II. "On the Forces that produce the great Currents of the Air and of the Ocean." By THOMAS HOPKINS, Esq. Communicated by J. P. JOULE, LL.D. Received December 2, 1859.

(Abstract.)

In this paper the writer pointed out the fact that we have at present no satisfactory evidence in books of what are the immediate causes of the great currents of the air and of the ocean; and he maintained that the liberated heat of condensing vapour is the cause of these currents. He then proceeded to show that all the great winds terminate in comparative vacua created in particular localities where much vapour has been condensed; and contended that such vacua enable and cause heavier air to press and flow towards the parts which have been rendered light,—to re-establish the equilibrium of atmospheric pressure,—thus making heat the disturbing power in the aërial ocean, and leaving gravitation to act to restore an equilibrium. The great primary currents of the ocean were also described, and they were shown to be so situated as to be under the influence of the principal winds, which, in their passage over the waters, press on them, and force them forward as currents. These currents were maintained to be of a velocity, extent, and depth proportioned to the strength and continuity of the wind, showing that the pressure of the air on the water, whilst moving over it, is capable of producing the movement which takes place. When, however, water is put into motion, it may be obstructed by land, and turned from its direct course, and in that way be made to form secondary currents. But it was contended that heat of vapour, set free in the atmosphere, is the force which disturbs the equilibrium of pressure, and either directly or indirectly produces all the great continuous movements that take place both in the atmosphere and the ocean.

III. "On the Movements of Liquid Metals and Electrolytes in the Voltaic Circuit." By GEORGE GORE, Esq. Communicated by Professor TYNDALL. Received December 1, 1859.

1. It has long been known that when a globule or layer of pure

and clear mercury is placed upon a smooth non-metallic surface, a watch-glass for example, and covered to a small depth with a watery electrolyte, sulphuric acid in particular, and two terminal platinum wires from a voltaic battery are dipped into the electrolyte, one on each side of the globule, the mercury makes a movement towards the negative wire, and a rapid and *continuous stream* of the supernatant liquid flows from the negative to the positive electrode over the surface of the mercury, and back again by the sides of the containing vessel. Also that when a small drop of a watery electrolyte, especially sulphuric acid, is placed upon the surface of pure and dry mercury, the latter connected with the negative pole of a battery, and a platinum wire from the other pole momentarily immersed in the electrolyte, the drop of liquid is *suddenly repelled* and spreads over the surface of the mercury.

2. These phenomena have been examined by Herschel*, Erman, H. Davy, Runge, Pfaff, and others†, and some of the results have been recorded in the 1st volume of 'Gmelin's Handbook of Chemistry,' page 486 (published by the Cavendish Society); but no definite cause of the movements seems to have been discovered. Herschel has, however, shown that the continuous movement of the supernatant liquid is unaffected by the approach of strong magnets, and that it is influenced by the chemical nature of the electrolyte; also that its direction is notably influenced by the presence of various metallic impurities in the mercury.

3. Being desirous of ascertaining the conditions under which the movements are produced, the relations of the phenomena to ordinary and recognized actions, and the more immediate cause or causes of the movements, I have undertaken the following experimental investigation.

4. In describing the experiments I shall have frequent occasion to speak of the continuous flow of the electrolyte, and of the sudden repulsion of drops of liquid already mentioned, and shall therefore speak of the former as the *continuous* action or movement, and of the latter as the *sudden* or *momentary* one. Also in speaking of the continuous motion, I shall call it *positive* flow or movement when the super-

* "On certain Motions produced in Fluid Conductors when transmitting the Electric Current," Phil. Trans. 1824.

† Draper has recorded some experiments of a similar kind.—Philosophical Magazine, S. 3. vol. xxvi. p. 185.

natant liquid proceeds from the positive wire towards the negative one, and *negative* flow, &c. when it passes in the opposite direction.

5. The usual method of manipulation I have adopted has been to take a watch-glass of about 2 inches diameter and place in it by means of a small gutta-percha spoon capable of containing from 20 to 50 grains of mercury, a globule of that metal of about 30 grains weight, adding sufficient of the electrolyte to just cover or nearly cover the globule of metal, and sifting a few particles of finely powdered charcoal or asphaltum upon the surface of the liquid, to facilitate observation of the movements; next, using a Smee's battery of 22 pairs of plates 4 inches deep and $2\frac{1}{2}$ inches wide with terminal platinum wires, charged with one measure of oil of vitriol and 15 measures of water, I place the end of the negative wire in the liquid about $\frac{1}{4}$th of an inch from the mercury, and then carefully immerse the end of the positive wire in the liquid on the opposite side of the globule, at a greater distance from the mercury than the negative wire in the case of an alkaline solution, and at a less distance in the case of an acid one, in order to prevent the mercury from touching the electrodes by its movement and thus vitiating the first and purest result. A polished oval space 2 inches long, $\frac{3}{4}$ths of an inch wide, and $\frac{3}{8}$ths of an inch deep, with a curved bottom, formed in a thick plate of glass and substituted for the watch-glass, did not admit of such satisfactory freedom of motion. In doubtful cases of movement, a small porcelain boat, such as is used in organic chemical analysis, was sometimes employed instead of the watch-glass; and in certain special experiments a V-tube was employed. In nearly all cases the mercury gradually became impure, and therefore fresh mercury was taken for each experiment.

### A. *Conditions of the Movements.*

6. *Two* substances are always required in these experiments, with one alone the movements never occur.

