



Renjie Hua and Yuan Dong*

Revisit nonequilibrium thermodynamics based on thermomass theory and its applications in nanosystems

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Abstract: The development of non-Fourier heat conduction models is encouraged by the invalidity of Fourier's law to explain heat conduction in ultrafast or ultrasmall systems. The production of negative entropy will result from the combination of traditional nonequilibrium thermodynamics and non-Fourier heat conduction models. To resolve this paradox, extended irreversible thermodynamics (EIT) introduces a new state variable. However, real dynamics variables like force and momentum are still missing from nonequilibrium thermodynamics and EIT's generalized force and generalized flux. Heat has both mass and energy, according to thermomass theory and Einstein's mass-energy relation. The generalized heat conduction model containing non-Fourier effects was established by thermomass gas model. The thermomass theory reshapes the concept of the generalized force and flux, temperature, and entropy production in nonequilibrium thermodynamics and revisits the assumption for the linear regression of the fluctuations in Onsager reciprocal relation. The generalized heat conduction model based on thermomass theory has been used to study thermal conductivity, thermoelectric effect, and thermal rectification effect in nanosystems.

Keywords: non-Fourier heat conduction; nonequilibrium thermodynamics; extended irreversible thermodynamics; thermomass theory; generalized heat conduction model

1 Introduction

1.1 Local equilibrium thermodynamics

Equilibrium thermodynamics, developed in the 19th century, is concerned with the macroscopic properties of matter at near-equilibrium, but it only involves the initial and final equilibrium states and cannot describe the process itself. In 1931, Onsager [1] used fluctuation linear regression and the microscopic reversibility assumption to derive general reciprocity relationships that apply to transport processes like heat conduction, electrical conduction, and diffusion. In 1961, Prigogine [2], [3] discovered a dissipative system that operates in an environment with which it exchanges energy and matter, often far from thermodynamic equilibrium. These two pioneering works, along with a series of other developments [4], gave rise to local equilibrium thermodynamics, also known as classical irreversible thermodynamics (CIT).

In CIT, the entropy production obtains

$$\sigma^s = \sum_i J^s X^s \quad (1)$$

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Nonequilibrium Thermodynamics In Biophys

**Aharon Katzir-Katchalsky, Peter F.
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Biophysics C. Sybesma, 2012-12-06 Today courses on biophysics are taught in almost all universities in the world often in separate biophysics departments or divisions This reflects the enormous growth of the field even though the problem of its formal definition remains unsettled In spite of this lack of definition biophysics which can be considered as an amalgamation of the biological and the physical sciences is recognized as a major scientific activity that has led to spectacular developments in biology It has increased our knowledge of biological systems to such an extent that even industrial and commercial interests are now beginning to put their stamps on biological research A major part of these developments took place during the last two decades Therefore an introductory textbook on biophysics that was published a dozen years ago c Sybesma *An Introduction to Biophysics* Academic Press 1977 no longer could fulfil the need for a comprehensive but elementary textbook R Cammack *Nature* 272 1978 96 However because of the increased proliferation of biophysics into higher education the need for introductory course texts on biophysics is stronger than ever This fact together with valuable comments of many readers have encouraged me to revise the original book **Nonequilibrium Thermodynamics in Biophysics** Aharon Katzir Katchalsky, 1965 **General Biophysics** M Volkenstein, 2012-12-02 *General Biophysics Volume I* deals with the theoretical physics underlying biological phenomena and presents some pertinent experimental results It explores the molecular foundations of biophysics the thermodynamics of nonequilibrium systems and membrane transport nerve impulses and mechanochemical processes Comprised of five chapters this volume begins with an overview of molecular biophysics and the concept of molecular recognition followed by a discussion of the interaction between antibodies and antigens the primary processes that determine odor reception and the importance of intercellular interactions in the existence and development of multicellular organisms The next chapters explain how protein biosynthesis is regulated by molecules and how proteins are biosynthesized in eukaryotic cells along with the application of thermodynamics to the analysis of biophysical problems and the coupling of chemical reactions near equilibrium The reader is also introduced to the stability conditions of a steady state the concept of entropy for an open system the thermodynamics of the sodium pump ionic equilibrium between sodium and potassium solutions separated by an active membrane the conformational properties of membranes and the general phenomenological theory of facilitated transport and the role of the carriers The book concludes with a chapter on biological mechanochemical processes and their thermodynamics This book is a valuable resource for physicists and biophysicists graduate and postgraduate students having the necessary knowledge of physics and anyone

acquainted with proteins and nucleic acids Introduction to Modern Biophysics Mohammad Ashrafuzzaman, 2023-12-15

