Entransy

Entransy:

An Alternative Perspective on Thermal Phenomena

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Cambridge
Scholars
Publishing

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This book first published 2023

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN (10): 1-5275-1273-8
ISBN (13): 978-1-5275-1273-3

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ACKNOWLEDGMENTS

This book is dedicated to my lost days in the past two decades.

When I was alone during that period of unforgettable time, I often recited a Chinese poem with a cadence:

"All waves in all oceans have the same essence;
All knowledge of all disciplines has the same source;
When Confucius got confused about etiquette,
He went to consult Lao-tzu several times."

After thousands of years of searching for the truth, we may obtain grand unified theories that can explain all phenomena in the universe. After decades of pursuing the truth of life, we may return to the original dream that can give us the most real and perfect happiness.

The lost days are not really lost. This is because the difficult and painful process of pursuing the truth of life in the days itself is also a kind of harvest.

PREFACE

There is a story named “blind man touching an elephant”, which is very well-known and tells us that we may have different viewpoints or even wrong conclusions when observing the same thing from different angles. Therefore, we should not be surprised at the different viewpoints of other people, let alone be impatient to express our opposition. On the contrary, it is helpful for getting a correct and comprehensive understanding of the world and promoting the development and progress of science and technology by treating different viewpoints with an open attitude and taking them carefully and seriously. Whether for one individual or for all people, it is always a wonderful experience to feel that we are correct today but were wrong yesterday in the process of finding the truth.

However, to say is one thing, to do is another, especially for the objective, scientific and rational attitude to different viewpoints. This is true for anyone, and is especially true for the whole society. For this reason, a new idea, concept or theory often has to go through a long and difficult process from its birth to wide acceptance, and a lot of cost would be paid. Of course, new ideas, concepts or theories are not necessarily correct. Hence, more discussions, questions and even criticisms are often not all harmful to their developments, but beneficial in most cases. Obviously, every correct understanding of the world is never free.

In this book, the author introduces an alternative perspective to recognize and understand thermal phenomena, the concept of entransy and its relevant principles, applications, discussions and extensions. The entransy concept was proposed based on two analogies about two

decades ago, which are the analogy between heat and electric conductions and the analogy between heating a solid body and charging a capacitor. At present, rich contents have been developed for the concept, and a theory named entransy theory has gradually been obtained and widely used in the analyses and optimizations of various thermal processes, including conductive heat transfer, convective heat transfer, radiative heat transfer, thermodynamic cycle, heat pump systems, etc. With the theory, many practical problems have been solved successfully, and its important scientific significance and application value have been clearly demonstrated. Certainly, the theory is also inevitably questioned, and there are even abnormal criticisms and accusations that are not real academic discussions. This may be the baptism that must be experienced before the theory can be more widely accepted.

As the contents of the entransy theory are very rich, the author does not intend to introduce every aspect of the theory in a comprehensive and detailed way, but only briefly introduces the main parts in this book. Therefore, the present book can only be an introductory one for the entransy theory. The derivations of some important principles are slightly more detailed, but generally speaking, they are still very simplified. Especially with regard to the applications, the author has only selected a few cases that are sufficient to show the advantages and necessity for the application of the theory.

The author hopes to give readers a general impression of the entransy theory through this short book. If someone is interested in a certain part, he or she can refer to the corresponding literature cited in the book and other relevant academic papers. Although the author has studied and worked in the entransy theory for about seventeen years, his level is still limited, and his understanding of the theory and thermal science is also insufficient. Therefore, it is never surprising if there are problems or even mistakes in the book, and it is hoped that the readers would not be hesitated to give their suggestions and corrections.

The author would be very satisfied if this book could be helpful to the undergraduates, graduates, teachers, engineers, scientists and researchers in thermal science and engineering.

CHAPTER ONE

INTRODUCTION

Part I About understanding the world

The world we live in is comprehensible, and people are always curious about the unknown things in this beautiful and wonderful world. In order to understand these unknown things, the human beings have made great efforts over thousands of years, gone through a long and tortuous course, and obtained proud achievements[1] that are bound to deepen their understandings.