7. To determine whether *both* the substances must be in a *liquid* state:—1st. A portion of mercury in a watch-glass was connected with the negative pole of a battery and covered with a flat piece of platinum foil; a drop of solution of sulphate of potash was placed upon the foil and the end of the positive wire dipped into it. No movement, either sudden or continuous, of the solution or mercury took place. On substituting for the foil a circular piece of filtering paper varnished all round its edge and covered with several drops of the

solution of sulphate of potash, the sudden repulsions were produced readily, but were much less powerful than when the liquid was placed alone upon the mercury. 2nd. Two circular clean spaces, $\frac{1}{2}$ an inch wide, were scraped with a knife upon a horizontal plate of zinc; one of them was amalgamated with mercury and left covered with a very shallow layer of that metal, the other was also amalgamated, but the excess of mercury was wiped off; each of the spots was now covered with a shallow layer of a weak solution of sulphate of alumina, the zinc plate connected with the negative plate of the battery, and the end of the positive platinum wire dipped in succession into the supernatant portions of liquid; the solution above the thin layer of liquid mercury was powerfully repelled on making the contact, whilst that upon the other spot was unaffected. Similar results were obtained with a solution of caustic potash, also with a plate of tin. 3rd. A portion of Newton's fusible alloy was melted under a layer $\frac{1}{8}$th of an inch deep of a solution of chloride of zinc, and the ends of the platinum wires from the battery immersed in the supernatant liquid until the alloy cooled and solidified; the zinc solution flowed from the negative towards the positive wire as long as the surface of the alloy remained in the liquid state, and ceased to flow immediately the surface of the metal solidified. Also a drop of a strong solution of caustic potash placed upon the melted fusible alloy, the latter connected with the negative pole and the former with the positive pole, exhibited the usual momentary repulsions as long as the surface of the alloy remained fluid. I therefore conclude that *both* the substances must be in a *liquid* state.

8. To ascertain whether *both* the substances must be *conductors of electricity*:—1st. I formed melted globules of phosphorus in warm oil of vitriol, also in a hot mixture of one measure of distilled water and two measures of oil of vitriol, and immersed the wires in the usual manner, but no motion of the liquid occurred. 2nd. No movements were obtained with a globule of bromine under warm oil of vitriol; a large globule of bromine was placed in a porcelain boat, and dilute sulphuric acid added until the bromine was partly covered; the wires were then applied, but no movements took place. Also the addition of sulphur and of selenium to the bromine did not ensure a different effect. 3rd. With a large globule of selenium under fused chloride of zinc no motion was obtained. 4th. I made similar experiments with globules of chloroform, also of bisulphide of carbon in dilute sul-

phuric acid, but obtained no movements. 5th. No movements took place with globules of chloroform in a solution of caustic potash or of sulphate of alumina.

9. To determine whether one of the substances must be *metallic* :—1st. A definite layer of oil of vitriol was placed beneath a layer of distilled water weakly acidulated with sulphuric acid, and the terminal wires immersed in the upper liquid; no movements occurred at the boundary line of the two liquids. 2nd. A dense solution of cyanide of potassium was placed in a small glass beaker, a few particles of charcoal were sifted upon its surface, and a layer of aqueous ammonia $\frac{1}{2}$ an inch deep carefully poured upon it. A vertical diaphragm of thin sheet gutta percha was then fixed so as completely to divide the upper liquid into two equal parts; the vessel was placed in a strong light, and two horizontal platinum wire electrodes from 66 pairs of freshly-charged Smee's batteries immersed $\frac{1}{8}$th of an inch deep in the liquid ammonia on each side of the diaphragm. A copious current of electricity circulated, but no movements of the liquids at their mutual boundary line could be detected. A small globule of mercury placed in the lower liquid at once produced evident signs of motion. One of the substances must therefore be a *metallic* conductor of electricity.

10. To ascertain whether the capability of producing these movements was a general property of metals and alloys when in the liquid state :—1st. Bismuth was fused beneath a layer of chloride of zinc; tin was also melted under a similar layer, and the terminal wires immersed in the supernatant liquid; a steady negative flow occurred in each case. 2nd. Cadmium was similarly treated under fused cyanide of potassium, and a positive flow obtained. 3rd. Cadmium, lead, Britannia-metal, and fusible metal were melted separately, small pieces of cyanide of potassium placed upon them and melted, the metal connected with the negative platinum wire, and the positive wire dipped into the melted cyanide; positive repulsions took place with each metal on making contact. I conclude from these experiments that the power of rotating under the influence of an electrolytic current is a general property of metals and alloys when in a liquid state.

11. That the *mass* or *body* of the metal is not essential to the production of the movements, is evident from the fact that the movements have been readily obtained with *thin layers* of mercury upon amalgamated zinc (7) and copper plates.

12. I have endeavoured to obtain the movements without the presence of an electrolyte, by passing an electric current through a small globule of zinc fused upon the surface of bismuth, but the ready mingling of the melted metals, and their rapid oxidation, prevented a reliable experiment being made.

13. It has already been shown, in the instances of fused salts upon melted metals (10), that the presence of *water* is not a necessary condition of the phenomena.

14. The power of producing the movements is a general property of electrolytes as well as of liquid metals ; I have experimentally found it in the following classes of substances :—organic and inorganic acids ; water ; aqueous solutions of caustic alkalies* ; alkaline carbonates, bicarbonates, borates, hypophosphites, phosphates, sulphides, hyposulphites, sulphites, sulphates, bisulphates, iodides, bromides, chlorides, chlorates, nitrates, and silicates ; salts of alkaline earths and of alumina ; salts of tungsten, molybdenum, chromium, uranium, manganese, arsenic, and of the malleable heavy metals ; also with fused salts, aqueous solutions of organic salts, and solutions of salts in alcohol. The salts of tungsten, molybdenum, chromium, uranium, and manganese, generally gave the weakest and most variable results ; whilst sulphuric acid and solutions of alkaline cyanides yielded very strong and definite movements. In feeble cases of motion the globule of mercury should be placed in a narrow porcelain boat, and a strong solution of the substance added until the metal is only covered at its sides with the liquid ; and for still greater sensitiveness, the experiment of placing a drop of the liquid upon the surface of the mercury should be adopted.

