

On the results of a series of experiments on the decomposition of water by the galvanic battery : with a view to obtain a constant and brilliant lime light / by N.J. Callan.

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From Dr Callan
15/2/54

ON THE RESULTS
OF A
SERIES OF EXPERIMENTS
ON THE
DECOMPOSITION OF WATER BY THE
GALVANIC BATTERY,
WITH A VIEW TO OBTAIN A CONSTANT AND
BRILLIANT LIME LIGHT.

BY

THE REV. N. J. CALLAN,

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SOON after I had discovered the nitric acid cast-iron battery, and before I had completed the large one which I made for the College, I began to make experiments on the decomposition of water with a view to obtain a lime light which might answer for lighthouses. I soon succeeded in obtaining a steady and brilliant light. In a paper on our new galvanic battery, dated April 6, 1848, and published in the London Philosophical Magazine of the following July, I stated that "I got the lime light by igniting mixed gases as they were produced by the decomposition of water and throwing the flame on lime." I believe I was the first who obtained a constant lime light by means of the galvanic battery. My experiments were frequently interrupted on account of the state of my health. They were at one time suspended for more than two years, and several times for five or six months. The same cause which obliged me to interrupt them now compels me to bring them to a close before I could complete all the experiments I intended to make. These experiments have led to the following results:—First, a new apparatus for applying with perfect safety the mixed gases, oxygen and hydrogen, to the production of a flame of the most intense heat, which, when thrown on lime, produces a most dazzling light. Secondly, a new voltameter, to which a common jet may be screwed, and the gases inflamed as they issue

from it without the smallest risk of injury, and by which the full decomposing effect of a battery of a hundred or five hundred pairs, arranged in one series, may be produced without exhausting the power of the battery more rapidly than if it contained only three or four cells. Thirdly, a new negative element far cheaper, far more durable, and one which may be made to act more powerfully than the platinized silver used in Smee's battery. Fourthly, a new mode of protecting iron against the action of the weather and of various corroding substances, so that iron thus protected may be used for all the purposes to which sheet lead and galvanized iron are applied. Fifthly, a method of producing a brilliant intermittent lime light by means of a small galvanic battery. Sixthly, a new mode of exhibiting the dissolving views by means of the lime light. Lastly, a new sine galvanometer, which is the only instrument yet made by which very powerful galvanic currents can be measured.

The first result was a new apparatus for applying with perfect safety the mixed gases to the production of the oxyhydrogen flame and lime light. In my first experiments on the decomposition of water, I made use of a glass vessel containing dilute sulphuric acid and four parallel plates of platinized platina, each having a surface of about 14 square inches. The mouth of the vessel was stopped by a thick piece of wood, through which the wires from the electrodes passed. In this wood was cemented a tapped brass nut to which a stopcock and Hemming's jet might be screwed; the mouth of the vessel was made air-tight by cement. I soon found that with a glass vessel the use of Hemming's jet was unsafe. On one occasion, when I employed twenty 6-inch cells of our cast-iron battery, the Hemming's jet did not let out all the gases produced in the vessel; for after breaking the connexion between the battery and electrodes, the gases continued for some time to issue from the jet and kept up the lime light, although the battery had not worked for more than a minute or two. Had I allowed the battery to work nine or ten minutes, the gases would have been condensed within, and would have burst the vessel; I therefore saw that I must either get the gases separately, or devise some means by which the mixed gases might be safely inflamed, and might at the same time pass without much resistance from the glass vessel. I attempted both. To get the gases separate, I put a plate of porous earthenware between the electrodes so as to form two air-tight cells. I thus succeeded in obtaining the gases separate; but finding so much difficulty in making the cells air-tight, I gave up the idea of looking for the gases separately. In order to avoid dangerous explosions in igniting the mixed gases, and at the same time to allow them to pass freely to the jet, I sent them

through water contained in an iron vessel, to the top of which was screwed the jet belonging to our large gas microscope and polariscope. The first iron vessel which I used was about $5\frac{1}{2}$ inches high and 2 inches in diameter; its sides were an inch thick. This vessel was found to be too small. On two occasions, all, or nearly all the water was thrown out of the vessel through the jet; the flame went back and exploded the gases in the bags. On these two occasions the pressure was very irregular. The quantity of the gases contained in the bags was too small to be forced out by weights on the pressure-boards. They were driven through the jet by a person who pressed frequently and violently on the bags with his arm. This violent and irregular pressure forced the water through the jet. Had the pressure been uniform, it is probable the explosions would not have occurred. Dangerous explosions can happen only because the water may be gradually ejected from the iron vessel through the jet or into the gas bag; or because, when the gases are made to pass rapidly through water in large quantities, there is a continuous series of large bubbles rushing through it; and should the uppermost bubble be ignited, the flame might possibly descend through the series of bubbles without being extinguished by the surrounding water. In the apparatus which I have made, a dangerous explosion from any of these causes is impossible. The apparatus consists of two wrought-iron vessels of unequal size. The smaller is the one already described. The large one is about $7\frac{1}{2}$ inches high and 4 inches in diameter; its sides are about $\frac{7}{8}$ ths of an inch thick. On the top of the vessel is laid a collar of thick vulcanized India-rubber. An iron plate about $\frac{5}{4}$ ths of an inch thick is then screwed down to it by five iron bolts. The vessel is thus made air-tight. The top of this vessel is connected by an India-rubber tube with the bottom of the small one; the bottom of it is connected by a similar tube with the gas bag, gasometer, or voltameter. The two vessels are nearly filled with water. The gas is sent into the bottom of the large one, ascends through the water, passes through the tube to the bottom of the small one, then through the water, and issues from the jet screwed to the top of the small vessel. Since the two vessels are of very unequal size, it is impossible that all the water should be carried out of both at the same time by the stream of the gases; and should an explosion occur after the small vessel became empty, the flame would be stopped by the water in the large vessel. In each vessel the gases are made to pass through wire-gauze or perforated zinc, or through small pieces of porous earthenware, in order to break the bubbles, and thus prevent the gases from ascending in a continued series of large bubbles. To prevent the water from being driven into the gas bag or voltameter which may be