However, when we look back at the history of our understandings of the world, perhaps we would feel that the past understandings are very childish, shallow and even ridiculous. For instance, in history, almost all people have tried to understand the world with myths and supernatural power. There are stories in which gods created the world and every creature including human beings in almost all human civilizations. In this kind of world outlook, thunder and rain may depend on some gods, the rise and fall of a country may also be determined by the gods, and even the destiny of every person could be controlled by the gods. However, such understandings cannot satisfy the people who are rebellious and unyielding to the gods. As early as more than 2000 years

[1] a) Zhang J. 2012. "Translation and Annotation of Xunzi (in Chinese)." Shanghai Classics Publishing House, Shanghai, China.
b) Halton B. 2017. "Science, truth, and practice." *Fire Eng*, 7: 8.
c) Planck M. 1949. "Scientific Autobiography and Other Papers." Philosophical Library, New York, USA.
d) Yang B J. 2017. "Translation and Annotation of Analects (in Chinese)." Zhonghua Book Company, Beijing, China.

ago, Xunzi, a pre-Qin philosopher in ancient China, gave the famous saying, "*The world works in its own way, not for Yao, not for Jie*"[1a], in which Yao is a famous wise monarch in ancient Chinese legend, while Jie is a well-known fatuous monarch in Xia dynasty of China. Considering the background of the time for the people like Xunzi, we can see that they had respectable great courage to face the universe directly without relying on gods. No matter how rough their understandings of the world are, such as that the sky was round and the earth was square, we should never underestimate them. This is because these people are the heroes who opened the door to truth. Their understandings of the world may be preliminary or even wrong, but they are still towering figures in the history of human civilization.

Along the way to truth, we can observe that the world may be different in different times and from different viewpoints. The world in the eyes of Aristotle, Galileo, Newton and Einstein must be very different. When facing a snow mountain, meteorologists may think about the change of climate, biologists may consider the survival of species, physicists may analyze the structure of ice and snow, and anthropologists may be concerned about the amount of pollen and other substances in ice samples. If what we research is a person or a group of people, psychologists and sociologists would also express their different considerations.

In general, as time goes on, we still have reason to believe that the progress of science and technology makes the world we know closer to its true colors, although we still have many unsettled questions and will have even more questions in the future. In the development of science and technology, various theories have been put forward and constantly faced with the test of practice. For any scientific theory, it is clear that we cannot fully verify it. As Karl Popper said, "*The game of science is, in principle, without end. He, who decides one day that scientific statements do not call for further test, and that they can be regarded as*

finally verified, retires from the game."[1b] As long as a theory is a still scientific theory rather than a theological theory, it cannot be retired from the game. It should either continue to face the test of one observational fact after another, or it should be falsified or corrected even if its prediction is inconsistent with only one observational fact. Therefore, thousands of observational facts that are consistent with Newton's gravitational theory are not enough to fully prove its correctness. It is very well known that the theory has some intrinsic difficulties, such as the non-Lorentz covariant of the gravitational field, the orbital precession of Mercury, etc., which lead to the Waterloo of the theory. Similarly, Aristotle's viewpoint that heavy objects landed faster than light objects was falsified by Galileo's experiment with the Leaning Tower of Pisa, and the geocentric theory and the hollow earth theory were also falsified. Such stories are very common in almost every period of time in every discipline.

Sometimes, scientific controversies seem far away from the life of a common person. However, in fact, the understanding of the world directly affects our reaction to what is happening in the world, as well as the progress of science and technology, so it will affect our lives sooner or later. For instance, the study of viruses seems to be a matter for scientists and researchers, and there are different academic conclusions about the COVID-19[2]. The group of Zhang Wenhong, a doctor specializing

[2] a) Ma X, Ai J W, Cai J P, et al. 2022. "Dynamic disease manifestations among non-severe COVID-19 patients without unstable medical conditions: A follow-up study-Shanghai municipality, China, March 22-May 03, 2022." *China CDC Weekly* 4: ps1-ps6. (This paper has been withdrawn for some reason.)
b) Lu G, Ling Y, Jiang M H, et al. 2023. "Primary assessment of the diversity of Omicron sublineages and the epidemiologic features of autumn/winter 2022 COVID-19 wave in Chinese mainland." *Front Med*, DOI: 10.1007/s11684-022-0981-7.
c) Zheng H, Cao Y L, Chen X S, et al. 2022. "Disease profile and plasma neutralizing activity of post-vaccination Omicron BA.1 infection in Tianjin, China: a retrospective study." *Cell Res* 32: 781-784.