15. The *mass* or *body* of the liquid is not essential to the movements ; mere films of solution adhering to the under surface of a circular disc of brass, brought into contact with mercury under the influence of a voltaic current, exhibited the phenomenon readily.

16. To ascertain whether the current of electricity must pass from the electrolyte into the metal, or *vice versâ* :—1st. A layer of mercury was placed in a narrow glass beaker, upon it a shallow layer of chlo-

* Herschel found no movements with solutions of caustic alkalies (*Vide* Gmelin's Handbook, vol. i. page 490) ; I have readily obtained them with pure mercury in solutions of pure alkalies by using strong solutions and a powerful electric current, and placing only a small quantity of the liquid above the mercury so as to produce the maximum of effect. Alkaline solutions in general act much more feebly han acids.

roform, and above this, in one instance a dilute solution of sulphate of alumina; and in the other instance, asolution of caustic potash, and the wires from the battery dipped into the upper liquid; no movements at either of the contiguous surfaces occurred. 2nd. Similar experiments were made, substituting in one case a definite layer of oil of vitriol with a very dilute solution of sulphuric acid above it, and in the other case a dense solution of chloride of zinc with a very dilute solution of the same salt above it, for the chloroform and its supernatant liquid; in each case only feeble movements in the usual direction at the surface of the mercury occurred; the weakness of the movements was probably a consequence of the increased distance of the electrodes from the mercury. 3rd. The lower part of a V-tube of half an inch bore was just filled with mercury, and a small quantity of solution of cyanide of potassium poured into each leg; on dipping the polar wires, one into the solution of each leg, the saline liquid rapidly flowed from the positive to the negative leg until it was $1\frac{1}{4}$ inch high in that limb. From these experiments I infer that the electric current must pass from the electrolyte into the metal, or *vice versâ*, and that the continuous movements are not results of any power *radiating* from the electrodes.

17. It is not essential that the electric current should pass both into and out of the metallic globule by the electrolyte; with a globule of mercury in rather strong sulphuric acid and either of the polar wires immersed in the acid, the other wire being in contact with mercury, the movements occurred: also with the negative wire touching a globule of mercury in a solution either of cyanide of potassium or strong caustic potash and the positive wire in the liquid, movements were readily obtained.

18. To ascertain whether the electrodes were essential to the movements, I placed a large globule of mercury in the middle part of a slightly bent horizontal glass tube, 20 inches long and $\frac{1}{2}$ an inch diameter, then filled the tube with a strong solution of cyanide of potassium, and immersed the polar wires a short distance in the liquid at each end; a strong positive flow of the solution over the surface of the mercury occurred, but no movements took place at the surfaces of the electrodes, except such as were produced by the evolution of gas. The electrodes evidently operate merely as conductors of the electricity, and are not, in an abstract sense, at all connected with the movements.

19. Herschel has shown that the approach of strong magnets has no effect on the motions (*vide* Gmelin's Handbook, vol. i. p. 490), and I have also found that the movements are not electro-magnetic. A watch-glass—containing in one instance a solution of cyanide of potassium, in a second instance a solution of hydrochlorate of ammonia, and in a third instance oil of vitriol,—was placed upon one of the poles of a vertical horse-shoe electro-magnet capable of sustaining about 100 pounds, and the end of a large soft-iron armature which rested upon the other pole brought near the glass. The polar wires from the Smee's battery of twenty-two pairs were now immersed in the electrolyte on each side of the globule, and the magnet connected with a separate battery of large surface. The direction of flow of the electrolyte was instantly changed to a circular one all round the glass, and was reversed by reversing the polarity of the magnet. In each case the direction of motion of the electrolyte corresponded with that of the electric current beneath it; *i. e.* with a south pole beneath, the liquid moved in the same direction as the hands of a watch;—this circular motion was evidently a case of ordinary electro-magnetic action, as it occurred equally well without the presence of a liquid metal in the electrolyte. No real connexion of the magnetism with the movements under investigation was detected.

20. To ascertain whether the movements varied with the quantity of the electric current, I prepared a single series of sixty-six pairs of Smee's batteries, forty of which were charged with spring-water, and the remainder with a mixture of one measure of sulphuric acid and fifteen measures of water. The movements obtained on applying the current from the whole series to very dilute sulphuric acid containing a globule of mercury, were much more feeble and the amount of electrolysis much less than when the current from the twenty-six strongly-charged pairs alone was applied. On substituting distilled water for the dilute acid, the movements were stronger and the electrolysis greater with the whole series than with the twenty-six pairs. In all cases the movements appear to be dependent upon the quantity of electricity circulating.

21. It is highly probable, from the experiments just described, that the movements are intimately dependent upon electro-chemical action occurring at the surface of the liquid metal, especially as the amount of motion varies with the quantity of electricity which passes from the electrolyte into the metal, or *vice versâ*; and it would be very

desirable to obtain a negative proof of this by an experiment with a globule of one liquid metal in a bath of some other liquid metal, as already attempted (12).

22. With every liquid yet examined the movement of the liquid has invariably been attended by a simultaneous movement of the fluid metal; and the greater the movement of the liquid the greater was the movement of the metal, from which I infer that the movements of the two substances are mutually dependent.

23. The results in general indicate that the *sudden* movements are of the same general character as the *continuous* ones, the effect in the former case being heightened by the concentration of the electric force within a small compass, together with the additional electric energy always displayed at the moment of making contact with a battery.

