



## XXXVII. Contributions to electricity and magnetism. No. III. On electro-magnetic induction

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female. All the following sizes common : 1-4365th, 1-4268th, 1-4173rd, and 1-4000th. Extreme sizes 1-5333rd and 1-3555th of an inch. Blood from a prick of the nose.

135. Alexandrian Rat, (*Mus Alexandrinus*, albino, var.,) an adult male. 1-4173rd, 1-4000th, 1-3810th, and 1-3764th, very common sizes. Small corpuscles 1-4800th; the large 1-3200th. Edges of disks 1-14,000th of an inch thick. Blood from a vein of the hind leg.

136. Coendu or Ring-tailed Porcupine, (*Synetheres prehensilis*,) a full-grown male. Common diameters 1-3428th, 1-3309th, and 1-3600th. Extreme sizes 1-4570th and 1-2460th of an inch. Blood from a cut at the end of the tail.

Error in the last paper (No. 2.) p. 108, l. 28, for Haller, read Harvey.

XXXVII. *Contributions to Electricity and Magnetism.*  
*No. III. on Electro-magnetic Induction.* By JOSEPH  
 HENRY, LL.D., *Prof. of Natural Philosophy in the College*  
*of New Jersey, Princeton\*.*

INTRODUCTION.—SECTION I. *Conditions which influence the induction of a Current on itself.*—SECTION II. *Conditions which influence the production of Secondary Currents.*—SECTION III. *On the Induction of Secondary Currents at a distance.*—SECTION IV. *On the Effects produced by interposing different Substances between the Conductors.*—SECTION V. *On the Production and Properties of induced Currents of the Third, Fourth and Fifth Order.*—SECTION VI. *The Production of induced Currents of the different Orders from ordinary Electricity.*—NOTE *on the investigations of Professor Ettingshausen.*

1. SINCE my investigations in reference to the influence of a spiral conductor, in increasing the intensity of a galvanic current, were submitted to the Society, the valuable paper of Dr. Faraday, on the same subject, has been published, and also various modifications of the principle have been made by Sturgeon, Masson, Page, and others, to increase the effects. The spiral conductor has likewise been applied by Cav. Antinori to produce a spark by the action of a thermo-electrical pile: and Mr. Watkins has succeeded in exhibiting all the phenomena of hydro-electricity by the same means. Although the principle has been much extended by the re-

\* From the Transactions of the American Philosophical Society, vol. vi, having been read Nov. 2, 1838.

searches of Dr. Faraday, yet I am happy to state that the results obtained by this distinguished philosopher are not at variance with those given in my paper.

2. I now offer to the Society a new series of investigations in the same line, which I hope may also be considered of sufficient importance to merit a place in the Transactions.

3. The primary object of these investigations was to discover, if possible, inductive actions in common electricity analogous to those found in galvanism. For this purpose a series of experiments was commenced in the spring of 1836, but I was at that time diverted, in part, from the immediate object of my research, by a new investigation of the phænomenon known in common electricity by the name of the lateral discharge. Circumstances prevented my doing anything further, in the way of experiment, until April last, when most of the results which I now offer to the Society were obtained. The investigations are not as complete, in several points, as I could wish, but as my duties will not permit me to resume the subject for some months to come, I therefore present them as they are; knowing, from the interest excited by this branch of science in every part of the world, that the errors which may exist will soon be detected, and the truths be further developed.

4. The experiments are given nearly in the order in which they were made; and in general they are accompanied by the reflections which led to the several steps of the investigation. The whole series is divided, for convenience of arrangement, into six sections, although the subject may be considered as consisting, principally, of two parts; the first relating to a new examination of the induction of galvanic currents; and the second to the discovery of analogous results in the discharge of ordinary electricity\*.

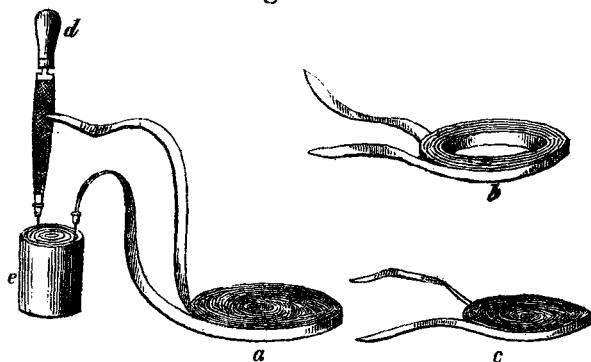
5. The principal articles of apparatus used in the experiments, consist of a number of flat coils of copper riband, which will be designated by the names of coil No. 1, coil No. 2, &c.; also of several coils of long wire; and these, to distinguish them from the ribands, will be called helix No. 1, helix No. 2, &c.

