

PHYSICS

Heat Is Motion

"A Classic of Science"

Heat as the Kinetic Energy of Molecules in Motion is Explained by a Great 19th Century English Physicist

THEORY OF HEAT. By J. Clerk Maxwell. London: Longmans, Green, and Co. 1871.

IT IS MANIFEST that a body may be hot without any motion being visible, either of the body as a whole, or of its parts relatively to each other. If, therefore, the body is hot in virtue of motion, the motion must be carried on by parts of the body too minute to be seen separately, and within limits so narrow that we cannot detect the absence of any part from its original place.

The evidence for a state of motion, the velocity of which must far surpass that of a railway train, existing in bodies which we can place under the strongest microscope, and in which we can detect nothing but the most perfect repose, must be of a very cogent nature before we can admit that heat is essentially motion.

Let us therefore consider the alternative hypothesis—that the energy of a hot body is potential energy, or, in other words, that the hot body is in a state of rest, but that this state of rest depends on the antagonism of forces which are in equilibrium as long as all surrounding bodies are of the same temperature, but which as soon as this equilibrium is destroyed are capable of setting bodies in motion. With respect to a theory of this kind, it is to be observed that potential energy depends essentially on the relative position of the parts of the system in which it exists, and that potential energy cannot be transformed in any way without some change of the relative position of these parts. In every transformation of potential energy, therefore, motion of some kind is involved.

Now we know that whenever one body of a system is hotter than another, heat is transferred from the hotter to the colder body, either by conduction or by radiation. Let us suppose that the transfer takes place by radiation. What-

ever theory we adopt about the kind of motion which constitutes radiation, it is manifest that radiation consists of motion of some kind, either the projection of the particles of a substance called caloric across the intervening space, or a wave-like motion propagated through a medium filling that space. In either case, during the interval between the time when the heat leaves the hot body and the time when it reaches the cold body, its energy exists in the intervening space in the form of the motion of matter.

Cold Body Unnecessary

Hence, whether we consider the radiation of heat as effected by the projection of material caloric, or by the undulations of an intervening medium, the outer surface of a hot body must be in a state of motion, provided any cold body is in its neighborhood to receive the radiations which it emits. But we have no reason to believe that the presence of a cold body is essential to the radiation of heat by a hot one. Whatever be the mode in which the hot body shoots forth its heat, it must depend on the state of the hot body alone, and not on the existence of a cold body at a distance, so that even if all the bodies in a closed region were equally hot, every one of them would be radiating heat; and the reason why each body remains of the same temperature is, that it receives from the other bodies exactly as much heat as it emits. This, in fact, is the foundation of Prevost's Theory of Exchanges. We must therefore admit that at every part of the surface of a hot body there is a radiation of heat, and therefore a state of motion of the superficial parts of the body. Now this motion is certainly invisible to us by any direct mode of observation, and therefore the mere fact of a body appearing to be at rest cannot be taken as a demonstration that its parts may not be in a state of motion.

Hence part, at least, of the energy of

a hot body must be energy arising from the motion of its parts, or kinetic energy.

The conclusion at which we shall arrive, that a very considerable part of the energy of a hot body is in the form of motion, will become more evident when we consider the thermal energy of gases.

Every hot body, therefore, is in motion. We have next to enquire into the nature of this motion. It is evidently not a motion of the whole body in one direction, for however small we make the body by mechanical processes, each visible particle remains apparently in the same place, however hot it is. The motion which we call heat must therefore be a motion of parts too small to be observed separately; the motions of different parts at the same instant must be in different directions; and the motion of any one part must, at least in solid bodies, be such that, however fast it moves, it never reaches a sensible distance from the point from which it started.

We have now arrived at the conception of a body as consisting of a great many small parts, each of which is in motion. We shall call any one of these parts a molecule of the substance. A molecule may therefore be defined as a small mass of matter the parts of which do not part company during the excursions which the molecule makes when the body to which it belongs is hot. . .

Kinetic Theory of Gases

A gaseous body is supposed to consist of a great number of molecules

The Eclipse of 1868

was noted for the discovery of a method of seeing prominences on the sun at any time.