24. The movements require for their production two substances (6); both these substances must be in a liquid state (7), and be conductors of electricity (8); one of them must be a metal or a metallic alloy (9); any metal or alloy will do (10), and only a mere film of it is essential (11); the other must be an electrolyte, and need not contain water (13): any electrolyte will do (14), and only a thin layer of it is requisite (15): the electric current must pass from the electrolyte into the metal, or *vice versâ* (16), but need not pass both into and out of it by the electrolyte (17); the electrodes are not essential (18); the movements are not electro-magnetic (19), they are dependent upon the quantity of the electric current (20), and are intimately connected with electro-chemical action (21); the movements of the metal and electrolyte are mutually dependent (22), and the momentary movements are of the same nature as the continuous ones (23).

25. The pure or abstract conditions of the production of the phenomena are,—a liquid metal (or alloy) in contact with a liquid electrolyte, and a quantity current of electricity passing between them.

### B. *Conditions of the* continuance *of the Movements.*

26. With regard to the *continuance* of the movements:—1st. In some cases the metal becomes covered with an insoluble film, produced by ordinary chemical action of the liquid, which prevents the continuance of the action; this occurs particularly with mercury in strong solutions of sulphides, iodides, bromides, and chlorides.

2nd. If the positive wire is connected with the mercury and the negative wire with the liquid previous to placing both the wires in the electrolyte, films are in nearly all cases instantly produced (but not with strong sulphuric acid) and interfere with further action; films are also frequently produced by a similar cause upon the end of the mercury nearest to the negative wire when *both* the wires are in the solution, and in many such cases the mercury creeps in a peculiar serpent-like form beneath the film towards the negative wire. 3rd. In many instances the metallic globule becomes of a pasty consistence by absorbing substances deposited upon its surface by electrolysis, and the motion declines; this takes place particularly with mercury in solutions of salts of ammonia, baryta, strontia, magnesia, and lime, but most with those of magnesia and lime; and it occurs very rapidly if, instead of placing both the polar wires in the electrolyte, the negative wire is immersed in the globule of mercury. It is evident from these facts, that it is essential to the continuance of the movements, that the particles composing the surface of the metallic globule should retain a sufficient degree of mobility to admit of free motion.

27. The best method of obtaining a *continuous* movement is to place a globule of pure mercury in a watch-glass, barely cover it with dilute sulphuric (or nitric) acid, connect it with the negative platinum wire and the liquid with the positive platinum wire of a battery of sufficient power to produce a moderate flow without overheating the liquid: ten small Smee's batteries are sufficient. By this means I have obtained undiminished motion for upwards of six hours.

C. *Conditions of the* direction *of the Movements.*

28. In speaking of the *direction* of the movements, I always mean those of the supernatant liquid, unless otherwise stated, because the true movements of the mercury are generally less easily detected than those of the electrolyte: the movements of the liquid are best observed by means of charcoal or asphaltum (5), and those of the mercury by the aid of a few parallel scratches upon the under surface of the watch-glass.

29. The directions of flow of the metal and liquid are intimately dependent upon each other, for in every instance the metal moves in an opposite direction to the electrolyte (see also 22); and in those cases

where two opposite flows of the liquid towards the centre of the vessel occur (as with a solution of sulphate of potash), the globule of mercury is elongated at both ends into a pointed shape, and its two ends point toward the two electrodes, its largest diameter being directly under the point of meeting of the flows of the solution, and its acutest apex under the strongest flow. The relation between the metal and liquid is apparently of a dual or polar character, the movements of the two bodies being always opposite and equal. This mutual dependence of the motions explains the necessity of *both* the substances being in a liquid state (7).

30. With regard to the *direction* of the flows, there are *three* cases to be distinguished:—1st. The movements obtained by immersing the negative wire in the metal and the positive one in the electrolyte. 2nd. Those obtained whilst the positive wire is in the globule and the negative one in the electrolyte. 3rd. Those produced by immersing *both* the wires in the supernatant liquid with the globule between them.

31. Upwards of 150 different liquids, including organic and inorganic acids, alkalies, salts of alkalies, earths and heavy metals, also organic salts, were examined by the first of these methods, and in almost every instance the flow of the supernatant liquid was *positive*, the clearest exception being with a solution of persulphate of iron. With concentrated sulphuric acid the motion (if any) was very feeble, but with diluted acid of various degrees of dilution it was strongly positive. The flow of the liquid declined quickly with solutions which contained an alkali-metal, apparently in consequence of the mercury becoming less mobile (?) by absorption of that metal; but with dilute acids it continued a long time; with very dilute nitric acid, in one experiment the movement was sustained with scarcely any diminution during $2\frac{1}{2}$ hours; and with dilute sulphuric acid, in a second experiment it continued $6\frac{1}{4}$ hours, and did not then appear to slacken: the battery employed in this experiment consisted of ten small Smee's elements. A globule of strong sulphuric acid was placed upon a surface of mercury, the latter connected with the negative pole, and the end of the positive wire dipped into the acid; much gas was evolved from the anode, and the liquid was not repelled on making contact, but collected in a heap around the wire;—a globule of solution of caustic potash

similarly treated exhibited repulsion on making contact. It is evident from these uniform results that the direction of flow obtained by immersing the positive wire in the electrolyte and the negative one in the mercury is almost uniformly *positive*.

32. The movements obtained by this method are not produced by the act of deposited substances dissolving in the mercury, for they occur equally well whether hydrogen gas is set free and escapes or alkali-metal is deposited and dissolves in the mercury, until in the latter case the diminished mobility of the globule interferes with the result.