in liver disease in Huashan Hospital, analyzed 33,816 SARS-CoV-2 positive participants in Shanghai from March 22 to May 03, 2022, and obtained some incredible results, including the declarations that 76.2% and 78.6% of participants were ultimately diagnosed with asymptomatic infection in the risk group and the non-risk group, respectively, only 4% of the participants have fever symptom, and severity rates among all subjects and risk-group subjects were only 0.065% and 0.238%, respectively[2a]. Zhang Wenhong even stated that the symptoms of COVID-19 infection were similar to those of influenza, and it was not necessary to go to hospital at all. These absurd results and claims not only conflict with the other research conclusions, but also differ greatly from the observational facts. For instance, Chen Saijuan group[2b] found that the severity rate was 3.03% in their research, while a report from Tianjin showed that there are only 7 asymptomatic infections in 430 patients[2c]. There are many other unscientific declarations and suggestions about the COVID-19 from Zhang Wenhong during the past three years, which can be easily found on the internet[3]. However, the completely unreliable data and conclusions from Zhang Wenhong group have been widely disseminated because Zhang Wenhong seemed not a doctor, but an internet celebrity that often participated in social activities and accepted media interviews very frequently. This made the public greatly underestimate the harmfulness from the Omicron virus, finally suffer a lot and impose a great cost. Obviously, we should firmly remember these lessons, and some ones should be doomed to be nailed in the history of shame. Therefore, it is never bad news for scientific theories and the people in the world that the theories and researches are facing doubts and challenges. Only with the doubts and challenges, wrong viewpoints and results can be cleared out, the theories have the

[3] a) https://zhuanlan.zhihu.com/p/594850501.
b) https://www.zhihu.com/question/388618128/answer/2060075586.

opportunity to be improved, new theories may be developed, our understandings of the world have the opportunity to get closer to the reality, and our lives may become better.

However, we do not mean that the understandings of the world in every historical stage are more accurate than those of the previous stages. History may be developing in a spiral way. In a specific period of time, it is entirely possible for human beings to take two steps back before taking three steps forward. Historically, the heliocentric theory was denied, as were the particle nature of light and the existence of atoms. Hence, the questioning spirit is very important. This is because there may be a huge fallacy, or even a complete mistake, in a theory that is widely accepted and applied.

At the same time, we should also maintain an inclusive and open attitude towards the newly proposed ideas, concepts and theories. Before proposing the new things, there are always some problems, new observational facts or new physical phenomena that cannot be solved or explained after numerous attempts with the existing theories and methods. Therefore, scientists and researchers have to muster up courage to break the old theoretical framework and make new attempts. When a new idea, concept or theory is proposed, the first ones that should be persuaded are the proposers themselves. This is never easy for serious scientists and researchers. Meanwhile, it is very difficult for people to accept new things because they are always accustomed to the way of thinking formed under the existing theories, especially for those who have made important achievements with the existing approaches. In the process of accepting the new things, people have to update a lot of knowledge, change their way of thinking, and even comprehensively reassess their past work. This may not be the work that people are willing to take the initiative to complete. Correspondingly, many people always have enough reasons to oppose new things. In particular, the newly proposed ideas, concepts or theories are often not well-established

when they are first put forward, and there may be a lot to be improved. This also provides some reasons for the opponents to question or even deny the new things. Hence, whether the new idea, concept or theory is correct or not, it naturally faces a lot of challenges and development resistance. Many historical stories have told us that the traditional conservative forces shown in the maintenance of the existing theories are very powerful, and can often cause great obstacles to the growth and development of new things. However, we still should remember that being eager to shoot new things to death may delay us from obtaining the truth. In order to get a possible new understanding that is closer to the true colors of the world, we need to give new things enough development time and a tolerant growth environment.