used, I have put a strip of vulcanized India-rubber across the hole through which the gases enter into each of the iron vessels. The strip of vulcanized India-rubber acts as a valve, which opens inwards and admits the gases into the vessel; and when pressed outwards by the expansive force of the exploded gases, it closes the hole and prevents the escape of any part of the water into the gas bag or voltameter. Hence it is evident that in our apparatus dangerous explosions cannot happen, either because the water may be gradually ejected from the iron vessel through the jet or back into the gas bag, or because the flame might ascend through a continued series of bubbles of the mixed gases. The size of the iron vessels should be in proportion to the quantities of mixed gases inflamed, and to the length of time the flame is kept up. Should a person wish to continue the lime light for a very long time, he would do well to have two pairs of vessels and change them every hour or half-hour, or examine occasionally whether the water was carried away by the stream of the gases. I have several times tried the large vessel alone without any accident, although the gases above the water occasionally exploded when they were not pressed through the jet with sufficient force. I believe that this vessel may be used alone without danger; but I would recommend in all cases the use of two vessels, one of which should be a good deal larger than the other, that the small one be about 3 inches in diameter and 6 inches high, and that the experimenter examine occasionally whether they contain water. I always kept the gas bag in a place in which, though an explosion should occur, no injury could be done to any person. On one occasion I filled the small iron vessel with shot instead of water. The shot prevented the return of the flame for a little time, but after five or six minutes the gases in the small vessel and in the upper part of the large one exploded, but the flame did not descend through the water. The mixed gases which I employed were always obtained by the decomposition of water. One of the gas bags commonly used for the gas microscope and polariscope may be filled in two or three hours by a cast-iron battery of six cells and as many zinc plates, each 6 inches square. I always employed nitrosulphuric acid which had been previously used. Acid which had been used before answers very well for producing decomposition; because, for this effect, the cells of the battery must be so arranged that its intensity will not exceed that of three, or at most four cells in series. When the gases are obtained by the decomposition of water, they are always mixed in the proportions in which they answer best for the production of intense heat and light; hence, when it can be done without danger, it is better to produce the lime light by the decompo-

sition of water than by getting the gases into separate vessels, and then mixing them in the proper proportions. With half a dozen of cells of the cast-iron battery, a voltameter, a pair of gas bags, and the apparatus just described, the gas microscope and polariscope, as well as the dissolving views, may be exhibited. But the experimenter must, until he acquires experience, proceed with great caution.

The second result was a new voltameter, to which a common jet may be screwed, and the mixed gases inflamed as they issue from it without the slightest risk of injury, and by which the full decomposing power of a battery of 100 or 500 cells arranged in one series may be exerted without exhausting the power of the battery more rapidly than if it consisted of three or four plates. This voltameter is new in every respect,—in the material of which it is made, in the manner in which the electrodes are connected with the opposite ends of the battery whilst the vessel remains air-tight; new in the metallic plates employed as electrodes, and in the arrangement of these plates; finally, new in the fluid which is used for the decomposition. After having succeeded in making the apparatus for preventing dangerous explosions, I found that a glass vessel was totally unfit for a voltameter such as I wanted: first, because it is extremely difficult to make a glass vessel permanently air-tight; secondly, because it is not sufficiently strong to bear the pressure of the condensed gases; thirdly, because on one occasion, by unscrewing a bag which I had filled with the mixed gases, a spark which was produced by accidentally breaking connexion with the battery, or by the contact and separation of the electrodes, inflamed the gases and caused an explosion which shattered the vessel. I fortunately escaped unhurt. The vessel which I have used for nearly the last two years is made of wrought iron about an inch thick. Its form is cylindrical, its height about 16 inches, and its inside diameter 6 inches. It is open at the top, which was turned flat in a lathe; the bottom is laid on a circular piece of wood, which is placed on an iron plate about $\frac{5}{8}$ ths of an inch thick and 8 inches square. On the top of the vessel is laid a thick collar of vulcanized India-rubber, and on this an iron plate similar to the one under the bottom. In the top plate there are two holes, to one of which a stopcock is adapted; to the other is fitted, air-tight, a perforated piece of brass which projects about an inch and a half above the plate. The hole in this brass is large enough to admit a thick wire. The upper part of the brass is tapped in order that a brass cap may be screwed to it, to prevent the escape of the gases through the hole. When the electrodes are placed in the vessel, one of them is connected by solder or pressure with the inside; to the other is soldered or riveted a copper wire, which passes through

the hole in the brass screwed into the top iron plate. By means of four $\frac{5}{8}$ -inch bolts of iron, which pass through the top and bottom iron plates, the top plate is screwed down on the India-rubber collar. The wire is then wedged against the side of the hole in the piece of brass, and the brass cap is screwed on. The board between the bottom of the vessel and under iron plate, and the India-rubber collar between the top and upper iron plate, insulate both plates from the iron vessel. The outside of the vessel is connected with one end of the battery, and the top or bottom plate with the other. Thus the two electrodes are connected with opposite ends of the battery; and if acidulated water, or water containing any of the alkalis, be poured into the vessel, it will be decomposed by the voltaic current. If a stopcock to which a jet is attached be screwed to the top plate, the gases will rush through the jet and may be ignited without the smallest danger, for the explosion of the gases contained within can never burst a vessel of such strength. I have had frequent explosions without producing any injurious effect, though the vessel was sometimes nearly half-filled with the mixed gases. Before discarding the glass vessel, I began to use sheet iron instead of platina electrodes. I found that when the intensity of the battery exceeded that of three or four cells, the power of the battery was soon exhausted; hence in using a battery of eighty cells, I was obliged to arrange them in twenty rows, each containing four cells, and to connect all the end zinc plates so as to form one, and all the iron cells at the other end so as to act as one. I also found, that, to obtain the full effect of the decomposing power of the battery, the acting surface of each electrode should be as large and a half as the acting surface of the zinc in each circle. Hence about 9 square feet of sheet platina, which would cost nearly 30*l.*, are necessary for a voltameter large enough for a battery of eighty 4-inch plates, when they are properly arranged for decomposition. Platina plates are not only very expensive, but they are also very easily torn and rendered unfit for use. I used a pair of sheet-iron plates about 4 feet long and 9 inches broad. To one of them I soldered a piece of thick sheet copper, and to the other a thick copper wire. I then covered one of them with linen, and rolled the two into a coil about 4 inches in diameter. I had then two plates of iron, nearly 3 square feet in surface, separated from each other by the interposed linen. The coil was put into the iron vessel. The copper plate soldered to one of the iron plates was connected with the inside of the vessel, and the copper wire attached to the other was connected with the perforated brass in the top. The vessel was then filled with a solution of carbonate of potash. I employed this solution in order to prevent the oxygen from