33. Considerable difficulty was experienced in examining liquids by the second method, in consequence of the rapid and in many cases instantaneous oxidation or filming of the metallic globule; but by using very dilute liquids and immersing the negative wire from seventy-two small Smee's elements during only a moment at a time, this difficulty was in most cases sufficiently overcome to allow distinct starts of the mercury to occur in the particular direction beneath its film, and thus to indicate an opposite motion of the supernatant liquid, although in nearly all cases the movement of the electrolyte itself could not be detected. Upwards of 100 liquids, consisting of organic and inorganic compounds—acid, alkaline, and neutral—were examined, and in more than three-fourths of them distinct movements of the metal were obtained, which were in every instance in a positive direction, thus indicating a *negative* flow of the electrolyte. In some liquids, viz. oil of vitriol, moderately dilute nitric acid, strong solutions of sulphate of ammonia, iodide of ammonium, and sulphite of potash, very dilute solutions of bisulphate of potash, iodide of potassium, nitrate of cobalt, hydrocyanic acid, cyanide of potassium, and acetic acid,—visible movements of the liquid itself in a *negative* direction were also obtained. The movements of the liquid and of the metal very quickly ceased. These experiments show that the direction of flow obtained by placing the positive wire in the metal and the negative wire in the electrolyte is always *negative*.

34. The movements obtained both by methods 1 and 2 appear to be produced by a mutual attraction of the liquid and metal; in the former case the mercury attracts an electro-positive element of the liquid (hydrogen or an alkali-metal), and produces a positive flow;

and in the latter case it attracts an electro-negative element (generally oxygen), and produces a negative flow.

35. Herschel found by the third method of operating, that with pure mercury in acids and saline liquids the flow was negative, and was weaker as the base was stronger, and more rapid as the acid was stronger and more concentrated; and that in solutions of nitrates two opposite flows occurred, one from each wire (*vide* Gmelin's Handbook, i. 490). I have found by an examination of pure mercury in various liquids the results exhibited in the following Table. The arrows indicate the direction of flow of the liquid, ← being positive and → negative; and the numbers affixed to them afford a rough approximation of the velocity or magnitude of the movements. The battery employed consisted of twenty-two small Smee's elements. The substances were dissolved in water, and the solutions were of moderate strength unless otherwise stated. Manifestly impure substances were rejected, and fresh mercury was taken for each experiment. The results obtained were in many cases verified several times :—

| | | |
|---|---|---|
| Distilled Water........... | → faint | |
| Boracic Acid................ | →3 | |
| Phosphoric Acid ......... | →5 | |
| Strong Sulphuric Acid... | →10 | |
| Strong Sulphuric Acid 1 measure, Water 5 ,, | →5 | |
| Strong Sulphuric Acid 1 measure, Water 15 ,, | →5 | |
| Strong Hydriodic Acid 1 measure, Water 15 ,, | →6 | |
| Hydrobromic Acid, very dilute ...... | →2 | |
| Strong Hydrochloric Acid 1 measure, Water 5 ,, | →4 | |
| Strong Hydrochloric Acid 1 measure, Water 15 ,, | →3 | |
| Perchloric Acid, very dilute .............. | →4 | ←3 |
| Strong Hydrofluoric Acid | →2 | |
| Strong Hydrofluoric Acid 1 measure, Water 5 ,, | →3 | |
| Strong Nitric Acid, 1 measure, Water 1 ,, | →2 | |
| Strong Nitric Acid, 1 measure, Water 5 ,, | →3 | |
| Strong Nitric Acid, 1 measure, Water 15 ,, | →3 | |
| Aqueous Ammonia, strong .............. | | ←2 |
| Sesquicarbonate of Ammonia .............. | | ←4 |
| Phosphate of Ammonia . | →2 | ←5 |
| Sulphide of Ammonium, 1 measure, Water 15 ,, | | ←2 |
| Sulphate of Ammonia... | →3 | ←2 |
| Hydrochlorate of Ammonia .............. | →3 | |
| Nitrate of Ammonia...... | →3 | ←2 |
| Caustic Potash ........... | | ←3 |

| | | |
|---|---|---|
| Carbonate of Potash ... | -+ 1 | +- 6 |
| Bicarbonate of Potash ... | -+ 4 | +- 2 |
| Sulphide of Potassium, dilute .............. | | +- 1 |
| Sulphite of Potash ...... | -+ 2 | +- 1 |
| Sulphate of Potash ...... | -+ 3 | +- 2 |
| Bisulphate of Potash ... | -+ 3 | +- 1 |
| Iodide of Potassium ... | -+ 3 | +- 3 |
| Bromide of Potassium... | -+ 2 | +- 3 |
| Chloride of Potassium ... | -+ 4 | |
| Chlorate of Potash ...... | -+ 3 | +- 2 |
| Nitrate of Potash......... | -+ 3 | +- 2 |
| Caustic Soda.............. | | +- 4 |
| Carbonate of Soda ...... | -+ 1 | +- 4 |
| Bicarbonate of Soda...... | -+ 2 | +- 2 |
| Biborate of Soda ......... | | +- |
| Diphosphate of Soda ... | -+ 2½ | +- 3 |
| Sulphide of Sodium, dilute................. | | +- 2 |
| Hyposulphite of Soda ... | -+ ¼ | +- 3 |
| Sulphite of Soda ......... | | +- 5 |
| Sulphate of Soda -+ 4 and then | -+ 4 | +- 3 |
| Chloride of Sodium ...... | -+ 4 | |
| Nitrate of Soda........... | -+ 3 | +- 2 |
| Phosphate of Soda and Ammonia ........... | -+ ¼ | +- 3 |
| Baryta Water ........... | | +- 2 |
| Carbonate of Baryta ... | -+ 2 | +- 1½ |
| Chloride of Barium ...... | -+ 2 | |
| Nitrate of Baryta......... | -+ 3 | +- 2 |
| Strontia Water........... | | +- 8 |
| Chloride of Strontium ... | -+ 2 | |
| Nitrate of Strontia ...... | -+ | |
| Sulphate of Magnesia ... | -+ 3 | +- 1 |
| Chloride of Magnesium, strong .............. | -+ | |
| Chloride of Magnesium, weak ................. | | +- |
| Nitrate of Magnesia, strong .............. | | +- |
| Nitrate of Magnesia, weak ................. | -+ 2 | |
| Lime Water .............. | | +- 1 |
| Sulphate of Lime ......... | -+ 2 | |

