XVII. *An Experimental Inquiry undertaken with the view of ascertaining whether any, and what signs of current Electricity are manifested during the organic process of Secretion in living animals, being an attempt to apply some of the discoveries of* FARADAY *to Physiology*. By* H. F. BAXTER, *Esq.*

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THE conjecture and experiment of WOLLASTON†, the cautious opinion of PROUT‡, the experiments of DONNÉ§ and of MATTEUCCI‖, are so well known that a mere allusion to them may be deemed sufficient. BECQUEREL¶, in speaking of MATTEUCCI's experiment, adds, "Si de nouvelles expériences confirment les résultats, il faudrait en conclure réellement que les organes qui sécrètent un liquide acide ou alcalin, ont des facultés électriques analogues à celles de la pile."

POUILLET** inserted one of the platinum extremities of a galvanometer into the jugular vein of a rabbit, the other into the carotid artery, without any effect being produced on the needle. MÜLLER†† says, "With the galvanometer no electric current can be discovered in the blood. I perceived no variation of the magnetic needle of the multiplier, even when I inserted one wire into an artery of a living animal, the other into a vein."

The galvanometer‡‡ that was used in these experiments is one of the common and ordinary construction, astatic, consisting of but few coils; the needles suspended by silk-worm silk, and the electrodes attached by screws. As the object was to ascer-

* It would be unjust to BECQUEREL not to state, that great and important assistance was obtained during the progress of the inquiry from his valuable work, entitled "Traité de l'Électricité," respecting one class of phenomena especially, viz. the action of an acid and an alkali upon each other when separated by a membrane or any other porous diaphragm. But, at the very commencement of the inquiry, it soon became apparent that no real progress could be reasonably expected until clearer ideas had been obtained as to the origin of the power in the voltaic circle. This led to the study of those admirable memoirs of FARADAY. The inquiry and the study of those memoirs went hand-in-hand. The opinions *supposed* were those from FARADAY; the experiments, tests of those opinions. The endeavour to master the *meaning* of that important, comprehensive, and expressive phrase, "*an axis of power having contrary forces, exactly equal in amount, in contrary directions,*" was the mental difficulty; in *that* consists the requisite mental labour. It is not too much to add, that without those memoirs the inquiry would not have been continued.

† Philosophical Magazine, vol. xxxiii. p. 488. ‡ On Stomach and Urinary Diseases, 3rd edit. p. xxv.

§ BECQUEREL, Traité de l'Électricité, tom. i. p. 327. ‖ Ibid. tom. iv. p. 300. ¶ Ibid. p. 301.

** Journal de Physiologie, tom. v. p. 5. †† MÜLLER's Physiology, translated by BALY, vol. i. p. 148, 2nd edit.

‡‡ Made by NEWMAN of Regent Street. There is one advantage attending the use of a galvanometer that is not very delicate in its construction in these experiments; the vibrations of the needle soon subside, and consequently more information can be obtained from a single experiment.

tain, if possible, the existence of the current, an accurate description of its delicacy will not be necessary. It is sufficiently so to indicate the existence of a current during the combination of an acid with an alkali, such as very dilute solutions of nitric acid and of potash, when separated by a membrane.

In several unsuccessful experiments, the following electrodes were used:—Two platinum wires, $\frac{1}{24}$th of an inch in thickness and eleven inches in length, were pointed at one extremity, to be easily inserted into a blood-vessel or an organ, and coated with sealing-wax for about two inches, leaving the extreme point bare to the extent of one-fourth of an inch, the other extremities being attached to the galvanometer. But during the inquiry, in consequence of the stiffness of the wires forming the electrodes occasioning a motion of the whole instrument, when making and breaking contact, the following alteration was made in the arrangement. Thick copper wires ten inches in length were connected with the galvanometer by the screws, and each of the free extremities so bent as to rest in a separate wooden cup containing mercury. A platinum plate, an inch square, was attached to one extremity of each of the platinum electrodes to increase the extent of surface, and being placed in the wooden cups, a communication was formed with the galvanometer by means of the mercury, the pointed extremities serving, as before, to be inserted into the different parts of the animal. Great care was taken to ascertain that the different contacts were perfect, and no result upon the needle occurred from the whole arrangement, when a circuit was formed with a weak solution of salt, or water, previous to each experiment.