6. Coil No. 1 is formed of thirteen pounds of copper plate, one inch and a half wide and ninety-three feet long. It is well covered with two coatings of silk, and was generally used in the form represented in fig. 1, which is that of a flat spiral sixteen inches in diameter. It was however sometimes formed

\* The several paragraphs are numbered in succession, from the first to the last, after the mode adopted by Mr. Faraday, for convenience of reference.

into a ring of larger diameter, as is shown in fig. 4, Section III.

Fig. 1.

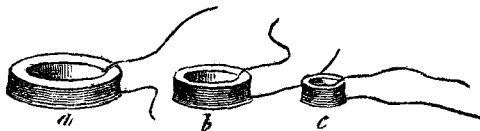


*a* represents coil No. 1, *b* coil No. 2, and *c* coil No. 3; *e* the battery, *d* the rasp.

7. Coil No. 2. is also formed of copper plate, of the same width and thickness as coil No. 1. It is, however, only sixty feet long. Its form is shown at *b*, fig. 1. The opening at the centre is sufficient to admit helix No. 1. Coils Nos, 3, 4, 5, 6, &c. are all about sixty feet long, and of copper plate of the same thickness, but of half the width of coil No. 1.

8. Helix No. 1. consists of sixteen hundred and sixty yards of copper wire,  $\frac{1}{8}$ th of an inch in diameter; No. 2, of nine hundred and ninety yards; and No. 3, of three hundred and

Fig. 2.



*a* represents helix No. 1, *b* helix No. 2, *c* helix No. 3.

fifty yards, of the same wire. These helices are shown in fig. 2, and are so adjusted in size as to fit into each other; thus forming one long helix of three thousand yards: or, by using them separately, and in different combinations, seven helices of different lengths. The wire is covered with cotton thread, saturated with bees-wax, and between each stratum of spires a coating of silk is interposed.

9. Helix No. 4 is shown at *a*, fig. 4, Section III.; it is

formed of five hundred and forty-six yards of wire,  $\frac{1}{40}$ th of an inch in diameter, the several spires of which are insulated by a coating of cement. Helix No. 5 consists of fifteen hundred yards of silvered copper wire  $\frac{1}{100}$ th of an inch in diameter, covered with cotton, and is of the form of No. 4.

10. Besides these I was favoured with the loan of a large spool of copper wire, covered with cotton,  $\frac{1}{16}$ th of an inch in diameter, and five miles long. It is wound on a small axis of iron, and forms a solid cylinder of wire, eighteen inches long, and thirteen in diameter.

11. For determining the direction of induced currents, a magnetizing spiral was generally used, which consists of about thirty spires of copper wire, in the form of a cylinder, and so small as just to admit a sewing needle into the axis.

12. Also a small horseshoe is frequently referred to, which is formed of a piece of soft iron, about three inches long, and  $\frac{2}{5}$ ths of an inch thick; each leg is surrounded with about five feet of copper bell wire. This length is so small, that only a current of electricity of considerable quantity can develop the magnetism of the iron. The instrument is used for indicating the existence of such a current.

13. The battery used in most of the experiments is shown in fig. 1. It is formed of three concentric cylinders of copper, and two interposed cylinders of zinc. It is about eight inches high, five inches in diameter, and exposes about one square foot and three quarters of zinc surface, estimating both sides of the metal. In some of the experiments a larger battery was used, weakly charged; but all the results mentioned in the paper, except those with a Cruickshanks trough, can be obtained with one or two batteries of the above size, particularly if excited by a strong solution. The manner of interrupting the circuit of the conductor by means of a rasp, *b*, is shown in the same figure.

#### SECTION I.—*Conditions which influence the induction of a Current on itself.*

14. The phenomenon of the spiral conductor is at present known by the name of the induction of a current on itself, to distinguish it from the induction of the secondary current, discovered by Dr. Faraday. The two, however, belong to the same class, and experiments render it probable that the spark given by the long conductor is, from the natural electricity of the metal, disturbed for an instant by the induction of the primary current. Before proceeding to the other parts of these investigations, it is important to state the results of a number of preliminary experiments, made to determine

more definitely the conditions which influence the action of the spiral conductor.

15. When the electricity is of low intensity, as in the case of the thermo-electrical pile, or a large single battery weakly excited with dilute acid, the flat riband coil No. 1, ninety-three feet long, is found to give the most brilliant deflagrations, and the loudest snaps from a surface of mercury. The shocks, with this arrangement, are, however, very feeble, and can only be felt in the fingers or through the tongue.