attacking the positive electrode. When the plates were connected with the opposite ends of a battery, the water was rapidly decomposed, and a considerable quantity of the mixed gases obtained. From the intensity of the lime light produced by the gases, it appeared that the potash effectually prevented the combination of the oxygen with the positive electrode. The iron plates worked well for about an hour; the decomposition then began to decline very rapidly, though the battery was in good order. I then took up the iron plates, separated them from each other, and removed the linen cover. One of the plates was coated with a non-conducting black deposit. This was the first time I found such a deposit on either of the plates; on all former occasions they were separated from each other by slips of wood or gutta serena. I afterwards got a pair of lead plates, which I rolled up in the same way as the iron plates; they, too, ceased to act after some time, because one of them became covered with a black non-conducting substance. I then got four concentric hollow cylinders made of sheet iron $\frac{1}{8}$ th of an inch thick, so that the largest of them fitted in the iron vessel. The first or innermost one was connected with the third, and the second with the fourth; they were separated from each other by wedges of wood, and also insulated from the bottom of the vessel. The first and third were connected with the top plate, and the second and fourth with the side of the vessel. These acted tolerably well; but when I used a pair of lead electrodes with a battery of ten 6-inch plates, the lime light was considerably larger and more steady than when I employed the iron cylinders. Hence I resolved, if possible, to give up the use of iron electrodes. I saw at the same time that lead plates would not answer; for when they are placed near each other, a slight pressure, and sometimes even their own weight, brings them into contact with each other. It then occurred to me to try strong tin plates immersed for a few seconds in melted lead, or in a liquid alloy of lead and tin, in which alloy the quantity of tin would be small compared with that of lead. Not having any new tin plates at hand, I cut up some old tin vessels, and made three plates, each nearly 4 inches wide and 6 long. I coated one of them, by means of a soldering iron, with an alloy, containing about seven parts by weight of lead and one of tin; and another with an alloy containing about three parts of lead and one of tin. On the third, after being coated with the alloy, I sprinkled some powdered sulphur, and held the plate over the fire until the sulphur was inflamed: the plate was thus covered with a black coating of burnt sulphur. I then tried each of the three, and also a plate of lead about the same size, as the negative element of a nitric acid battery; that is, I put each successively, instead

of platina or cast iron, into a porous cell containing nitrosulphuric acid. Each of the three acted far more powerfully than the lead plate. The plate coated with the alloy containing the largest proportion of lead acted better than the one whose coating contained least lead, but not so well as the plate on which sulphur was burnt. This last plate produced a galvanic current very nearly equal to that of a platina or cast-iron plate. I afterwards put into concentrated nitric acid a piece of the tin which was coated with the alloy of lead and tin, and with sulphur, a piece of one of the alloys of lead and tin and a piece of lead, and left them in the acid for about twenty hours. On taking them out of the acid, I found that a good deal of the lead had been dissolved, but the piece of coated tin and the alloy were merely blackened on the surface. From the results of these experiments, it is evident that tin plates, coated with an alloy of lead and tin, in which the proportion of tin is small, are more passive in nitric acid, less oxidable, and consequently better suited for the electrodes of a voltmeter than lead plates. The tin plates are stronger and more elastic than leaden ones, and therefore are not so easily brought into contact with each other. It was in last March or April that I discovered that tin plates, coated with an alloy of lead and tin, are less oxidable than lead. Since that time I have in all my experiments used the coated tin plates as electrodes. I have arranged these electrodes in two ways; in one way for a battery of low intensity, and in another for batteries of high intensity, or of a large number of cells all in one series. In one of the former arrangements there were twenty plates, each 12 inches by 4; they were all parallel, and separated from each other by slips of wood about $\frac{1}{16}$ th of an inch thick. Ten of them were connected with one end of the battery; these were of course the alternate plates; the other ten were connected with the opposite end. The acting surface of each electrode, including both sides of each plate, was something more than 3 square feet. The electrodes for batteries of high intensity are also parallel and separated from each other, about one-sixteenth of an inch, by a non-conductor. But the two outside or terminal plates only are connected with the battery; one with the negative, the other with the positive end. The terminal plate, which is connected with the top iron plate of the voltmeter, must be covered on the outside by a non-conductor, otherwise the voltaic current would pass to the side of the iron vessel, and would not pass through the plates and fluid interposed between the two outside or terminal plates. The cells between each pair of plates must be made nearly water-tight, and must be open only on the top, in order that when the terminal plates are connected with the battery, the voltaic current may have no way of

Decomposition of Water by the Galvanic Battery.

passing from one end of the battery to the other but through the interposed plates and fluid. In each plate there should be a small hole near the bottom, that the cells may always remain nearly filled with the fluid. The fluid should never rise above the upper edge of the electrodes, otherwise a great part of the galvanic current would be transmitted by it from one terminal plate to the other without passing through the interposed plates or fluid. The number of cells formed by the interposed plates should be about one-fourth of the number of cells in the battery. Thus for a battery of 12 cast-iron cells, there should be 3 cells or 2 plates between the two terminal plates. For a battery of 100 cast-iron cells in series, there may be 25 decomposing cells or 24 interposed plates. A battery of 100 cells has twenty-five times the intensity of a battery of 4 cells, therefore the current from it will overcome twenty-five times as much resistance as the current from 4 cells, and will pass through 25 decomposing cells successively as freely as a current from a battery of 4 cells will pass through a single decomposing cell. If the current from a battery of a hundred well *insulated* cells be sent through 25 decomposing cells, and afterwards through the coil of a galvanometer, which coil is made of thick copper wire, it will be found that the deflection of the needle will be equal to that which will be produced by a current from a battery of 4 cells passing through one decomposing cell and through the coil of the same galvanometer. Hence there is as much of the mixed gases produced in each of the 25 decomposing cells as in the single cell through which the current from the battery of 4 cells passed, that is, twenty-five times as much of the mixed gases as is produced by a battery of four cells. Hence the full decomposing power of a battery of a hundred cells is exerted; and because the intensity of the current is reduced to that of a battery of four cells, the power of the battery is not exhausted more rapidly than if it consisted of four cells in series. If the current of a battery of a hundred cells in one series were sent through the electrodes as they are commonly arranged, the power of the battery would be exhausted about twice as soon as if the current passed through the electrodes arranged for batteries of high intensity, and the twelfth part of the full decomposing power of the battery would not be effective. To those who wish to show with the same battery the deflagrating power of the voltaic current, the coke light, and the decomposition of water, and the lime light, an arrangement of the electrodes similar to that which has been just described will be useful, because a battery arranged for intensity will answer for all these effects. But when a battery is put up for the sole purpose of decomposing water, it is better to arrange the cells in such a way that the intensity may not exceed

that of four cells in series; because if a battery of 100 cells be arranged in series, a single bad porous cell or bad zinc plate will diminish considerably the power of the entire battery; but if the 100 cells be arranged in twenty-five rows, each containing four cells, and all the terminal zinc plates be connected so as to act as one plate, and all the end iron cells be connected so as to act as one, a bad porous cell or zinc plate will diminish the power only of the row to which it belongs, but not of the other rows.

Some of my experiments led me to believe, that, by means of the arrangement of the electrodes for a current of high intensity, the decomposing power of the battery may be considerably increased; from other experiments I was somewhat disposed to infer that by such arrangement no increase of power can be gained. I am at present in doubt, and must remain so till the state of my health enables me to repeat my experiments.

