

The Analytical Theory of Heat

热的解析理论

JOSEPH FOURIER

TRANSLATED, WITH NOTES, BY
ALEXANDER FREEMAN



© in this compilation Higher Education Press 2016

This edition first published 1878, Cambridge: At the University Press

This book reproduces the text of the original edition. The content and language reflect the beliefs, practices and terminology of their time, and have not been updated.

图书在版编目(CIP)数据

热的解析理论 = The Analytical Theory of Heat:
英文 / (法) 傅里叶 (Fourier, J.) 著. -- 北京: 高等
教育出版社, 2016. 1

ISBN 978-7-04-044257-1

I. ①热… II. ①傅… III. ①热学 - 解析理论 - 英文
IV. ①O551

中国版本图书馆 CIP 数据核字 (2015) 第 275326 号

策划编辑 李 鹏
责任校对 刘丽娴

责任编辑 李 鹏
责任印制 韩 刚

封面设计 王凌波

版式设计 于 婕

出版发行 高等教育出版社
社 址 北京市西城区德外大街 4 号
邮政编码 100120
印 刷 涿州市星河印刷有限公司
开 本 787mm × 1092mm 1/16
印 张 25.5
字 数 670 千字
购书热线 010-58581118

咨询电话 400-810-0598
网 址 <http://www.hep.edu.cn>
<http://www.hep.com.cn>
网上订购 <http://www.landaco.com>
<http://www.landaco.com.cn>
版 次 2016 年 1 月第 1 版
印 次 2016 年 1 月第 1 次印刷
定 价 128.00 元

本书如有缺页、倒页、脱页等质量问题, 请到所购图书销售部门联系调换
版权所有 侵权必究
物 料 号 44257-00

Open and Read
Find Something Valuable

HEP Academic Classics

There is a Chinese saying: "It is beneficial to open any book." It is even more fruitful to open and read classic books. The world is keeping on changing, but really fundamental and essential things stay the same since there is nothing new under the sun. Great ideas have been discovered and re-discovered, and they should be learnt and re-learned. Classic books are our inheritance from all the previous generations and contain the best of knowledge and wisdom of all the people before us. They are timeless and universal. We cannot travel back in time, but we can converse with the originators of current theories through reading their books. Classic books have withstood the test of time. They are reliable and contain a wealth of original ideas. More importantly, they are also books which have not finished what they wanted or hoped to say. Consequently, they contain unearthed treasures and hidden seeds of new theories, which are waiting to be discovered. As it is often said: history is today. Proper understanding of the past work of giants is necessary to carry out properly the current and future researches and to make them to be a part of the history of science and mathematics. Reading classics books is not easy, but it is rewarding. Some modern interpretations and beautiful reformulations of the classics often miss the subtle and crucial points. Reading classics is also more than only accumulating knowledge, and the reader can learn from masters on how they asked questions, how they struggled to come up with new notions and theories to overcome problems, and answers to questions. Above all, probably the best reason to open classic books is the curiosity: what did people know, how did they express and communicate them, why did they do what they did? It can simply be fun!

This series of classic books by Higher Education Press contains a selection of best classic books in natural history, mathematics, physics, chemistry, information technology, geography, etc. from the past two thousand years. They contain masterpieces by the great people such Archimedes, Newton, Lavoisier, Dalton, Gauss, Darwin, Maxwell, and hence give a panorama of science and mathematics. They have been typeset in modern fonts for easier and more enjoyable reading. To help the reader understand difficult classics better, some volumes contain introductions and commentaries by experts. Though each classic book can stand in its own, reading them together will help the reader gain a bigger perspective of science and mathematics and understand better interconnection between seemingly unrelated topics and subjects.

Higher Education Press has been the largest publisher in China. Besides the long tradition of providing high quality books for proper education and training of university and graduate students, she has also set out to provide research monographs and references books to people at all levels around the world. Higher Education Press considers it her duty to keep the world science and mathematics community informed of what has been achieved in their subjects in easy and accessible formats. This series of classic books is an integral part of this effort.

THE
ANALYTICAL THEORY OF HEAT

BY
JOSEPH FOURIER.