A scientific theory may be derived from some basic assumptions or summarized from a large number of observational facts. No matter how the theory is obtained, it must have two major elements, namely, concept and logic. Concepts are the cornerstones of a scientific theory. With logic, the concepts can be expanded, and people can make inferential analysis and have the corresponding conclusions. Finally, we may have a knowledge system and form a scientific theory. Taking the well-known Newtonian mechanical theory as an example, we can see that its main content is to reveal the relationship between force and motion. In the theory, force, time, mass, displacement, velocity, acceleration, work, power, momentum, kinetic energy and potential energy are the main concepts, with which we can describe the state of an object and its motion, and obtain the mathematical relationship of these concepts through physical analyses and mathematical derivations. In electromagnetics, based on the concepts of current density, potential difference, resistance, charge, electric intensity, magnetic flux, etc., the laws and applications of electromagnetic phenomena can be described by physical analyses and mathematical expressions. Moreover, for the same kind of physical phenomena, the same conceptual system and logical inference rules give

a standard for discussing and analyzing the problems. With the same standard, people can talk to and understand each other, so as to avoid misunderstandings. These points are very obvious.

When a new theory is proposed, new concepts may sometimes be developed, which would often lead to new understandings of physical phenomena. These new understandings may be more in-depth and essential, thus giving us a chance to get closer to the true nature of the corresponding physical phenomena. For example, when we are hungry, we directly feel that we need “food”. But in fact, we may not need all the components of food. The part we take from the food is called “nutrient”, and the rest is discharged as residue. Furthermore, the explanation closer to the essence tells us that what we need is not “nutrients”, but “energy” to support life. Is this explanation essential enough? The answer is no. A more substantive explanation to the essence comes from the second law of thermodynamics, which tells us that what hungry people ingest into their bodies is actually “negative entropy” that is used to maintain a highly ordered life system. Is there any explanation closer to the essence? With the deepening of human understanding of the world, there should still be. In the above example, we have seen the four concepts of “food”, “nutrients”, “energy” and “negative entropy”. They are just answering the simple question: What do people need when they are hungry? We can note that each of the following three concepts does not simply deny the answers given by the previous ones, but they all answer the question more deeply and essentially. However, in scientific research and engineering, the problems we face are often much more complex. Therefore, when a new concept is proposed, which may help us understand the physical processes more essentially and solve the problems more conveniently, we should obviously welcome it. Moreover, if a new concept is useful on a specific problem, it should reveal something new. Therefore, we have reason to believe that more valuable results on more issues may be obtained with the new concept, and even a

new theory is hopeful to be developed. Of course, it does not mean that we can violate Occam's Rrazor, which points out that entities should not be multiplied unnecessarily. On the contrary, anyone who proposes a new concept must carefully demonstrate the necessity, physical significance and application value of this concept. Otherwise, how can the scientists, engineers and researchers in the scientific community accept it? If there were no sufficient and powerful demonstration, the new concept would naturally become the self entertainment of the proposer, and make no sense to the progress of science and technology, and eventually disappear in the torrent of scientific history.

Here, we should point out that a new scientific theory is not necessarily accompanied by the emergence of new concepts. For instance, we may obtain in-depth understandings of the internal mechanism of some physical processes with new research equipments, so as to develop new theories. We may also reveal the internal relationships of physical quantities in some physical processes using new mathematical tools. The scientific concepts themselves are highly abstract. Some physical quantities themselves are just functions of several other physical quantities, which are often used and finally summarized and abstracted, such as the dimensionless numbers in fluid mechanics. In this case, the scientific theory is ready-made, and the new concepts are just summarized and abstracted at proper time. Anyway, useful new concepts are very important and should be paid enough attention to. With their help, we may know more about the world we live in.

With the discussion about understanding the world above, we can see: First, the world is comprehensible, and human beings have made great efforts to develop many theories to make the world they know more and more close to the truth. Second, it is necessary to keep questioning and doubting in the development of science and technology. At the same time, we should keep an inclusive and open attitude towards new

theories, so as to obtain the possibility of a more essential understanding of the world. Third, the basic elements of scientific theory are concepts and logic. Useful new concepts may be expected to give birth to new scientific theories, which may help us to understand the world more deeply and should attract enough attention.