The fluid which I first used in the voltameter was a solution of caustic potash. When a current was sent through the solution, the iron vessel was soon filled with foam, which came out through the jet with the mixed gas and extinguished the flame. I then tried a solution of carbonate of soda. The soda prevented the oxidation of the positive electrode as well as potash, and did not foam so much. However, even with soda, the quantity of foam was so great, that the iron voltameter, 16 inches high and 6 inches in diameter, would be very soon filled with it if a battery of more than about twelve 6-inch cells were employed. I tried various means of preventing the foam. I first covered the electrodes all round with a cloth, so that the gases should pass through it. Many of the bubbles were thus broken; but when a powerful battery was used, the voltameter was soon filled with foam. I then put about a teaspoonful of coal naphtha into the vessel. This prevented the foam from rising to any considerable height in the vessel, but it was somewhat injurious to the light. I also tried turpentine: it diminished the foam, but injured the light more than the naphtha. I think it increased the violence of the explosion of the gases. I afterwards tried some nitre, and also common salt; each of them prevented the foam, but destroyed the light. After failing in all my efforts to prevent the foam, I thought there was no alternative but to get an iron vessel so large that all the foam which could be produced by a powerful battery would be contained between the top of the electrodes or surface of the fluid, and the top of the vessel without rushing through the jet. Latterly, I have tried carbonate of ammonia instead of soda, and have found that it foams much less, and that it prevents the action of the oxygen on the positive electrode. A solution of the proper strength will be obtained by dissolving an ounce and a quarter, or an ounce of the carbonate

of potash, soda, or ammonia in a quart of water. If there be more than an ounce and a quarter to each quart of water, the quantity of foam will be very considerable; if there be less than an ounce, the conducting power of the solution will not be sufficient, and the quantity of the gases produced will be greatly diminished.

For either of the two arrangements of the electrodes I have described, a cylindrical vessel does not answer well. For them a prismatic vessel having a rectangular bottom is the most convenient. The inside of the iron vessel should be coated with an alloy of lead and tin, or of lead, tin and antimony, in which the proportion of tin, or of tin and antimony, is small,—first, in order to preserve it from rust; secondly, to protect it against the action of sulphuric acid, and thus render it fit for a voltameter, in which the positive electrode is platina; the negative one, tin plates coated with an alloy of lead and tin; and the fluid through which the voltaic current passes is dilute sulphuric acid. The coated sides of the vessel may be the negative electrode. With an iron voltameter such as I have described, the mixed gases may, without the slightest danger, be inflamed as they are produced by the decomposition of water, and a constant and brilliant lime light may be obtained.

The third result is a new negative element, cheaper, more durable, and one which may be made to act with greater power than the platinized silver used in Smee's battery. It is sheet tin, coated with an alloy of lead and tin, in which the proportion of tin is not greater than that of lead, or of lead, tin and a small quantity of antimony. On tin plates thus coated, the dilute sulphuric acid commonly used in Smee's battery will scarcely exert any action. It may be platinized like sheet silver; or it may be coated with borax, and will then answer as well, or very nearly as well, as if it were platinized. It is evident that tin plates thus prepared are far cheaper and more durable than platinized silver; and because they can be brought nearer than platinized silver to the zinc plates without danger of touching them, they may be made to act with greater power.

The fourth result is a new means of protecting iron against the action of the weather and of various corroding substances, so that iron thus protected will answer for all the purposes to which sheet lead and galvanized iron are applied. Besides the experiments by which I have proved the superiority of tin plates (that is, of sheet-iron plates), coated with an alloy of lead and tin, over leaden ones, as the electrodes of a voltameter, I have made many others, in order to compare the action of concentrated nitric, sulphuric and muriatic acid, as well as of dilute sulphuric and muriatic acid on lead and galvanized iron, with their action on iron coated with an alloy of lead and tin, in which the quan-

tity of lead was about equal to that of tin, or from two to seven or eight times as great as that of tin; and from these experiments I infer that iron, coated with any of the above-mentioned alloys, is less oxidable and less liable to corrosion than lead or galvanized iron, the zinc coating of which, as every one knows, is rapidly dissolved by the acids, even when they are greatly diluted with water. Iron, then, coated with an alloy of lead and tin, in which the quantity of lead is nearly equal to, or exceeds that of tin, will answer as well as lead or galvanized iron for roofing, cisterns, baths, pipes, gutters, window-frames, telegraphic wires, for marine and various other purposes. A small quantity of zinc, mixed with the alloy with which the iron is coated, hardens the coating, but diminishes its power of resisting corrosion. But the addition of a little antimony not only hardens the coating, but also makes it less oxidable and less liable to corrosive action. Iron, coated with the alloy of lead and tin, or of lead, tin and antimony, may answer better than lead for vitriol chambers. It may be sometimes used instead of copper for the sheathing of ships; and bolts and nails of coated iron may be sometimes employed instead of copper bolts and nails. It may also be used for some of the purposes for which enamelled iron or cast iron is employed, such as the enamelled cast-iron cisterns and pipes used in water-closets. At the last meeting of the British Association at Hull, Dr. Gladstone stated that the owners of iron-built ships object to sugar cargoes, because the saccharine juices that exude from the casks corrode the metal. If the casks or the ships were lined with thin sheet iron, coated with an alloy of lead and tin, containing two or three times as much lead as tin, it is highly probable that the corrosion of the ships would be prevented. I have left for a considerable time a small piece of an alloy of lead and tin, in which the quantity of lead was four or five times as great as that of tin, in a solution of sugar and common water; and the alloy came out as bright as when it was put into the solution.

The fifth result is a new mode of producing, by means of a small galvanic battery, a brilliant intermittent lime light. By means of a battery of twelve 4-inch cast-iron cells, or of four cells each 6 inches by 8, a small voltameter, such as I have described, and a good Hemming's jet, a constant lime light, about a quarter of an inch in diameter, may be produced. If then the jet be attached to a stopcock, by which the gases are confined in the iron voltameter for fifty-five seconds in every minute, and are allowed to issue from the jet only for five seconds in each minute, twelve times as much of the gases must pass through the jet in these five seconds as would pass through it in the same time were the stopcock always open. Hence if the gases produced by the battery are ignited for five seconds in each

