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Experiments on the Settlement of Sand in Running Water

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etc. With very few exceptions intransitive verbs have no place in the Ibo language. What affinity, if any, this language may have to the languages of the circumadjacent tribes remains to be properly investigated. Space does not admit of a discussion of the general laws of the Ibos beyond stating that practically all property is entailed. Land is inalienable from the family, and though leased or loaned can always be reclaimed by the owners at will. The head of the family holds the property in trust for his lifetime, and is bound by strict limitations in the administration thereof.

Sufficient has been said, perhaps, to arouse some interest in this great tribe. The Ibo-speaking people are now under British protection, and consequently the savage customs of cannibalism, human sacrifice, infanticide, etc., are being gradually swept away. With the advance of education through the agency of the Government and missionary societies, a new civilization is springing up, but if the sociological upheavals are to prove really beneficial they must be directed into right channels.

There is a vast amount to be done in developing the Ibo country, and England's responsibility is a heavy one in dealing with one of the greatest and most virile tribes in her West African possessions.

EXPERIMENTS ON THE SETTLEMENT OF SAND IN RUNNING WATER.*

By Dr. JOHN S. OWENS.

As the experiments described in my last paper before the Department—published in the *Journal* for January, 1911—dealt only with settlement in still water, the present paper deals with an attempt to determine the rates of settlement of different grades of sand in a current of water, and is a description of certain experiments undertaken with this object in view. As the results obtained are contrary to what might have been expected, it will be necessary to go somewhat carefully into the several factors which might affect these results.

The generally accepted theory is that a particle of higher specific gravity than water will settle to the bottom at the same rate in running as in still water, provided there are no eddies or disturbances, and the motion of the water is strictly stream-line in form. As a purely stream-line motion is seldom or never likely to be found in natural rivers, it follows that natural streams have a somewhat eddying flow, and the inference would be that the rate of settlement in such would always be somewhat slower than that in still water.

In planning out these experiments it was not a case of adopting the best method; but rather the best which circumstances permitted, and as it was soon found impracticable to aim at a direct measurement of the time of settlement in a running stream, an indirect method was adopted, based on the following general principle. If a stream of known depth and of measured velocity carried a grain of sand a certain horizontal distance while settling, the time and rate of settlement could be calculated; then if the fall of sand of the same grade in

* Research Department, January 18, 1912.

still water at the same temperature as the stream was timed, the rates of settlement in running and still water might be compared. There were, of course, many points which had to be considered, but this illustrates the principle worked on. Through the kindness of Mr. Hamon Lestrangle, I had access to a small river running through his property at Holme, Norfolk; and here the experiments were made.

Details of Method adopted.—In order to measure the horizontal travel of a sand grain the following method was devised :—

A board 11 inches wide and 4 feet long was marked transversely on one face by a series of very small ridges or corrugations, running across from side to side and covering the whole face of the board. These ridges were spaced accurately a quarter of an inch apart, crest to crest, and were shaped somewhat like sand-ripples, having a vertical face and a sloping back. The height of the ridges was about a sixteenth of an inch from crest to trough; and it was intended to make these trap the sand grains as they fell, in the same way as sand ripples trap particles of shingle. The ridges were numbered 1 to 192, and the board was provided with four projecting nails on its edge which fitted into slots cut in four stakes: the stakes could be driven into the bed of the river, and the board fixed horizontally to the stakes on or near the bottom, with the vertical faces of the ridges facing upstream. In order to avoid eddies the stakes supporting the board were fixed, two at the downstream end, and two a foot upstream from there, so that 3 feet of board projected unsupported upstream of the stakes. The board was only about five-eighths of an inch thick, so that its upstream edge would not cause much disturbance. Having fixed this board in the bed of the stream and carefully levelled it with a spirit-level, a mark was fixed vertically over the upstream end, or in some cases 1 foot further upstream, and a plumb-bob hung just clear of the water to give a mark for dropping in the sand. A heavy plank crossing the stream at this part made it possible to do this without placing obstructions in the water. In making an observation, the current velocity was first taken by means of a "velocity rod," weighted so as to float vertically in the stream with its lower end just clear of the board, the intention being to get the mean velocity by direct observation; several runs of this were timed and the average taken, each run being about 4 or 5 feet long, as the current was slow, and the path directly over the board. Having obtained the velocity, the temperature was taken, and then a pinch of graded and numbered sand dropped carefully into the water, or rather set free at the surface under the plumb-bob. This was done very carefully, the sand being first moistened and then rubbed into the water at the surface, grain by grain, between the finger and thumb, so as to make certain no lumps of sand fell in, but separated grains; if a lump fell in the experiment was abandoned, the board cleared, and a new one done. When the sand had settled, the number of the ridge on the board which contained the first group of grains was read by means of a roughly made water-telescope, which prevented the surface-ripples obstructing the view. Thus the velocity of current, depth of water, and number of corrugation the sand grain rested in were known.