TRANSLATED, WITH NOTES,

BY
ALEXANDER FREEMAN, M.A.,
FELLOW OF ST JOHN'S COLLEGE, CAMBRIDGE.

EDITED FOR THE SYNDICS OF THE UNIVERSITY PRESS.

Cambridge :
AT THE UNIVERSITY PRESS.

LONDON: CAMBRIDGE WAREHOUSE, 17, PATERNOSTER ROW.

CAMBRIDGE: DEIGHTON, BELL, AND CO.

LEIPZIG: F. A. BROCKHAUS.

1878

[All Rights reserved.]

PREFACE.

IN preparing this version in English of Fourier's celebrated treatise on Heat, the translator has followed faithfully the French original. He has, however, appended brief foot-notes, in which will be found references to other writings of Fourier and modern authors on the subject: these are distinguished by the initials A. F. The notes marked R. L. E. are taken from pencil memoranda on the margin of a copy of the work that formerly belonged to the late Robert Leslie Ellis, Fellow of Trinity College, and is now in the possession of St John's College. It was the translator's hope to have been able to prefix to this treatise a Memoir of Fourier's life with some account of his writings; unforeseen circumstances have however prevented its completion in time to appear with the present work.

TABLE OF CONTENTS OF THE WORK¹.

	PAGE
PRELIMINARY DISCOURSE	1

CHAPTER I.

Introduction.

SECTION I.

STATEMENT OF THE OBJECT OF THE WORK.

ART.

1. Object of the theoretical researches	12
2—10. Different examples, ring, cube, sphere, infinite prism; the variable temperature at any point whatever is a function of the coordinates and of the time. The quantity of heat, which during unit of time crosses a given surface in the interior of the solid, is also a function of the time elapsed, and of quantities which determine the form and position of the surface. The object of the theory is to discover these functions.....	12
11. The three specific elements which must be observed, are the <i>capacity</i> , the conducibility proper or <i>permeability</i> , and the external conducibility or <i>penetrability</i> . The coefficients which express them may be regarded at first as constant numbers, independent of the temperatures	15
12. First statement of the problem of the terrestrial temperatures.....	16
13—15. Conditions necessary to applications of the theory. Object of the experiments	17

¹Each paragraph of the Table indicates the matter treated of in the articles indicated at the left of that paragraph. The first of these articles begins at the page marked on the right.

16—21. The rays of heat which escape from the same point of a surface have not the same intensity. The intensity of each ray is proportional to the cosine of the angle which its direction makes with the normal to the surface. Divers remarks, and considerations on the object and extent of thermological problems, and on the relations of general analysis with the study of nature.....	18
---	----

SECTION II.

PRELIMINARY DEFINITIONS AND GENERAL NOTIONS.

22—24. Permanent temperature, thermometer. The temperature denoted by 0 is that of melting ice. The temperature of water boiling in a given vessel under a given pressure is denoted by 1	21
25. The unit which serves to measure quantities of heat, is the heat required to liquify a certain mass of ice.....	22
26. Specific capacity for heat	22
27—29. Temperatures measured by increments of volume or by the additional quantities of heat. Those cases only are here considered, in which the increments of volume are proportional to the increments of the quantity of heat. This condition does not in general exist in liquids; it is sensibly true for solid bodies whose temperatures differ very much from those which cause the change of state.....	22
30. Notion of external conducibility	23
31. We may at first regard the quantity of heat lost as proportional to the temperature. This proposition is not sensibly true except for certain limits of temperature.....	23
32—35. The heat lost into the medium consists of several parts. The effect is compound and variable. Luminous heat	23
36. Measure of the external conducibility	24
37. Notion of the conducibility proper. This property also may be observed in liquids.....	24
38, 39. Equilibrium of temperatures. The effect is independent of contact .	25
40—49. First notions of radiant heat, and of the equilibrium which is established in spaces void of air; of the cause of the reflection of rays of heat, or of their retention in bodies; of the mode of communication between the internal molecules; of the law which regulates the intensity of the rays emitted. The law is not disturbed by the reflection of heat.....	25
50, 51. First notion of the effects of reflected heat	29

- 52—56. Remarks on the statical or dynamical properties of heat. It is the principle of elasticity. The elastic force of aeriform fluids exactly indicates their temperatures. 30

SECTION III.

