THE CAUSE OF MOTION IN THE RADIOMETER.

IT has been satisfactorily determined that the fly-wheel of the radiometer will not revolve in a bulb from which all residual gas has been removed, and that it will not revolve from the action of light from which heat has been eliminated. These determinations demonstrate that the motion of the fly must result in some way from the action of heat on the residual gas in the bulb. But beyond this, demonstration has not yet gone. The theory generally adopted by scientists is that the application of heat increases the vibration of the molecules of which the residual gas is constituted, and that, heat being more readily absorbed by the black sides than by the bright sides of the vanes of the fly-wheel, the molecules in contact with, or adjacent to, the black sides of the vanes thus become more heated, and vibrate with more force, than the molecules on the opposite side; and this increased vibration of the molecules against the black sides of the vanes pushes them around, thus causing the rotation.

Again, when the bulb has been heated and is cooling, the blackened sides of the vanes cool more rapidly than the bright sides, and consequently the vibration diminishes more rapidly on that side, and, the vanes being pushed by the greater vibration on the bright sides, the fly revolves backwards. This explanation is plausible, but it has not been demonstrated; and, with our present knowledge of molecules and of their vibrations, its demonstration is impossible.

There is another explanation equally plausible, which, I think, can be demonstrated. It is that the heat imparts to the residual gas in the bulb an impetus to motion in a direction radiant or tangential from the source of heat. If we suppose that the effect of heat on the tenuous matter in the bulb of the radiometer is to impart to it an impetus to move in a direction away from the source of heat, then all the results follow which are supposed to follow from molecular vibration. The particles of tenuous matter in contact with the blackened sides of the vanes, receiving more heat, would feel more intensely the impetus to radiant motion, and would push the vanes around; and again, when, in process of cooling, the greater heat is on the bright sides of the vanes, the particles in contact with that side, having the greater impetus, would push the vanes in the opposite direction.

The general effect of heat on matter is to increase its tenuity. By expansion, commencing with the solid form, heat reduces matter to the liquid, and then to the gaseous form, or, as in some conditions of matter, causes it to pass directly from the solid to the gaseous form without having become liquid; and, after reaching the gaseous form, the further application of heat increases the expansion and consequent tenuity, so far as has been observed, indefinitely. But if we suppose that matter, after reaching a certain degree of tenuity, begins to resist further expansion, the effect of the application of heat to matter in that condition would be necessarily to put the matter in motion in a direction radiant from the source of heat; and this motion would continue until the matter reached a temperature where no expansion was required.

Motion, or increase of tension, which is merely resisted motion, must result when heat is applied to matter; and, if the matter resists expansion, it must move to a place where no expansion is required, unless restrained by a countervailing force.

After various efforts to find some means of determining whether the motion imparted by the heat to the residual gas in the radiometer was vibratory or radiant, it occurred to me that a simple and satisfactory test could be found by applying radiant heat to the bulb from all directions at the same time. If the motion was caused by increased vibration, it could make no difference from what direction the radiation came; but if the motion was the result of an impetus imparted to the residual gas to move in a direction radiant from the source of heat, then, if the radiation came from all directions at once, the impetus to motion in any given direction would be counteracted, and the fly would not move. Some crude experiments, such as could be made by an amateur without skill or facilities, show very clearly, according to this test, that the motion of the residual gas is radiant from the source of heat, and not mere vibration.

A piece of iron pipe four inches in diameter was heated sufficiently to cause the fly of the radiometer to revolve rapidly when brought within three or four inches of it; and the radiometer was then suspended inside of the pipe, the fly being about three inches from the top of the pipe. The fly at first revolved very rapidly, but in a few seconds began to move slower, and at the expiration of three minutes had come to a full stop. I had no thermometer which could measure the temperature inside the pipe, but it was sufficient to char paper. The radiometer lost some of its delicacy by the heating, but the experiment was repeated with the same radiometer, and with the same result. The heated pipe caused the fly to revolve when the radiometer was brought near it on the outside, but stopped in a few minutes when the radiometer was suspended inside of the pipe.