calling v = velocity of current in f.s,

d = depth in feet,

c = number of corrugation the grains lodged in,

r = rate of settlement of sand in f.s.,

then, since each ridge on the board is $\frac{1}{4}$ " wide, the horizontal travel of a grain

will be = $\frac{c}{48}$ feet, and the time required to travel this distance at the velocity of

the current will be $\frac{c}{48v}$ seconds, which must also be the time required for the sand grain to fall through the depth d ; the rate of fall in f.s. will therefore be $\frac{48dv}{c}$. In the case of a particular experiment with sand 0.036 inch diam., where the depth d was 18", velocity v was 0.37 f.s., and the sand lodged in the ridge number 69, the rate of settlement was $\frac{48 \times 1.5 \times 0.37}{69}$ or 0.386 f.s. This is to illustrate the method adopted.

There were, however, two things which had to be considered before basing conclusions on this method. The first was the fact that the sand grains do not settle from surface to bottom with a uniform velocity, but have an accelerating stage at the start; if this accelerating stage was long enough it would invalidate the above reasoning, which assumes a uniform rate of fall from the start. It is very important, in view of the results obtained, to note further that any effect which the neglect of the accelerating stage in the fall of the grains would have would be in the direction of lengthening the horizontal travel of the sand and giving too slow a rate of settlement as calculated from this travel. A preliminary experiment was made to find if the accelerating stage could or could not be neglected. Two sand grades were taken, the larger about $\frac{1}{10}$ inch diam. and the smaller about $\frac{1}{16}$ inch diam., really a little smaller, as they were graded through sieves of 8 and 40 meshes per inch respectively. The largest grain it was intended to work with in the current was chosen, as in it the accelerating stage would be the longest, therefore its effect would be greatest. These two grades of sand were timed when falling through water in a $\frac{3}{4}$ inch glass tube; (a) through the first 30 inches from surface, and (b) through the first 60 inches from the surface. As the whole accelerating stage was obviously included in the first 30 inches of fall, the time of falling through this part should be more than half the time of falling through 60 inches, if the accelerating stage was important enough to make any difference. Five runs were made with the $\frac{1}{10}$ inch sand, and these gave a mean rate of fall through the first 30 inches = 0.549 f.s., and through 60 inches = 0.546. Clearly, therefore, the error introduced by neglecting the effect of acceleration was more than swamped by the errors of observation, and might be neglected. In the case of the $\frac{1}{16}$ inch grain the mean rate of fall from eight runs through 30 inches was 0.237 f.s., and through 60 inches 0.233 f.s., so that it was considered, with sand below $\frac{1}{10}$ inch diameter, the effect on the accuracy of the results of neglecting the preliminary accelerating stage of fall was so small as to be entirely within the limit of experimental error, and would not therefore affect the result.

