PHYSICS

"A Classic of Science"---
Fourier's Theory of Heat

THIS YEAR is the one hundredth anniversary of the death of the French statesman and mathematician, Fourier. He had been active in the stirring politics of the Revolution, the Empire and the Restoration. He had gone to Egypt with Napoleon and was instrumental in starting archaeological study there. His mathematical work on the theory of heat helped to bring to order many apparently conflicting phenomena. Here he explains something of his method.

JEAN BAPTISTE JOSEPH FOURIER

THEORIE ANALYTIQUE DE LA CHALEUR, par M. Fourier. Paris, 1822. *Translated for the Science News Letter by Helen M. Davis.*

THE PRECEDING examples suffice to give a good idea of the various questions which we have studied. The solution of these questions has taught us that the effects of the propagation of heat depend, for each solid substance, upon three elementary qualities which are: the capacity for heat, the true conductibility and the external conductibility. It has been observed that, if two bodies of the same volume and of different nature have equal temperature and are treated with the same quantity of heat, the increases of temperature are not the same; the relation between the increases is to each as their capacities for heat.

Thus the first of the three specific elements which govern the action of heat is exactly defined, and physicists have known for a long time many ways of determining its value. It is not the same with the other two; but there has not been an exact theory which could well distinguish them, to define and measure them with precision. The true or interior conductibility of a body expresses the ease with which heat is conducted in passing from one interior molecule to another. The external or relative conductibility of a solid body depends upon the ease with which heat penetrates its surface and passes from the body into a given medium, or passes from the medium into the solid. This latter property is modified by the more or less polished state of the surface; it varies also with the medium in which the body is plunged; but the true conductibility can change only with the nature of the solid.

These three elementary qualities are represented in our formulas by constant numbers, and the theory itself shows the proper experiments for measuring the value. Once those are determined, all questions relative to the propagation of heat depend only upon numerical analysis. The knowledge of these specific properties can be immediately used in many applications of the physical sciences; it is moreover an element in the study and description of the various substances. It is to know a body very imperfectly to ignore the relations which it has with the principal agents of nature. In general, there is scarcely a mathematical theory which has more connection than this with public economy, since it can serve to clarify and perfect the usages of the numerous arts which are founded upon the use of heat.

Applied to the Earth

The question of terrestrial temperatures offers one of the most beautiful applications of the theory of heat; here is the general idea upon which it may be formed. The different parts of the surface of the globe are unequally exposed to the effect of the sun's rays; the intensity of this action depends upon the latitude of the place; it changes also depending upon the duration of the day and upon the time of the year, and is affected by other less sensible inequalities. It is evident that there exists, between this variable state of the surface and that of the internal temperature, a necessary relation which could be deduced from theory. It is known that at a certain depth below the surface of the earth, the temperature has no annual variation at a given place: the permanent temperature of these deep places is lessened in proportion as the place is removed from the equator. One may therefore set aside an external envelope, whose thickness is incomparably small compared to the radius of the earth, and regard this planet as a mass nearly spherical whose surface is subject to a temperature which is fixed for all the points on a given parallel, but which is not the same for any other parallel. It results from this that any interior molecule also has a fixed temperature determined by its position. The mathematical problem will consist in knowing the fixed temperature of a given point and the law which the heat of the sun follows in penetrating into the interior of the globe.

This diversity of temperatures interests us the more, if we consider the changes which succeed one another in the envelope itself, whose surface we inhabit. Those alternations of heat and cold which recur every day and in the course of every year, have been till now the object of multiplied observations. Now it is possible to submit them to calculation and to deduce from one common theory all the particular cases with which experience has acquainted us. This question reduces itself to the hypothesis that all the points on the surface of an immediate sphere are affected by periodic temperatures; calculation then tells us that following some law the intensity of the variations decreases proportionally as the depth increases; that is, for a given depth the amount of the annual or diurnal changes, the period of the changes, and even the fixed degree of the subterranean temperature is deduced from the variable temperatures observed at the surface.