This textbook provides an introduction to the fundamental and applied aspects of biophysics for advanced undergraduate and graduate students of physics chemistry and biology The application of physics principles and techniques in exploring biological systems has long been a tradition in scientific research Biological systems hold naturally inbuilt physical principles and processes which are popularly explored Systematic discoveries help us understand the structures and functions of individual biomolecules biomolecular systems cells organelles tissues and even the physiological systems of animals and plants Utilizing a physics based scientific understanding of biological systems to explore disease is at the forefront of applied scientific research This textbook covers key breakthroughs in biophysics whilst looking ahead to future horizons and directions of research It contains models based on both classical and quantum mechanical treatments of biological systems It explores diseases related to physical alterations in biomolecular structures and organizations alongside drug discovery strategies It also discusses the cutting edge applications of nanotechnologies in manipulating nanoprocesses in biological systems

Key Features Presents an accessible introduction to how physics principles and techniques can be used to understand biological and biochemical systems Addresses natural processes mutations and their purposeful manipulation Lays the groundwork for vitally important natural scientific technological and medical advances

Mohammad Ashrafuzzaman a biophysicist and condensed matter scientist is passionate about investigating biological and biochemical processes utilizing physics principles and techniques He is a professor of biophysics at King Saud University s Biochemistry Department in the College of Science Riyadh Saudi Arabia the co founder of MDT Canada Inc and the founder of Child Life Development Institute Edmonton Canada He has authored *Biophysics and Nanotechnology of Ion Channels* *Nanoscale Biophysics of the Cell and Membrane Biophysics* He has also published about 50 peer reviewed articles and several patents edited two books and has been serving on the editorial boards of Elsevier and Bentham Science journals Dr Ashrafuzzaman has held research and academic ranks at Bangladesh University of Engineering Technology University of Neuchatel Switzerland Helsinki University of Technology Finland Weill Medical College of Cornell University USA and University of Alberta Canada During 2013 2018 he also served as a Visiting Professor at the Departments of Oncology and Medical Microbiology and Immunology of the University of Alberta Dr Ashrafuzzaman earned his highest academic degree Doctor of Science D Sc in condensed matter physics from the University of Neuchatel Switzerland in 2004

Thermodynamics of Non-Equilibrium Processes for Chemists with a Particular Application to Catalysis V. Parmon, 2009-09-26

Thermodynamics of Non Equilibrium Processes for Chemists with a Particular Application to Catalysis consists of materials adapted from lectures on the thermodynamics of nonequilibrium processes that have been taught at the Department of Natural Sciences of Novosibirsk State University since 1995 The thermodynamics of nonequilibrium processes traditionally required students to have a strong background in physics However the materials featured in this volume allow anyone with knowledge in classical thermodynamics of

equilibrium processes and traditional chemical kinetics to understand the subject Topics discussed include systems in the thermodynamics of irreversible processes thermodynamics of systems that are close to and far from equilibrium thermodynamics of catalysts the application of nonequilibrium thermodynamics to material science and the relationship between entropy and information This book will be helpful for research into complex chemical transformations particularly catalytic transformations Applies simple approaches of non equilibrium thermodynamics to analyzing properties of chemically reactive systems Covers systems far from equilibrium allowing the consideration of most chemically reactive systems of a chemical or biological nature This approach resolves many complicated problems in the teaching of chemical kinetics

Biophysics Roland Glaser, 2004-10-22 Biophysics is the science of physical principles underlying the phenomenon of life on all levels of organization This book begins by explaining molecular and ionic interactions movements excitation and energy transfer and the self organization of supramolecular structures Then the biological organism is introduced as a non equilibrium system Finally system analyses are discussed as well as environmental biophysics ecological interactions growth differentiation and evolution A growing number of applications in biotechnology are based on these biophysical concepts