It will be unnecessary to relate the experiments, thirteen in number, upon cats, kittens, a guinea-pig and rabbits, in which an endeavour was made to ascertain whether the effect of a diverted current might not be obtained by inserting the electrodes into the portal vein alone, supposing that the stomach and liver formed poles similar to those of a galvanic circle; or whether a current might not be obtained by inserting them into the portal and hepatic veins. These failures, combined with theoretical reasoning, led to the supposition that the effect sought for existed in a different quarter. The inquiry will therefore commence with relating the last of the unsuccessful experiments.

Experiment 1.—Rabbit, six weeks old. (*a*). One electrode inserted into the vena porta, the other into the vena cava, at the entrance of the hepatic veins; no effect. (*b*). Caput coli, and a vein coming from the same part; a slight effect appeared: the electrodes were cleaned and reinserted, but the same effect did not occur. (*c*). Stomach and liver. (*d*). Stomach and vena porta. (*e*). Stomach and gall-bladder; no effect.

In these and the following experiments the electrodes were cleaned after the formation of a previous circuit, whenever the substances adhering to them might influence the result. Repeating the experiments of MATTEUCCI and of DONNÉ, only once did the effect occur, and that but slight, in the guinea-pig. The following fact may perhaps account for it.

Instead of the plates dipping into the mercury, the points were used for this purpose, and the surface of the plates served to form the free extremities of the electrodes.

The stomach was laid open, one of the plates pressed on the mucous membrane, the other upon the surface of the liver; a decided effect was now produced upon the needle, and by making and breaking contact so as to catch the vibrations of the needle, made to increase to 15° or 20°. The points were used as before; no effect. When the surface of the plate of one electrode was connected with the mucous membrane of the stomach, and the point of the other electrode with the liver, the effect upon the needle was greater than when the pointed extremity of the electrode was connected with the stomach, and the surface of the plate with the surface of the liver; in the latter instance the effect was very slight; but in neither instance was the effect so great as when both plates were used. The direction of the current, as indicated by the needle, was from the stomach along the metallic conductor to the liver.

The liver was removed and placed upon the intestines, the stomach remaining; the same actions occurred, but not to the same extent.

Stomach almost empty.

Considering that the failure in former experiments arose from the want of surface at the free extremities of the electrodes, the sealing-wax was removed.

Experiment 2.—Rabbit. The pointed extremity of one electrode was inserted into the caput coli, and pressed against the mucous membrane, the inferior mesenteric vein was wounded, and the plate of the other electrode dipped into the blood; the latter positive 5°, and made to increase by making and breaking contact.

An incision was made into the stomach, and the plate of one electrode inserted into it; the plate of the other lightly pressed on the surface of the liver; stomach positive 10°, and made to increase by making and breaking contact.

In cleaning one of the electrodes it broke, about half an inch from the plate. The plate of the electrode was in contact with the mucous membrane of the ilium, and the pointed extremity of the broken electrode inserted into a vein coming from the same part; blood slightly positive.

A platinum wire (No. 18), six inches in length, was flattened out at one extremity so as to present a surface three-fourths of an inch in length, and one-sixth of an inch in breadth. This will be called electrode A (E A). The former electrode with the plate attached, electrode B (E B). The broken electrode, having the broken extremity flattened out to the extent of one-fourth of an inch in length and to one-eighth of an inch in breadth, electrode C (E C).

In describing the circuits, when the pointed extremity is in contact with the animal, it will be stated the *p* of E A, &c., otherwise the broad extremity is used.

Experiment 3.—Rabbit. Mucous membrane of the ilium and vein from the same part; the *p* of E A in contact with the former to the extent of an inch and a half, the *p* of E B with the latter; blood positive 4°; when E B was used a greater effect, and made to increase; no effect ensued when the *p* of E B was inserted into a different vein; returning to the former vein, the action upon the needle occurred; should the blood however from the two veins become mixed, then an effect upon the needle ensued, more especially if E B be used. No effect when E B was placed

on the outside of the gut over E A where the blood had not been, whereas with blood flowing from the vein, they may be separated to the extent of an inch or more, the effect occurring. Stomach and liver; the *p* of E A inserted into the former to the extent of an inch, E B lightly pressed on the surface of the latter; stomach positive 8°; an attempt was made to insert the *p* of E B into a vein coming from the stomach, but failed from the difficulty in obtaining a vein of sufficient size; when it was inserted into the portal vein, no effect. E C inserted into the caput coli; stomach slightly positive.