Part II About thermal science

Thermal phenomena are common in nature and our daily life. From clothing for keeping warm and cooking for eating to thermal power generation and central heating required for urban operation, from cars, ships and aircraft involved in personal travel to rockets and space stations involved in space exploration, thermal phenomena are very ubiquitous and can be found almost everywhere and every second. The development process for the understandings of thermal phenomena is also similar to those for other physical processes in general. There is not much particularity. And, understanding thermal phenomena accurately is never easy.

For instance, in the 17th and 18th centuries, the phlogiston theory about combustion was widely spread. According to this theory, fire was a material entity composed of numerous small and active particles. The particles could combine with other elements to form compounds. Meanwhile, they could also exist in the form of dissociation. If a large number of particles gathered together, they would form a flame. When these particles diffused in the atmosphere, they could give a feeling of heat. The element of fire composed of such particles was called “phlogiston”. This theory was finally overturned by the Oxygen Theory of Combustion proposed by A. L. Lavoisier based on his experiments in 1777. Now we all know that Lavoisier is right. The flame generated by burning the substances in the air is not due to the existence of phlogiston, but due to the luminous and exothermic oxidation reaction between the

substances and the oxygen.

In the late 18th century, the Caloric theory was developed. In this theory, heat is a kind of substance called caloric, which is a kind of massless gas. If an object absorbed caloric, its temperature would increase. The caloric would flow from an object with high temperature to that with low temperature, and could pass through the pores of solid or liquid. Now, we all know that this understanding is wrong. The essence of thermal phenomenon is not substance itself, but the movement of substance. In 1851, Kelvin clearly revealed the essence of thermal phenomenon in his book entitled *On the Dynamic Theory of Heat*, and pointed out that there must be an equal relationship between mechanical work and heat. However, the Caloric theory is not completely unhelpful. For instance, there is caloric in Dalton's gas molecular model. Based on the Caloric theory, Carnot proposed the Carnot cycle and related laws, forming the basis of heat engine theory.

In 1877, Boltzmann derived the famous Boltzmann Entropy Formula based on the existence of molecules and atoms. Today, we all know the significance of this achievement. However, Boltzmann was strongly criticized by many scientists including F. W. Ostwald, who firmly denied the existence of atoms and molecules and insisted on the energetics. Until 1909, Ostwald finally admitted that he was wrong. However, the debates had already damaged the physical and mental health of Boltzmann to some extent, and even made him try to commit suicide twice[4]. On September 5, 1906, Boltzmann died three years before the end of the controversy.

As above, we have presented three well-known stories. Today, when we look back on history, it is very difficult for us to imagine how fiercely people argued over different viewpoints at that time. Whether

[4] Cercignani C. 2006. "Ludwig Boltzmann (Translated into Chinese by Hu Xinhe)." Shanghai Scientific & Technical Publisher, Shanghai, China.

the people in the debates are right or wrong, they may all have paid a huge price for these arguments. The truth is definitely not free. It is never fluent to obtain and confirm correct knowledge. Sometimes, it even may take a generation of opponents to leave the world before the truth has opportunity to be established. In the book entitled *Scientific Autobiography and Other Papers*[1c], Max Planck sadly remarked that "*A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.*" From a certain perspective, this has already been an objective law proven by history.

Although there were sad stories like Boltzmann's experience in history, we still have to say that these scientific debates and controversies are generally very necessary. In the garden of science and technology, there are many beautiful flowers. However, weeds are often inevitable. Scientific debates and controversies can be treated as gardeners. If there were no debates or controversies, there were no care of gardeners in the garden, and the weeds could not be identified or removed. Especially, if the grower of a weed is an influential academic authority, the weed may obtain fertile soil and sufficient nutrients, and the silence of the academic community would also make the weed grow more vigorous and look more like a vibrant flower tree. In this case, if ones want to find out the true nature of this weed as soon as possible, they have to challenge the authority, thus requiring having more valuable extraordinary courage. In contrast, flower trees are always flower trees. Even if they do not bloom immediately, they will bloom sooner or later. Anyway, truth is not afraid of controversy. In the debates, the truth will stand firm in the end. Therefore, scientific debates and controversies may make us wander in a certain place or a certain period of time, but they will not allow falsehoods to mislead us all the time, nor will they let the human beings miss the truth.