16. The induced current in a short coil, which thus produces deflagration, but not shocks, may, for distinction, be called one of quantity.

17. When the length of the coil is increased, the battery continuing the same, the deflagrating power decreases, while the intensity of the shock continually increases. With five riband coils, making an aggregate length of three hundred feet, and the small battery, fig. 1, the deflagration is less than with coil No. 1, but the shocks are more intense.

18. There is, however, a limit to this increase of intensity of the shock, and this takes place when the increased resistance or diminished conduction of the lengthened coil begins to counteract the influence of the increasing length of the current. The following experiment illustrates this fact. A coil of copper wire  $\frac{1}{16}$ th of an inch in diameter, was increased in length by successive additions of about thirty-two feet at a time. After the first two lengths, or sixty-four feet, the brilliancy of the spark began to decline, but the shocks constantly increased in intensity, until a length of five hundred and seventy-five feet was obtained, when the shocks also began to decline. This was then the proper length to produce the maximum effect with a single battery, and a wire of the above diameter.

19. When the intensity of the electricity of the battery is increased, the action of the short riband coil decreases. With a Cruickshanks trough of sixty plates, four inches square, scarcely any peculiar effect can be observed, when the coil forms a part of the circuit. If however the length of the coil be increased in proportion to the intensity of the current, then the inductive influence becomes apparent. When the current, from ten plates of the above-mentioned trough, was passed through the wire of the large spool (10.), the induced shock was too severe to be taken through the body. Again, when a small trough of twenty-five one-inch plates, which alone would give but a very feeble shock, was used with helix No. 1, an intense shock was received from the induction when the contact was broken. Also a slight shock in this

arrangement is given when the contact is formed, but it is very feeble in comparison with the other. The spark, however, with the long wire and compound battery is not as brilliant as with the single battery and the short riband coil.

20. When the shock is produced from a long wire, as in the last experiments, the size of the plates of the battery may be very much reduced, without a corresponding reduction of the intensity of the shock. This is shown in an experiment with the large spool of wire (10.). A very small compound battery was formed of six pieces of copper bell wire, about one inch and a half long, and an equal number of pieces of zinc of the same size. When the current from this was passed through the five miles of the wire of the spool, the induced shock was given at once to twenty-six persons joining hands. This astonishing effect placed the action of a coil in a striking point of view.

21. With the same spool and the single battery used in the former experiments, no shock, or at most a very feeble one, could be obtained. A current, however, was found to pass through the whole length, by its action on the galvanometer; but it was not sufficiently powerful to induce a current which could counteract the resistance of so long a wire.

22. The induced current in these experiments may be considered as one of *considerable intensity*, and *small quantity*.

23. The form of the coil has considerable influence on the intensity of the action. In the experiments of Dr. Faraday, a long cylindrical coil of thick copper wire, inclosing a rod of soft iron, was used. This form produces the greatest effect when magnetic reaction is employed; but in the case of simple galvanic induction, I have found the form of the coils and helices represented in the figures most effectual. The several spires are more nearly approximated, and therefore they exert a greater mutual influence. In some cases, as will be seen hereafter, the ring form, shown in fig. 4, is most effectual.

24. In all cases the several spires of the coil should be well insulated; for although in magnetizing soft iron, and in analogous experiments, the touching of two spires is not attended with any great reduction of action, yet in the case of the induced current, as will be shown in the progress of these investigations, a single contact of two spires is sometimes sufficient to neutralize the whole effect.

25. It must be recollected that all the experiments with these coils and helices, unless otherwise mentioned, are made without the reaction of iron temporarily magnetized; since the introduction of this would, in some cases, interfere with the action, and render the results more complex.

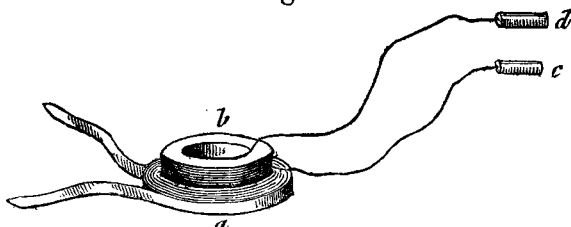
SECTION II.—*Conditions which influence the production of Secondary Currents.*

26. The secondary currents, as it is well known, were discovered in the induction of magnetism and electricity, by Dr. Faraday, in 1831. But he was at that time urged to the exploration of new, and apparently richer veins of science, and left this branch to be traced by others. Since then, however, attention has been almost exclusively directed to one part of the subject, namely, the induction from magnetism, and the perfection of the magneto-electrical machine. And I know of no attempts, except my own, to review and extend the purely electrical part of Dr. Faraday's admirable discovery.