Experiment 4.—Cat. Prussic acid dropped on the nose. Mucous membrane of the ilium, and a vein from the same part; the *p* of E A in contact with the former to the extent of an inch and a half, the *p* of E B with the latter; blood positive 5°, and made to increase: a vein coming from a different part was punctured, no effect: with the former vein the effect ensued, but not when it had become empty.

Mucous membrane of the stomach and blood from the same organ; the *p* of E A was in contact with the great curvature of the stomach to the extent of an inch, a vein corresponding to the lesser curvature was punctured with the *p* of E B; no effect: the portal vein was punctured at its commencement; as the blood flowed out a slight effect occurred, blood positive: E B was lightly pressed on the surface of the liver; the latter slightly positive.

Mucous membrane of the upper part of the colon, and vein from the same part; *p* of E A in contact with the former to the extent of an inch and a half, the *p* of E B with the latter; blood positive: E B pressed on the surface of the liver; the latter positive. The liver and intestines covered with blood.

The *p* of E A inserted into the stomach, E C into the colon; no effect.

Stomach and small intestines empty.

Experiment 5.—Cat. Killed as the last. In opening the abdomen the liver was wounded. The mucous membrane of the upper part of the small intestine, where active digestion was going on, was in contact, to the extent of an inch, with the *p* of E A; an artery going to the same part was punctured with the *p* of E B; no effect: when the vein was wounded, a decided result; blood positive. The inside and outside of the gut were formed into a circuit; no effect.

The mucous membrane of the stomach, in contact with the *p* of E A, to the extent of an inch, E B with blood flowing from the vena porta; blood slightly positive: placed on the liver; the same result, but not when the point was used. The liver covered with blood from the wound.

The pelvis and renal vein of the same kidney were formed into a circuit, with the *p* of E C and of E B; vibrations occurred, but impossible to obtain any decided effect by making and breaking contact.

Between the mucous membrane of the colon and vein; blood positive.

Stomach half-full of food.

The following experiment was to ascertain how far the different solid and fluid substances in contact with the electrodes might interfere with the result.

Experiment 6.—E B covered with some blood from the cat, was dipped with E A into water. A similar circuit was formed with fresh blood and water containing fæcal matter from the colon, the electrodes were close to each other. A portion of the colon of the cat, with its contents, was removed and placed in a weak solution of potash; E A and E B were dipped, one into the solution, the other into the gut, and then changed; in no instance did any effect occur. Some very dilute nitric acid was mixed with the contents of the colon and the same circuit formed; contents of the colon positive 3°. Can the difference, which is observed between cats and rabbits, as to the direction of the current when the stomach and liver are formed into a circuit, be attributed to the action of the poison, although no poison had been taken into the stomach?

Experiments 7 and 8 were upon rabbits; in one, prussic acid was used as in *experiment* 5; in the other, after a circuit had been formed between the mucous membrane of the stomach and blood flowing from the aorta, an opening was made and about ten drops of prussic acid poured into the stomach. The results only need be detailed. The mucous membrane of the stomach was positive to the following parts: surface of liver, mesentery, blood flowing from the vena porta and aorta, gall-bladder, mucous membrane of the duodenum and of the caput coli.

The blood flowing from the mucous membrane of the ilium and of the caput coli was positive to these parts from 3° to 5°.

The surface of the liver and the mesentery were slightly positive, when E B was in contact with them, to the mucous membrane of the ilium and caput coli.

In the following circuits no result was obtained:—Mucous membrane of the stomach and vena porta, the pointed extremity being inserted into the latter. Gall-bladder and vena porta. Mucous membrane of the ilium and that of the caput coli. Mucous membrane of the ilium and vein coming from the same part; this occurred when the aorta had been wounded, no blood flowed and the intestine was pale.