Biophysics W. Hoppe, W. Lohmann, H. Markl, H. Ziegler, 2012-12-06 What is biophysics As with all subjects which straddle traditional boundaries between fields it eludes a precise definition Furthermore it is impossible to do biophysics without having a certain foundation of knowledge in biology physics physical chemistry chemistry and biochemistry One approach to a biophysics textbook would be to refer the student to the literature of these neighboring fields and to leave the selection of the appropriate supplementary material up to the student The editors of this volume are of the opinion that it is more useful and less time consuming to present a selection of the supplementary knowledge in concentrated form together with the subject matter specific to biophysics The reader will thus find in this book introductions to such subjects as the structure and function of the cell the chemical structure of biogenic macromolecules and even theoretical chemistry What indeed is biophysics Must we consider it to include physiology electromedicine radiation medicine etc The field has evolved continuously in recent years Molecular understanding of life processes has come more and more to the fore Just as the field of molecular physics has developed to describe structures and processes in the realm of non living systems there has been a corresponding development of molecular biophysics

Biophysics and Other Topics Aharon Katzir-Katchalsky, 2013-10-22 Biophysics and Other Topics Selected Papers by Aharon Katzir Katchalsky covers papers on polyelectrolytes mechanochemistry irreversible thermodynamics membrane processes network thermodynamics biophysics and science and humanities The book discusses on polyelectrolytes the electrostatic potential thermodynamic properties interaction with small molecules and ions and cooperative transitions The text also describes mechanochemistry dynamics of macromolecular interactions hysteresis and memory Irreversible thermodynamics theory of membrane processes and network thermodynamics are also considered The book further tackles the reactions of amino acids with aldoses polypeptide

synthesis and prebiotic synthesis The text then encompasses topics on surface activity of polyelectrolytes properties of the red cell membrane and science and the humanities People involved in the study of the above mentioned topics will find the book invaluable *Bioenergetics and Linear Nonequilibrium Thermodynamics* S. Roy Caplan, Alvin Essig, 1983 No

description is available at this time **Thermodynamic Network Analysis of Biological Systems** J.

Schnakenberg, 2012-12-06 This book is devoted to the question What fundamental ideas and concepts can physics contribute to the analysis of complex systems like those in biology and ecology The book originated from two lectures which I gave during the winter term 1974/75 and the summer term 1976 at the Rheinisch Westfälische Technische Hochschule in Aachen The wish for a lecture with this kind of subject was brought forward by students of physics as well as by those from other disciplines like biology physiology and engineering sciences The students of physics were looking for ways which might lead them from their monodisciplinary studies into the interdisciplinary field between physics and life sciences The students from the other disciplines suspected that there might be helpful physical concepts and ideas for the analysis of complex systems they ought to become acquainted with It is clear that a lecture or a book which tries to realize the expectations of both these groups will meet with difficulties arising from the different trainings and background knowledge of physicists and nonphysicists For the physicists I have tried to give a brief description of the biological aspect and significance of a problem wherever it seems necessary and appropriate and as far as a physicist like me feels authorized to do so Biophysics

Patrick F. Dillon, 2012-01-19 They are each directed toward the understanding of a biological principle with a particular emphasis on human biology Journal of Non-equilibrium Thermodynamics, 1989 *Biophysical Thermodynamics of*

Intracellular Processes Lev A. Blumenfeld, Alexander N. Tikhonov, 2012-12-06 This book is aimed at a large audience from students who have a high school background in physics mathematics chemistry and biology to scientists working in the fields of biophysics and biochemistry The main aim of this book is to attempt to describe in terms of physical chemistry and chemical physics the peculiar features of machines having molecular dimensions which play a crucial role in the most important biological processes viz energy transduction and enzyme catalysis One of the purposes of this book is to analyze the physical background of the high efficiency of molecular machines functioning in the living cell This book begins with a brief review of the subject Chapter 1 Macromolecular energy transducing complexes operate with thermal chemical and mechanical energy therefore the appropriate framework to discuss the functioning of biopolymers comes from thermodynamics and chemical kinetics That is why we start our analysis with a consideration of the conventional approaches of thermodynamics and classical chemical kinetics and their application to the description of bioenergetic processes Chapter 2 Critical analysis of these approaches has led us to the conclusion that the conventional approaches of physical chemistry to the description of the functioning of individual macromolecular devices in many cases appear to be incomplete This prompted us to consider the general principles of living machinery from another point of view Biophysical Chemistry Peter R. Bergethon, Elizabeth