The second point which had to be considered was the effect of the accelerating stage of motion with the current. The sand was at rest when placed in the current, and had to be accelerated up to the speed of the current; the question was what, from a quantitative point of view, would be the effect of this on the horizontal travel. It is important to note that the effect on the distance travelled would be to reduce it below what it would be had the sand moved off from the start with the speed of the current, and thus the effects of the two accelerations considered would be in opposite directions. However, to find what this effect might amount to, the distance which the sand would travel horizontally during the period of acceleration was calculated and deducted from the distance which it would travel at the uniform velocity of the current, in order to find by how much the observed travel might fall short of the true if acceleration were neglected. For this purpose the largest grain experimented

with was used so as to obtain the maximum effect; that is, a grain 0.05 inch diameter in a current 1.11 f.s. It was found that the reduction in horizontal travel due to this cause amounted only to about 0.18 of an inch for the whole accelerating stage. Hence it was considered safe to neglect it also, since apparently the total error would not amount to more than 1 per cent. from this cause alone, and considering that the effect of the accelerating stage of the fall operated in the opposite direction, the effect of both combined must be less than of either alone. In fact, when the rate of settlement of the sand in still water is the same as the current velocity the horizontal travel is unaffected, the distance covered being the same as if the sand fell at a uniform velocity and moved forward at the full current velocity.

Experiment I.—In this silicious sand from the seashore was graded through sieves and numbered, and the diameter deduced from the number of meshes per inch, deducting the thickness of the wires. It is probable that this method gives somewhat different results from measurement direct by microscope and micrometer, as used in experiment (2) to be described, the sieves probably measure the smallest diameter and the micrometer the largest; as grains can pass a mesh endwise, whereas they lie on a microscope slide with their greatest diameter horizontal, also the meshes were probably not all strictly the same size.

The corrugated board having been fixed and levelled, the depth, velocity, and temperature measured as described, the sand was dropped in, and the number of the ridge the first group occupied on the board noted. On returning home the same sand grades were timed through a four-foot fall in a $\frac{3}{4}$ -inch glass tube full of water at exactly the same temperature as the stream. The results are worked out and embodied in Table I., only final results being given.

Column (1) gives the reference number or grade of sand.

Column (2) gives the diameter of grain in thousandths of an inch obtained as described.

Column (3) gives the rate of settlement in still water, each observation being the mean of about five runs, which differed very slightly from each other.

TABLE I.—EXPERIMENT (1).

Comparing the rates of settlement of different grades of silicious sand in running and in still water from separate experiments made with each grade of sand in running water on August 12, 1911, and in still water Dec. 27, 1911.

1	2	3	4	5	6
Grade No.	Approximate diameter in thousandths of an inch.	Rate of settlement in still water f.s.	Rate of settlement in running water f.s.	Velocity of current f.s.	Temp. ° Fahr.
1	103	0.715	0.814	0.37	70°
2	80	0.631	0.697	"	"
3	43	0.527	0.565	"	"
4	37	0.379	0.386	"	"
5	18.8	0.265	0.268	"	"
6	15	0.217	0.224	"	"
5	18.8	0.265	0.266	0.327	69
6	15	0.217	0.234	"	"
7	12	0.163	0.171	"	"

In obtaining the rate given in column (4) a mean of five or six separate runs or experiments with each grade was taken.

To give an idea of the regularity of the results—the times of fall of grade 4 through 4 feet in still water and measured in fifths of a second were 52, 50, 53, 55, 54 respectively. Also, with the same grade in the current, in five runs the sand lodged respectively in corrugations number 68, 69, 69, 69, 69, having been dropped in over number 0.

In both the current experiments and the still water the first grains of a group only were noted, since these represented the largest and most spherical; the reasons for this were gone into in my last paper of January, 1911.

It was found in doing Experiment I. that with the finer grades of sand it was very difficult to see the few isolated grains resting on the board which represented the first to fall, and there is a probability in this case that the horizontal travel of the small grades, five to seven was read too long, as the silicious grains were hard to see through the water. It is worth noting this, as owing to it some black sand was procured which was easily visible, and this was used in the next experiment.