| | | |
|---|---|---|
| Chloride of Calcium ... | -+ 2 | |
| Chloride of Calcium in Alcohol .............. | -+ 1 | |
| Nitrate of Lime ......... | -+ 4 | +- 2 |
| Sulphate of Alumina ... | -+ 3 | +- 2 |
| Potash Alum............... | -+ 4 | +- 1 |
| Hydrofluosilicic Acid ... | -+ 4 | +- 3 |
| Silicate of Potash......... | | +- 4 |
| Molybdate of Ammonia . | -+ | |
| Chloride of Chromium, very weak ........... | -+ 1 | |
| Monochromate of Potash | -+ 2 | |
| Nitrate of Uranium ...... | -+ 2 | |
| Sulphate of Manganese . | -+ | |
| Arsenic Acid.............. | -+ 2 | |
| Arseniate of Ammonia... | -+ 3 | +- 5 |
| Fluoride of Antimony... | -+ 2 | |
| Antimoniate of Potash... | -+ 4 | |
| Nitrate of Bismuth ...... | -+ 2 | |
| Sulphate of Zinc ......... | -+ 4 | +- 1 |
| Iodide of Zinc, strong ... | -+ | |
| Nitrate of Zinc ........... | -+ 3 | |
| Iodide of Cadmium ...... | -+ 2 | |
| Iodide of Tin, strong ... | -+ 6 | |
| Nitrate of Lead........... | -+ 3 | |
| Protosulphate of Iron ... | -+ 4 | +- 2 |
| Persulphate of Iron...... | -+ | |
| Chloride of Cobalt, weak | -+ | |
| Nitrate of Cobalt ......... | -+ 3 | |
| Sulphate of Nickel ...... | -+ 4 | |
| Nitrate of Nickel ......... | -+ 5 | |
| Sulphate of Copper, weak | -+ | |
| Chloride of Copper, very weak ................. | -+ | |
| Nitrate of Copper......... | -+ 3 | |
| Nitrate of Mercury ...... | -+ 1 | |
| Strong Aqueous Hydrocyanic Acid ......... | | +- 2 |
| Strong Aqueous Hydrocyanic Acid, 4 measures; Aqueous Ammonia, 1 measure | | +- 10 |
| Cyanide of Potassium ... | | +- 10 |

| | | |
|---|---|---|
| Strong Aqueous Hydrocyanic Acid, 5 measures ...... Caustic Soda Solution, 1 measure ... ..... | | +- 8 |
| Cyanide of Mercury...... | -+ faint | |
| Ferrocyanide of Potassium .............. | | +- 4 |
| Sulphocyanide of Potassium .............. | -+ 1 | +- 3 |
| Oxalic Acid .............. | -+ 2 | |
| Oxalate of Ammonia ... | -+ 3 | +- 4 |
| Acid Oxalate of Potash... | -+ 3 | |
| Neutral Oxalate of Potash | -+ 4 | +- 3 |
| Formic Acid.............. | -+ 3 | |
| Acetic Acid .............. | -+ 3 | |
| Acetate of Potash......... | -+ 3 | +- 1 |
| Acetate of Soda ......... | -+ 3 | +- 3 |
| Acetate of Baryta......... | -+ 2 | +- 2 |
| Acetate of Uranium...... | -+ faint | |
| Acetate of Zinc........... | -+ 4 | |
| Acetate of Lead ......... | -+ 1 | |
| Acetate of Copper ...... | -+ 1 | |
| Tartaric Acid ........... | -+ 5 | +- 1 |
| Monotartrate of Potash . | -+ 3 | +- 2 |
| Bitartrate of Potash...... | -+ 5 | |
| Bitartrate of Soda ...... | -+ 3 | +- ½ |
| Tartrate of Potash and Soda .................. | -+ 3 | +- 3 |
| Tartrate of Potash and Antimony ........... | -+ 3 | |
| Citric Acid .............. | -+ 4 | |
| Succinic Acid ........... | -+ 4 | |
| Gallic Acid ..... ....... | -+ 2 | |
| Pyrogallic Acid ......... | -+ ½ | |
| Carbazotic Acid ......... | -+ 4 | |
| Benzoic Acid.............. | -+ 2 | |

Numerous interesting phenomena of motion and of colour, especially with solutions of salts of the earth-metals and with metallic iodides, were observed during the examination.

36. On examining these numerous results we find :—1st. That all alkalies and some alkaline salts produce a positive flow only. 2nd. That some alkaline and many neutral salts produce both positive and negative flows. 3rd. That some neutral and many acid salts, and nearly all acids, both organic and inorganic, produce a negative flow only. The stronger influence of acids, compared to that of alkalies (14, Note) in the production of these movements, is probably the reason why various salts of alkaline reaction give a negative as well as a positive flow, and why many neutral salts containing a strong acid (chlorides, for example) give a negative flow only. No substance of alkaline reaction has been observed to give a negative flow only, nor any strongly acid substance to give only a positive flow. An *alkaline* or electro-positive substance as the electrolyte, produces therefore by the 3rd method a *positive* flow, and an acid or electro-negative substance produces a *negative* flow. Numerous analogies may be detected in the behaviour of similar salts on examining the Table.