PRINCIPLE OF THE COMMUNICATION OF HEAT.

- 57—59. When two molecules of the same solid are extremely near and at unequal temperatures, the most heated molecule communicates to that which is less heated a quantity of heat exactly expressed by the product of the duration of the instant, of the extremely small difference of the temperatures, and of a certain function of the distance of the molecules 32
60. When a heated body is placed in an aeriform medium at a lower temperature, it loses at each instant a quantity of heat which may be regarded in the first researches as proportional to the excess of the temperature of the surface over the temperature of the medium 33
- 61—64. The propositions enunciated in the two preceding articles are founded on divers observations. The primary object of the theory is to discover all the exact consequences of these propositions. We can then measure the variations of the coefficients, by comparing the results of calculation with very exact experiments 33

SECTION IV.

ON THE UNIFORM AND LINEAR MOVEMENT OF HEAT.

65. The permanent temperatures of an infinite solid included between two parallel planes maintained at fixed temperatures, are expressed by the equation $(v - a)e = (b - a)z$; a and b are the temperatures of the two extreme planes, e their distance, and v the temperature of the section, whose distance from the lower plane is z 35
- 66, 67. Notion and measure of the flow of heat 37
- 68, 69. Measure of the conducibility proper 39
70. Remarks on the case in which the direct action of the heat extends to a sensible distance. 40
71. State of the same solid when the upper plane is exposed to the air 41
72. General conditions of the linear movement of heat 42

SECTION V.

LAW OF THE PERMANENT TEMPERATURES IN A PRISM OF SMALL THICKNESS.

- 73—80. Equation of the linear movement of heat in the prism. Different consequences of this equation. 43

SECTION VI.

ON THE HEATING OF CLOSED SPACES.

- 81—84. The final state of the solid boundary which encloses the space heated by a surface b , maintained at the temperature α , is expressed by the following equation:

$$m - n = (\alpha - n) \frac{P}{1 + P}.$$

The value of P is $\frac{\sigma}{s} \left(\frac{g}{h} + \frac{ge}{K} + \frac{g}{H} \right)$, m is the temperature of the internal air, n the temperature of the external air, g, h, H measure respectively the penetrability of the heated surface σ , that of the inner surface of the boundary s , and that of the external surface s ; e is the thickness of the boundary, and K its conductivity proper 47

- 85, 86. Remarkable consequences of the preceding equation 50

- 87—91. Measure of the quantity of heat requisite to retain at a constant temperature a body whose surface is protected from the external air by several successive envelopes. Remarkable effects of the separation of the surfaces. These results applicable to many different problems 51

SECTION VII.

ON THE UNIFORM MOVEMENT OF HEAT IN THREE DIMENSIONS.

- 92, 93. The permanent temperatures of a solid enclosed between six rectangular planes are expressed by the equation

$$v = A + ax + by + cz.$$

x, y, z are the coordinates of any point, whose temperature is v ; A, a, b, c are constant numbers. If the extreme planes are maintained by any causes at fixed temperatures which satisfy the preceding equation, the final system of all the internal temperatures will be expressed by the same equation 56

- 94, 95. Measure of the flow of heat in this prism 57

SECTION VIII.

MEASURE OF THE MOVEMENT OF HEAT AT A GIVEN POINT OF A SOLID MASS.

- 96—99. The variable system of temperatures of a solid is supposed to be expressed by the equation $v = F(x, y, z, t)$, where v denotes the variable temperature which would be observed after the time t had elapsed, at the point whose coordinates are x, y, z . Formation of the analytical expression of the flow of heat in a given direction within the solid 59

100. Application of the preceding theorem to the case in which the function F is $e^{-gt} \cos x \cos y \cos z$ 63

CHAPTER II.

Equations of the Movement of Heat.

SECTION I.

EQUATION OF THE VARIED MOVEMENT OF HEAT IN A RING.