minute as they issue from the jet, and are confined in the vol-
tameter for the remaining fifty-five seconds, the flame will, when
thrown on lime, give a light twelve times as large as one a quarter
of an inch in diameter, or nearly seven-eighths of an inch in
diameter. If the breadth of the hole in the key of the stopcock
be $\frac{1}{24}$ th of the circumference of the key, and if the key make a
revolution in every two minutes, the stopcock, because it is
opened twice in each complete revolution of the key, will be
opened once in every minute for five seconds, and will be closed
for fifty-five seconds. Now by clockwork it is very easy to
make the key of the stopcock perform a revolution once in
every two minutes, and consequently to produce a lime light
seven-eighths of an inch in diameter for five seconds in every
minute. It is easy to make the motion of the key and the ratio
of the diameter of the hole to the circumference of the key such
that the stopcock will be opened once in two minutes for ten
seconds, and will be closed for a minute and fifty seconds. In
order to light the gases whenever the stopcock is opened, it is
necessary to have a small flame of gas or of a candle always at
the nozzle of the jet. A lime light of seven-eighths of an inch
in diameter would be seen at a far greater distance, particularly
in foggy weather and in snow-storms, than the light of a lamp;
and is therefore of the utmost importance in lighthouses. Had
there been such a light in the Bayley Lighthouse, the Victoria
would in all probability not have been lost. The expense or
trouble of such a light would not be very great, and would be
amply compensated by saving the lives of many every year. The
light might be used only in foggy weather or in snow-storms,
when a light capable of penetrating through a dense atmosphere
or a shower of snow would be required. On other occasions the
ordinary lights might be employed. The expense of an inter-
mittent lime light, such as I have described, would be the cost
of working a cast-iron battery containing four zinc plates, each
6 inches by 8, for sixteen or seventeen hours a day, and of a very
minute flame of common coal-gas for the same space of time, as
often as the light might be required. Surely such an expense
could not be very great. Should it be apprehended that the
action of the battery would not be sufficiently constant to give
the light required, then three large gas bags, each of which
would contain as much of the mixed gases as would be sufficient
to maintain a lime light three-fourths or seven-eighths of an
inch in diameter for half an hour, might be filled during the
day with the mixed gases by two or three small batteries. Then,
by means of the apparatus which I have devised for safely ap-
plying the mixed gases to the production of intense heat and
light, of a proper jet, a suitable adjustment of clockwork, and a
very small flame of coal-gas, the intermittent light may be kept

up for eighteen hours; for the light would last only five seconds in each minute, and consequently only five minutes in each hour, or an hour and a half in eighteen hours. Therefore, since the three gas bags, filled with the mixed gases, would maintain a constant light for an hour and a half, they should keep up the intermittent light for eighteen hours. I believe such an intermittent would answer very well for lighthouses. In the lighthouse on the eastern pier at Kingstown, the light is a revolving one, which completes a revolution in about a minute. The brilliant white light, the only one which can be seen at a distance, shines out only for about five seconds in each minute. Hence I infer that an intermittent lime light which lasts for five seconds in each minute would be sufficient for lighthouse purposes. It is necessary to observe, that, when gases are gradually cut off from the jet, the gases in the upper part of the voltameter, or vessel to which the jet is attached, will explode if a Hemming's jet be not used; and this explosion, though perfectly free from danger, will be attended with inconvenience, for a vacuum will be produced in the upper part of the voltameter or vessel, and no gases can pass to the jet till this vacuum is filled. Hence, in producing an intermittent lime light, a Hemming's jet should be employed. Since the discovery of the cast-iron battery, several persons have obtained patents for apparatuses for the coke light, or, as it is now called, the electric light. If they arranged their apparatus so as to produce an intermittent coke-light similar to the intermittent lime light I have described, they would confer a great benefit on society. When the coke light is constant, the battery is soon exhausted, the coke points are consumed, and must be frequently renewed; but were the light intermittent, a single charge of the battery might last for an entire night, and it would be sufficient to renew the coke points two or three times in the course of the night. And if an intermittent coke light were used in lighthouses only on very dark and foggy nights and in snow-storms, the expense could not be considerable. I think the coke light is more intense than the lime light, and also somewhat less expensive. To produce a coke light sufficient for all illuminating purposes, forty cast-iron cells, each containing a zinc plate 2 inches by 4, will suffice. To obtain a lime light of equal illuminating power, a battery containing at least twice as large a surface of zinc will be required. A battery with a given charge will scarcely work twice as long in decomposing water as in igniting a pair of coke points. Therefore, on the whole, I think the lime light is more expensive, but much more easily managed than the coke light. The former requires a battery of only four large plates; the latter depends on the intensity of the current, and requires a battery of at least thirty-five or forty cells. The coke points will require to be

changed more frequently than the lime; and there is more reason to fear that the coke light will fail on account of the destruction of the positive coke point, than that the lime light will go out on account of the wearing of the lime. For the coke light, the zinc plates should not contain more than 8 square inches of surface. If they be larger, the positive coke point will be rapidly destroyed, without a proportional increase of light.

The sixth result is a new mode of exhibiting the dissolving views by means of the lime light. In the common apparatus for showing the dissolving views, the apertures of the lanterns are gradually opened and gradually closed, in order to make the figures come gradually into view and gradually disappear. By using the mixed gases, the apertures may be left always open, and the figure in either lantern may be gradually brought out on the screen, and may be made to fade away by degrees; for by opening very slowly the stopcock through which the gases pass to the jet, the light in the lanterns may be made to increase very slowly till it has acquired its full intensity, and consequently the image thrown on the screen will become gradually brighter till it attains its full brightness; and by very slowly closing the stopcock, the light, and consequently the image, will gradually fade away. By exhibiting the dissolving views in this way, there is a great saving of the mixed gases; for the light shines out fully in each lantern only when it is necessary to exhibit the image in full brightness on the screen. Besides, by diminishing the quantity of the gases which passes through one jet, the quantity which passes through the other jet, and consequently the brightness of the full image, is increased.

The last result is a new sine galvanometer, which is the only instrument yet devised for measuring with accuracy very powerful galvanic currents*. Some of my experiments raised doubts in my mind about some of the generally received theories relating to the action of the galvanic battery. The galvanometers which I had were not fit for measuring very powerful currents, such as I employed. I was therefore obliged to get a new one. After a good deal of reflection, I resolved to get one which would answer for a sine instrument, for the common tangent instrument, and for the new tangent galvanometer, the principle of which is demonstrated in the *Comptes Rendus* of the 24th of last January. The galvanometer which I have made consists of a mahogany circle 2 feet 4 inches in diameter and nearly 2 inches thick, in the circumference of which is turned a groove half an inch wide and $3\frac{1}{2}$ inches deep; of seven concentric coils of $\frac{3}{8}$ -inch copper wire in the groove, and well insulated from each other; of a strong frame in which the circle is moveable on an axis, and

* The voltameter will not measure powerful currents produced by a single circle, or by two or three circles.