At present, there are many charming flowers in the garden of thermal science after thousands of years of accumulation. However, at the same time, there are also some weeds, and some of them were planted by well-known researchers. Good news is that the gardeners are still working and the debates between different academic viewpoints continue. For instance, there are many scientific discussions on the applicability of thermal optimization theories. In engineering, we often need to find the optimal solutions for the problems under certain constraints to achieve the best system performances. To effectively solve these problems, researchers have developed many thermal optimization theories. Understandably, researchers often hope that the wider the application scopes of their theories are, the better, but the facts often do not satisfy them, so there will always be some scientific debates and controversies on the applicability and effectiveness of the theories.

The entropy generation minimization[5] is one typical example. In this theory, the decrease of entropy generation means the decrease of irreversibility and could improve the thermodynamic performance of thermal systems. In heat-work conversion, the minimization of entropy generation could lead to the maximum output mechanical work for heat engine systems and the minimum input mechanical work for refrigeration systems, respectively. In heat transfer enhancement design, the entropy generation minimization indicates that the thermal conductance should be improved to decrease the heat transfer temperature difference and entropy generation for fixed heat transfer rate, while it shows that the thermal conductance should be decreased to decrease the heat transfer rate and entropy generation for fixed heat transfer temperature difference in thermal insulation design. In one word, the minimum entropy generation becomes the design objective for thermal systems. Based on this idea, researchers have done much work, and many

[5] Bejan A. 1995. “Entropy Generation Minimization.” CRC Press, Florida, USA.

academic papers have been published.

However, we can see that the entropy generation minimization approach cannot be universally applicable with a very simple thought experiment. In different thermal systems, we may have different design objectives, such as the minimum heat transfer temperature difference[6], the maximum heat exchanger effectiveness[7], the minimization of system mass[8], the homogenization of temperature field[9], the maximum output power[10], the maximum coefficient of performance (COP) in heat pump systems[11], the best thermo-economic performance[12], etc. If all these objectives could be achieved with the entropy generation minimization method, the optimization direction of entropy generation minimization should be consistent with those of all the different objectives. Then, all these objectives should be consistent with each other. However, in different application cases, these optimization design objectives may be inconsistent or even completely opposite. For instance, in a heat transfer system, when the design objective is to enhance heat transfer, it is obvious that the larger heat transfer rate means better system performance. However, when the optimization objective is thermal insulation, the smaller the heat transfer rate is, the better the system

[6] Guo Z Y, Zhu H Y and Liang X G. 2007. "Entransy-A physical quantity describing heat transfer ability." *Int J Heat Mass Transfer* 50: 2545-2556.
[7] Guo Z Y, Zhou S Q, Li Z X, et al. 2002. "Theoretical analysis and experimental confirmation of the uniformity principle of temperature difference field in heat exchanger." *Int J Heat Mass Transfer* 45: 2119-2127.
[8] Zhou B, Cheng X T and Liang X G. 2013. "Conditional extremum optimization analyses and calculation of the active thermal control system mass of manned spacecraft." *Appl Thermal Eng* 59: 639-647.
[9] Cheng X T, Xu X H and Liang X G. 2009. "Homogenization of temperature field and temperature gradient field." *Sci China Ser E: Tech Sci* 52: 2937-2942.
[10] Sun C, Cheng X T and Liang X G. 2014. "Output power analyses for the thermodynamic cycles of thermal power plants." *Chin Phys B* 23: 050513.
[11] Cheng X T and Liang X G. 2013. "Entransy and entropy analyses of heat pump systems." *Chin Sci Bull* 58: 4696-4702.
[12] Vos A D. 1995. "Endoreversible thermoeconomics." *Energy Convers Manage* 36: 1-5.

performance is.