If Columns 3 and 4 be compared, it will be seen that in all cases the rate of settlement in the stream was greater than in still water. This appears a most extraordinary result, and its explanation is one of the things which it is hoped the discussion will throw light upon. Of course, the first possibility which will no doubt occur to all is that of error in observation or method. I have gone carefully into the matter and cannot detect any source of error to account for the anomaly, and it may be here stated that the results are consistent with those of four other experiments I have to describe. It is owing to this that the effects of acceleration have been considered at some length.

Experiment II., August 16, 1911.—Settlement of black sand. In this a heavy black sand composed of rounded and polished grains was graded so that a sample was obtained which passed a sieve of 40 meshes per inch and was held on a 50-mesh sieve. The approximate diameter of the largest grains in this was 18 thousandths of an inch. This was dropped carefully into a current as described under Experiment (1). The current velocity was taken by a velocity rod, and three runs over 5 feet each gave exactly 10 seconds, and therefore a velocity of current (mean) of 0.5 f.s.

The temperature of the water was 64.5° F., and depth to surface of board 18 inches. Four trials were made with the sand, and the number of the ridge on which the first grain or group of grains rested was respectively No. 69, 65, 67, 73, average 68.5. As the sand was dropped in one foot upstream of ridge No. 0 on board, this gives an average travel of 2.43 feet, and a rate of settlement of 0.308 foot per second.

In order to compare this result with the rate of settlement in still water, the same grade of black sand was timed over a 4-foot fall in a $\frac{3}{4}$ -inch glass tube filled with water at the same temperature as the current—64.5° F. The time of fall measured in fifths of a second on a stop-watch was for five runs respectively 72, 71, 72, 74, 72, average 72.2, which gives a rate of settlement of 0.277 foot per second. In this case, also, the first grain or the head of a group of grains was timed, and an initial fall of one foot allowed before commencing to time. The rate of settlement in running water as calculated by the method described was 0.308 f.s. as against only 0.277 f.s. in still water, being an increase of about 11 per cent.

Experiment III., August 16, 1911.—I now tried a somewhat different method, which gave a great deal of information with less trouble than those

previously adopted. Having provided myself with a sample of sand of all grades from about one-eighth inch diameter down, and of mixed silicious and black grains, the corrugated board was fixed in the stream as before, and levelled; the depth, velocity, and temperature were measured; and then, at a point 1 foot upstream of corrugation 0, I carefully dropped in the mixed sand. The grains sorted themselves out, and the large settled near the upstream end, the small towards the downstream end of the board. The next step was to lift the board carefully out of its supports, without disturbing the sand, and to measure the diameters of the grains and note the number of the corrugation they rested in. To measure the diameters a micrometer microscope was used measuring to one five-hundredth of an inch, and about five grains in every fifth or tenth groove were measured, the mean being taken as the diameter of grain in any particular groove. Further, the most spherical grains were chosen, so as to eliminate the effect of flatness, since a large flat grain would possibly settle at the same rate as a small spherical grain. In noting the results the black sand was kept separate from the silicious.

The results of this experiment are given in the form of a curve, in which the horizontal travel of each size of grain is plotted against its diameter. In order to obtain a comparable figure for still water to plot with these the rates of settlement of the same sand in still water at the same temperature as the current were obtained experimentally; then, assuming that the grains settled at the same rate in the current as in still water, and taking the depth and current velocity as in the experiment in the river, I calculated the horizontal travel; this distance was plotted for each sand grain against its diameter on the same sheet with the actual travel in the current, and both are shown for the silicious sand in Fig. I. It will be seen that the distance travelled horizontally in the current was less than that as calculated from the rate of settlement in still water at the same temperature. In other words, in this experiment also the rate of settlement in the current was greater than in still water, both obtained as above indicated.

