

## Chapter 5. Chemical potential and Gibbs distribution

### 1 Chemical potential

So far we have only considered systems in contact that are allowed to exchange “heat”, *i.e.* systems in thermal contact with one another. In this chapter we consider systems that can also exchange particles with one another, *i.e.* systems that are in *diffusive* contact.

Consider 2 systems  $\mathcal{S}_1$  and  $\mathcal{S}_2$  that are in diffusive contact with one another and in thermal contact with a 3rd system, a reservoir at temperature  $\tau$ . We have shown that the Helmholtz free energy for the combined system  $\mathcal{S}_1 + \mathcal{S}_2$  will be a minimum when it is in equilibrium with the reservoir. We must therefore minimise

$$F = F_1 + F_2$$

with respect to the distribution of the particles between  $\mathcal{S}_1$  and  $\mathcal{S}_2$  to find the equilibrium state of this combined system. The total number of particles in the system is fixed, so that

$$dF = \left( \frac{\partial F_1}{\partial N_1} \right)_{\tau} dN_1 - \left( \frac{\partial F_2}{\partial N_2} \right)_{\tau} dN_1 = 0$$

in equilibrium, *i.e.*

$$\left( \frac{\partial F_1}{\partial N_1} \right)_{\tau} = \left( \frac{\partial F_2}{\partial N_2} \right)_{\tau}.$$

The quantity

$$\mu(\tau, V, N) = \left( \frac{\partial F}{\partial N} \right)_{\tau, V}$$

is known as the *chemical potential*, so that our equilibrium condition is that

$$\mu_1 = \mu_2.$$

Inspecting the expression for  $dF$ , we see that when  $\mu_1 > \mu_2$  moving particles from  $\mathcal{S}_1$  to  $\mathcal{S}_2$  decreases  $F$ , taking the system closer to equilibrium. Thus, particles tend to flow from systems of high chemical potential to systems of lower chemical potential.  $\mu$  is the (Helmholtz) free energy “per particle” in a system.

If several chemical species are present within a system, then there is chemical potential associated with each distinct species, *e.g.*

$$\mu_j = \left( \frac{\partial F}{\partial N_j} \right)_{\tau, V, N_1, N_2, \dots}$$

is the chemical potential for species  $j$ .

#### 1.1 Example: the ideal gas

In chapter 3 we showed that the Helmholtz free energy of an ideal monatomic gas is

$$F = -N\tau \ln(n_Q V) + N\tau \ln N - N\tau,$$

so that

$$\mu = -\tau \ln(n_Q V) + \tau \ln N = \tau \ln \left( \frac{n}{n_Q} \right).$$

# Chapter 5 Chemical Potential And Gibbs Distribution 1

**Herbert Spencer Harned, Benton  
Brooks Owen**



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*Thermal Physics* Charles Kittel, Herbert Kroemer, 1980-01-15 CONGRATULATIONS TO HERBERT KROEMER 2000 NOBEL LAUREATE FOR PHYSICS For upper division courses in thermodynamics or statistical mechanics Kittel and Kroemer offers a modern approach to thermal physics that is based on the idea that all physical systems can be described in terms of their discrete quantum states rather than drawing on 19th century classical mechanics concepts Biochemical Energetics and Kinetics Alva Rae Patton, 1965 **The Physical Chemistry of Electrolytic Solutions** Herbert Spencer Harned, Benton Brooks Owen, 1943 **Phase Equilibria in Chemical Engineering** Stanley M. Walas, 1985 Macromolecules, Volume 3 Hans-Georg Elias, 2005 Providing a broad survey of the entire field Macromolecules integrates representations of chemistry physics and technology as well as including precise descriptions of basic phenomena and balanced treatments of facts and theory Physical Chemistry Johannes Nicolaus Brønsted, 1938 Macromolecules · 1 Hans-Georg Elias, 1984-02-29 The second edition of this textbook is identical with its fourth German edition and it thus has the same goals precise definition of basic phenomena a broad survey of the whole field integrated representation of chemistry physics and technology and a balanced treatment of facts and comprehension The book thus intends to bridge the gap between the often oversimplified introductory textbooks and the highly specialized texts and monographs that cover only parts of macromolecular science The text intends to survey the whole field of macromolecular science Its organization results from the following considerations The chemical structure of macromolecular compounds should be independent of the method of synthesis at least in the ideal case Part I is thus concerned with the chemical and physical structure of polymers Properties depend on structure Solution properties are thus discussed in Part II solid state properties in Part III There are other reasons for discussing properties before synthesis For example it is difficult to understand equilibrium polymerization without knowledge of solution thermodynamics the gel effect without knowledge of the glass transition temperature etc Part IV treats the principles of macromolecular syntheses and reactions Separation and Preconcentration Methods in Inorganic Trace Analysis Jerzy Minczewski, Jadwiga Chwastowska, Rajmund Dybczyński, 1982 **Progress in Liquid Physics** Clive Anthony Croxton, 1978 **Principles of General Physiology: General physiology** Leonard Ernest Bayliss, 1959 Macromolecules H.G. Elias, 1984-05-31 The second edition of this textbook is identical with its fourth German edition and it thus has the same goals precise definition of basic phenomena a broad survey of the whole field integrated representation of chemistry physics and technology and a balanced treatment of facts and comprehension The book thus intends to bridge the gap between the often oversimplified introductory textbooks and the highly specialized texts and monographs that cover only parts of macromolecular science The text intends to survey the whole field of macromolecular science Its organization results from the following considerations The chemical structure of macromolecular compounds should be independent of the method of synthesis at least in the ideal case Part I is thus concerned with the chemical and physical structure of polymers Properties

depend on structure Solution properties are thus discussed in Part II solid state properties in Part III There are other reasons for discussing properties before synthesis For example it is difficult to understand equilibrium polymerization without knowledge of solution thermodynamics the gel effect without knowledge of the glass transition temperature etc Part IV treats the principles of macromolecular syntheses and reactions Fundamentals of Interface and Colloid Science J. Lyklema,1991

This volume sets out the physical chemical concepts behind interface and colloid science **Separation Process Principles** J. D. Seader, Ernest J. Henley, D. Keith Roper, 2016-01-11 Separation Process Principles with Applications Using Process Simulator 4th Edition is the most comprehensive and up to date treatment of the major separation operations in the chemical industry The 4th edition focuses on using process simulators to design separation processes and prepares readers for professional practice Completely rewritten to enhance clarity this fourth edition provides engineers with a strong understanding of the field With the help of an additional co author the text presents new information on bioseparations throughout the chapters A new chapter on mechanical separations covers settling filtration and centrifugation including mechanical separations in biotechnology and cell lysis Boxes help highlight fundamental equations Numerous new examples and exercises are integrated throughout as well Comparative Morphology and Behavior Norman R. Joseph, 1979

**Chemical Thermodynamics of Solid Solutions of Interest in Radioactive Waste Management** Organisation for Economic Co-operation and Development, 2007 This volume provides a state of the art report on the modelling of aqueous solid solution systems by the combined use of chemical thermodynamics and experimental and computational techniques These systems are ubiquitous in nature and therefore intrinsic to the understanding and quantification of radionuclide containment and retardation processes present in geological repositories of radioactive waste The various approaches are illustrated with case studies from the literature **The Chemical Engineer**, 2001 *Physics Briefs*, 1989

**Engineering Thermodynamics** Murlin T. Howerton, 1962 The Theory of the Photographic Process Thomas Howard James, 1977 *Introduction to Surface Chemistry and Catalysis* Gabor A. Somorjai, 1994-03-18 Among the topics covered are adhesion and tribological properties friction crack formation and lubrication

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