- 101—105. The variable movement of heat in a ring is expressed by the equation

$$\frac{dv}{dt} = \frac{K}{CD} \frac{d^2v}{dx^2} - \frac{hl}{CDS} v.$$

The arc x measures the distance of a section from the origin O ; v is the temperature which that section acquires after the lapse of the time t ; K, C, D, h are the specific coefficients; S is the area of the section, by the revolution of which the ring is generated; l is the perimeter of the section 65

- 106—110. The temperatures at points situated at equal distances are represented by the terms of a recurring series. Observation of the temperatures v_1, v_2, v_3 of three consecutive points gives the measure of the ratio $\frac{h}{K}$:

We have $\frac{v_1 + v_3}{v_2} = q, \omega^2 - q\omega + 1 = 0$, and $\frac{h}{K} = \frac{S}{l} \left(\frac{\log \omega}{\lambda \log e} \right)^2$. The distance between two consecutive points is λ , and $\log \omega$ is the decimal logarithm of one of the two values of ω 67

SECTION II.

EQUATION OF THE VARIED MOVEMENT OF HEAT IN A SOLID SPHERE.

- 111—113. x denoting the radius of any shell, the movement of heat in the sphere is expressed by the equation

$$\frac{dv}{dt} = \frac{K}{CD} \left(\frac{d^2v}{dx^2} + \frac{2}{x} \frac{dv}{dx} \right) \dots\dots\dots 69$$

- 114—117. Conditions relative to the state of the surface and to the initial state of the solid 70

SECTION III.

EQUATIONS OF THE VARIED MOVEMENT OF HEAT IN A SOLID CYLINDER.

- 118—120. The temperatures of the solid are determined by three equations; the first relates to the internal temperatures, the second expresses the continuous state of the surface, the third expresses the initial state of the solid 72

SECTION IV.

EQUATIONS OF THE UNIFORM MOVEMENT OF HEAT IN A SOLID PRISM OF INFINITE LENGTH.

- 121—123. The system of fixed temperatures satisfies the equation

$$\frac{d^2v}{dx^2} + \frac{d^2v}{dy^2} + \frac{d^2v}{dz^2} = 0;$$

- v is the temperature at a point whose coordinates are x, y, z 74
- 124, 125. Equation relative to the state of the surface and to that of the first section 76

SECTION V.

EQUATIONS OF THE VARIED MOVEMENT OF HEAT IN A SOLID CUBE.

- 126—131. The system of variable temperatures is determined by three equations; one expresses the internal state, the second relates to the state of the surface, and the third expresses the initial state..... 77

SECTION VI.

GENERAL EQUATION OF THE PROPAGATION OF HEAT IN THE INTERIOR OF SOLIDS.

- 132—139. Elementary proof of properties of the uniform movement of heat in a solid enclosed between six orthogonal planes, the constant temperatures being expressed by the linear equation,

$$v = A - ax - by - cz.$$

The temperatures cannot change, since each point of the solid receives as much heat as it gives off. The quantity of heat which during the unit of time crosses a plane at right angles to the axis of z is the same, through whatever point of that axis the plane passes. The value of this common flow is that which would exist, if the coefficients a and b were nul 80

- 140, 141. Analytical expression of the flow in the interior of any solid. The equation of the temperatures being $v = f(x, y, z, t)$ the function $-K\omega \frac{dv}{dz}$ expresses the quantity of heat which during the instant dt crosses an infinitely small area ω perpendicular to the axis of z , at the point whose coordinates are x, y, z , and whose temperature is v after the time t has elapsed 84
- 142—145. It is easy to derive from the foregoing theorem the general equation of the movement of heat, namely

$$\frac{dv}{dt} = \frac{K}{CD} \left(\frac{d^2v}{dx^2} + \frac{d^2v}{dy^2} + \frac{d^2v}{dz^2} \right) \dots (A) \dots \dots \dots 86$$

SECTION VII.

GENERAL EQUATION RELATIVE TO THE SURFACE.

- 146—154. It is proved that the variable temperatures at points on the surface of a body, which is cooling in air, satisfy the equations

$$m \frac{dv}{dx} + n \frac{dv}{dy} + p \frac{dv}{dz} + \frac{h}{K} v q = 0; \quad m dx + n dy + p dz = 0,$$

being the differential equation of the surface which bounds the solid, and q being equal to $(m^2 + n^2 + p^2)^{\frac{1}{2}}$. To discover this equation we consider a molecule of the envelop which bounds the solid, and we express the fact that the temperature of this element does not change by a finite magnitude during an infinitely small instant. This condition holds and continues to exist after that the regular action of the medium has been exerted during a very small instant. Any form may be given to the element of the envelop. The case in which the molecule is formed by rectangular sections presents remarkable properties. In the most simple case, which is that in which the base is parallel to the tangent plane, the truth of the equation is evident 88

SECTION VIII.