The results obtained with black sand are given in Fig. II. The sand used was black or dark brown, probably ferruginous, with polished rounded grains, and there was no difficulty in picking out and measuring the black grains when

mixed with silicious on the board. In this case also special measurements were made of the rate of settlement of the sand grains in still water at the same temperature as the current in which the board experiment was made. The sand was so very uniform in size of grain that I could not get a sufficient number of the larger grains to measure the rate in still water by noting the travel of the head of a group of graded sand, so in these cases I had to use single grains measured by the microscope micrometer, choosing rounded grains; so that the results obtained are more irregular than they should be. I also suspect that the individual grains may vary in specific gravity, which would also tend in the same direction.

As in the case of the silicious sand, the horizontal travel as actually obtained in the current is plotted in the curve, Fig. II., against the sand diameter; and the theoretical distance which the sand would travel if it settled at the same rate in

the current as in still water is plotted from the still-water results for each sized grain.

In this case also the sand travelled a shorter distance in the current than it should have done if settling at the same rate as in still water; the inference apparently being that it settled more rapidly in the current than in the still water.

All the experiments I have described were made in a little river about 12 feet wide and 1 foot 6 inches deep. The current was very slow and steady and the bottom muddy. The experiments were made in the middle of the stream, and the board rested on the bottom. There was probably a considerable retardation of the bottom layers of current owing to weed, but the neighbourhood of the board was cleared of weed. The velocity of the current did not exceed 0.5 foot per second.

Experiment IV., August 24, 1911.—In order to get a current of higher velocity I had to go to a part of the river where it flowed over a sandy bed, across tidal flats; and here I obtained a current of 1.11 feet per second; but the depth which I could use was only 8 inches.

The velocity of the current was measured as before, with a rod-float nearly reaching to the board, timed over a 6-foot run; the average of five runs being

taken. The temperature of the water was 65° F., and mixed silicious sand was dropped in one foot upstream of the board. When the sand had settled the board was carefully removed, the diameters measured, and number of corrugation the grains rested in noted.

The results are given in the curve, Fig. III., in which the horizontal travel both actual and theoretical as calculated from the rate of settlement in still water is plotted against the diameter of sand grain.

In this case the same curious result appears; that is, the apparent rate of settlement in the current is more rapid than in the still water, and further, the difference is greater than in the case of the slower current experiments.

In this case when the diameters were measured I preserved the board with the sand grains on it by running thin size over it and letting it dry, so that the grains were stuck on that you might be able to see exactly what happened.

On examining the board it will be seen that the coarse sand is near the upstream end (the vertical sides of the ridges faced upstream). The difference in rate of settlement due to shape of particle is also clearly brought out, for large flat grains are found in the same groove with small spherical ones, thus showing that both settled at the same rate. A flat grain and a spherical one of the same diameter are never found in the same groove. From this it is clear that the flat grains settle more slowly than the spherical of the same diameter. The same effect is seen with irregularly shaped grains; they are always found further downstream than the spherical grains. The smallest grain, therefore, in any groove is the most spherical.

Another curious result obtained in this experiment was that on removing the board it was found to be sprinkled evenly from end to end with very fine sand, of from 2 to 6 thousandths of an inch diameter. This made it impossible to rely upon picking out and measuring the sand dropped in when below about 11 thousandths of an inch in diameter. The most interesting inference is, however, that this very fine sand was suspended in the water; the quantity was so small as to be invisible to the eye on looking into the stream, as this appeared quite clear. This fine sand could not have got on to the board from the sample I dropped in, as it settled too slowly, and it was found in the grooves with the coarse and fine grains alike. The river was surrounded by

weed-grown, muddy, tide flats, and hence it could not be blown sand. It would therefore seem that this current of 1.11 f.s. was able to pick up and hold in suspension sand of from 0.002 to 0.006 inch diameter.

