



A Comparative Evaluation on the Spontaneity at the Ambient Conditions of the Evaporation and Condensation in the Context of Temperature and Entropy Change of the Surroundings

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HIGHLIGHTS

- > Evaporation is an endothermic process that can occur spontaneously in entropy-controlled atmospheric conditions at any temperature at the expense of the entropy decrease of the environment.
- > Condensation is an exothermic process that can occur spontaneously, at the expense of a decrease in the entropy of the system, but with an increase in the entropy of the environment and with temperature control under atmospheric conditions.
- > The spontaneity of condensation is dependent on the increase in entropy that can occur with the heat flow to the environment at low temperature to compensate for the decrease in the entropy of the system so that the total entropy can be positive.

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ABSTRACT

Evaporation and condensation are thermodynamic events that occur under the influence of temperature and pressure variables. Gases tend to condense at high pressure and low temperature. However, evaporation can occur at any temperature. This suggests that the temperature variable is more effective in condensation. For a system in equilibrium, the chemical potentials of the liquid and gas phases are equal to each other. The chemical potential, which encompasses the change in entropy of the particles and the effect caused by the change in enthalpy separately, corresponds to the molar Gibbs energy for a pure substance. In this context, the spontaneity of evaporation and condensation must be directly related to entropy change and temperature in order to fully conceptualize them. The aim of this study is to compare the spontaneities of evaporation and condensation at atmospheric pressure, considering the temperature and entropy change of the environment, and also to correct common misconceptions about these two processes.

1. Introduction

Condensation is defined into two main types, drop by drop and film condensation. Condensation occurs as drops on hydrophobic surfaces and as a film layer that can wet the surface on hydrophilic surfaces [1,2]. Evaporation is an endothermic process taking place by heat transfer from the environment into any liquid system [3]. There are three main mechanisms for surface evaporation by mass and energy transfer: convective and diffusive convection in two phases, temperature discontinuity at the interface, and

chemical potential discontinuity at the interface. It is easier to explain evaporation via chemical potential, which is a function of enthalpy and entropy, as the simultaneous evaluation of these mechanisms makes theoretical and experimental analysis difficult [4]. The spontaneity of evaporation in the liquid systems at all temperatures and atmospheric pressure is due to a huge increase emerging in the entropy of the system during the phase change. A very higher translational freedom degree of the particles in the gas phase in the entropy context means that a much larger disorderliness could be created or much more micro-states could be generated. Moreover, the reduction of entropy in

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the surroundings is also decreased with increasing of the phase transition temperature. Therefore, an increasing tendency to evaporation with increasing temperature at atmospheric pressure and hence a higher vapor pressure of the liquid can be expected [5]. The evaporation entropy at temperature T is equal to $\Delta H_{\text{vap}} / T$. Clapeyron equation is given in Eq 1.

$$\frac{dp}{dT} = \frac{\Delta_{\text{vap}}H}{T\Delta_{\text{vap}}V} \quad (1)$$

In Eq.1, $\Delta_{\text{vap}}V$ is the molar volume of vapor and $\Delta_{\text{vap}}H$ is the enthalpy of evaporation the greater the $\Delta_{\text{vap}}V$ in the Clapeyron equation, the greater the d_T / d_P ratio, indicating a greater dependence of the boiling temperature on the pressure.

Whereas, the condensation to the liquid of any vapor is the exothermic process and it can occur by a significant decrease in entropy of the system. The spontaneity of this process is controlled by the increase in entropy of the surroundings as well as the phase transition temperature. According to the second law of thermodynamics, the spontaneity of any process is assessed by considering the total entropy change including the system and the surroundings, and its value must be positive. In the light of these discussions, we aim to make a useful comparison that evaporation occurs spontaneously at every temperature, unlike condensation. On the other hand, according to the gas kinetics theory used in modeling evaporation and condensation, a phase transition occurs only under non-equilibrium conditions and therefore it is not possible to ensure the continuity of thermodynamic variables such as temperature and pressure [6,7]. The Gibbs free energy, which corresponds to the maximum amount of energy that can be obtained from a chemical reaction to do a useful job, is also the energy available to do useful work after any energy transfer occurs so that the total entropy change ($\Delta S_{\text{system}} + \Delta S_{\text{surroundings}}$) is not negative. There are three restrictions in the application of phase equilibrium solutions: maintaining of matter equilibrium, the absence of a driving force from any phase to the next phase for equilibrium phase systems, and having the smallest possible Gibbs energy of the system in equilibrium phase systems [8].