Therefore, it is not feasible to use the entropy generation minimization approach to optimize all kinds of thermal systems in engineering. When the entropy generation minimization is applied, it is not strange that the optimal system performances may not be obtained in practical application cases. For the applicability of the entropy generation minimization, many cases and discussions were presented systematically and comprehensively, and the above conclusions have been fully proved[13].

The constructal theory[14] is another typical example. When the theory was applied, it was deemed that an easier access for flow could be provided. To achieve this objective, the constructal analysis or design started with the basic element in some application cases. After the optimal geometries of the basic element and the corresponding flow channel were deduced theoretically, a larger element composed of a number of basic elements was taken into consideration to obtain the corresponding optimal geometrical parameters. By repeating these optimization steps, it was noted that the final constructal structure of flow channels could be obtained theoretically and deterministically for the whole region, and what made the constructal method deterministic was the time arrow from small to large. It was claimed that the constructal optimization processes reflected the evolution of shape or

[13] a) Cheng X T. 2019. "A Critical Perspective of Entropy Generation Minimization in Thermal Analyses and Optimizations." Cambridge Scholars Publishing, Newcastle upon Tyne, UK.
b) Cheng X T and Liang X G. 2013. "Applicability of minimum entropy generation method to optimizing thermodynamic cycles." *Chin Phys B* 22: 010508.
c) Cheng X T and Liang X G. 2016. "Discussion on the application of entropy generation minimization to the optimizations of heat transfer and heat-work conversion (in Chinese)." *Acta Phys Sin* 65: 180503.

[14] Bejan A. 1998. "Constructal theory: From thermodynamic and geometric optimization to predicting shape in nature." *Energy Convers Manage* 39: 1705-1718.

structure in nature. Accordingly, as Darwin's evolutionism shows that the natural structures are the fittest, the constructal shapes or structures were regarded as the optimal ones. With this consideration, the constructal theory has been applied to analyzing and optimizing many shapes and structures in engineering and social phenomena, including the pattern and formation of street networks[15], the heat transfer optimization[16], the optimization of flow structures[17], the disc-to-point flow problems[18], the design of fuel cells[19], the analyses of power systems[20], etc., and treated as a universally applicable law that could govern the evolutions of the shapes and structures in physics, biology, technology and society[21]. It seems that the theory is omnipotent for analyzing and designing all kinds of shapes and structures in the world.

Obviously, it is a beautiful dream to analyze or optimize all the shapes and structures in living and nonliving system with only one theory. If this dream come true, it must be great news that could attract the attention of the whole world, and the corresponding theory may even deserve a Nobel Prize. Unfortunately, the constructal theory cannot make the dream come true. In the book entitled *Critique of Constructal Theory*[22], the models, methods, applications and results of the theory

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[15] Bejan A. 1996. "Street network theory of organization in nature." *J Adv Transport* 30: 85-107.
[16] Bejan A. 1997. "Constructal-theory network of conducting paths for cooling a heat generating volume." *Int J Heat Mass Transfer* 40: 799-816.
[17] Bejan A, and Errera M R. 1997. "Deterministic tree networks for fluid flow: Geometry for minimal flow resistance between a volume and one point." *Fractals* 5: 685-692.
[18] Wechsatol W, Lorente S and Bejan A. 2002. "Optimal tree-shaped networks for fluid flow in a disc-shaped body." *Int J Heat Mass Transfer* 45: 4911-4924.
[19] Vargas J V C, Ordonez J C and Bejan A. 2004. "Constructal flow structure for a PEM fuel cell." *Int J Heat Mass Transfer* 47: 4177-4193.
[20] Kim Y S, Lorente S and Bejan A. 2009. "Distribution of size in steam turbine power plants." *Int J Energy Res* 33: 989-998.
[21] Bejan A and Lorente S. 2013. "Constructal law of design and evolution: Physics, biology, technology, and society." *J Appl Phys* 113: 151301.
[22] Cheng X T. 2019. "Critique of Constructal Theory." Cambridge Scholars

to the explanations or optimizations of the shapes and structures in living and nonliving systems are reviewed and discussed in details with theoretical analyses and some typical application cases. The theory is shown to be clearly questionable and significantly flawed, and the main problems are summarized and analyzed. With the theory, it has been fully proved that the real optimal shapes or structures cannot be obtained in most cases.

