maldi discovered the existence of fringes of light and shade when a beam is received through a narrow slit. Huygens soon afterward advanced the undulatory theory, which was originated independently about the same time by Hooke. This involved them in vigorous disputes with Newton, without the definite establishment of their theory. In 1802, Thomas Young revived the undulatory theory, accounting by it for all the phenomena of interference then known. In 1817, Fresnel extended the researches of Young, and Newton's corpuscular theory began to fall into discredit. The elementary phenomena of polarization were discovered by Malus in 1808, and this subject was afterward studied with great thoroughness by Fresnel, Arago, Biot, and Brewster.

VIII.

ON HEAT.

"THE combustion of a single pound of coal, supposing it to take place in a minute, is equivalent to the work of three hundred horses; and the force set free in the burning of 300 lbs. of coal is equivalent to the work of an able-bodied man for a life-time."

ANALYSIS OF HEAT.

HEAT.

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HEAT.

I. PRODUCTION OF HEAT.

1. Definitions.—*Radiant Energy* is the name of what we receive from the sun, stars, and other heated bodies. It may be manifested as light, as temperature, as chemism, or in all of these ways at the same time.

2. Relation between the Forms of Radiant Energy.—Thrust a cold iron into the fire. It is at first dark, but soon becomes luminous, like the glowing coals.—Raise the temperature of a platinum wire. We quickly feel the radiation of obscure heat-rays. As the metal begins to glow, our eyes detect a red color, then orange combined with it, and so on through the spectrum. At last all the colors are emitted, and the metal is dazzling white. Like light, heat may be reflected, refracted, and polarized. It radiates in straight lines in every direction, and decreases in intensity as the square of the distance increases. It moves with the same velocity as light.

It is believed that each of the forms of radiant energy is merely the manifestation of wave-motion at a special rate.* The longer and slower waves of

* According to Tyndall, 95 per cent. of the rays from a candle are

ether fall upon the nerves of touch, and produce the sensation of heat. The more rapid affect the optic nerve and produce the sensation of light. The shortest and quickest cause chemical changes.

3. Theory of Heat.—Heat is motion. The mole-

invisible or heat-rays. These may be brought to a focus and bodies fired in the darkness.—Each of the five classes of nerves seems to be adapted to transmit vibrations of its own kind, while it is insensible to the others. Thus, if the rate of oscillation be less than that of red, or more than that of violet, the optic nerve is uninfluenced by the waves. We can not see with our fingers, taste with our ears, or hear with our nose. Yet these are organs of sensation and sensitive to their peculiar impressions.—"Suppose, by a wild stretch of imagination, some mechanism that will make a rod turn round one of its ends, quite slowly at first, but then faster and faster, till it will revolve any number of times in a second; which is, of course, perfectly imaginable, though you could not find such a rod or put together such a mechanism. Let the whirling go on in a dark room, and suppose a man there knowing nothing of the rod; how will he be affected by it? So long as it turns but a few times in the second, he will not be affected at all unless he is near enough to receive a blow on the skin. But as soon as it begins to spin from sixteen to twenty times a second, a deep growling note will break in upon him through his ear; and as the rate then grows swifter, the tone will go on becoming less and less grave, and soon more and more acute, till it will reach a pitch of shrillness hardly to be borne, when the speed has to be counted by tens of thousands. At length, about the stage of forty thousand revolutions a second, more or less, the shrillness will pass into stillness; silence will again reign as at first, nor any more be broken. The rod might now plunge on in mad fury for a long time without making any difference to the man; but let it suddenly come to whirl some million times a second, and then through intervening space faint rays of heat will begin to steal toward him, setting up a feeling of warmth in his skin; which again will grow more and more intense, as now through tens and hundreds and thousands of millions the rate of revolution is supposed to rise. Why not billions? The heat at first will be only so much the greater. But, lo! about the stage of four hundred billions there is more—a dim red light becomes visible in the gloom; and now, while the rate still mounts up, the heat in its turn dies away, till it vanishes as the sound vanished; but the red light will have passed for the eye into a yellow, a green, a blue, and, last of all, a violet. And to the violet, the revolutions being now about eight hundred billions a second, there will succeed darkness—night, as in the beginning. This darkness too, like the stillness, will never more be broken. Let the rod whirl on as it may, its doings can not come within the ken of that man's senses."