Free Gibbs energy is used to determine whether a process occurs spontaneously under constant pressure and temperature conditions, and it is not necessary to know the entropy change of the environment directly in the case of use of this function, because as can be seen from Eq. 2, all quantities in the equation are related to the system.

$$\Delta G = \Delta H_{(\text{system})} - T\Delta S_{(\text{system})} \quad (2)$$

From this equation, it is understood that if $G < 0$, the change will occur spontaneously under certain conditions. Since the entropy change of the system will decrease in the condensation, the compensation of the decrease with the entropy change of the environment will be directly related to the temperature. On the other hand, again from Eq. 2, it can be clearly seen that temperature is a much more critical variable in the condensation process than evaporation since $\Delta S_{(\text{system})} > 0$ in any case for evaporation.

The spontaneity of condensation is dependent on the transferred temperature of heat as well as the size of the surrounding entropy change. To increase the entropy, change in the environment, the only way is to use the enthalpy changes of condensation to produce a larger

entropy change. The solution to this requirement can be found in Eq.3 based on the second law.

$$\Delta S = \frac{q_{\text{rev}}}{T} \quad (3)$$

In Eq.3, q_{rev} and T, respectively reversible heat, and corresponds to the temperature at which heat is transferred. As can be seen from this equation, a significant increase in the entropy may be achieved by the higher enthalpy change or decreasing the temperature at which the heat is transferred. In the exothermic process, the surroundings in the context of spontaneity are responsible for the increase of entropy. It can be concluded that if a process takes place with the entropy decrease, its spontaneity primarily depended on temperature. Consequently, it can be said that in the condensation process, the temperature is a much more crucial variable, compared to the evaporation. On the other hand, it has been suggested that learners have many misconceptions about the concept of condensation and it may be more effective to explain the macro-micro relationship between particles in condensation to avoid these misconceptions [9]. A study conducted with second-year chemical engineering students revealed that students have a misconception that a temperature gradient is required for evaporation and condensation to occur [10]. However, it has also been reported that students who do not realize that condensation occurs in a dynamic equilibrium process and that evaporation and condensation are reversible claims that condensation only occurs on low temperature surfaces [11]. Undoubtedly, this argument is valid for the closed system and equilibrium situation, and it cannot be generalized that if there is evaporation at all temperatures, there will be condensation. A study conducted with university students, it was determined that when it was questioned that evaporation occurs at every temperature, students have the misconception that water should be heated to evaporate and that water placed in a cold environment cannot evaporate because water gives energy to the environment [12]. In another study conducted with 6th, 8th and 11th grade students, misconceptions about the condensation of water vapor were examined and it was concluded that most of the students had difficulty understanding this issue and had misconceptions about condensation [13].

Concluding Comment

As a result, the following concise results can be presented about the nature of two easily observable critical processes such as evaporation and condensation and their spontaneity under atmospheric conditions:

Evaporation is an endothermic process, and although entropy decreases in the environment, it can occur spontaneously at any temperature under atmospheric conditions, since it is an entropy-controlled process. The decrease in the entropy of the environment is compensated by the enormous disorder or entropy increase that occurs in the system due to the gas transition and so the total entropy is positive.

The endothermicity of the evaporation should also be conceived as heat flow from the environment as a result of the relative decrease in the temperature of the system itself parallel to the transition to the highly disordered gas phase, otherwise, the heat flow from the environment to the system may create a paradoxical situation, especially at low temperatures.

The fact that heat can only flow spontaneously from the high-temperature zone to the low-temperature zone is a consequence of the second law of thermodynamics.

