goes hand in hand with the chemical changes which occur. From the spectroscopic appearance it is argued that the blue precipitated oxide is not a hydrate, but that it does very readily undergo change as the mere alteration of colour which takes place shows. Aqueous solutions of the bromide and iodide of cobalt when acted on by alkalies undergo changes similar to those which the chloride undergoes, and, as in the former cases, the iodide spectrum is always nearer the red end of the spectrum than the corresponding bromide spectrum, and the bromide than the chloride spectrum.

The salts of the oxygen acids when in aqueous solution do not give sharp banded spectra as the haloïd salts do, but only a large shading off absorption like the hydrate of the cobalt chloride.

The other points discussed in detail are, first, the nature of the precipitate formed by the action of sodic or potassic carbonate on a cobaltous salt, and it is shown that the formation of the oxide always found in this precipitate is owing to an after decomposition, the precipitate as first formed being entirely free from all oxide, and it gradually appearing after a short time. The other point is the action of heat on cobalt phosphate dissolved in fused microcosmic salt; when cold there appears somewhat indistinctly a banded spectrum of a phosphate, on heating this the spectrum disappears, and the spectrum of the oxide very distinctly takes it place; on cooling, the first spectrum returns, and this change may apparently be repeated any number of times.

Drawings of all the different spectra are given in the full paper.

IV. "On the Friction of Water against Solid Surfaces of Different Degrees of Roughness." By Professor W. C. Unwin, M.I.C.E., Professor of Hydraulic Engineering at the Royal Indian Engineering College. Communicated by J. H. Cotterill, F.R.S., Professor of Applied Mechanics, Royal Naval College, Greenwich. Received August 31, 1880.

(Abstract.)

These experiments relate to the friction of fluids when flowing against rough solid surfaces. It is well known that a board dragged through water suffers a resistance which, at speeds not very small, varies nearly as the square of the velocity. The fluid surrounding the board does not behave as a solid, but shearing and eddying motions are set up which give rise to losses of energy distributed throughout the fluid mass.

Most of the existing knowledge of fluid friction has been derived from the observation of the flow of water in pipes and canals. But in

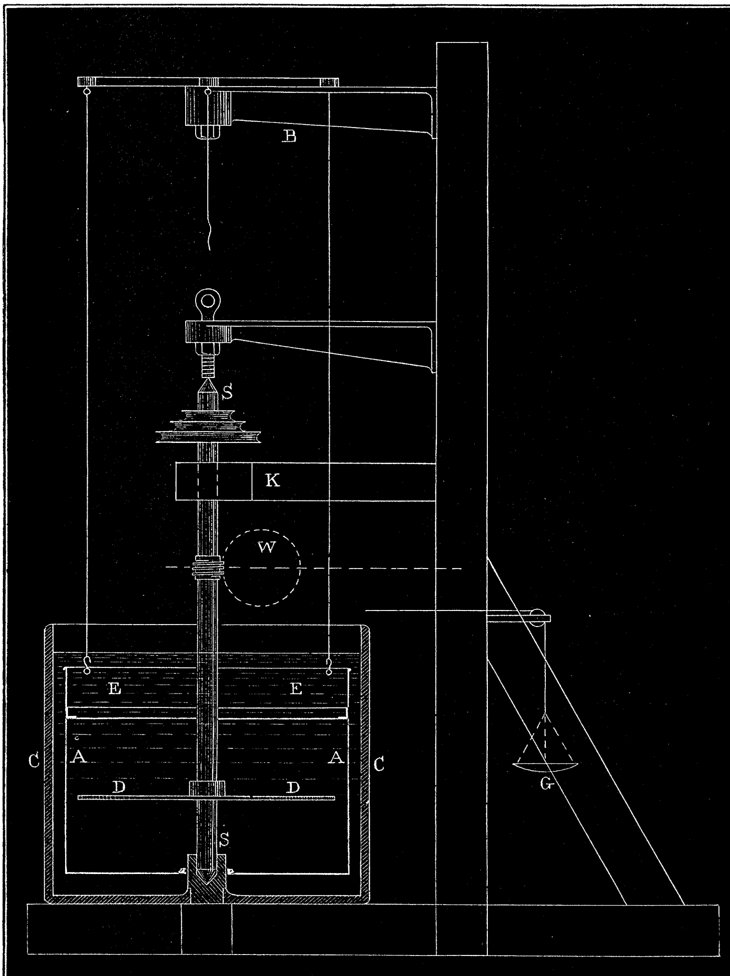
these cases, the motion of the fluid is complex, and the observations themselves are difficult. The principal direct experiments on fluid friction are those of Coulomb and of the late Mr. W. Froude. Coulomb's experiments were made by oscillating a thin disk, suspended in the fluid by a wire, in its own plane. The gradual diminution of the range of the oscillations gave a measure of work lost in fluid friction, on the surface of the disk. Coulomb's experiments were made at very low velocities, and, indeed, the method which he employed would be quite unsuitable for greater speeds of oscillation. The results at which he arrived were these :—(*a.*) The frictional resistance to the motion of the disk varied nearly as the velocity; (*b.*) The friction was nearly independent of the roughness of the surface; (*c.*) The friction was very much increased if the viscidity of the fluid was increased.