37. The movements obtained by the 3rd method appear to be

results of a similar mutual attraction of the mercury and the elements of the liquid to those obtained by methods 1 and 2. The mercury moves towards the cathode in acids because its positive end has acquired, by the aid of the electric current, a stronger affinity for the negative element of the liquid than its negative end has for the positive element, and moves towards the anode in alkalies because its negative end has acquired a stronger attraction for the positive element of the liquid than its positive end has for the negative element. *I do not, however, give either this or the previous explanation* (34) *as an ascertained fact, but merely as a temporary hypothesis to aid further investigation.*

38. The amount of positive flow produced by the 3rd method in strong aqueous hydrocyanic acid, or strongest solution of ammonia, is comparatively small, apparently on account of their inferior electric conductivity; but if the smallest amount of ammonia is added to the hydrocyanic acid, the positive flow obtained is very strong; also, if instead of ammonia a small quantity of caustic potash, soda, baryta, strontia, magnesia, lime, or even alumina is added to the acid, similar effects are produced: a little strontia or lime causes the nearest part of the mercury to dart up the watch-glass more than half an inch towards the positive electrode, if the battery is sufficiently strong. Silica had no effect. The addition of oxide of zinc, dioxide or protoxide of copper to the acid, reversed the direction of the flow, and dioxide of mercury neutralized the positive movement and diminished the conduction. The strongest positive flows obtained by the 3rd method were with strong solutions of alkaline cyanides, and the strongest negative flows with sulphuric acid.

39. The behaviour of liquids upon mercury in V-tubes by the three methods is not essentially different from their behaviour in a watch-glass; the former, indeed, may be safely predicted from the latter. Sufficient pure mercury was placed in a V-tube of half an inch bore just to fill it at the bend, then a strong solution of sulphate of alumina poured upon it half an inch deep in each leg; on connecting the platinum wires from twenty-two pairs of small Smee's batteries with the solutions in the two legs, the liquid at once flowed from the *negative to the positive* leg; but by lowering the negative wire into the mercury, it flowed from the positive to the negative leg: no flow of the liquid was produced by placing the positive wire in

the mercury and the negative one in the solution of the negative leg. If the mercury was too deep to allow the liquid to pass, the solution insinuated itself down the sides of the mercury in the positive leg (the positive wire being in the solution, and the negative one in the mercury); but by using a suitable depth of mercury, the whole of the liquid flowed from the positive into the negative leg. This is the usual behaviour of an *acid* liquid (or of one in which the negative flow of method 3 predominated) with a suitable quantity of mercury in a V-tube. With a *strongly alkaline* liquid the only difference of behaviour is, that when the two wires are in the solutions of the two legs, the liquid flows from the *positive to the negative* limb (see 16), *i. e.* opposite to the direction of flow with an acid.

40. There is a fixed relation between the direction of the electric current and the direction of each of the classes of movements; for in every case where the former is reversed, the latter also becomes reversed; but this effect is, of course, not observable in those cases of method 3 where two opposite and equal motions to the centre of the metallic globule exist.

41. I have examined the influence of the chemical nature of the metallic globule upon the movements obtained by the 1st method, in the following manner. The globule of mercury was first connected with the positive pole and the liquid with the negative pole for about ten seconds, and then the wires placed as in method 1; a *temporary negative* flow was produced for a few moments with certain liquids, apparently in consequence of the mercury absorbing a minute portion of an electro-negative constituent of the solution (?), and that substance causing a negative flow in the succeeding operation until the whole of it was redissolved. The following liquids exhibited this phenomenon of reversion :—very dilute solutions of nitric acid, nitrates of ammonia, potash, soda, baryta, strontia (not of magnesia, apparently on account of viscosity of the mercury being produced), lime, zinc, lead, cobalt, nickel, copper, and dioxide of mercury; also sulphates of ammonia and potash; hypophosphite and diphosphate of soda; and, strongest, the alkaline nitrates;—but not dilute solutions of caustic potash, soda, baryta, or lime; carbonates or bicarbonates of potash or soda; carbonate of baryta; chlorides of ammonium, potassium, sodium, barium, strontium, magnesium, or

calcium; iodide or bromide of potassium; sulphites of potash or soda; biborate, hyposulphite, or sulphate of soda; sulphate of lime; arsenic acid; cyanide of potassium; oxalate of ammonia. The battery used was a series of 72 small Smee's elements. It appears from these experiments, that the direction of flow obtained by immersing the positive wire in the electrolyte and the negative one in the globule is strongly influenced by the chemical composition of the metallic globule.

42. The chemical nature of the globule exercises an equally powerful influence upon the direction of the movements obtained by the second method. If the mercury was first connected with the negative wire and the solution with the positive wire for a few seconds, and then the connexions reversed or made as in method 2, a *temporary* and strong *positive* flow of the electrolyte for a few moments was obtained, apparently in consequence of the mercury absorbing a little alkali-metal or other electro-positive constituent of the liquid, and that substance causing a positive flow of the solution until the whole of it was redissolved. This positive flow did not occur while there was above a certain quantity of the alkali-metal in the mercury. The reversions were obtained in the following liquids:—dilute and strong solutions of caustic potash; weak solutions of caustic soda, baryta, and lime; carbonate of baryta; chlorides of potassium, sodium, barium, strontium (not of magnesium, owing to viscosity of the globule), and calcium; iodide and bromide of potassium; sulphites of potash and soda; biborate, hyposulphite, and sulphate of soda; sulphate of lime; arsenic acid; cyanide of potassium; and oxalate of ammonia; also in solutions of hypophosphite and diphosphate of soda;—but not in very dilute nitric acid, nitrates of ammonia, potash, soda, baryta, strontia, magnesia, lime, uranium, zinc, cobalt, nickel, copper, or dioxide of mercury; sulphates of ammonia, potash, or alumina. It is worthy of notice that these two series are almost precisely the reverse of those named with method 1 (41); *i. e.* those liquids which have the property of reversing the flow of one method have not that property with the other method, except hypophosphite and diphosphate of soda. The explanation suggested (34), of the cause of the true movements of methods 1 and 2 does not appear applicable to these phenomena of reversion.

