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Attention is called to the "Wants" column. All are invited to use it in soliciting information or seeking new positions. The name and address of applicants should be given in full, so that answers will go direct to them. The "Exchange" column is likewise open.

MOLECULAR MOTION IN HYDRODYNAMICS.

PROFESSOR JOSIAH P. COOKE'S "New Chemistry" has done much to dissipate the mystery which hung around the subject of molecules in my mind before this light was turned on. The physicist, says Professor Cooke, "may prefer to define molecules as those small particles of bodies which are not subdivided when the state of aggregation is changed by heat, and which move as units under the influence of this agent. To the chemist, on the other hand, the molecules determine those differences which distinguish substances. . . . Hence the chemist's definition of a molecure: 'The smallest particles of a substance in which the qualities inhere, or the smallest particles of a substance which can exist by themselves,' for both definitions are essentially the same" ("New Chemistry," pp. 99, 100). When we try to contemplate the magnitude of these small particles, the mind becomes bewildered by the immensity of the minuteness, in the same way that it is bewildered by the immensity of the expansion when it tries to penetrate the uttermost depths of the celestial spaces. But every child who sees the stars at night peers into these depths, and every one who hears the whistle or the rumble of a steam-engine is listening to the sound of work done by the movement of these minute particles

In the long series of experiments which enabled Mr. William Crookes to develop the radiometer and Crookes's tubes, he became very familiar with these small bodies: not quite enough so to handle them as a boy does his marbles, or a sportsman his shot; but he furnished abundant proof, if any further proof was required, that the molecules are separate bodies of matter, each with the capacity for its own proper motion and of doing its own proper work. It is true that he did not prove that one molecule by itself could be made to do work like a rifle ball, because he failed to separate one from all others; but he leaves no doubt that when moving together, like shot from a smooth-bore gun, each molecule has its own proper motion and does its own proper work.

Applying this determination to the phenomena of hydromechanics, the explanation it affords is astonishing for its simplicity. This application is entirely legitimate; for while Mr. Crookes's operations were on matter in gaseous form, it is now well known that all matter can be changed from one form to another, and the change of the substance which is the subject of hydromechanics from the solid form of ice to the liquid form of water and the gaseous form of vapor, are amongst the most obvious of all phenomena. Moreover, the very fact that water flows, demonstrates its separation into particles each capable of independent motion of its own. When grain passes along a conduit in an elevator, or when seed or shot are poured from one bag or vessel into another, there is a flow, each particle having a certain motion of its own; one moves faster and another slower, as it happens to be more or less subjected to the impelling force. If the particles did not change position in respect to each other, the phenomena would be sliding, not flowing. The essential difference between sliding and flowing is that in the one case, the particles, large or small, constituting the moving body, do not necessarily change position in respect to each other, while in the other this change of relative position of the particles really constitutes the movement of the mass. This is beautifully illustrated by pouring corn into a hopper or bin. When the bag or vessel containing the corn is tilted the grains on top begin to move toward the lower side, and presently begin to pour over, and are followed by the others, each one moving in obedience to its own gravitation and the pressure, if any, from grains above it, and its movement is determined by the resistance it encounters from other grains and the sides of the containing vessel. When the operation is completed no two grains probably occupy the same position in respect to each other, in the hopper or bin, that they did in the vessel from which they were poured. It is said that no two grains are precisely alike in every particular, and it is certainly probable that when a mass of grain flows from one vessel into another, no two of them have identically the same motion both in direction and velocity. The gravitational pull on each is the same, but the variation in pressure and resistance to which they are respectively subjected is practically infinite.

This phenomenon of flow is impossible except in a mass composed of particles free to move in respect to each other, and, therefore, the flowing of water is itself sufficient evidence that the water is composed of particles free to move in respect to each other, and that this motion of particles actually occurs whenever water or any other liquid flows. The decomposition of water has demonstrated that the particles composing it are molecules, as defined by Professor Cooke; that is to say, the particles constituting the water itself are the smallest in which the qualities of the substance inhere, and not aggregations of these smallest particles. When a molecule of water is subdivided, as it may be, there is no water left; the water is destroyed, and the matter assumes the form of oxygen and hydrogen, which in certain combination form the molecule of water. (Decomposition, *ex vi termini*, imports a separation of particles; thus when ice is decomposed into water, the particles separate, and there is a further separation of particles when water is decomposed into vapor; therefore when further decomposition destroys the substance itself, it is obvious that the substance must have been subdivided by precedent decomposition into the smallest particles in which its qualities inhere.) It is obvious, therefore, that a vessel full of water is filled with an aggregation of molecules, in the same sense precisely that a bushel measure full of corn is filled with an aggregation of grains.