In many cases, it is found to be irresponsible to abuse the constructal theory or the constructal structures without checking the applicability. Even if many works are related to structure, shape and size, they may be included in the application cases of the constructal theory. This kind of research work can be easily found in the main academic paper databases by searching for the keyword, "constructal". Frankly speaking, we rarely see a theory being blindly abused to this extent. Obviously, the constructal theory is no longer an ordinary weed in the garden of thermal science, but has actually become an alien species with competitive advantages over normal flower trees, which is similar to the rampant rabbits in Australia. Now, it is not easy to eliminate it completely, but we still want to try our best to finish the work as soon as possible.

Standing by the long river of the development history of thermal science, we can feel that no matter how lively and eye-catching the above debates and controversies are at present, they will eventually become ordinary, and even a small wave may not be remembered by most people. For the objects or natural phenomena that we want to understand deeply, new concepts or theories are constantly developed. The application scopes of these concepts and theories are constantly explored, questioned and even denied. This is very beneficial to scientific development, and also very common. Both the participants in the scientific debates and controversies and the bystanders need an

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Publishing, Newcastle upon Tyne, UK.

ordinary mind. Of course, as the civilization has developed to the current level, the scientific debates and controversies should have its norms. No matter how fierce the debates and controversies are, they should be strictly confined to the scope of academic discussions. Today, no one can accept the death of another Bruno or Boltzmann. In ancient China, Confucius once said, "*A man of virtue is still a man of virtue in his competition*"[1d]. This is what we should pay enough attention to and abide by together. Only in this way can our scientific debates and controversies be more benign, and the man-made harm in our exploration of the unknown can be less.

The above discussion shows that thermal science, as an integral part of natural sciences, is not special. For thousands of years, many new concepts and theories have been put forward, questioned and debated in this discipline. Among them, some concepts and theories are finally established because they have revealed the truth, some are denied and abandoned, and some are not yet conclusive, and the debates and controversies continue. We have reason to believe that this is the normal state in the development of science and technology.

Part III About this book

As above, the new concepts and theories developed in the process of understanding the world and the possible disputes they may face have been briefly analyzed, and the characteristics of the development of science and technology and those of the academic debates and controversies have been preliminarily summarized. Some examples in thermal science are presented, which can be used as evidences for the characteristics summarized above. Why do we take thermal science as an example for discussion? This is because this book mainly focuses on this discipline.

In this book, the author will introduce a young concept in thermal science, *entransy*[6]. This concept has been developed for about twenty years, and has been widely applied to the analyses and optimizations of many thermal systems, including conductive heat transfer[6], convective heat transfer[23], radiative heat transfer[24], thermodynamic cycle[10], heat pump systems[11], etc. Now, a scientific theory in which entransy is the core concept has been obtained, and is still under developing. Meanwhile, what is essential is that this young concept and the corresponding theory have also been questioned. There are supporters and opponents, and the two sides are having a heated debate.

In the present book, the author does not intend to give detailed mathematical and physical derivations and demonstrations of the entransy concept and corresponding theory, applications and controversies. There are many academic papers on the entransy theory, and the controversial articles are also very easy to find. Interested readers can refer to our references or other papers, which are very rich in details.

On the contrary, the author would like to introduce the entransy concept in a macro way. Therefore, the author will try the best to avoid lengthy mathematical derivations, complex calculations and overly professional discussions. For necessary physical analyses, he will try to make them simple and easy for understanding, and feel very honored if readers think that the author has achieved his goal.

Are you ready to recognize and understand thermal phenomena with the entransy concept, which can give you a different perspective from the traditional one? If yes, let us have a different journey with reading the following chapters. Of course, for those who are familiar with thermal

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[23] Chen Q, Liang X G and Guo Z Y. 2013. "Entransy theory for the optimization of heat transfer-A review and update." *Int J Heat Mass Transfer* 63: 65-81.

[24] Cheng X T and Liang X G. 2011. "Entransy flux of thermal radiation and its application to enclosures with opaque surfaces." *Int J Heat Mass Transfer* 54: 269-278.