43. Herschel has shown that with pure mercury in solutions of

alkalies or of sulphate of soda (*vide* Gmelin's 'Handbook, i. 490, 492), if a little alkali-metal be introduced into the globule by connecting the latter for a few moments with the negative wire (the other wire being in the solution), a *positive* flow occurs on placing *both* the wires in the electrolyte with the mercury between them, and continues until all the alkali-metal is redissolved; and that similar effects are produced by adding small quantities of an easily oxidizable metal to the mercury—for example, potassium, sodium, barium, zinc, iron, tin, lead, or antimony, in the order given; but not by bismuth, copper, silver, or gold. I have found that zinc added to mercury under a solution of sulphate of potash changed the direction of flow from positive and negative (obtained by method 3) to positive only; cadmium did the same, but more feebly, and tin still more feebly; bismuth had no apparent effect, but by using treble the electric power its effect was also similar, antimony also the same; gold had no apparent effect even with a current from 72 pairs of Smee's elements. No positive flow was obtained by connecting the mercury with the negative wire and the solution with the positive wire for a short time in a liquid consisting of acid and water, and then placing both the wires in the electrolyte. Although there are many liquids (most of those which contain an alkali-metal) in which a temporary *positive* flow (or *increase* of positive flow) may be obtained by the 3rd method by first placing the *negative* wire in the mercury for a short time and then returning it to the electrolyte, there are but few (among which are diphosphate of soda and arseniate of ammonia) in which a temporary *negative* flow is produced by placing the *positive* wire in the mercury and then returning it to the solution. It has been constantly observed with the 3rd method, that purity of the mercury is essential to the production of uniform results. From these various facts it appears that the chemical nature of the metallic globule strongly influences the direction of the movements obtained by method 3; also that an electro-positive globule produces a positive flow, and an electro-negative substance dissolved in the mercury produces a negative flow.

44. In some instances of the 3rd method—for example, with solutions of chloride of magnesium and nitrate of magnesia (35, Table), even the degree of dilution appears to determine the direction of the motion. No variation in the direction of the movement obtained by

either method was observed on varying the strength of the electric current, or on varying either the actual or relative distances of the electrodes from the metallic globule.

45. The presence of an electro-positive metal in one portion of the surface of the mercury will (by generating a small electric current) sometimes cause rotation of the electrolyte after the battery-wires are removed, especially if the mercury is touched with a platinum wire beneath the surface of the liquid; this is seen most frequently with mercury into which some alkali-metal has been deposited.

46. The general phenomena of the movements may be briefly redescribed thus:—A. When *both* the wires are in the electrolyte, and the mercury between them, several cases occur: 1. With a strongly *alkaline* liquid, a *positive* flow of the solution from the positive wire over the mercury to the negative wire occurs; 2. With a strongly *acid* liquid, a *negative* flow of the solution takes place; and 3. With a solution of a *neutral* or slightly alkaline salt, especially of a salt composed of a strong acid and a strong base, *two* flows occur, a negative one from the negative wire towards the centre of the mercury, and a positive one from the positive wire towards the centre of the mercury,—the negative one being generally the strongest. If in this 3rd case the mercury contains any impurity, or if a substance be caused by any means to dissolve in the mercury, the movements are notably affected: an electro-positive substance (zinc, alkali-metal, &c.) increases the positive flow so as partly or completely to overpower the negative movement; and an electro-negative substance increases the negative flow, in a few instances, so as to overpower the positive movement. These influences are also frequently detectable when liquids are used of alkaline or acid reaction, as in cases 1 and 2.

B. When the negative wire is in the mercury and the positive one in the liquid, two cases occur: 1. With pure mercury, the motion is positive in nearly all liquids, whether acid, alkaline, or neutral; and 2. With mercury containing a small amount of an electro-negative substance, imparted to it by reversing the connexions of the wires for a short time, a temporary negative flow is produced in certain liquids, chiefly nitrates, but not in certain other liquids.

C. When the positive wire is in the mercury and the negative

one in the liquid, also two cases occur: 1. With pure mercury, the motion is negative in all liquids—acid, alkaline, or neutral; and, 2. With mercury containing a *small* quantity of an electro-positive substance imparted to it by reversing the connexions of the wires for a few moments, a temporary and strong positive flow is produced in certain liquids and not in certain others—and these liquids are almost precisely the reverse of those named under B, 2.

The general influence of electro-positive substances dissolved in the *globule* is in all classes of cases to produce a positive flow, and of electro-negative substances to produce a negative motion; and the influence of electro-positive substances dissolved in the *liquid* is, in cases of A only, to produce a positive flow, and of electro-negative substances to produce a negative flow.

47. The primary motions of the liquid and metal are, in all cases, wholly at their *surfaces of mutual contact*; whilst the movements observed are only secondary effects, useful in enabling us to infer the direction of the original motions: the *masses* of liquid and metal serve merely as conductors of the electricity, and as stores of material for supplying the acting surfaces. The movements obtained are singularly symmetrical, probably in consequence of their essentially dual or polar character.

48. The essential nature or principle of the movements appears to be *electro-chemical motion*, i. e. definite motion directly produced by electro-chemical action.

49. To illustrate the action, I have constructed an apparatus consisting of two pairs of electrodes of platinum foil and mercury, suspended at opposite ends of two copper wires upon a central pivot, and rotating in an annular channel filled with dilute sulphuric acid; but the power was too feeble to produce revolution of the necessary moveable parts: it was not more than sufficient to produce a manifest tendency to motion.

In conclusion, I beg leave to suggest a trial of the sudden starts of the mercury by momentary currents as signals in electro-telegraphic apparatus.