Mr. Froude's experiments were made in a very different way. He towed boards of lengths varying from 5 to 50 feet, in a still water canal, and measured by a spring dynamometer the resistance to the motion. His experiments were all made at speeds much higher than those employed by Coulomb. His results may be summarised thus :—(*a.*) The friction varies nearly as the square of the velocity of the board, the precise index of the speed to which the friction is proportional depending on the nature of the surface of the board; (*b.*) The frictional resistance per square foot of the surface of the board is greater for short than for long boards; (*c.*) The frictional resistance varies very greatly with the roughness of the surface of the board.

The differences between the results of the experiments of Coulomb and Froude show that the phenomena of fluid friction at very low and at high speeds are essentially different. It appeared to the author that it would be useful to make some experiments at speeds similar to those in Mr. Froude's experiments, but with an apparatus on a smaller scale, which would permit a greater variation of the conditions of the experiments. A series of disks, of 10 inches to 20 inches in diameter, were rotated in water by an engine, and the resistance to continuous rotation at different speeds was measured. Thus the experiments were virtually the same as Mr. Froude's, but with a surface of infinite length substituted for surfaces of limited length. The roughness of the surface of the disk was varied, the smoothest disks being of turned and polished brass; the roughest having surfaces of sand and gravel cemented on to the metal disk.

The disks were rotated in a cylindrical chamber, the size of which could be varied, so that the mass of water operated on, or the thickness of the layer of water in contact with the disk, could be modified at will. Further, the roughness of the surface of the chamber in which the disks were rotated was varied in the same way as the roughness of the disks themselves. To determine the effect of the viscidity of the liquid in altering the amount of friction, experiments were made with

a solution of sugar in water. Lastly, a series of experiments were made with water at different temperatures. Altogether several hundred observations of the resistance of the disks under different conditions were recorded.



The figure shows a section of the apparatus employed. DD is the disk, the friction of which, when rotated in fluid, is to be measured. This is keyed on a shaft, SS, which was driven from a hot-air engine by means of a catgut belt. The disk is placed in a cast-iron cistern, CC,

containing the fluid. Between the disk C and the outer cistern, however, is the light cylindrical copper chamber, AA, suspended by three fine wires from a crosshead, B. EE is a diaphragm, which could be moved up or down so as to alter the volume of water in the chamber in which the disk rotates. K is a brake for regulating the speed of the disk. W is the position of a counting arrangement for determining the speed of the disk. G is a scale-pan in which weights were placed. This was connected by a fine silk cord with an arc attached to the chamber AA. The weight in this scale-pan exactly measures the tendency of the chamber AA to rotate, in consequence of the rotation of the fluid inside it. But since action and reaction are equal, the tendency of the chamber AA to rotate is, when the motion is uniform, exactly equal to the friction of the surface of the disk, DD. This method of measuring the friction of the disk, by measuring the reaction of the vessel containing it, was first used (so far as the author is aware) by Professor James Thomson. A short note on some experiments made in this way was communicated by him to the Royal Society in 1855, but the details of these experiments have never been published. The principle is the same as that employed by Mr. Froude, in his "Fluid Dynamometer." The general results of the experiments made with the apparatus described above are in striking numerical agreement with Mr. Froude's results, so far as the conditions of the experiments are similar. But, from the small size of the apparatus, it has been possible to vary the conditions somewhat more than would be possible with the great canal of Mr. Froude. The results obtained may be summarised as follows :—

(1.) The resistance of disks of different diameters, but similar in other respects, varies as the fifth power of the diameter nearly, or, more exactly, as the 4·85th power.

(2.) The resistance varies with the roughness of the surface of the disk to an extent quite as great as in the experiments of Mr. Froude.

(3.) The friction *increases* in every case with the size of the chamber in which the disk is rotated. This result was certainly unexpected. Even if the increase of resistance is due to the increase of the surface of the chamber, this result indicates another marked difference between the phenomena of fluid friction at high and at low speeds. At very low speeds the resistance would decrease considerably as the size of the chamber increased.

(4.) Roughening the surface of the chamber in which the disk is rotated increases the resistance of the disk considerably; in some cases the increase is as great as when the disk itself is roughened.