27. The energetic action of the flat coil, in producing the induction of a current on itself, led me to conclude that it would also be the most proper means for the exhibition and study of the phenomena of the secondary galvanic currents.

28. For this purpose coil No. 1 was arranged to receive the current from the small battery, and coil No. 2 placed on this, with a plate of glass interposed to ensure perfect insulation; as often as the circuit of No. 1 was interrupted, a

Fig. 3.



*a* represents coil No. 1, *b* helix No. 1, and *c*, *d*, handles for receiving the shock.

powerful secondary current was induced in No. 2. The arrangement is the same as that exhibited in fig. 3, with the exception that in this the compound helix is represented as receiving the induction, instead of coil No. 2.

29. When the ends of the second coil were rubbed together, a spark was produced at the opening. When the same ends were joined by the magnetizing spiral (11.), the enclosed needle became strongly magnetic. Also when the secondary current was passed through the wires of the iron horseshoe (12.), magnetism was developed; and when the ends of the second coil were attached to a small decomposing apparatus, of the kind which accompanies the magneto-electrical machine, a stream of gas was given off at each pole. The shock, however, from this coil is very feeble, and can scarcely be felt above the fingers.



30. This current has therefore the properties of one of moderate intensity, but considerable quantity.

31. Coil No. 1 remaining as before, a longer coil, formed by uniting Nos. 3, 4 and 5, was substituted for No. 2. With this arrangement, the spark produced when the ends were rubbed together, was not as brilliant as before; the magnetizing power was much less; decomposition was nearly the same, but the shocks were more powerful, or, in other words, the intensity of the induced current was increased by an increase of the length of the coil, while the quantity was apparently decreased.

32. A compound helix, formed by uniting Nos. 1 and 2, and therefore containing two thousand six hundred and fifty yards of wire, was next placed on coil No. 1. The weight of this helix happened to be precisely the same as that of coil No. 2, and hence the different effects of the same quantity of metal in the two forms of a long and short conductor, could be compared. With this arrangement the magnetizing effects, with the apparatus before mentioned, disappeared. The sparks were much smaller, and also the decomposition less, than with the short coil; but the shock was almost too intense to be received with impunity, except through the fingers of one hand. A circuit of fifty-six of the students of the senior class, received it at once from a single rupture of the battery current, as if from the discharge of a Leyden jar weakly charged. The secondary current in this case was one of small quantity, but of great intensity.

33. The following experiment is important in establishing the fact of a limit to the increase of the intensity of the shock, as well as the power of decomposition, with a wire of a given diameter. Helix No. 5, which consists of wire only  $\frac{1}{125}$ th of an inch in diameter, was placed on coil No. 2, and its length increased to about seven hundred yards. With this extent of wire, neither decomposition nor magnetism could be obtained, but shocks were given of a peculiarly pungent nature; they did not however produce much muscular action. The wire of the helix was further increased to about fifteen hundred yards; the shock was now found to be scarcely perceptible in the fingers.

34. As a counterpart to the last experiment, coil No. 1 was formed into a ring of sufficient internal diameter to admit the great spool of wire (11.), and with the whole length of this (which, as has before been stated, is five miles) the shock was found so intense as to be felt at the shoulder, when passed only through the fore-finger and thumb. Sparks and decomposition were also produced, and needles rendered mag-

netic. The wire of this spool is  $\frac{1}{16}$ th of an inch thick, and we therefore see from this experiment, that by increasing the diameter of the wire, its length may also be much increased, with an increased effect.

35. The fact (33.) that the induced current is diminished by a further increase of the wire, after a certain length has been attained, is important in the construction of the magneto-electrical machine, since the same effect is produced in the induction of magnetism. Dr. Goddard of Philadelphia, to whom I am indebted for coil No. 5, found that when its whole length was wound on the iron of a temporary magnet, no shocks could be obtained. The wire of the machine may therefore be of such a length, relative to its diameter, as to produce shocks, but no decomposition; and if the length be still further increased, the power of giving shocks may also become neutralized.

36. The inductive action of coil No. 1, in the foregoing experiments, is precisely the same as that of a temporary magnet in the case of the magneto-electrical machine. A short thick wire around the armature gives brilliant deflagrations, but a long one produces shocks. This fact, I believe, was first discovered by my friend Mr. Saxton, and afterwards investigated by Sturgeon and Lenz.

37. We might, at first sight, conclude, from the perfect similarity of these effects, that the currents which, according to the theory of Ampere, exist in the magnet, are, like those in the short coil, of great quantity and feeble intensity; but succeeding experiments will show that this is not necessarily the case.