APPLICATION OF THE GENERAL EQUATIONS.

- 155, 156. In applying the general equation (A) to the case of the cylinder and of the sphere, we find the same equations as those of Section III. and of Section II. of this chapter 95

SECTION IX.

GENERAL REMARKS.

- 157—162. Fundamental considerations on the nature of the quantities x, t, v, K, h, C, D , which enter into all the analytical expressions of the Theory of Heat. Each of these quantities has an exponent of dimension which relates to the length, or to the duration, or to the temperature. These exponents are found by making the units of measure vary 98

CHAPTER III.

Propagation of Heat in an infinite rectangular solid.

SECTION I.

STATEMENT OF THE PROBLEM.

- 163—166. The constant temperatures of a rectangular plate included between two parallel infinite sides, maintained at the temperature 0, are expressed by the equation $\frac{d^2v}{dx^2} + \frac{d^2v}{dy^2} = 0$ 102
- 167—170. If we consider the state of the plate at a very great distance from the transverse edge, the ratio of the temperatures of two points whose coordinates are x_1, y and x_2, y changes according as the value of y increases; x_1 and x_2 preserving their respective values. The ratio has a limit to which it approaches more and more, and when y is infinite, it is expressed by the product of a function of x and of a function of y . This remark suffices to disclose the general form of v , namely,

$$v = \sum_{i=1}^{i=\infty} a_i e^{-(2i-1)x} \cdot \cos(2i-1) \cdot y.$$

It is easy to ascertain how the movement of heat in the plate is effected . . . 104

SECTION II.

FIRST EXAMPLE OF THE USE OF TRIGONOMETRIC SERIES IN THE THEORY OF HEAT.

- 171—178. Investigation of the coefficients in the equation

$$1 = a \cos y + b \cos 3y + c \cos 5y + d \cos 7y + \&c.$$

From which we conclude

$$a_i = \frac{1}{2i-1} \frac{4}{\pi} (-1)^{i+1},$$

or

$$\frac{\pi}{4} = \cos y - \frac{1}{3} \cos 3y + \frac{1}{5} \cos 5y - \frac{1}{7} \cos 7y + \&c. \dots\dots\dots 107$$

SECTION III.

REMARKS ON THESE SERIES.

- 179—181. To find the value of the series which forms the second member, the number m of terms is supposed to be limited, and the series becomes a function of x and m . This function is developed according to powers of the reciprocal of m , and m is made infinite..... 113
- 182—184. The same process is applied to several other series..... 115
- 185—188. In the preceding development, which gives the value of the function of x and m , we determine rigorously the limits within which the sum of all the terms is included, starting from a given term..... 118
189. Very simple process for forming the series

$$\frac{\pi}{4} = - \sum_{i=1}^{i=\infty} \frac{(-1)^i}{2i-1} \cos(2i-1)x. \dots\dots\dots 121$$

SECTION IV.

GENERAL SOLUTION.

- 190, 191. Analytical expression of the movement of heat in a rectangular slab; it is decomposed into simple movements..... 122
- 192—195. Measure of the quantity of heat which crosses an edge or side parallel or perpendicular to the base. This expression of the flow suffices to verify the solution..... 123
- 196—199. Consequences of this solution. The rectangular slab must be considered as forming part of an infinite plane; the solution expresses the permanent temperatures at all points of this plane..... 125
- 200—204. It is proved that the problem proposed admits of no other solution different from that which we have just stated..... 127

SECTION V.

FINITE EXPRESSION OF THE RESULT OF THE SOLUTION.

- 205, 206. The temperature at a point of the rectangular slab whose coordinates are x and y , is expressed thus

$$\frac{1}{2}\pi v = \arctan \left(\frac{2 \cos y}{e^x - e^{-x}} \right) \dots\dots\dots 130$$