JANSSEN AND LOCKYER

made the discovery independently. Their reports will form

THE NEXT CLASSIC OF SCIENCE



JAMES CLERK MAXWELL

—*physicist, who made many fundamental discoveries in the fields of heat and electromagnetism.*

moving with great velocity. During the greater part of their course these molecules are not acted on by any sensible force, and therefore move in straight lines with uniform velocity. When two molecules come within a certain distance of each other, a mutual action takes place between them, which may be compared to the collision of two billiard balls. Each molecule has its course changed, and starts on a new path. I have concluded from some experiments of my own that the collision between two hard spherical balls is not an accurate representation of what takes place during the encounter of two molecules. A better representation of such an encounter will be obtained by supposing the molecules to act on one another in a more gradual manner, so that the action between them goes on for a finite time, during which the centres of the molecules first approach each other and then separate.

We shall refer to this mutual action as an Encounter between two molecules, and we shall call the course of a molecule between one encounter and another the Free Path of the molecule. In ordinary gases the free motion of a molecule takes up much more time than that occupied by an encounter. As the density of the gas increases, the free path diminishes, and in liquids no part of the course of a molecule can be spoken of as its free path.

In an encounter between two molecules we know that, since the force of

the impact acts between the two bodies, the motion of the centre of gravity of the two molecules remains the same after the encounter as it was before. We also know by the principle of the conservation of energy that the velocity of each molecule relatively to the centre of gravity remains the same in magnitude, and is only changed in direction.

Distribution of Velocity

Let us next suppose a number of molecules in motion contained in a vessel whose sides are such that if any energy is communicated to the vessel by the encounters of molecules against its sides, the vessel communicates as much energy to other molecules during their encounters with it, so as to preserve the total energy of the enclosed system. The first thing we must notice about this moving system is that even if all the molecules have the same velocity originally, their encounters will produce an inequality of velocity, and that this distribution of velocity will go on continually. Every molecule will then change both its direction and its velocity at every encounter; and, as we are not supposed to keep a record of the exact particulars of every encounter, these changes of motion must appear to us very irregular if we follow the course of a single molecule. If, however, we adopt a statistical view of the system, and distribute the molecules into groups, according to the velocity with which at a given instant they happen to be moving, we shall observe a regularity of a new kind in the proportions of the whole number of molecules which fall into each of these groups.

And here I wish to point out that, in adopting this statistical method of considering the average number of groups of molecules selected according to their velocities, we have abandoned the strict kinetic method of tracing the exact circumstances of each individual molecule in all its encounters. It is therefore possible that we may arrive at results which, though they fairly represent the facts as long as we are supposed to deal with a gas in mass, would cease to be applicable if our faculties and instruments were so sharpened that we could detect and lay hold of each molecule and trace it through all its course. . . .

"Maxwell's Demon"

Before I conclude, I wish to direct attention to an aspect of the molecular theory which deserves consideration.

One of the best established facts in

thermodynamics is that it is impossible in a system enclosed in an envelope which permits neither change of volume nor passage of heat, and in which both the temperature and the pressure are everywhere the same, to produce any inequality of temperature or of pressure without the expenditure of work. This is the second law of thermodynamics, and it is undoubtedly true as long as we can deal with bodies only in mass, and have no power of perceiving or handling the separate molecules of which they are made up. But if we conceive a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are still as essentially finite as our own, would be able to do what is at present impossible to us. For we have seen that the molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform, though the mean velocity of any great number of them, arbitrarily selected, is almost exactly uniform. Now let us suppose that such a vessel is divided into two portions, A and B, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole, so as to allow only the swifter molecules to pass from A to B, and only the slower ones to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of thermodynamics.

Science News Letter, July 23, 1932

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The Science Service radio address next week will be on the subject,

**EARTHQUAKES:
WHAT ARE THEY?**

by

Dr. J. B. Macelwane

Professor of Geophysics at St. Louis University, St. Louis, and president of the Jesuit Seismological Association

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