In our case there is no magnetic field at any time inside the tube where the induced E.M.F. exists.

How are we to look upon this case of induction? To those who are completely satisfied with the statement that the induced E.M.F. in a circuit is equal to the rate of variation of the flux through the surface of which this circuit is the contour nothing more need be said. For this case of induction is perfectly in accord with that statement. To those who admit that the above statement is only short-hand mathematics and not physics it may be worth while to say that this statement ascribes an effect (the induced E.M.F. in a wire inside a tube) to a cause (a variation in magnetic flux outside of the tube) which does not exist where the effect is produced.

Can we save our face in this matter and still preserve the imagery of an induced E.M.F. being produced by lines of magnetic flux sweeping across the fixed conductor? I think we may do so in the following manner: Suppose when the current in the tube is being built up from a zero value that closed lines of flux of molecular dimensions originate in the *substance* of the tube and expand with rising current until they surround the tube. In expanding each line must cut across the tubular space and in doing so contribute its part to the induced E.M.F. in the interior of the tube. This method of imagining the process of induction will probably appear satisfactory to many but still the difficulty remains that induction takes place inside the tube while the resultant field is zero everywhere and at all times. The flux lines which we have imagined to be snapping across the tube come symmetrically from all sides in such a way that they mutually cancel each other with regard to the production of a magnetic field. Here enters an idea which seems to me worth consideration. Inside the tube we have a vector field which may be looked upon as the sum of two equal and opposite vectors and therefore a field of zero intensity. However, if these two equal and opposite components are varying, their inductive effects are arithmetically additive and a zero magnetic field is not a field of nothingness but still possesses electromagnetic properties.

I am perfectly aware of the fact that the induction in the case of a transformer in which the primary is uniformly wound on a ring and is overwound uniformly by the secondary is of exactly the same character as the case of induction I have been discussing. The case of the tube was the form in which this "puzzle" first appealed to me, but the fact that this condition occurs in such a familiar case does not make it any the less a puzzle.

Princeton University.

Note on the Physiological Effect of the Current.[1]

By F. J. Rogers.

FOR some years I have regularly required students to measure the resistance of their own bodies when current flows from one hand to the other, and to observe the maximum current, from a direct current source, that they were

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 24–25, 1914.

willing to endure. Of course the resistance depends greatly on the character and area of contact. The maximum current which the average person is willing to endure proves to be not greatly different in different individuals. If the whole hand is immersed in water or if the electrodes are large, metal handles or plates grasped firmly, then practically every one is willing to endure 20 milliamperes of direct current, on the other hand I have seen not more than one or two who would not say enough before the current reached 40 milliamperes.

Even this difference is principally due, on the one hand to those who are disinclined to endure a little physical pain and on the other to those, who through emulation or otherwise, will not cry enough until their pain has become rather intense.

I have had this experiment performed on scores of students before paying heed to the very occasional remark that the pain was more intense in one arm than in the other. Finally with fewer students to pass through the ordeal and coming across one who was more insistent on the difference in sensation in the two arms or wrists, I reversed the current, when he declared the pain was now greater in the other wrist. With this beginning I proceeded to extend operations upon every one I could drag up to be tested, with uniformly the same result for all persons, male and female, old and young. This difference is not an absolute one. When the sensation is mild there is practically no difference in sensation according to the direction of the current, but just as soon as the painful sensation becomes rather intense the victim uniformly says that the pain is decidedly greater in one wrist or arm than in the other and this always proves to be the cathode arm, the one out of which the current is flowing.

The same condition prevails when the current flows from one finger to the corresponding finger of the other hand. In this case the pain is most intense in the cathode finger although still more or less distant from the electrode. If, however, the electrodes are in contact with the little finger of one hand and the thumb of the other hand, the pain is more intense in the little finger, no matter in which direction the current flows.

Without having attempted experimentation on others in this regard I at least know in my own case that when the current flows from one foot to the other the pain is more intense in the cathode ankle than in the other one.

When current flows through a moderately small electrode in contact with a sensitive portion of the skin, as for example the arm, the pain, in this case a sort of burning sensation, is always more intense at the surface immediately in contact with the electrode; this is well known but is not the fact which I have been trying to describe. It is not however well known to physiologists that when current flows through electrodes in contact with the outside of the face that a decided taste sensation is caused in the proper place for such sensations. I tried the same experiment with sugar and salt in my mouth (on separate occasions) to see whether epicures might possibly derive greater pleasure from such stimuli, however with negative results.

It is well known among physiologists that when a nerve is stimulated by an electric current, the sensation is more intense at the cathode than at the anode. However in my experiments with a large electrode in contact with the palms of the hands practically no sensation was produced at either electrode while at a distance fıom the electrode, namely in the wrist and forearm the sensation, when it become intense, depended upon the direction of the curıent, being more painful in the cathode wrist.

This fact which the physiologists seem not to know about may be harmonized with the greater sensitiveness at the cathode by making use in our explanation of what are called physiological cathodes. Wherever current flows from nerve tissue across a surface of separation into another kind of tissue such as muscle or tendon we have a change of material in the path of the current and physiologists call this a physiological cathode. Now I am told that in the wıist there are a great many sensory nerve endings which terminate in tendons. If these are called physiological cathodes when the corresponding hand is the cathode, the greater pain in the cathode wrist is brought into line with the greater sensitiveness of the cathode in nerve stimulation.

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Photographs of Retrograde Rays, (*a*) from the Cold Cathode, (*b*) from the Hot Lime Cathode.[1]

By O. H. Smith.

At the Thanksgiving, 1912, meeting of the American Physical Society several photographs were exhibited by Knipp showing retrograde rays. Thomson had photographed them, however with limited detail, a few months before. The present paper deals with a more extended photographic study of these rays using both the cold and the hot lime cathodes. The apparatus employed is essentially that described by Knipp.[2]

(*a*) The photographs, in the case of the cold cathode, with very weak deflecting fields, show in a very striking manner the three kinds of carriers—the electron, the carriers atomic in size with a negative charge, and carriers atomic in size with a positive charge. For a given magnetic field these heavy ions show a deflection that is 2 or 3 per cent. of that of the electron. For strong deflecting fields the electrons are blown off the plate and in place of the single line representing each the heavy positively and negatively charged ions there appear a number of parabolic lines characteristic of the gas in the discharge vessel. Under favorable conditions some of the negative lines are duplicated on the positive side, *i. e.*, a negative line having a corresponding positive component.

(*b*) For the case of the hot lime the problem presents additional difficulty. First, in lining up the cathode, and second, apparently the heavy carriers do not possess sufficient energy to affect the photographic plate upon which they

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 24–25, 1914.

[2] Phil. Mag., December, 1911; Phys. Rev., XXXIV., March, 1912.