooled, at a constant barometric pressure, for water vapor to condense into water.

8. An infinitesimal ………………. object is an object which is smaller than any feasible measurement, hence not zero size, but so small that it cannot be distinguished from zero by any available means.

9. According to the general theory of relativity, a black hole ……………. is a region of space from which nothing, including light, can escape.

10. The usage of thermodynamics describes how systems respond to changes in their surroundings ………….. .

- Choose the best choice using your knowledge of metallurgy and the details in the previous reading.

1. There are several ………….. methods for calculation of the enthalpy of defects.

   a) external ✓ b) empirical c) compressible d) agitated

2. Which of the following is always a characteristic of an adiabatic process?

   a) $\Delta T = 0$ b) $\Delta U = 0$ ✓ c) $Q = 0$ d) $W = 0$

3. ………… is a measure of how organized or disorganized a system of atoms or molecules.

   a) Energy b) Enthalpy ✓ c) Entropy d) Exergy

4. In exothermic and endothermic reactions, respectively, enthalpy is ………… .

   a) positive, negative b) positive, positive ✓ c) negative, positive d) negative, negative

5. The ………….. of all systems and of all states of a system is zero at absolute zero.

   a) Energy b) Enthalpy ✓ c) Entropy d) Exergy

6. The disposition of a gaseous or solid material into a liquid (or a liquid into a liquid) to provide an apparently homogenous material: …………. .

a) solvent b) dissolution ✓ c) solution d) solute

7. Solid solution is:

✓ a) an alloy of two or more metals or metal(s) and nonmetal which is a single-phase atomic mixture.

b) a mixture of two or more metals or a metal and a nonmetal.

c) a mixture of two or more liquids in which one is present in the form of minute droplets.

d) a suspension of minute bubbles of gas in a liquid.

8. It is common experience to observe that only processes which occur are those which bring the system to a state of rest, i.e., to a state of equilibrium. Which fact is explained by the sentence?

a) Reversibility b) First law of thermodynamics ✓ c) Second law of thermodynamics d) Equilibrium

9. In a spontaneous reaction ……………

✓ a) reactant are more order than product b) product are more order than reactant

c) ordering don't change d) no one

4. Selected vocabulary

En	Fa	En	Fa
Heat capacity	ظرفیت گرمایی	Infinitesimal	بی‌نهایت کوچک
Intensive property	خاصیت شدتی	Quasistatic	شبه تعادلی
Extensive property	خاصیت مقداری	Spontaneously	به طور خود بخودی
Asymptotic	خط مجانب	Surroundings	محیط
Adiabatic	بی‌درو	Probability	احتمال
Combustion	احتراق، سوختن	Propulsion	پیشرانش
Conversion	تبدیل	Isothermal	هم‌دما
Diathermic	هادی حرارت	Isobar	هم‌فشار
Configuration entropy	انتروپی وضعیت	Equivalence	هم ارزی
Exothermic	گرماده	Dewpoint	نقطه شبنم
Endothermic	گرماگیر	Concentration	غلظت
Exergy	پتانسیل انجام کار سیستم	Oxidant	اکسید کننده
Irreversible	برگشت‌ناپذیر	Reductant	احیا کننده
Compressible	تراکم‌پذیر	Activity	اکتیوته