It is not necessary for us to determine whether the molecules of water are held apart and kept separate by intermolecular vibration, as supposed in the kinetic theory: nor whether the atoms constituting the molecules "are in a state of vibration or rotation motion, in short, comparable to the bodies of the solar system," as suggested by Mr. William Crookes in a recent article in *The Forum*. These interesting qualities, supposed to be possessed by molecules, or by atoms constituting the molecules, but not by particles composed of an aggregation of molecules, are in no wise inconsistent with the obvious fact that molecules possess some of the qualities of other particles of matter: they are subject to the force of gravitation; that is, they have weight. and weight is simply the evidence and measure of the earth's gravitational attraction. Considering, then, that a body of water consists of molecules in the same sense that a body of corn consists of grains, it is manifest that the molecules below the surface must sustain the pressure caused by the weight of the superincumbent molecules above, and that this pressure must increase with the depth, because the quantity of superincumbent molecules increases in the same ratio. An increase of pressure not essentially different occurs whenever particles of any kind are superimposed, as in a grain elevator or a brick wall. It is therefore obvious that nothing but the weight of the superincumbent molecules is necessary to account for hydrostatic pressure; and the molecules being free to move in respect to each other, all the phenomena of hydrostatic pressure must follow, under the general law of the conservation of energy, and its resultant, that motion is always in the direction of least resistance.

But it is not necessary to consider in detail the phenomena of hydrostatic pressure, for they are the secondary and not the immediate results of molecular motion, that is, of the motion of the molecules constituting the water. This motion is the change of position of molecules which constitute the mass or body of water, in respect to each other, and is contra-distinguished from molar motion, which is the change of position of the mass in respect to other masses, or of part of a mass in respect to other parts of the same mass. Molecular motion may occur from convection without molar motion, as when heat below the boiling point is applied to the bottom of a vessel containing water; the heated molecules rise to the surface, and the colder molecules at the surface sink towards the bottom, the body or mass of the water remaining stationary. So there may be molar motion without molecular motion, as when a vessel full of water is moved from one place to another without agitating the water. But in the phenomena of flowing or pouring, both of these motions necessarily occur: there is a change of the position of the molecules if the subject be water, or of the particles if the subject be grain, seed, shot, etc., in respect to each other, and there is also a change of position of the mass in respect to other things, and of parts of the mass in respect to other parts of the same mass. When corn is poured from one vessel into another, we can see the grains change position in respect to each other, and if this did not occur we would know at once that the grain was sliding, not pouring or flowing. We cannot see, even with the most powerful glasses, the molecules of water: one grain of corn equals in bulk many billions of them; but the results of the phenomena of flowing and pouring water leave no more doubt that the molecules do change position in respect to each other, than if we saw the motion of each one separately. Indeed, if the lower part of the water in a vessel be colored with sediment or other matter, and the water be poured into another vessel, we have visible evidence of the change of position of the molecules in respect to each other by the transfusion of the colored particles throughout the mass in the second vessel.

Flowing and pouring are terms used to express different phases of the same phenomenon. What actually occurs in every case of flowing or pouring is the transference of a fluid or semi-fluid—that is, of a mass composed of small particles—from one place or vessel to another by the action of gravitation or some other force acting directly on the mass itself, and not merely on the vessel containing the mass. We know by observation when this phenomenon occurs in a quasi-fluid, consisting of grains or particles large enough to

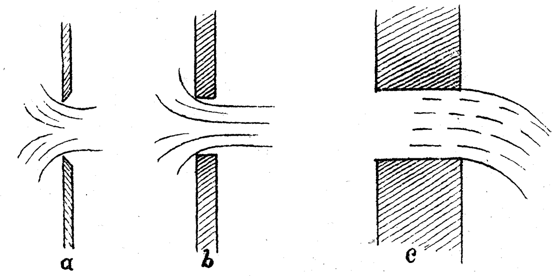

FIG. 20.

be observed, that each grain or particle has a motion of its own, and is subject to the mechanical laws applicable to all moving bodies; and assuming the same to be true in respect to the invisible molecules constituting a fluid proper, we find an explanation of the phenomena of hydraulics, absolutely simple and perfectly satisfactory.