cules of a solid are in constant vibration. When we *increase* the rapidity of this oscillation, we heat the body; when we *decrease* it, we cool the body. The vacant spaces between the molecules are filled with ether. As the air moving among the limbs of a tree sets its boughs in motion, and in turn may be kept in motion by the waving of branches, so the ether puts the molecules in vibration, or is thrown into vibration by them.—*Example:* Insert one end of a poker in the fire. The particles immersed in the flame are made to vibrate intensely; the swinging molecules strike their neighbors, and so on, continually, until the oscillation reaches the other end. If we handle the poker, the motion is imparted to the delicate nerves of touch; they carry it to the brain, and pain is felt. In popular language, "the iron is hot," and we are burned. If, without touching it, we hold our hand near the poker, the ether-waves set in motion by the vibrating molecules of iron strike against the hand, and produce a less intense sensation of heat. In the former case, the fierce motion is imparted directly; in the latter, the ether acts as a carrier to bring it to us.

4. The Sources of Heat are the sun, the stars, and mechanical and chemical energy.

(1.) The molecules of the sun and stars are in rapid vibration. These set in motion waves of ether, which are propagated across the intervening space, and meeting the earth, give up their motion to it. (2.) Friction and percussion produce heat, the motion of a mass being changed into motion among molecules.* (3.) Chemical action is seen in fire. The oxygen of the air has an affinity for the carbon and hydrogen of the fuel. They combine, and chemical energy is transformed into that of sensible heat.

5. Mechanical Equivalent of Heat (*Joule's Law*).—In these various changes of mechanical motion into motion of molecules no energy is destroyed, though some of it may be so transformed as to become incapable of being made to do *useful* work. If the energy transformed by the fall of a blacksmith's hammer on his anvil could be gathered up, it would be sufficient to lift the hammer to the point from which it fell. *A pound-weight falling vertically 772 feet, will generate enough heat to raise the temperature of 1 pound of water through 1° F.;* conversely, this amount of heat is the equivalent of the energy required to lift 1 pound mechanically to a height of 772 feet. This important truth was first demonstrated by Mr. Joule, of Manchester, England, and we express it by saying 772 foot-pounds is the mechanical equivalent of heat. Expressed in metric measures, it is 424 kilogram-meters for 1° C.

* A horse hits his shoes against a stone and "strikes fire"; little particles of the metal being torn off are heated by the shock, and some of the energy is manifested also as light.—A train of cars is stopped by the pressure of the brakes. In a dark night, we see the sparks flying from the wheels, the motion of the train being converted into heat.—A blacksmith pounds a piece of iron until it glows. His strokes set the particles of metal vibrating rapidly enough to send ether-waves of such swiftness as to affect the eye of the observer.—As a cannon-shot strikes an iron target, a shower of sparks is scattered around.—Were the earth instantly stopped, enough heat would be produced to "raise a lead ball the size of our globe to 384,000° C." If it were to fall to the sun its impact would produce a thousand times more heat than its burning.

II. PHYSICAL EFFECTS OF HEAT.

1. Expansion.—If the molecules of a body have an increase of energy imparted to them they swing, like pendulums, through wider arcs. Each tends to push against its neighbor, and the mass as a whole grows larger. Hence the general law, "Heat expands and cold contracts," cold being merely a relative term implying the withdrawal of energy. The ratio of the increase of volume to the original volume for a change of 1° in temperature is called the *Co-efficient of Expansion.* Generally this is greatest for gases, less for liquids, and least for solids, each particular substance having its own co-efficient. The force of expansion is for many substances irresistible. A rise in temperature of 80° F. will lengthen a bar of wrought-iron, 10 feet long, about $\frac{1}{17}$ of an inch; and if its cross-section is one square inch it will push in expanding with a force of about 25 tons. When the metal cools it will contract with the same force.*

A familiar application of expansion is in the pen-

* A carriage-tire is put on when hot, in order that, when cooled, it may bind the wheel together.—Rivets used in fastening the plates of steam-boilers are inserted red-hot.—"The ponderous iron tubes of the Britannia Bridge writhe and twist, like a huge serpent, under the varying influence of the solar heat. A span of the tube is depressed only a quarter of an inch by the heaviest train of cars, while the sun lifts it $2\frac{1}{2}$ inches." The same may be noticed on the great Brooklyn Bridge, more than a mile long, where an allowance of nearly a yard has to be made for expansion with the change of seasons.—The Bunker-hill monument nods as it follows the sun in its daily course.—Tumblers of thick glass break on the sudden application of heat, because the surface dilates before the heat has time to be conducted to the interior.