

XIV. *Electrical Experiments made in order to ascertain the non-conducting Power of a perfect Vacuum, &c.* By Mr. William Morgan; *communicated by the Rev. Richard Price, LL.D. F.R.S.*

Read February 24, 1785.

THE non-conducting power of a perfect vacuum is a fact in electricity which has been much controverted among philosophers. The experiments made by Mr. WALSH, F.R.S. in the double barometer tube clearly demonstrated the impermeability of the electric *light* through a vacuum; nor was it, I think, precipitate to conclude from them the impermeability of the electric *fluid* itself. But this conclusion has not been universally admitted, and the following experiments were made with the view of determining its truth or fallacy. When I first attended to the subject, I was not aware that any other attempts had been made besides those of Mr. WALSH; and though I have since found myself to have been in part anticipated in one of my experiments, it may not perhaps be improper to give some account of them, not only as they are an additional testimony in support of this fact, but as they led to the observation of some phænomena which appear to be new and interesting.

A mercurial gage B (see tab. IX. fig. 1.) about 15 inches long, carefully and accurately boiled till every particle of air was expelled from the inside, was coated with tin-foil five inches down from its sealed end (A), and being inverted into
mercury

mercury through a perforation (D) in the brass cap (E) which covered the mouth of the cistern (H), the whole was cemented together, and the air was exhausted from the inside of the cistern through a valve (C) in the brass cap (E) just mentioned, which producing a perfect vacuum in the gage (B) afforded an instrument peculiarly well adapted for experiments of this kind. Things being thus adjusted (a small wire (F) having been previously fixed on the inside of the cistern to form a communication between the brass cap (E) and the mercury (G) into which the gage was inverted) the coated end (A) was applied to the conductor of an electrical machine, and notwithstanding every effort, neither the smallest ray of light, nor the slightest charge, could ever be procured in this exhausted gage. I need not observe, that if the vacuum on its inside had been a conductor of electricity, the latter at least must have taken place, for it is well known (and I have myself often made the experiment) that if a glass tube be exhausted by an air-pump, and coated on the outside, both light and a charge may very readily be procured. If the mercury in the gage be imperfectly boiled, the experiment will not succeed; but the colour of the electric light, which, in air rarefied by an exhauster, is always violet or purple, appears in this case of a beautiful green, and, what is very curious, the degree of the air's rarefaction may be nearly determined by this means; for I have known instances, during the course of these experiments, where a small particle of air having found its way into the tube (B), the electric light became visible, and as usual of a green colour; but the charge being often repeated, the gage has at length cracked at its sealed end, and in consequence the external air, by being admitted into the inside, has gradually produced a change in the electric light from green to blue, from blue to indigo, and

so on to violet and purple, till the medium has at last become so dense as no longer to be a conductor of electricity. I think there can be little doubt from the above experiments of the non-conducting power of a perfect vacuum; and this fact is still more strongly confirmed by the phenomena which appear upon the admission of a very minute particle of air into the inside of the gage. In this case the whole becomes immediately luminous upon the slightest application of electricity, and a charge takes place, which continues to grow more and more powerful in proportion as fresh air is admitted, till the density of the conducting medium arrives at its maximum, which it always does when the colour of the electric light is indigo or violet. Under these circumstances the charge may be so far increased as frequently to break the glasses. In some tubes, which have not been completely boiled, I have observed, that they will not conduct the electric fluid when the mercury is fallen very low in them, yet upon letting in air into the cistern (H), so that the mercury shall rise in the gage (B), the electric fluid, which was before latent in the inside, shall now become visible, and as the mercury continues to rise, and of consequence the medium is rendered less rare, the light shall grow more and more visible, and the gage shall at last be charged, notwithstanding it has not been near an electrical machine for two or three days. This seems to prove, that there is a limit even in the rarefaction of air, which sets bounds to its conducting power; or, in other words, that the particles of air may be so far separated from each other as no longer to be able to transmit the electric fluid; that if they are brought within a certain distance of each other, their conducting power begins, and continually increases till their approach also arrives at its limit, when the particles again become so near as to resist the passage

of the fluid entirely, without employing violence, which is the case in common and condensed air, but more particularly in the latter. These experiments, however, belong to another subject, and may possibly be communicated at some future time.

It is surprising to observe, how readily an exhausted tube is charged with electricity. By placing it at ten or twelve inches from the conductor the light may be seen pervading its inside, and as strong a charge may sometimes be procured as if it were in contact with the conductor: nor does it signify how narrow the bore of the glass may be; for even a thermometer tube, having the minutest perforation possible, will charge with the utmost facility; and in this experiment the phænomena are peculiarly beautiful.