For example we will take the diminution in the diameter of a jet projected from an orifice in a plain surface; and to illustrate the phenomenon we will borrow the following explanation and diagrams from the last edition of the "Encyclopedia Britannica": "When a jet issues from an aperture

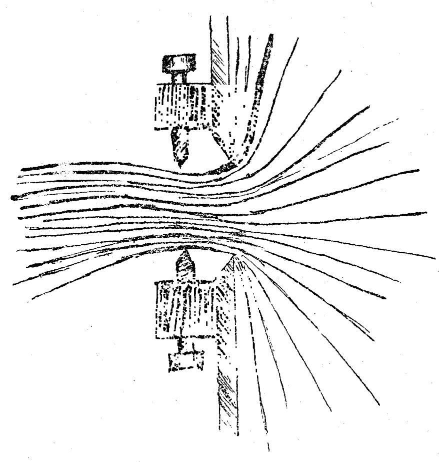

FIG. 21.

in a vessel, it may either spring clear from the inner edge of the orifice as at *a* or *b* [Fig. 20], or it may adhere to the sides of the orifice as at *c*. The former condition will be found if the orifice is beveled outwards as at *a*, so as to be sharp-edged, and it will occur generally for a prismatic aperture like *b*, provided the thickness of the vessel round the aperture is less than the diameter of the jet. But if the thickness is greater the condition shown at *c* will occur. When the discharge takes place as at *a* or *b*, the section of the jet is smaller than the section of the orifice. This is due to the formation of the jet from filaments converging to the orifice in all directions inside the vessel. The inertia of the filaments opposes sudden change of direction of motion at the edge of the orifice, and the convergence continues for a distance of about half the diameter of the orifice beyond it. . . . When the orifice is a sharp-edged orifice in a plain surface, . . . the section of the jet is very nearly five-eighths of the orifice. . . . Hence the actual discharge when contraction occurs is . . . 0.62." "The co efficient of contraction is directly determined by measuring the dimensions of the jet. For this purpose fixed screws of fine pitch [Fig. 21] are convenient. These are set to touch the jet, and the distance between them can be measured at leisure." Without stopping to inquire what reason there may be, either in theory or from observation, for the assumption that the molecules, or particles of water, form themselves into *filaments*, and that the jet is formed from these filaments, it is obvious that the assumption is not necessary to account for the phenomenon, and that the diminution of the jet is the necessary result of well-known mechanical laws operating on each molecule separately.

Each molecule put in motion by the outflow of the jet moves from its position in the vessel towards the orifice: the motion is constantly accelerated until it reaches the orifice, and its velocity is determined by the pressure to which the molecule is subjected and the resistance it encounters. The molecules on the same horizontal plane as the orifice, and

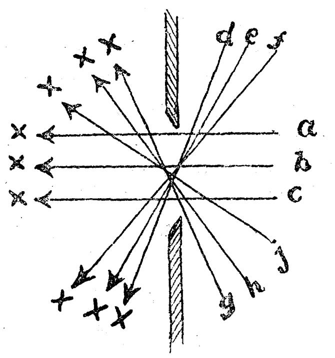

FIG. 21 (modified).

on lines which lead through it, move on these lines directly outwards through the orifice; but the molecules above and below and on each side of the orifice move towards it at an angle to the direction of the outflow, and a part of the kinetic energy of the molecules moving directing in the line of outflow is necessarily consumed in changing the direction of the molecules from above, below, and from the sides, which are moving at an angle to this direction. In other words, it is the ordinary simple problem of moving bodies coming into contact at an angle to their lines of motion, and the direction of motion and kinetic energy are the resultant of the forces operating at the impact.

This can be illustrated by reproducing Fig. 21, omitting the set-screws, and substituting for the filaments a few molecules with lines showing the direction of their motion. The molecules a, b, and c move on the lines ax, bx, and cx, while the molecules d, e, f, move on the lines dx, ex, and fx, and the molecules g, h, i, move on the lines gx, hx, and ix, and so with all the others. The amount of kinetic energy consumed in changing the direction of the molecules moving to the orifice at an angle to the direction of the outflow, determines the diminution of area of the jet as compared with the area of the orifice, and determines also the co-efficient of discharge.