R. Simons, 2012-12-06 Biophysical Chemistry Molecules to Membranes is a one semester textbook for graduate and senior undergraduate students. Developed over several years of teaching the approach differs from that of other texts by emphasizing thermodynamics of aqueous solutions by rigorously treating electrostatics and irreversible phenomena and by applying these principles to topics of biochemistry and biophysics. The main sections are 1 Basic principles of equilibrium thermodynamics 2 Structure and behavior of solutions of ions and molecules. The discussions range from properties of bulk water to the solvent structure of solutions of small molecules and macromolecules 3 Physical principles are extended for the non homogenous and non equilibrium nature of biological processes. Areas included are lipid water systems transport phenomena membranes and bio electrochemistry. This new textbook will provide an essential foundation for research in cellular physiology biochemistry membrane biology as well as the derived areas bioengineering pharmacology nephrology and many others. Membrane Biophysics: As Viewed from Experimental Bilayer Lipid Membranes H.T. Tien †, A.

Ottova-Leitmannova, 2000-01-11 This book summarizes the current status of research on bilayer lipid membranes planar lipid bilayers and spherical liposomes. In addition to describing the properties of lipid bilayers and examining biomembrane phenomena the book has two other objectives. The first is to present practical methods for the formation and study of lipid bilayers with either aqueous or metal lipid bilayer interfaces. The second aim is to treat planar lipid bilayers as a new type of interfacial adsorption phenomena. The first nine chapters cover properties of biomembranes basic principles of membrane biophysics transport electrochemistry physiology bioenergetics and photobiology. Chapter 10 presents the following topics: lipid bilayers in medicine supported lipid bilayers as sensors a short discussion of liposomes and solar energy transduction via semiconductor septum photovoltaic cells based on natural photosynthesis.

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□ skor rata rata skor maksimal adalah 5 dan skor minimal adalah 1 maka berdasarkan konversi diperoleh klasifikasi penilaian perangkat pembelajaran seperti pada tabel 3 sebagai berikut tabel 3 pedoman kriteria kevalidan interval skor kriteria □ 4 2 sangat baik 3 4 □ q4 2 baik 2 6 □ q3 4 cukup 1 8 □ q2 6 kurang baik

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rumus □□ □ 2 1 pheasant 2003 hlm 18 dimana s d simpangan deviasi □ data pengukuran yang diambil persentile m nilai rata rata mean □ jumlah sampel e perhitungan bka dan bkb bka bkb wignjosoebroto 2015 hlm 31 f persentil nurmianto 2004 hlm 54 mengemukakan bahwa percentile adalah

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rumus rata rata sudjana 3 3 runtut waktu untuk proyeksi jangka pendek dan jangka panjang bagian ketiga menerangkan hal hal berkaitan dengan metode analisa regresi dan teknik pola time series yang terdiri dari metode analisa regresi serta teknik pola time series bagian keempat menguraikan hal hal yang berhubungan

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dalam skala interval atau rasio sering dideskripsikan dengan nilai rata rata mean atau total sementara itu dalam penentuan ukuran sampel melalui model pendekatan statistika terdapat rumus rumus yang berlainan untuk pengukuran rata rata total

maupun proporsi

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resmi gazete de yayımlanan kararname ile 01 01 2013 tarihinden sonra açılan hesaplar için tl ve döviz mevduat hesaplarında vadeye göre stopaj oranları farklılaştırılmıştır tl mevduatta stopaj oranları 6 aya kadar olan vadelerde 5 6 aydan 1 yıla kadar 1 yıl dahil olan vadeler için 3 1 yıldan uzun vadeler için ise