always kept in vertical position; and of a compass-box, which, by means of a slide 3 feet long and at right angles to the circle at its centre, may be moved in a direction perpendicular to the circle to the distance of 3 feet from it, so that the centre of the needle, which is a bar-needle $5\frac{1}{8}$ inches long, will always be in the axis of the circle and of the coil, and that the line joining the north and south points of the compass-box will be always parallel to the horizontal diameter of the mahogany circle and coil. From this description of the instrument, it is evident that (no matter where the compass-box is placed on the slide) the needle is parallel to the mahogany circle and coil, or perpendicular to their axis, whenever it points to 0° . Hence, if a voltaic current, sent through the coil, deflect the needle, and if the circle and coil be turned round so as to follow the needle until it points to 0° , the needle, no matter where it may be placed on the slide, will then be parallel to the coil and perpendicular to its axis. The magnetic power of the coil is exerted in the direction of its axis. The effective part of the earth's magnetism in impelling the needle to the magnetic meridian is also exerted in the direction of a perpendicular to the needle or of the axis of the coil, but opposite to that in which the magnetic force of the coil acts. Since the needle is kept at rest by these two forces acting in opposite directions, they must be equal. But the effective part of the earth's magnetism in impelling the needle to the magnetic meridian, varies as the sine of the angle which it makes with that meridian. Therefore the magnetic power of the current flowing through the coil also varies as the sine of the angle which the needle, when it points to 0° , or the mahogany circle D, makes with the magnetic meridian. If the connexion with the battery be broken, the needle will immediately return to the magnetic meridian. The graduated circle of the compass-box will give the number of degrees the needle was deflected from the magnetic meridian. For measuring the angle of deviation, I have used a large graduated circle about 13 inches in diameter, which is attached to the upper part of the mahogany circle, and at right angles to it and to the axis about which it is moveable. By means of seven brass bolts, each three-eighths of an inch in diameter, I can send the current from the battery through one coil, or seven, or through any intermediate number of coils. I scarcely ever use more than one coil, and that is the outside one, the diameter of which is about 2 feet 2 inches. When the current is sent through seven coils, the deflection is so great that only very feeble currents can be measured on the sine galvanometer. When the needle is in the centre of the coil, this galvanometer, used as a sine instrument, large as is its diameter, is not capable of measuring the power of a current produced by a single circle of the cast-iron battery, in which the

zinc plate is an inch broad and 4 inches long. The coil, when made to follow the needle, drives it always before it, so that the needle will never remain parallel to the coil. Hence, in Pouillet's sine galvanometer, in which the centre of the needle is in the centre of the coil, only feeble galvanic currents can be measured. But by sliding the compass-box and needle to 2 or 3 feet from the coil, a current of very great power may be measured. A current which produces a deflection of 75° when the needle is in the centre of the coil, will produce a deflection of only 3° when the needle is at a distance of 3 feet from the coil and its centre in the axis of the coil. Hence, by our galvanometer, in which, and in which alone, the needle may be moved to a distance from the mahogany circle or coil whilst its centre is in the axis of the coil, currents of enormous power may be measured. With this galvanometer I expect to determine,—first, the smallest number of circles the currents of which will be fully effective, or at least as effective as any larger number of galvanic circles in decomposing water, and consequently the number which may be used with the greatest advantage in decomposition; secondly, whether Mr. Faraday's law, viz. that the quantity of the mixed gases produced by a voltaic current is proportional to the quantity of electricity which passes, holds for currents of great power; thirdly, the proportion which the surface of the decomposing plates should bear to the acting surface of zinc in each circle; fourthly, whether a battery with a given charge will work longer in producing the lime light by decomposing water than in producing the coke light, and which of the two lights is the more economical.

To determine the smallest number of cells of the cast-iron battery which are as effective as any larger number in decomposing water, I measured the quantity of the mixed gases produced in two minutes by 3, 4, 5, 6 and 12 cells, and also the deflection of the needle produced by the current from each battery when it passed through a solution of carbonate of soda in which there was about an ounce and a half of soda to each quart of water*. From the steadiness of the needle, it was evident that the current from each battery was perfectly constant during the two minutes it was allowed to act. The quantity of the gases produced by 3 cells was less than three-fourths of the quantity produced by 4, and less than half the quantity produced by 6.

Hence 3 cells are not as effective as 4, 5 or 6. The quantity of the gases produced by 3 cells was sensibly less in proportion to the sine of the angle of deviation shown by the sine galvanometer, than it was when 4 or 5 cells were employed. Hence it

* The quantities of the gases produced by 1 or 2 cells were so small, compared with that which was produced by 3 or 4, that I did not measure them.

appears, that, for want of sufficient intensity, a sensible portion of the electric current produced by 3 cast-iron cells passes through a solution of carbonate of soda without producing decomposition; and therefore in decomposing water, 3 cells cannot be used with advantage. On one occasion the current was sent from 3, 4 and 6 cells, through a solution of sulphate of soda mixed with some carbonate of soda. The quantity of the mixed gases was very nearly in proportion to the number of cells and to the sines of the angle of deviation shown by the sine galvanometer. The sine of deviation appeared to be a little less, in proportion to the quantity of the gases produced, with 4 than with 3 or 6 cells. In this case, the sulphate of soda, as well as the water, was decomposed; for when the flame of the gases was thrown on lime, the bright white light produced by the oxyhydrogen flame was surrounded by another dim light of a purple hue. With the solution of carbonate of soda alone, the quantity of the gases produced by 4, 5, or 6 cells appeared proportional to the number of cells and to the sines of deviation. Hence, cast-iron batteries of 4, 5, or 6 cells will be equally effective in producing decomposition. But a battery of 4 cells will work as long and a half with a given charge as one of 6 cells, and as long and a quarter as one of 5; because in these batteries the quantity of electricity constantly flowing through each cell is proportional to the number of cells. Hence in preparing a battery for decomposing water, all the cells should be arranged in rows of 4 each. Four cells produced more than half the quantity of the gases produced by 12 cells of the same size. A battery of 60 cells, arranged in one series, after having worked for some time, produced in one minute very little more than 4 cells of the same size. I have not yet tried the decomposing power of a battery of a larger number acting in one series; but I shall have occasion, in the month of February, to show to my class a battery of about 250 cells; and I will then measure the quantity of the gases produced in one minute when all act in one series. Eight cells, arranged in two rows of four each, so that the two end zinc plates were connected as one, and the two iron cells also acted as one, produced considerably more of the mixed gases in two minutes than was produced by 12 cells of the same size acting in one series. The quantities of the gases produced by the 8 and the 12 cells were in the ratio of $11\frac{1}{2}$ to 9. But with the 12 cells, the sine of deviation shown by the sine galvanometer appeared to be greater in proportion to the quantity of the gases produced than when the battery of 8 cells in two rows was employed. Hence it would appear, that when the intensity of the current is much greater than that of 4 or 6 cells of the cast-iron battery, the ratio of the quantity of water decomposed to the quantity of electricity passing through it is diminished; and consequently