Equilibrium of Temperature

Equilibrium of temperature is brought about not only by contact; it is established also between bodies separated from one another which remain for a long while in the same place. This effect is independent of contact of the medium; we have observed it in spaces entirely empty of air. It remains therefore, to complete our theory, to examine the laws which radiant heat follows in leaving the surface of bodies. It follows from the observations of many physicists and from our own experiments that the intensity of different rays which go out, in every direction, from every point of the surface of a heated body depends upon the angle which their direction makes with the surface at that point. We have demonstrated that the intensity of each ray is lessened as it makes a smaller angle with the element of the surface, and that it is proportional to the sine of that angle. This general law of the emission of heat, which different observations have already indicated, is a necessary consequence of the principle of equilibrium of temperatures and of the laws of propagation of heat in solid bodies.

These are the principal questions which have been treated in this work· they are all directed toward a sole end, which is to establish clearly the mathematical principles of the theory of heat and to assist also in the progress of useful arts and from these to the study of nature.

Laws Peculiar to Heat

One perceives, from the preceding, that there exists a very extended class of phenomena which are never produced by mechanical forces, but which result solely from the presence and the accumulation of heat. This part of natural philosophy can not adapt itself to dynamical theories; it has principles which are peculiar to itself, and it is attacked by a method similar to that of the other exact sciences. For example, the heat of the sun which penetrates the interior of the globe is distributed following a regular law, which does not depend at all upon those of motion and cannot be determined by the principles of mechanics. The expansions which produce the repulsive force of heat and whose observation serves to measure temperatures are, in truth, dynamic effects; but it is never these expansions which one calculates when one studies the laws of the propagation of heat.

Composite Forces

There are other more composite natural effects which depend at once upon the influence of heat and attracting forces; thus the variations of temperature, which the movements of the sun occasion in the atmosphere and in the ocean, continually change the density of the different parts of the air and the waters. The effect of the forces with which these masses obey is modified at every instant by a new distribution of heat, and one cannot doubt that this cause produces the regular winds and the principal currents of the sea; the solar and lunar attractions occasion in the atmosphere only slightly sensible movements and not general displacements. It should be necessary therefore to submit these large phenomena to calculation to discover the mathematical laws of the propagation of heat in the interior of the masses

One recognizes, in reading this work, that heat effects in a body a regular arrangement, independent of the original distribution which one may regard as arbitrary.

In whatever manner the heat was first distributed, the initial system of temperatures, changing more and more, immediately blends perceptibly into a determined state which depends only upon the form of the solid. In this last state, the temperatures of all points fall in the same time, but keep the same ratio among themselves; it is to express this property that the analytical formulas contain terms composed of exponentials and quantities analogous to trigonometric functions.

Many problems of mechanics present analogous results, such as the isochronism of oscillations, multiple resonance of sounding bodies. Common experiments have made them known, and calculation has afterward demonstrated the true cause. As for those which depend upon changes of temperature, they can only be recognized by very precise experiments, but mathematical analysis outstrips observations; it makes up for our senses and gives us a kind of evidence of regular and harmonic movement of heat within the interior of bodies.

These considerations offer a singular

Next Week

THE 137th CLASSIC OF SCIENCE

Presented by the Science News Letter will describe the first-micro-organisms seen by men, in the words of

LEEUWENHOEK

One of the earliest possessors of a microscope

example of the relationship which exists between the abstract science of numbers and natural causes.

When a metal bar is exposed at one end to the constant action of a fire and all its parts have reached their highest degree of heat, the system of fixed temperature corresponds exactly to a table of logarithms; the numbers are the elevations of thermometers placed at different points, and the logarithms are the distances of these points from the fire. In general, the heat distributes itself in the interior of solids, following a simple law expressed by an equation of partial differences, common to physical problems of a different order. Radiation of heat has a manifest relation to the table of sines; for the rays, which go out from any point of a heated surface, differ much among themselves, and their intensity is rigorously proportional to the sine of the angle which their direction makes with an element of the surface. If one could observe for every instant and at every point of a homogeneous solid mass, the changes of temperature, one could find in the series of these observations the properties of recurrent series, hose of sines and logarithms; one would find them, for example, in the diurnal or annual variations of temperatures of the different parts of the terrestrial globe which are near the surface.