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sudjana 2002 66 69 menjelaskan data itu adalah menentukan rerata mean nilai sering muncul modus dan nilai tengah data median rumus data tersebut adalah rumus yang digunakan untuk mencari rata rata mean adalah sumber sudjana 2004 keterangan mean rerata jumlah nilaihasil jumlah datasampel menentukan nilai yang sering muncul

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a rata rata mean rata rata digunakan untuk mencari nilai rata rata dari keseluruhan sampel yang ada dalam keseluruhan data yang akan dianalisis □ □ □ sudjana 2013 keterangan □ rata rata j □ □ jumlah keseluruhan data x □ banyaknya data b modus

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menggunakan rumus berikut banyaknya peserta didik rumus rata rata hitung dimodifikasi dari sudjana 2005 dari 70 nilai tes hasil belajar thb dan keterangan 30 nilai pengerjaan lkpd kemudian hasil rata rata skor aktivitas peserta didik dari pengamat ke i

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cara menghitung rata rata hasil belajar matematika dengan rumus sudjana 2005 67 keterangan nilai rata rata hasil belajar matematika siswa banyaknya subjek jumlah nilai seluruh siswa adapun untuk menentukan varians nantinya akan disusun terlebih dahulu dalam tabel distribusi frekuensi

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rumus rata rata diadaptasi dari sudjana 1975 keterangan $\bar{x}$ skor rata rata praktikalitas $\bar{y}$ skor rata rata praktikalitas peserta didik ke $\bar{z}$ banyak peserta didik 5 kemudian hasil dari skor rata rata kepraktisan yang dinilai oleh guru dan peserta didik tersebut

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sudjana 1996 metoda statistika bandung tarsito bandung banyak uji t digunakan dengan rumus seandainya ada empat rata rata n 4 maka banyak uji t dilakukan adalah sebelum uji kesamaan beberapa rata rata dilakukan maka persyaratannya haruslah dipenuhi terlebih dahulu persyaratan uji beberapa rata rata sama halnya

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3 1 objek penelitian menurut sugiyono 2014 2 menyatakan objek penelitian adalah sebagai berikut objek penelitian sasaran ilmiah untuk mendapatkan data dengan tujuan dan kegunaan tertentu tentang sesuatu hal objektif valid dan reliable tentang suatu hal variable tertentu

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menentukan rata rata simpangan simpangan baku varians bilangan baku t bilangan baku z dan koefisien variasi dari sekumpulan data yang diberikan memahami arti korelasi dan kaitannya dengan ramalan menghitung koefisien korelasi untuk sekelompok data dengan cara produk momen pearson data tidak tersusun dan data tersusun kegiatan belajar

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yang diberikan oleh penilai kemudian rata rata perolehan skor kepraktisan olehh masing masing penilai dengan menggunakan rumus berikut k rumus rata rata hitung diadaptasi dari sudjana 2005 bengkulu yaitu ibu velysa astari s pd dan keterangan ibu alin suhermi s pd kepraktisan oleh siswa rata rata skor kepraktisan oleh

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b rata rata untuk menghitung rata rata digunakan rumus berikut $\bar{x} = \frac{\sum f_i x_i}{\sum f_i}$ sudjana 2016 67 keterangan x mean rata rata x i jumlah nilai uji f i jumlah frekuensi untuk nilai x i yang bersesuaian c variasi untuk menghitung variasi digunakan rumus berikut $s^2 = \frac{\sum f_i x_i^2}{n} - \bar{x}^2$ sudjana 2016 95

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selanjutnya ialah menghitung nilai rata rata kelas untuk mengetahui hasil tes siswa secara keseluruhan berikut rumus menghitung rata rata sudjana 2011 hlm x nilai rata rata $\bar{x} = \frac{\sum x}{n}$ jumlah seluruh nilai siswa jumlah siswa presentase ketuntasan

belajar siswa yang diperoleh dari sudjana 2011 hlm 109

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 $\bar{a}$ percepatan rata rata t waktu v kecepatan benda dari rumus tersebut nantinya dapat diketahui bahwa jika percepatan positif maka benda mengalami percepatan yang searah dengan gerak benda

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