that Mr. Faraday's law of definite electro-chemical decomposition does not hold for powerful currents, which differ much in their intensity. In my last experiments I perceived a defect in the magnetic needle employed, and therefore do not feel myself warranted in drawing a positive conclusion. Besides, I am sure that my experiments were not made with as much accuracy as Mr. Faraday's were; but they incline me to believe that the decomposing power of strong currents decreases when their intensity increases. I am inclined to believe that there is a certain intensity above and below which there is a loss of decomposing power; and that, in a cast-iron battery, it is the intensity of 4 cells in one series. I am inclined to think that, when the intensity is greater than that, some of the electricity passes through water without meeting the resistance or reaction necessary for decomposition; and that the greater the intensity the greater the quantity which passes without the required resistance. The current from a battery of 12 cast-iron cells does not meet with much resistance in passing through a solution of carbonate of soda. For when the current was sent, without passing through the fluid, through the coil of the tangent galvanometer, it produced a deflection of 69° ; and when sent first through the fluid and then through the coil, the needle was deflected to 68° . When a current was sent from 60 cells, first through the fluid and then through a pair of coke points, the deflection was the same as when it passed through the coke points without passing through the fluid. Hence a current from a battery of 60 cells appears to meet with as little resistance in passing through a fluid as in passing through a wire. Hence a current of very high intensity experiences little or no resistance or reaction from the fluid, and therefore can produce little effect on it.

In comparing the deflection of the needle produced by a current from 6 cells through a solution of carbonate of soda with the deflection produced by the current from the same battery sent directly through the coil of the galvanometer, it occurred to me that if 12 cells were arranged in two rows, and the two end zinc plates connected as one, and the two iron cells connected so as to act as a single cell, the current from these two rows would, after passing through a fluid, produce a greater deflection of the needle than they would, if, whilst they acted in one series, the current were sent directly through the coil of the galvanometer. Subsequent experiments proved that my conjecture was well founded. When 12 cells were arranged in two rows of six each, and the current from both was sent through a solution of carbonate of soda and then through the coil, a deflection of 67° was produced in the needle of the tangent galvanometer. When the current was sent from the same 12 cells acting in one series through the coil alone, the deflection was

only 64° . Hence more electricity passed from the two rows of six each through the fluid, than from 12 cells through the wire. Now it is well known, that when a current of electricity passes from one end of a battery to the other through a conductor in which it meets no resistance, the same quantity will pass in a given time between the ends of the battery, whether it consist of a single pair, or of a hundred or of a thousand circles, or of any number whatever. Hence more electricity will pass in any time through a solution of carbonate of soda from 12 cells arranged in two rows of six each, than will pass in the same time through a wire or fluid from a thousand, or any number of cells of the same size. Therefore whether Mr. Faraday's law hold for powerful currents of great intensity, or whether the conclusion drawn from my experiments be just, 12 cells, arranged in two rows of six each, will produce more decomposition in a given time than will be produced by a thousand, or any number of cells acting in one series. I have found, in the same way, that 8 cells, in two rows of four each, will produce as much, or nearly as much, of the mixed gases in a given time as any number acting in one series. Hence, with the common voltameter, a battery of 500 cast-iron cells, arranged in rows of four, will produce more than fifty times as much of the mixed gases as it will produce when all the cells are arranged in one series. Besides, when the cells are arranged in rows of four, the battery with a given charge will act about twice as long as when all act in one series; for in the latter case about twice as much electricity passes constantly through each cell as in the former, and consequently the power of the battery is exhausted about twice as soon. Hence, on the whole, with the common voltameter, a battery of 500 cast-iron cells arranged in one series will not produce the hundredth part of its full decomposing effect; but with the voltameter I have described, it will, as I have shown, produce its full effect. If a battery of 4 cast-iron cells, and another of 1000 or of any number of cells of the same size be similarly charged, the former will, before its power is exhausted, produce as much of the mixed gases as the latter; because the former will produce in each minute as [half as much as?] the latter, and it will work twice as long.

I will here mention one of the experiments from which I inferred, that in a voltameter for a battery of a large number of cells arranged in one series, the number of decomposing cells should be about one-fourth of the number of cells in the battery. When the current was sent from 12 cells in series, through 4 decomposing cells and through the coil of the galvanometer, the deflection was a little less than that which was produced by the current from 3 cells when it passed through one decomposing cell and the coil. The difference arose from the imperfect insulation of the cast-iron cells. But when the current was

sent from the same 12 cells through 4 decomposing cells, and then through the helix of an electro-magnet by which a small magnetic machine was driven, the speed of the machine was considerably greater than when the current from 3 cells passed through one decomposing cell, and then through the coil of the electro-magnet. The wire coiled on the electro-magnet was about 50 feet long and one-eighth of an inch thick. The coil of the galvanometer is about 7 feet long and three-eighths of an inch in diameter. The resistance in the latter was insensible compared with the resistance in the former.

The ratio which the acting surface of each electrode should bear to that of the zinc in each circle may be found by putting a pair of large plates into a glazed vessel, and connecting them with the opposite ends of a battery of 4 cast-iron cells in each of which the zinc plate is small, so that the current will pass through the coil of a galvanometer. If a solution of carbonate of soda be then gradually poured into the glazed vessel until the needle ceases to recede from the magnetic meridian, that is, until no more electricity is transmitted through the fluid, it will be found that the acting surface of each of the electrodes, which is covered by the fluid, is about once and a half as great as the acting surface of the zinc plate in each circle. By pouring the fluid to any height whatever into the glazed vessel so as to increase the acting surface of the electrodes, no increase will be produced in the deflection of the needle. Hence there is a limit to the conducting power of fluids for electricity of low intensity. A solution of carbonate of soda (no matter how thick and short the column of fluid may be) will not, when interposed between the opposite ends of a nitric acid battery of 4 cells, conduct more than about one-half of the electricity which will be conducted by a short, thick wire connected with the opposite ends of the same battery. In investigating the ratio which the surface of the electrodes should bear to the surface of each zinc plate of the battery, I used solutions of carbonate of soda of different degrees of strength, and found that the conducting power of a solution, which contains an ounce in each quart of water, is very little inferior to that of the strongest solution, whilst it foams far less. If a neutral salt could be found, which, when mixed with carbonate of soda, would prevent its foaming, and would not be decomposed by the voltaic current, sheet-iron plates coated with an alloy of lead and tin would be in every way preferable to platina electrodes. I have tried nitrate of potash, bisulphate of potash, bichromate of potash, sulphate of soda, borate of soda, and chloride of sodium mixed with carbonate of soda. But they were all decomposed by the galvanic current, as was evident from the light which the gases produced. When the current was sent from the battery through a solution con-

taining three ounces of bichromate of potash and five of carbonate of soda in about five quarts of water, there was scarcely any foam, but the light produced by the gases was tinged with red, and not so intense as the oxyhydrogen light. The heat of the flame appeared not inferior to that of the oxyhydrogen flame. When bisulphate of potash was mixed with carbonate of soda, the light and heat produced were the same as when bichromate of potash was used. The light was injured much less by mixing bichromate of potash, or bisulphate of potash with the carbonate of soda, than by the mixture of any of the other salts with it.