One would recognize again the same results and all the principal elements of general analysis in the vibrations of elastic media, in the properties of lines or curved surfaces, in the movements of stars and in those of light or fluids. It is so also with the functions obtained by successive differentiations, which serve in the development of infinite series and in the numerical resolution of equations, corresponding also to some physical properties. The first of these functions, or fluxion properly so-called, expresses, in geometry, the inclination of the tangent of curved lines, and, in dynamics, the rate of motion during a variable movement: it measures, in the theory of heat, the quantity which is lost from every part of a body across a given surface. Mathematical analysis has thus the necessary connection with sensible phenomena; its object is never created by the mind of man; it is a pre-existing element of the universal order and has nothing of the contingent and the fortuitous; it is stamped on all nature.

Science News Letter, October 11, 1930

ENGINEERING

Use of Rubber Paving Brick Reported to Road Congress

RUBBER BRICKS have been used in slapstick movie comedies for years, but in some parts of Great Britain the streets are now paved with them. In a report to the Sixth International Road Congress held in Washington this week a British delegate told of the success that rubber paving has had in London, Newcastle, Edinburgh and Glasgow.

The first experiments to substitute rubber for brick and asphalt were made in 1913, it was stated. A rubber pavement in Glasgow, consisting of blocks of rubber 9x4½x1½ inches, was laid on a concrete base in 1923.

"Traffic in Glasgow is some of the heaviest and most trying class," the report states. "The cap of one block came away from its tread in 1925, this is the only defect reported. The paving is in good condition and shows no apparent wear after six years' use."

An installation in London was in New Bridge Street, which bears some of the city's heaviest traffic, with 17,623 vehicles, or 51,100 tons between 8 A. M. and 8 P. M., in addition to considerable night traffic. This was laid in 1926.

"After two years of wear, 416 blocks, or say four per cent., were renewed, and now at the end of the third year approximately another ten per cent. have to be renewed," the report states. "The defects are in the nature of blisters and the subsequent peeling off of thin layers of the cap where blisters appeared. The layers stripped off in no case extend the full surface of a block and are about one-fifth of an inch thick; the defects cause no inconvenience to traffic, but they collect dirt and are a blemish."

The paving costs about $22.00 a square yard, laid without foundation, it was stated.

Three Dots, Road Closed

Three black dots, on a white sign with a red border, mean "Road Closed," if you encounter them on a road in Germany. This has proven much more satisfactory than a more complicated international system of symbols that has been urged, it was stated in a report of a German delegation to the Road Congress.

"Attempts to indicate by various symbols on the face of the signs the particular types of vehicle to which the restriction is applicable, have not been entirely satisfactory, because single pictures do not stand out clearly from their background when viewed from a distance," the report states. "This was confirmed by experimental investigations carried out by the Psychological Research Board of the Police Institute for Technic and Traffic.

"These experiments, which so far have only been conducted in the laboratory and are not completed, have shown that the time required to grasp the meaning of the international symbol system is about twice that required in the case of the dot system. Even if the symbols on the signs were still more

STATEMENT OF THE OWNERSHIP, MANAGEMENT, CIRCULATION, ETC., REQUIRED BY THE ACT OF CONGRESS OF AUGUST 24, 1912

Of SCIENCE NEWS LETTER published weekly at Baltimore, Md., for October 1, 1930.

Washington }
District of Columbia } ss.

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Watson Davis, who, having been duly sworn according to law, deposes and says that he is the Editor of the SCIENCE NEWS LETTER and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management, etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, embodied in section 411, Postal Laws and Regulations, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are:

Editor, Watson Davis, 21st and B Sts., Washington, D. C.

2. That the owner is:

Science Service, Inc., 21st and B Sts., Washington, D. C., an endowed non-profit making corporation operating as the institution for the popularization of science, with no stock.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent. or more of total amount of bonds, mortgages, or other securities are: None.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

Watson Davis,
Editor.

Sworn to and subscribed before me this 13th day of September, 1930.

[SEAL]

Charles L. Wade.

(My commission expires April 6, 1933.)