Sand of such size formed part of the bed of the river, and was the smallest size of grain on the bed. In another place in the river where the depth was 6 inches and current 2.11 f.s., I trapped in a vessel near the surface of the water grains from 0.002 to 0.008 inch diameter.

Turning now to a consideration of results obtained in Experiments I. to IV., the most curious is the apparently increased rate of deposition in a current. It is obvious, that should this prove to be correct, it can only hold good under certain conditions. A very rapid current, full of swirls, will certainly suspend particles of higher specific gravity than water and thus reduce their rate of settlement; and in the case of Experiment IV. apparently large grains had their rate of fall increased, while those of 0.006 inch diameter were suspended. If it could be showed that the method of measuring current velocities by means of rod-floats gave too high a mean velocity it would explain the results obtained, as it would make the rate of settlement calculated from the rod-float too high. I cannot, however, find any evidence that the velocity rod does not give a practically true mean velocity. A. Cunningham, in his 'Roorkee Hydraulic Experiments,' gives evidence that the rod velocity is a very close approximation to the mean velocity, but states that "the rod velocity is, within limits of practice, always somewhat *less* than the mean velocity past the immersed portion of the rod." Unwin and Merriman, in their books on Hydraulics, support the statement that the rod velocity is a very close approximation to the mean.

I have worked out an elementary case of a body exposed to currents of different velocity and give the results here, as they also show that the rod will travel at a velocity which is the mean of those of the currents it is in. When a current of water strikes an immersed body the pressure may be calculated as follows:—

Let V = velocity of current in f.s., G = density of water, A = area of face exposed to current in square feet, and P = total pressure due to current. Then $P = \frac{KV^2GA}{2g}$, K being a constant depending on the shape of the body. This may be written $P = CV^2$, where C is a new constant = $\frac{KGA}{2g}$.

Considering a body of negligible thickness placed in a current, the upper part travelling at a velocity v_1 , the lower v_2 , and so that the plane of separation divides the surface into two equal parts thus (v_2 being greater than v_1),

and let body move with current at a velocity v_3 , then—

F = driving force = $C(v_2 - v_3)^2$, since body moves faster than v_1 and slower than v_2 .

$R = \text{Resistance} = C(v_3 - v_1)^2$. The question is what value of v_3 will make $F - R = 0$, as the body will move at this velocity. To find this, equate F to R . Thus—

$$\begin{aligned} C(v_2 - v_3)^2 &= C(v_3 - v_1)^2 \\ v_2^2 + v_3^2 - 2v_2v_3 &= v_3^2 + v_1^2 - 2v_3v_1 \\ 2v_3(v_1 - v_2) &= v_1^2 - v_2^2 \\ v_3 &= \frac{v_1^2 - v_2^2}{2(v_1 - v_2)} \\ &= \frac{v_1 + v_2}{2} \end{aligned}$$

which means that the body will travel with a velocity v_3 , equal to the mean between v_1 and v_2 .

There seems, therefore, to be no reason to suspect the velocity of the current in the experiments as being other than the true mean. The known fact that the velocity of a stream reduces from near the surface to the bed would seem to provide a reason for expecting a spherical body to travel *further* horizontally in such a current when falling through a given depth than if the current were uniform throughout. The particle falling from a rapid current into a slower one will always tend, by its inertia, to retain the velocity attained in the rapid layer, and so one would expect its velocity of translation to be a little higher than that of the mean velocity of the current.

The only explanation which I can suggest is this: I showed in my paper in the *Journal* of January, 1911, that bodies settling through still water dispose themselves so that the greatest diameter is horizontal, the effect being that flat sand grains settle more slowly than grains of the same weight and specific gravity, but more spherical shape. That being so, if there is any factor operating in a current to disturb this disposition of settling grains, its effect must be to increase the rate of settlement; that is, if a grain settles at its slowest rate when its greatest surface is horizontal, any departure from this state must increase its rate of fall.