To be certain that the injury to the radiometer in the first experiment did not affect the result, two new and very delicate radiometers were obtained. These were suspended from a rod so that while one hung in the pipe, the other would hang on the outside two inches from the pipe. The pipe was again heated, but more carefully, so as not to injure the radiometers; and they were suspended, one on the inside, and the other on the outside, of the pipe. The fly of the radiometer on the inside of the pipe revolved at first very rapidly, but in a few seconds began to go slower, and finally stopped; while the one on the outside kept up a steady motion, diminishing in speed very slowly as the pipe cooled. The experiment was repeated; the radiometer which had been on the outside of the pipe in the first experiment, being placed this time on the inside. The result was the same: the fly of the inside radiometer stopped, while the fly of the one outside of the pipe continued to revolve. Unless there is something in the nature of molecular vibration which has escaped my comprehension, it is impossible to account for the difference of effect in these two radiometers, operated on from the same source of heat, on any theory of vibratory motion in the residual gas; but it is just what ought to result if the heat imparts to the residual gas an impetus to motion radiant from the source of heat.

The importance of this determination is the chief reason for doubting its accuracy; but, surely, enough has been indicated to induce those who have the requisite skill and facilities to continue the experimental work until the question is satisfactorily settled.

The proposition that heat applied to highly tenuous matter imparts an impetus to motion in a direction radiant from the source of heat, explains the puzzling phenomena of comets' tails. "The tail, or train," says Professor Young (*General Astronomy*, art. 727), "is a streamer of light which ordinarily accompanies a bright comet, and is often found even in connection with a telescopic comet. As the comet approaches the sun, the tail follows it much as the smoke and steam from the locomotive trail after it. But that the tail does not really consist of matter simply left behind in that way, is obvious from the fact that, as the comet recedes from the sun, the train precedes it instead of following. It is always directed away from the sun, though its precise position and form are to some extent determined by the comet's motion. There is abundant evidence that it is a material substance in an exceedingly tenuous condition, which in some way is driven from the comet and then repelled by some solar action."

Professor Newcomb thus describes the phenomenon (*Popular Astronomy*, pp. 413, 414): "It has long been evident that the tail could not be an appendage which the comet carried along with it, and this for two reasons,—first, it is impossible that there could be any cohesion in a mass of matter of such tenuity that the smallest stars could be seen through a million miles of it, and which, besides, constantly changes in form; secondly, as a comet flies around the sun in its immediate neighborhood, the tail appears to move from one side of the sun to another with a rapidity which would tear it to pieces and send the separate parts flying off in hyperbolic orbits, if the movement were real. The inevitable conclusion is, that the tail is not a fixed appendage to the comet which the latter carries with it, but a stream of vapor rising from it like smoke from a chimney. As the line of smoke which we now see coming from the chimney is not the same which we saw a minute ago, because the latter has been blown away and dissipated, so we do not see the same tail of a comet all the time, because the matter which makes up the trail is constantly streaming outwards, and constantly being replaced by new vapor arising from the nucleus. The evaporation is, no doubt, due to the heat of the sun; for there can be no evaporation without heat, and the tails of comets increase enormously as they approach the sun. Altogether, a good idea of the operations going on in a comet will be obtained if we conceive the nucleus to be composed of water or other volatile fluid, which is boiling away under the heat of the sun, while the tail is a column of steam rising from it.

"We now meet a question to which science has not yet been able to return a conclusive answer,—'Why does the mass of vapor always fly away from the sun?' That the matter of the comet should be vaporized by the sun's rays, and that the nucleus should thus be enveloped in a cloud of vapor, is perfectly natural, and entirely in accord with the properties of matter which we observe around us; but, according to all known laws of matter, this vapor should remain around the head, except that the outer portions would be gradually detached, and thrown off into separate orbits. There is no known tendency of vapor, as seen on the earth, to recede from the sun, and no known reason why it should so recede in the celestial spaces."

The uniformity of nature justifies the inference that the tendency of highly tenuous matter to recede from the source of heat, here observed in the celestial spaces, will certainly be found in terrestrial matter when we reach the requisite conditions. The first supposition of Mr. Crookes, namely, that the rays of heat exerted a propelling force on the solid matter of the vanes in vacuum, has no analogy in the phenomena above described; but the hypothesis that the rays of heat exert this force on the residual gas in the bulb seems to be entirely in accord with what occurs in the celestial spaces. The cometary matter, having become extremely tenuous, is put in motion in a direction radiant from the sun, the source of heat. It was in the effort to find operative in terrestrial matter the force which causes the projection of a comet's tail, that my attention was attracted to the consideration of the cause of motion in the radiometer.