Condensation is an exothermic process that can occur spontaneously, at the expense of a decrease in the entropy of the system, but with an increase in the entropy of the environment and with temperature control under atmospheric conditions. The spontaneity of the process is dependent on the increase in entropy that can occur with the heat flow to the environment at low temperature to compensate for the decrease in the entropy of the system so that the total entropy can be positive.

Experience and observations show that learners generally think that "since evaporation happens spontaneously at every temperature, so condensation must occur spontaneously at every temperature". The emergence of this misconception is the result of overgeneralization in relation to the fact that in equilibrium, the system's tendencies and velocities of evaporation and condensation will be equal so that the chemical potentials are equal.

The correction of this misconception is undoubtedly dependent on the clarification of the realization conditions of both processes by the correct use of thermodynamic principles and related functions.

It can be argued that the approach developed in this study can be useful as a complementary or auxiliary tool or conceptual change material in the teaching of thermodynamic concepts such as enthalpy, entropy, chemical potential heat, and the concept of spontaneity, as well as providing solutions to this specific conceptual learning problem.

Compliance with Ethical Standards

There is no conflict of interest to disclose.

Conflict of Interest

The author(s) declares no known competing financial interests or personal relationships.

References

1. Bird, R.B.; Stewart, W.E.; Lightfoot, E.N. *Transport phenomena*; ohn Wiley and Sons, Inc.: New York, 1960;
2. Ghiaasiaan, S.M. *Two-Phase Flow, Boiling and Condensation*; Cambridge University Press: Cambridge, 2007; ISBN 9780511619410.
3. Gurses, A.; Ejder-Korucu, M. A View from the Conservation of Energy to Chemical Thermodynamic. In *Thermodynamics - Fundamentals and Its Application in Science*; InTech, 2012.
4. Bénet, J.-C.; Ouoba, S.; Ouedraogo, F.; Cherblanc, F. Experimental study of water evaporation rate, at the surface of aqueous solution, under the effect of a discontinuity of chemical potential – Effect of water activity and air pressure. *Experimental Thermal and Fluid Science* **2021**, *121*, 110233, doi:10.1016/j.expthermflusci.2020.110233.
5. Atkins, P.W. *Physical chemistry*; Oxford University Press: Oxford, 1998; ISBN 0198501021.
6. Cipolla, J.W.; Lang, H.; Loyalka, S.K. Kinetic theory of condensation and evaporation. II. *The Journal of Chemical Physics* **1974**, *61*, 69–77, doi:10.1063/1.1681672.
7. Young, J.B. The condensation and evaporation of liquid droplets in a pure vapour at arbitrary Knudsen number. *International Journal of Heat and Mass Transfer* **1991**, *34*, 1649–1661, doi:10.1016/0017-9310(91)90143-3.
8. Baker, L.E.; Pierce, A.C.; Luks, K.D. Gibbs Energy Analysis of Phase Equilibria. *Society of Petroleum Engineers Journal* **1982**, *22*, 731–742, doi:10.2118/9806-PA.
9. Osborne, R.J.; Cosgrove, M.M. Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching* **1983**, *20*, 825–838, doi:10.1002/tea.3660200905.
10. Gopal, H.; Kleinsmidt, J.; Case, J.; Musonge, P. An investigation of tertiary students' understanding of evaporation, condensation and vapour pressure. *International Journal of Science Education* **2004**, *26*, 1597–1620, doi:10.1080/09500690410001673829.
11. Chang, J.-Y. Teachers college students' conceptions about evaporation, condensation, and boiling. *Science Education* **1999**, *83*, 511–526, doi:10.1002/(SICI)1098-237X(199909)83:5<511::AID-SCE1>3.0.CO;2-E.
12. Canpolat, N. Turkish Undergraduates' Misconceptions of Evaporation, Evaporation Rate, and Vapour Pressure. *International Journal of Science Education* **2006**, *28*, 1757–1770, doi:10.1080/09500690600779957.
13. Boz, Y. Second Level Primary Education And Secondary Education Students' Misconceptions About The Condensation Concept. *Hacettepe University Journal of Education* **2005**, *28*, 48–54.