Now, in all streams the current is most rapid near the surface, and gradually reduces towards the bed; therefore a body falling in such a current will have its upper half exposed to a more rapid current than its lower half; there must therefore be a tendency for such a body to spin on a horizontal axis. This tendency can be observed in the case of a rod-float, as it does not lie vertically in the current, but with its upper end in advance of its lower. If, then, a settling sand-grain is caused to spin on a horizontal axis when in a current, it cannot dispose itself to settle at its slowest rate as it would in still water. The couple tending to cause a grain to spin would probably not be effective with very flat grains; but in these experiments such grains were neglected and the more spherical measured, none of which, of course, were true spheres.

Another inference from this is that spherical grains would be unaffected, and would settle at the same rate in running as in still water as far as this factor is concerned. It is a curious coincidence that the only grain of sand which I have noted as being a sphere did give the same rate of fall in still water as obtained in the current for grains of the same diameter; that is, the grain on Fig. II., which has a diameter of twenty-six thousandths of an inch, and is plotted as a square dot.

In conclusion, I have to acknowledge my indebtedness to Mr. Lestrangle, Mr. Algernon Hervey, of Hunstanton, and Mr. Eric Lestrangle, of Heacham, for

facilities given me to do the experiments; to Mr. N. F. Mackenzie for his valuable suggestions, to Mr. E. Wells for his voluntary assistance in making the observations, and to Mr. Pocock, my assistant, for his help both in making observations and working out results.

I should also like to say that I was most ably assisted by my wife in carrying out the experiments and making notes.

Prof. MYRES: We are met this afternoon to discuss a paper by Dr. Owens on some "Experiments on the Settlement of Sand in Running Water." The text of the paper has been circulated to members of the committee, and I will ask Dr. Owens to communicate to us briefly the points on which he would most value discussion.

The following letter was read from Mr. Philip Lake, after the paper:—

"In both Dr. Owens' series of experiments on the fall of sand-grains—in still and in running water—the rate of settlement is deduced from the fall of the first grains that reach the bottom. His experiments, therefore, prove conclusively the interesting fact that in running water some of the grains fall more rapidly than any of those in still water. But they do not show that the average rate is different.

"If a flattened particle is placed in a current in a slanting position with the lower edge up-stream, the current, acting upon its upper surface, will tend, for a short time at least, to make it fall more quickly than in still water; and the difference will be greater as the current is more rapid. This agrees with Dr. Owens' results.

"If, on the other hand, the particle slants in the opposite direction, the current, acting on its lower surface, will tend to make it fall more slowly; but such particles would not be observed in these experiments.

"I do not offer this as more than a suggestion; but it would be interesting if Dr. Owens, with the ingenuity that he has already shown, could devise an experiment to determine the average rate of all the grains. In default of this, observations of the last as well as of the first grain would be of some value."

Dr. STRAHAN: It has occurred to me that the black and white sands are composed of different materials. This may have been taken into account, and I will merely mention that the black sand is chiefly composed of small grains of iron-oxide, the white sand of small grains of quartz, and that the specific gravities of these materials are different. It would be a good test of Dr. Owens' methods to make experiments with black grains only, and again with white grains only, after noting the specific gravity, and to observe the difference in their behaviour.

Dr. OWENS: That is what I did. The black was compared with the black and the white with the white.

Dr. STRAHAN: Did you take the specific gravity? That should be done. Then the explanation of the slower fall of particles in still water than in moving water, which is founded upon Dr. Owens' experiments in illustration of the fall of cylindrical and other bodies, was exceedingly interesting and ingenious; the tendency of rods or discs to get, while sinking, into a position of greatest resistance is most marked. If this explanation is correct, the accelerating influence which is due to the movement in the water putting the grain out of the position of greatest resistance should not be observable when the grain is spherical. Now, it is easy to separate the sand-grains into spheres, rods, or discs, and observations on the behaviour of each would be likely to form a test of the truth of Dr. Owens' explanation.

No. III.—MARCH, 1912.]

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