38. All the experiments given in this section have thus far been made with a battery of a single element. This condition was now changed, and a Cruickshanks' trough of sixty pairs substituted. When the current from this was passed through the riband coil No. 1, no indication, or a very feeble one, was given of a secondary current in any of the coils or helices, arranged as in the preceding experiments. The length of the coil, in this case, was not commensurate with the intensity of the current from the battery. But when the long helix, No. 1, was placed instead of coil No. 1, a powerful inductive action was produced on each of the articles, as before.

39. First, helices No. 2 and 3 were united into one, and placed within helix No. 1, which still conducted the battery current. With this disposition a secondary current was produced, which gave intense shocks but feeble decomposition, and no magnetism in the soft iron horseshoe. It was there-

fore one of intensity, and was induced by a battery current also of intensity.

40. Instead of the helix used in the last experiment for receiving the induction, one of the coils (No. 3) was now placed on helix No. 1, the battery remaining as before. With this arrangement the induced current gave no shocks, but it magnetized the small horseshoe; and when the ends of the coil were rubbed together, produced bright sparks. It had therefore the properties of a current of quantity; and it was produced by the induction of a current, from the battery, of intensity.

41. This experiment was considered of so much importance, that it was varied and repeated many times, but always with the same result; it therefore establishes the fact *that an intensity current can induce one of quantity*, and by the preceding experiments, the converse has also been shown, that *a quantity current can induce one of intensity*.

42. This fact appears to have an important bearing on the law of the inductive action, and would seem to favour the supposition that the lower coil, in the two experiments with the long and short secondary conductors, exerted the same amount of inductive force, and that in one case this was expended (to use the language of theory) in giving a great velocity to a small quantity of the fluid, and in the other in producing a slower motion in a larger current; but in the two cases, were it not for the increased resistance to conduction in the longer wire, the quantity multiplied by the velocity would be the same. This, however, is as yet a hypothesis, but it enables us to conceive how intensity and quantity may both be produced from the same induction.

43. From some of the foregoing experiments we may conclude, that the quantity of electricity in motion in the helix is really less than in the coil, of the same weight of metal; but this may possibly be owing simply to the greater resistance offered by the longer wire. It would also appear, if the above reasoning be correct, that to produce the most energetic physiological effects, only a small quantity of electricity, moving with great velocity, is necessary.

44. In this and the preceding section, I have attempted to give only the general conditions which influence the galvanic induction. To establish the law would require a great number of more refined experiments, and the consideration of several circumstances which would affect the results, such as the conduction of the wires, the constant state of the battery, the method of breaking the circuit with perfect regularity,

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and also more perfect means than we now possess of measuring the amount of the inductive action; all these circumstances render the problem very complex.

[To be continued.]

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XXXVIII. *Researches of Mons. R. PIRIA on the Combinations of Salicyle\*.*

EVERY one who is at all acquainted with the gigantic strides made in organic chemistry since the discovery of the real nature of the oil of bitter almonds, and the development of the remarkable combinations of benzoyle, must have hailed with peculiar pleasure the discovery of an analogous series of compounds having for their base a compound radical termed spiroil, from its being present in the oil of the *Spiræa Ulmaria*, or meadow-sweet. This body was discovered by Löwig, who ascertained the volatile oil of the *Spiræa* to be really an hydracid, consisting of a compound radical analogous to benzoyl, combined with hydrogen. The researches of Löwig have been already presented to the English reader in the pages of the valuable Scientific Memoirs of Mr. R. Taylor. We have now the pleasure of laying before our scientific readers an account of a valuable series of researches of M. Piria on a new compound organic base, bearing considerable resemblance to benzoyl and spiroil, and promising, from this very resemblance, to throw much light on the nature of the respective combinations of these curious bases.

The active principle of the bark of different species of *salix* has been long known to chemists, and salicin is now an ordinary article of commerce, being employed in medicine as a substitute for quinine, as a remedy in intermittent fever.

Salicine was first obtained in a white crystallizable state, by M. Leroux, and has been submitted to ultimate analysis by MM. Jules Gay-Lussac and Pelouse. Piria has also analysed it, and its per centage composition was in three experiments found to be as follows:—

	Exp. 1.	Exp. 2.	Exp. 3.
Carbon.....	55.68	55.04	55.54
Hydrogen .....	6.36	6.39	6.43
Oxygen .....	37.96	38.57	38.03
	<hr/> 100	<hr/> 100	<hr/> 100

\* For this account of M. Piria's researches, the Editors are obliged to Dr. Golding Bird.