When the point of maximum contraction is reached, the molecules, under another well-known law of mechanics, rebound from each other, and at about the distance from the orifice to the point of maximum contraction, the area of the jet is enlarged so that it equals the area of the orifice, and farther on becomes much larger. The amount of contraction of the jet is necessarily variable, depending as it does on the direction of the molecules when they reach the orifice. If the vessel is narrow, or if, in Fig. 21, an obstruction be placed in the vessel in front of the orifice, so as to diminish the relative number of molecules which can move on the lines ax, bx, and cx, as compared with those which move at an angle to the line of outflow, the area of the jet and co-efficient of discharge will be measurably diminished.

If the orifice is bell-mouthed, or otherwise so constructed that the kinetic energy required to change the direction of all the molecules is exerted before any of them reach the orifice, then there is no contraction of the jet, and the co-efficient of discharge rises from about 0.62 to about 0.96 under the same conditions in other respects.

But it is in determining the depth at which the maximum velocity is found in a flowing stream that the molecular motion becomes of the greatest importance. We again have recourse to the "Encyclopedia Britannica" for a description of the phenomenon, and the existing theories in respect to it: "In the next place, all the best observations show that the maximum velocity is to be found, not at the free surface of the stream, but some distance below it. In the experiments on the Mississippi the vertical velocity curve in calm weather was found to agree fairly well with a parabola, the greatest velocity being at three-tenths of the depth of the stream from the surface. With a wind blowing down-stream the surface velocity is increased and the axis of the parabola approaches the surface. On the contrary, with the wind blowing up-stream the surface velocity is diminished, and the axis of the parabola is lowered, sometimes to half the depth of the stream. The American observers drew from their observations the conclusion that there was an energetic retarding action at the surface of a stream like that due to the bottom and sides. If there were such a retarding action, the position of the filament of maximum velocity below the surface would be explained. It is not difficult to understand that a wind acting on surface ripples should accelerate or retard the surface motion of the stream, and the Mississippi results may be accepted, so far as showing that the surface velocity of a stream is variable when the mean velocity is constant. Hence, observations on surface velocity by floats and otherwise should only be made in very calm weather. But it is very difficult to suppose that in still air there is a resistance at the free surface of the stream at all analogous to that at the sides and bottom. Further, in very careful experiments, Boileau found the maximum velocity, though raised a little above its velocity for calm weather, still at considerable distance below the surface velocity, even when the wind was blowing down-stream with a velocity greater than that of the stream, and when the action of the air must have been an accelerating and not a retarding action. Professor James Thomson has given a much more probable explanation of the diminution of the velocity at and near the free surface. He points out that portions of water, with a diminished velocity by retardation from the sides or bottom, are thrown off in eddying masses and mingle with the rest of the stream. These eddying masses modify the velocity in all parts of the stream, but have their greatest influence at the free surface. Reaching the free surface, they spread out and remain there, mingling with the water at that level, and diminishing the velocity which would otherwise be found there."

Then follow the determinations of Boileau and of Bazin, from which it may be inferred "that the ratio at which the maximum velocity is found to the whole depth ranges from zero to 0.2, except in some artificial channels, where it reached 0.35. The Mississippi experiments give different results, and Bazin inclines to believe that the method of experimenting was untrustworthy. The ratio is greatest in artificial channels with smooth bottoms, and least in natural streams with rough bottoms.

It is difficult to understand what force could cause the portions of water retarded by the sides or bottom to spread themselves with constant uniformity over the unimpeded current flowing below the surface in mid-stream, and especially how the portions retarded by the bottom could rise up through or pass around the more rapid portions above them. But the phenomenon becomes very simple if we suppose that each molecule of the water has its own proper motion, governed by well-known mechanical laws. The impetus to the motion is determined by the pressure, and the actual motion is necessarily the resultant of the difference between the pressure and the resistance. If there were no resistance to the flow of the stream, there would be constant acceleration of motion from top to bottom, just as there is in jets from the side of a vessel, the flow from each being determined by the pressure above it. But in a flowing stream there is great resistance from the sides and bottom, the resistance from the bottom necessarily increasing with the pressure, and this resistance which the molecules receive from the bottom is transmitted, just as pressure is from above, to the molecules adjacent to them. At the depth where the impetus to motion by the pressure from above comes into equipoise with the resistance to motion from below, there ought to be, as there is in fact, the greatest velocity of flow. The resistance from the bottom remains practically constant at any given place in the stream. Wind blowing up-stream increases the pressure by holding back the surface molecules; hence this increase of pressure, the resistance remaining constant, causes the level of maximum velocity to descend. On the other hand, when the wind blows down-stream there is a diminution of pressure, because the surface molecules are pushed forwards in the direction of their movement; hence this diminution of pressure, the resistance still remaining constant, causes the level of maximum velocity to ascend. When the flow is through a round pipe entirely filled with water, and under such pressure that the influence of gravity on the stream itself may be disregarded, it is obvious that the maximum velocity is through the centre of the pipe; the pressure is uniform in all parts of a cross-section of the pipe, and the resistance from friction against the pipe is likewise uniform in all directions from the centre.