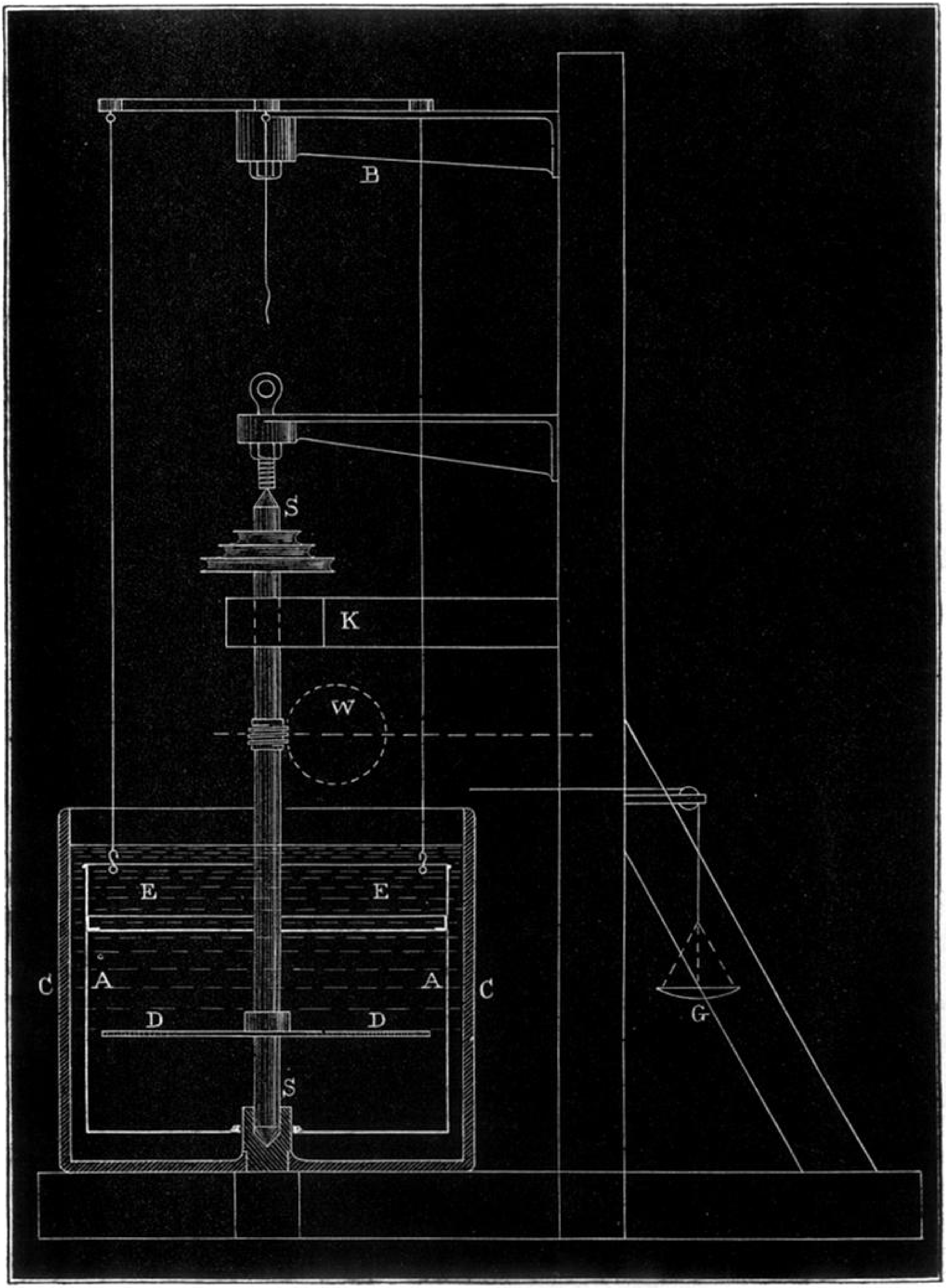
(5.) The resistance of the disk at different speeds varies nearly as the square of the speed. But the exact power of the speed to which the resistance is proportional varies a little for different surfaces. The indices of the powers of the speed to which the resistance is pro-

portional are almost exactly the same for similar surfaces, in these experiments, as in Mr. Froude's experiments.

(6.) A series of experiments were made on the influence of the temperature of the water on the friction, and the author is not aware that any direct experiments on fluid friction, at different temperatures, have previously been made. The experiments show that the friction diminishes rapidly with increase of temperature. The alteration is so great that even five degrees variation of temperature alters the friction by about one per cent.

(7.) When the viscidity of the fluid was increased by dissolving half a hundredweight of sugar in the water of the cistern, the frictional resistance of the disk was increased. But the proportionate increase of resistance was much less than that observed by Coulomb, in a similar experiment at a very low velocity.

At the close of the Meeting Professor Graham Bell made experiments with his Photophone.



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