Let one end of a thermometer tube be sealed hermetically. Let the other end be cemented into a brass cap with a valve, or into a brass cock, so that it may be fitted to the plate of an air-pump. When it is exhausted, let the sealed end be applied to the conductor of an electrical machine, while the other end is either held in the hand or connected to the floor. Upon the slightest excitation the electric fluid will accumulate at the sealed end, and be discharged through the inside in the form of a spark, and this accumulation and discharge may be incessantly repeated till the tube is broken. By this means I have had a spark 42 inches long, and, had I been provided with a proper tube, I do not doubt but that I might have had a spark of four times that length. If, instead of the sealed end, a bulb be blown at that extremity of the tube, the electric light will fill the whole of that bulb, and then pass through the tube in the form of a brilliant spark, as in the foregoing experiment; but in this case I have seldom been able to repeat the trials above three or four

times before the charge has made a small perforation in the bulb. If again a thermometer filled with mercury be inverted into a cistern, and the air exhausted in the manner I have described for making the experiment with the gage, a Torricellian vacuum will be produced; and now the electric light in the bulb, as well as the spark in the tube, will be of a vivid green; but the bulb will not bear a frequent repetition of charges before it is perforated in like manner as when it has been exhausted by an air-pump. It can hardly be necessary to observe, that in these cases the electric fluid assumes the appearance of a spark*, from the narrowness of the passage through which it forces its way. If a tube, 40 inches long, be fixed into a globe 8 or 9 inches in diameter, and the whole be exhausted, the electric fluid, after passing in the form of a brilliant spark throughout the length of the tube, will, when it gets into the inside of the globe, expand itself in all directions, entirely filling it with a violet and purple light, and exhibiting a striking instance of the vast elasticity of the electric fluid.

I cannot conclude this paper without acknowledging my obligations to the ingenious Mr. Brook, of Norwich, who, by communicating to me his method of boiling mercury, has been the chief cause of my success in these experiments†. I have lately learned

* By cementing the string of a guitar into one end of a thermometer tube, a spark may be obtained as well as if the tube had been sealed hermetically.

† Mr. Brook's method of making mercurial gages is nearly as follows. Let a glass tube L (see fig. 2.), sealed hermetically at one end, be bent into a right-angle within two or three inches of the other end. At the distance of about an inch or less from the angle let a bulb (K), of about $\frac{3}{4}$ of an inch in diameter, be blown in the curved end, and let the remainder of this part of the tube be drawn out (I)

I learned from him, that he has also ascertained the non-conducting power of a perfect vacuum ; but what steps he took for that purpose I know not. Of his accuracy, however, I am so well convinced, that had I never made an experiment myself, I should, upon his testimony alone, have been equally assured of the fact. To most of the preceding experiments Dr. PRICE, Mr. LANE, and some others of my friends, have been eye-witnesses, and I believe that they were as thoroughly satisfied as myself with the results of them. I must beg leave to observe to those who wish to repeat them, that the first experiment requires some nicety, and no inconsiderable degree of labour and patience. I have boiled many gages for several hours together without success, so as to be sufficiently long to take hold of, when the mercury is boiling. The bulb (K) is designed as a receptacle for the mercury, to prevent its boiling over, and the bent figure of the tube is adapted for its inversion into the cistern ; for by breaking off the tube at (M) within $\frac{1}{8}$ or $\frac{1}{4}$ of an inch of the angle, the open end of the gage may be held perpendicular to the horizon when it is dipped into the mercury in the cistern, without obliging us to bring our finger, or any other substance, into contact with the mercury in the gage, which never fails to render the instrument imperfect. It is necessary to observe, that if the tube be fourteen or fifteen inches long, I have never been able to boil it effectually for the experiments mentioned in this paper in less than three or four hours, although Mr. Brook seems to prescribe a much shorter time for the purpose ; nor will it even then succeed, unless the greatest attention be paid that no bubbles of air lurk behind, which to my own mortification I have frequently found to have been the case ; but experience has at length taught me to guard pretty well against this disappointment, particularly by taking care that the tube be completely dry before the mercury is put into it ; for if this caution be not observed, the instrument can never be made perfect. There is, however, one evil which I have not yet been able to remedy ; and that is, the introduction of air into the gage, owing to the unboiled mercury in the cistern ; for when the gage has been a few times exhausted, the mercury which originally filled it becomes mixed with that into which it is inverted, and in consequence the vacuum is rendered less and less perfect, till at last the instrument is entirely spoiled. I have just constructed a gage so as to be able to boil the mercury in the cistern, but have not yet ascertained its success.

and was for some time disposed to believe the contrary of what I am now convinced to be the truth. Indeed, if we reason *a priori*, I think we cannot suppose a perfect vacuum to be a perfect conductor without supposing an absurdity: for if this were the case, either our atmosphere must have long ago been deprived of all its electric fluid by being every where surrounded by a boundless conductor, or this fluid must pervade every part of infinite space, and consequently there can be no such thing as a perfect vacuum in the universe. If, on the contrary, the truth of the preceding experiments be admitted, it will follow, that the conducting power of our atmosphere increases only to a certain height, beyond which this power begins to diminish, till at last it entirely vanishes; but in what part of the upper regions of the air these limits are placed, I will not presume to determine. It would not, perhaps, have been difficult to have applied the results of some of these experiments to the explanation of meteors, which are probably owing to an accumulation of electricity. It is not, however, my present design to give loose to my imagination. I am sensible, that by indulging it too freely, much harm is done to real knowledge; and therefore, that one fact in philosophy well ascertained is more to be valued than whole volumes of speculative hypotheses.

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Fig. 1.

Fig. 2.