It is not necessary to seek further evidence of molecular motion in other phenomena of hydraulics. The evidence is manifest in all the phenomena that I have examined; and the motion is not only consistent with the facts, but the hypothesis of its existence clears up many things which without it are obscure. The explanation which it furnishes of the phenomena of wave motion is especially interesting, but the subject is too large for consideration in this paper.

It seems to me, therefore, that, without further illustration, we may assume as determined that, in all flowing, the particles or molecules constituting the body in which the phenomenon occurs, whether visible or invisible, have each its own proper motion, determined by the forces and resistances to which it is subjected, and that the molar motion is made up of the aggregation of these molecular or particle-motions, — and in this consists the specific difference between flowing and sliding.

This determination is evidently of theoretical importance in hydromechanics and in pneumatics, for the law must apply to the flowing of gas as well as to the flow of liquids, and it may lead to other determinations of great practical value in one or both of these sciences. But since Mr. Crookes has put the molecules of residual gas, in the bulb of the radiometer and in his tubes, to doing mechanical work, the basis has been laid for the development of the science of molecular mechanics, and it is in this new field that this determination has its greatest importance.

The eyes of scientists are being directed to what we might call the small end of nature, and we are discovering that microbes, bacilli, bacteria, etc., are of more importance to mankind than the cedars of Lebanon, or the beasts which roamed beneath them, or the birds which sought shelter in their branches. So in this new science of molecular mechanics, the way to which has been opened up to us by Mr. Crookes's researches, we have the promise of additions to scientific knowledge more important even than the magnificent results which followed the application of mechanical laws to the movements of the celestial bodies.

DANIEL S. TROY.

LETTERS TO THE EDITOR.

**** Correspondents are requested to be as brief as possible. The writer's name is in all cases required as proof of good faith.*

On request in advance, one hundred copies of the number containing his communication will be furnished free to any correspondent.

The editor will be glad to publish any queries consonant with the character of the journal.

Rain-Making.

IN the issue of *Science* of Aug. 28 there appears a communication from Professor H. A. Hazen attacking the artificial rain theory, to some points in which I ask the privilege of making reply.

Professor Hazen commences by saying that "ever since the time of Plutarch the idea has been prevalent that great battles are invariably followed by rain." Now, I would ask where Professor Hazen gets his authority for this broad and sweeping statement? In what writings, following those of Plutarch, does he find any reference to the matter up to the time of Benvenuto Cellini, who is said to have written that a discharge of artillery affected meteorological conditions? Plutarch lived in the first century of the Christian era, Cellini lived in the sixteenth century. Here is a great gap of about fifteen hundred years, and if there is any evidence that the idea prevailed, during that time, that battles caused rain, I challenge my critic to produce it.

A great many writers besides Professor Hazen have brought forward the statement of Plutarch relative to rains following battles as an argument against the concussion theory of rain-production, and some appear to think the argument quite unanswerable. It is, however, very easily disposed of, for the notion referred to by Plutarch was an entirely different matter from that which, so far as we know, did not come into notice until fifteen hundred years later. It was wholly different, in that it did not relate to rains immediately following battles. The only place in which Plutarch mentions the subject is in his life of Marius, in speaking of the defeat of the Ambrones by the Romans. The rains which he says followed that battle did not occur until the winter following. And in mentioning the subject in a general way in connection with this one specific instance, the whole tenor of what he says conveys the idea that the rains he referred to did not occur until a considerable time after the battles, nor until the bodies of the slain had putrified. To give what he says other meaning is to make his attempted explanation of the cause of the rains wholly