To estimate the comparative expense of the coke light and the lime light, it is necessary, first, to determine the size of the battery which will produce a brilliant coke light, with that of one, which, by decomposing water, will produce a lime light of equal illuminating power; and secondly, to determine the time each battery will work with a given charge. Although I made a battery of a size which I thought would be most advantageous for producing the coke light, I have not as yet succeeded in determining satisfactorily either of these two points. The battery which I prepared consisted of 60 cast-iron cells in which each zinc plate was 4 inches by 2. In the battery which I commonly used, the zinc plates were 4 inches square. I always found that this battery soon destroyed the coke points. On one occasion, about five years ago, I got a coke light sufficient for the gas microscope from a battery of 24 cells, which were only half-filled with acid. Hence I inferred that zinc plates, 2 inches by 4, would be large enough for a brilliant coke light. When the battery of 60 cells, in which the zinc plates were 2 inches by 4, was prepared, I sent the current, first, from thirty of them through a pair of coke points. The light was sufficiently brilliant for all illuminating purposes, but did not last very long. I then changed the connexion that I might try the effect of 40 cells. The light was then both steady and brilliant. I think that this is the smallest, and therefore the least expensive battery, by which, with the aid of a good apparatus for adjusting the coke points, a continuous light of great illuminating power can be obtained. If the plates be smaller, the illuminating power of the coke points will not be sufficient; and if the number of cells be less than 40, the electric current will not have sufficient intensity to pass through the flame between the coke points. With this battery a pair of coke points lasts a long time. I have found that when the battery is not very powerful, the brilliant light comes only from the positive coke point. For, if a coke point and a copper point be used instead of two coke points, and if the coke point be connected with the positive end of the battery, the light is as brilliant as if two coke points were employed. But if the coke point be connected with the negative,

and the copper point with the positive end, the light will be worthless. I forgot to make this experiment when I had occasion to use a very powerful battery. I may mention here that with 60 cast-iron cells in which the zinc plates were 2 inches by 4, I was able to fuse and deflagrate a round piece of steel $\frac{1}{4}$ inch diameter. Although I made a far greater number of experiments on the lime light than on the coke light, I am not able to state positively the size of the battery, which, by decomposing water, would produce a lime light equal in illuminating power to that of a pair of coke points ignited by a battery of 40 cast-iron cells in which the zinc plates are 2 inches by 4. I can only say that I think it probable that a battery twice, or very nearly twice the size, would be required. With regard to the length of time the two batteries would work with a given charge, I am equally uncertain. In decomposing water, all the cells must be arranged in rows of four each, so that the intensity of the current may not exceed that of 4 cells. Now, when a current is sent from 4 cells through a good conducting fluid, the quantity of electricity which passes through the fluid and through each cell of the battery is only about one-half of the quantity which would pass if the ends of the battery were connected by a short, thick wire. This I have found by the galvanometer. Hence the battery would work about twice as long in the former as in the latter case. When the coke points were ignited by 40 cells, I measured the angle of deviation of the sine galvanometer, and found it to be 31° when the needle was in the axis of the coil, and nearly 10 inches from its centre. When they were ignited by 60 cells, the deviation was 40° . Unfortunately, I did not measure the angle of deviation which would be produced by the current passing directly through the coil of the galvanometer. The experiments were made before my class, and I intended to measure on the next day the angle of deviation which would be produced by the current from 4 cells of the same size, sent through a fluid. I was prevented from making the experiment until I had occasion to remagnetize the needle, and consequently I cannot now depend on its indications being the same they would have been on the day the battery of 40 and 60 cells was used. I have since tried the effect of a current from four of the cells on the sine galvanometer after passing it through a solution of carbonate of soda, and found that a deflection of $22\frac{1}{2}^\circ$ was produced in the needle of the sine galvanometer. But I am inclined to think that had I made the experiment the day I used the 40 cells, the deflection would have been considerably less, because the needle was not then so highly magnetized. The impression made by all my experiments inclines me to believe that a battery would work nearly twice as long in decomposing water as in igniting coke points; that, therefore, the coke light and the lime light are nearly equally

expensive, but that the former is somewhat more æconomical. I shall soon have occasion to exhibit a battery of about 250 cast-iron cells, and intend then to compare the quantity of electricity which will pass between a pair of coke points ignited by 40 cells, with that which will pass through a thick wire connected with the opposite ends of the same 40 cells. I intended to investigate the decomposing power of the coil, but I must defer the investigation till health and leisure permit me to resume my experiments.

Maynooth College,
January 2, 1854.

P.S. I have got a new iron vessel made of a rectangular form, for which I am preparing two sets of electrodes; one for a battery of low intensity, the other for a battery of high intensity. The former will consist of 100 iron plates coated with an alloy of lead and tin; 50 of them (the alternate plates) will be connected with one end of the battery, and the other 50 with the opposite end. The 100 plates will be divided into twenty groups, each containing 5 plates. Each group will be covered all round with linen, so that the foam produced by the ascent of the gases in the solution of soda may be made to pass through the linen, and that thus the bubbles may be broken. This arrangement of the electrodes will answer for a battery of 60 cast-iron cells arranged in fifteen rows of four each, and in which each zinc plate is 6 inches by 4. The quantity of the gases produced by each group of 5 plates will be equal to that which would be produced by 3 cast-iron cells, or the $\frac{1}{20}$ th of 60. Now I have found that a linen cover on the electrodes prevents all foam when the battery does not contain more than 5 or 6 cells, in which each zinc plate is 6 inches by 4. Therefore in the arrangement just described there can be no foam. The electrodes for a battery of high intensity will consist of 156 coated iron plates, divided into twelve groups each containing 13 plates. The 13 plates of each group will form 12 decomposing cells nearly water-tight, and open only at the top. The first plate of each group will be connected with one end of the battery, and the last with the opposite end. Hence when the cells are nearly filled with a solution of soda, the voltaic current will pass simultaneously from the first to the last plate of each group, through the intermediate plates and fluid, and produce decomposition in each cell. This arrangement is intended for a battery of 60 cells, in which each zinc plate is 6 inches by 4, all acting in one series. The intensity of the current from this battery will be reduced to that of 5 cells by passing through the 12 decomposing cells. Each group of 13 plates will be covered with linen, which will prevent all foam, because in each group the quantity of the gases will be only equal to that which would be produced by 5 cells, or by $\frac{1}{12}$ th of 60.

January 25, 1854.