The tenuity of the matter in the bulb can be measured; and it would be interesting to know at what degree of tenuity the phenomenon will appear, when it reaches the maximum, and when, as perfect vacuum is approached, it disappears. It is evident that the phenomenon results from the tenuity, and not from the temperature, of the residual gas: for a radiometer immersed in melting ice and salt, and exposed to the sun, will revolve rapidly. Heat causes tenuity by expansion, and during this process heat is absorbed: but it seems from this determination, that, when a certain degree of tenuity is reached, matter begins to lose its capacity to absorb heat by further expansion, and then it develops the tendency to recede from the source of heat, the tendency increasing with increase of heat and tenuity. The work of pushing around the fly in the radiometer requires a momentum which is the product of the impetus and mass of the residual gas in the bulb; and, whether the motion be vibratory or tangential, it is possible to reduce the mass of gas in the bulb to so small a quantity that no possible impetus would put the fly in motion.

The phenomenon of incandescence also seems to indicate that matter reaches a condition of tenuity at which it begins to resist further expansion. In his beautiful description of the phenomena of combustion and incandescence in his "New Chemistry," Professor Josiah P. Cooke leaves no doubt that the incandescence incident to combustion results from the resistance of matter to heat-work. It is true that he does not refer to this as the cause of incandescence, but he shows most clearly that ordinary heat-work in matter is to produce chemical re-action or expansion, or both: and, when these are free and unrestricted, no incandescence appears; but when this work is resisted, incandescence results. Vibratory motion always results from two forces, that is, from force resisted; and, light being a form of vibratory motion more intense than that of heat, it is certainly not improbable that the light from combustion is the result of the resistance of matter to the less intense vibratory motion of heat. Assuming this to be true, we have a very simple explanation of the incandescence of highly tenuous matter. The Geissler tubes, Crookes's tubes, Tyndall's tubes, and many other phenomena, demonstrate that highly tenuous matter becomes incandescent from the application of heat at a temperature far below that required for incandescence in matter less tenuous; and the same thing seems to occur in a comet's tail, which shines with a light of its own, and in the *aurora borealis*.

If it be true that when matter reaches a certain degree of tenuity it begins to resist further expansion, we ought to expect it to become incandescent at low temperatures, the temperature at which the phenomenon would occur being determined by the degree of tenuity. Professor Tyndall was not looking for this law in his experiments, but they come very near demonstrating its existence.

The proposition that matter at a certain degree of tenuity resists further expansion, and for this reason, on the application of heat, is put in motion in a direction radiant from the source of heat, and becomes incandescent at low temperatures, does not involve a denial of the molecular theory of matter, nor of the kinetic theory of gases. The proposition is entirely consistent with the theory that matter is composed of molecules, and that in the gaseous form, or in any other form of matter, these molecules are in constant vibration. It simply requires us to admit, that, if there be molecules in vibration, the vibration, like every thing else in nature, can go so far, and no farther. It does require us to deny the deduction from the kinetic theory to the effect that the vibrations are infinite, and that if the molecules of gas "were in space, where no external force could act on them, they would fly apart and disappear in immensity." But this is a mere vagary without legitimate parentage either in reason or experiment, and ought to be discarded from physical science even if the proposition here presented is not established. A much more serious objection to the proposition will come from those who have accepted the motion of the radiometer as visible evidence of molecular vibration. There is something intensely enticing in the idea that we have a wheel revolved by these scientific elves, and the theory has taken deep root in the minds of scientists in this country and in Europe. But the proposition here presented, if it can be scientifically established, opens the way to determinations in respect to the constitution of nature of far greater importance than any here mentioned; and I earnestly hope that some competent scientist will take up the subject, and continue the experimental work until no doubt remains. DANIEL S. TROY.

BOOK-REVIEWS.

Harvard Historical Monographs. Edited by ALBERT B. HART. No. 1. The Veto Power. By EDWARD C. MASON. Boston, Ginn. 8°. $1.

THE study of history is now carried on quite extensively in this country, and new works are constantly appearing; but we cannot say that many of them have a very high value, while not a few are almost unreadable. We are glad, therefore, to meet with a work of the kind that is somewhat superior to the mass, and such a work we have in this pamphlet by Mr. Mason. It has, indeed, no particular excellence of style, but it shows more thought and more political intelligence than is usually the case with such works. The author has not only studied his facts with great care and diligence, but discusses the principles involved, and often with much acuteness. He gives a brief chronological list of all the bills that the Presidents of the United States have vetoed, with an extended account of the more important ones. The body of the work is divided into chapters dealing with the different classes of vetoes, and showing their significance. The constitutional questions involved in the use of the veto power, and also its bearing on party politics, are carefully noted; and, though the author has confined himself to the national government, his work will be of interest and of real use both to students of history and to practical politicians. This series of historical monographs has been well begun, and we wish it good success; but we trust that the writers will not confine themselves to American history nor to the history of politics, but will treat the whole subject of the past life of humanity.