The contents of the stomach were positive to those of the colon when formed into a circuit out of the body; the effect was not so great as when the circuit was formed between the stomach and caput coli, the parts remaining *in situ*. In one experiment, the stomach, liver and intestines were removed from the body: the stomach was positive to every other part; it was detached, emptied of its contents, and washed, the same circuits then formed, but no effect; some of the food replaced, the former effects were reproduced, but not so decided. The caput coli was slightly negative to the liver and mesentery. With the small intestines no effect. In both experiments the contents of the stomach reddened litmus paper, and formed a coarse, dry, compact mass; those of the caput coli a soft homogeneous mass, but produced no effect either on litmus or turmeric paper. From these two experiments, the difference of effect between cats and rabbits, when the stomach and liver are formed into circuits, cannot be attributed to the action of the poison.

At the present stage of the inquiry we may be justified in drawing the following

inference:—*When the electrodes of a galvanometer are brought into communication, one with the mucous membrane of the alimentary canal, the other with the blood flowing from the same part, a deviation of the needle takes place, indicating that the secreted product and the blood are in opposite electric states.*

The two following *experiments* 9 and 10, upon rabbits, were undertaken to ascertain how far they would confirm this inference. To avoid unnecessary repetition, it may be stated, that the same results occurred as in experiments 7 and 8; and, in addition, the following circuits were formed.

Renal vein and pelvis of the same kidney; renal vein of the opposite kidney and urinary bladder: in both instances vibrations only were produced.

Mucous membrane of the stomach and bile flowing from the gall-bladder; the former positive.

Food from stomach and blood; former positive.

No result was obtained in the following circuits:—Gall-bladder and vena cava at the entrance of the hepatic veins. Gall-bladder and vena porta. Mucous membrane of the ilium and superior mesenteric artery. Stomach and gall-bladder (the pointed extremity being inserted into its whole length). Mucous membrane of the stomach and vena cava at the entrance of the hepatic veins. Mucous membrane of the stomach and vena porta. Contents of caput coli and blood. Mucous membrane of the ilium and blood on its outer surface.

In one experiment the liver was much diseased, dark-coloured, and half the usual size; the rabbit appeared weak and unable to support itself.

The parts in the last experiment were covered over with a towel and allowed to remain undisturbed for eight hours. It will be unnecessary to state the circuits that were then formed, with their results, and likewise those in a rabbit, which died from natural causes, twenty-two, twenty-five, and thirty-nine hours after death, as the following experiment containing the principal facts worthy of notice will be related at full length.

Experiment 11.—Rabbit six hours after death, which arose from natural causes. The surface of the viscera and contents of the abdomen were remarkable for their appearance, being so similar to that of a healthy and live rabbit. The veins being full of fluid blood, a favourable opportunity occurred of ascertaining whether the same effects would be produced as in the living animal.

The following circuits were formed:—The blood flowing from the ilium, an empty portion of the descending colon, and caput coli and the mucous membrane of these parts; in the latter only did any effect occur, the mucous membrane slightly positive.

Contents of the caput coli produced no effect on litmus paper.

Mucous membrane of the stomach and the following parts, surface of the liver, mesentery and small intestines; each of the latter slightly positive.

Food in the stomach acid: the moisture covering the different viscera restored the slightly reddened litmus, but produced no effect upon turmeric paper.

E A inserted into the centre of the mass of food in the stomach, E B lightly pressed on the upper external surface over E A; E B slightly positive: E B placed on the liver or intestines; E A slightly positive.

E B and the broken plate of E C were placed, one on the upper surface of the stomach, the other on the mesentery; no effect. Some food was taken out of the stomach and placed on the intestines, the broken plate on the mesentery, E B on the food; E B positive. The same arrangement was made with some of the contents of the caput coli; the latter slightly positive.

The following circuits were formed: food from the stomach and contents of the caput coli; the former positive: some food from the centre of the mass in the stomach, and some in contact with the mucous surface; the latter positive. The mass in the stomach was coarse, dry and compact; that in the caput coli of a finer and softer consistence.

The parts were covered over with a towel for twelve hours.

E B placed on the upper external surface of the stomach, E A inserted into the caput coli; E B positive. E A remaining, E B on the small intestines; effect very slight.

E C inserted into the centre of the contents of the stomach, E B lightly pressed on the upper external surface; E C positive. The stomach was moved over and E B placed on that which had been its inferior surface; E B positive: E B was placed on the part where the stomach had been lying; E B positive.

The different parts had become more moist.

No doubt can exist as to the cause of the production of the effects obtained in the last experiment, viz. the difference of the fluids and solids in contact with the electrodes. The proposition, that, when two heterogeneous fluids are separated from each other by a membrane, or any other porous diaphragm, that which performs the part of an acid takes positive electricity, the other, that of an alkali, takes negative electricity, has been well established by Becquerel*. The results observed in the last experiment beautifully illustrate it; and at the same time show how impossible it is to say, *à priori*, what would be the effect upon the needle when the electrodes are inserted into different parts of a dead animal. The mere circumstance of placing the electrodes in contact with different portions of the contents of the stomach produces an effect or not upon the needle; the state of the parts as to moisture, and the transudation of the secreted fluids or contents through the walls of the different viscera; the contents of the colon and of the stomach considered as a mass, forming one conducting body; the difference with respect to the extent of surface of the electrodes; each of these circumstances may be readily seen to be influential and unnecessary to particularize. There may be two or three acting points between the electrodes, determining the current in opposite directions, or assisting each other, the action upon the needle being the result of a differential, or of a combined current, according to circumstances.

Shall we be justified in referring the effects observed in experiments 2, 3, 4, 5, 7

* Traité de l'Électricité, tom. iii. p. 387. v. part. ii. p. 192.

and 8 to the same cause? Let us take the simple fact, that, when the mucous membrane of the small intestine and the blood flowing from it are formed into a circuit, a deviation of the needle amounting to 3°, 4° or 5° is obtained, the intestine being empty and therefore uninfluenced by the circumstances we have just now mentioned; why did the effect not occur in experiment 11? the conditions appeared to be precisely similar; or in experiments 7 and 10, when the artery was wounded; or in experiments 3 and 4, when blood flowing from a different part formed the circuit; or in experiments 3, 5, 9, when a circuit was formed between the inside and outside of the gut? Did not the failure arise in these instances in consequence of the absence of one necessary condition, the flowing of the blood from the same part, the transmission of the carrying particles from one electrode to the other, as shown in experiments 2, 3, 4, 5 and 7?

Without entering into any discussion as to the mode in which the effect may be supposed to be brought about in the living animal, and the difference observed when the stomach and other parts were formed into circuits in rabbits, and when the same circuits were formed in cats, we may be justified in adding the following to our former inference, viz. *that the effect is produced during the organic action of the part, it ceasing after the death of the animal.*

Instead of endeavouring to refute the notion that the stomach and liver form poles similar to those of a galvanic circle, let us briefly allude to the experiment and conjecture of Wollaston. Was not that experiment to *illustrate*, rather than to prove his conjecture? and are not these experiments identical with that conjecture? He evidently saw, mentally speaking, the *meaning* of that phrase "AN AXIS OF POWER," &c. This inquiry has been undertaken with the advantage both of Faraday's labours and the use of the galvanometer. Wollaston's conjecture and experiment have existed for forty years.

The following is a brief recapitulation of the general conclusions which may be deduced from the foregoing experiments and reasonings:—

1. When the electrodes of a galvanometer are brought into communication, one with the mucous membrane of the alimentary canal, the other with the blood flowing from the same part, a deviation of the needle takes place, indicating that the secreted product and the blood are in opposite electric states.

2. That the effect occurs during the life of the animal, it ceasing after its death.

3. That the effect may be considered as arising from the decomposition of the blood; *i. e.* the changes which occur during the formation of the secreted product and venous blood.

4. That these changes are effected by the *organic action* of the part.

The author begs to acknowledge the great kindness that he has received from Sir B. C. Brodie, Bart., and from Dr. Todd.

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Explanation of the Woodcut.

Fig. 1. Wooden mercurial cup.

Fig. 2. Copper wire to form the communication between the galvanometer and mercury.

Fig. 3. A section of the mercurial cup, showing the mode in which the thick copper wire was connected with it.

Fig. 4. Shows the manner in which the plate of platinum was soldered on to the platinum electrode, pure gold being used; all the part within the dotted line, and for a short distance up the wire, was coated with shell-lac to prevent the action of the mercury upon it.

Fig. 5. Electrode A. Fig. 6. Electrode B. Fig. 7. Electrode C.

Fig. 8. The arrangement with the galvanometer previous to each experiment.

Fig. 9. *a a a*, arteries; *b b b*, veins; the arrows indicate the course of the blood: *c*, point of the electrode in contact with the wounded vein; the dotted line of *d* the electrode in contact with the mucous surface of the small intestine.