

EXPÉRIENCES

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SUR

LA FORME ET LA NATURE DES ELECTRO-AIMANTS

Etant animé du désir de construire des électro-aimants qui fussent appropriés le mieux possible aux besoins de la télégraphie, je fus amené par quelques résultats, contradictoires en apparence, à rechercher de plus près les lois connues et inconnues qui régissent ces organes.

Dès le commencement de ces expériences, je sentis la nécessité d'employer un électro-chronographe pour donner la mesure exacte de la force obtenue sur l'électro-aimant, ainsi que la durée exacte du temps nécessaire pour que le courant produise son effet maximum sur les âmes en fer. Réflexion faite, je me déterminai à faire usage de mon télégraphe imprimant qui, sauf quelques légères modifications, remplissait merveilleusement le but que je me proposais.

Avant d'exposer les expériences que j'ai faites, une courte description de cet instrument est nécessaire<sup>1</sup>. La roue des types tourne avec une grande rapidité, et est réglée à une vitesse donnée au moyen d'un ressort vibrant. De cette manière, les révolutions de cette roue et de ses portions sont parfaitement isochrones. L'électro-aimant est polarisé au moyen d'un aimant artificiel. L'armature est attirée contre les pôles de cet électro-aimant par cette polarité. Un ressort de réglage tend constamment à éloigner l'armature des pôles, et la différence de force entre

<sup>1</sup> La description complète en a été donnée par M. Blavier dans le numéro de mai-juin 1862 des Annales télégraphiques.

le ressort et la polarité est la mesure vraie de la force électro-magnétique nécessaire pour détacher l'armature.

Supposons que l'électro-aimant retienne l'armature avec une force égale à 10 unités, le ressort opposé valant 9 unités, dans ce cas un courant d'une force égale à 2 et d'une direction telle qu'il diminue la polarité de l'électro-aimant permettrait au ressort de soulever l'armature avec une grande rapidité. A l'instant où cette armature s'élève, une impression est produite par une portion donnée de la roue des types à l'aide d'un mécanisme très-simple; de cette façon, la lettre imprimée marque exactement le moment où l'armature a été soulevée, ainsi que le temps nécessaire pour produire une quantité donnée d'effet électro-magnétique sur l'âme.

Ainsi, supposons que le ressort ou l'armature de l'électro-aimant, exigeant une force 2 pour être détachée, imprime constamment la lettre A et qu'il fût ensuite réglé de manière qu'il fallût un courant 8 avant que l'armature fût détachée. Dans ce cas, si la lettre imprimée est constamment B, C ou D, sachant que le nombre de révolutions de la roue des types est de 120 par minute, et celui des divisions de cette roue de 56, ce qui donne 112 divisions par seconde, nous pourrions dire aisément par la lettre ou chiffre imprimé la quantité de temps nécessaire pour produire une certaine quantité de force dans l'électro-aimant, et avoir ainsi un moyen correct d'obtenir les courbes de force magnétique produite dans un électro-aimant qui passe de son minimum à son maximum.

A l'aide de cet instrument, des divisions de temps égales à 1/1000 de seconde pourraient être obtenues avec exactitude, en même temps qu'il serait possible de dresser un tableau des variations de la force électro-magnétique,

depuis 1 gramme jusqu'à 300 grammes. La seule modification introduite pour les présentes recherches consiste dans la suppression de la roue correctrice, la roue des types étant fixée solidement à son axe, de façon que toute variation quelconque de temps puisse être distinguée plus aisément par l'impression plus ou moins parfaite des lettres.

L'électro-aimant et la roue des types sont arrangeés de manière à ce que, s'il n'était besoin d'aucun temps de contact, ni de force sur l'électro-aimant, le chiffre ou la lettre imprimée serait à ou, comme nous l'appellerons, 1.

En supposant qu'une force électro-magnétique produite avec un nombre donné d'éléments et par un contact de  $1/112$  de seconde, donnât une force de 8 grammes, et que l'aimant était réglé à cette force; la lettre ou le chiffre imprimé fut 2; un contact de  $1/16$  de seconde produirait une force totale de 12 grammes, et ce même poids enlevé à l'armature imprimerait 3; un contact de  $\frac{4}{37/5}$  de seconde, donnerait une force totale de 14 grammes, imprimant 4; un contact de  $1/28$  de seconde donnerait une force totale de 15; un contact de  $\frac{22}{21}$  de seconde donnerait une force totale de 15 grammes  $1/2$ , imprimant 6; un contact de  $\frac{1}{18 \frac{7}{9}}$  donnerait une force totale de 15 grammes  $3/4$ , imprimant 7; un contact de  $1/16$  de seconde donnerait une force totale de 15 grammes  $7/12$ , imprimant 8.

Si maintenant nous traçons une courbe des forces obtenues dans ces divisions de temps, nous observons qu'un électro-aimant exige un certain temps pour passer de son minimum à son maximum de saturation magnétique, et que l'accroissement de force dans les quatre premières divisions de temps serait comme 8, 4, 2, 1. Ces résultats

sont parfaitement constants, quelle que soit la forme ou la grandeur de l'électro-aimant ou de l'armature; la différence consistant uniquement dans l'accroissement de la courbe.

Avec dix comme avec trois éléments, avec ou sans résistance extérieure, le temps nécessaire pour passer de son minimum à son maximum était invariablement le même. Pour tous les besoins pratiques, le maximum d'effet s'obtiendrait par un contact d'une durée égale à  $1/28$  de seconde, et, si nous accordons le même temps pour décharger l'électro-aimant, 14 courants par seconde peuvent être envoyés à travers un électro-aimant dans un but télégraphique, produisant le maximum d'effet. Le retard causé par l'induction d'une ligne donnée serait également déduit de cette vitesse. En admettant comme probable, sur une ligne aérienne bien construite, une vitesse avec effet maximum de 10 contacts par seconde, les courbes (1), planche III, ont été produites avec des piles de 1 à 5 éléments sur un court circuit; les courbes (2) ont été produites avec des résistances variables de 100 à 800 kilomètres. On verra par ces courbes que le temps d'effet maximum est le même dans chaque cas, et que la résistance ajoutée à la ligne produit exactement le même effet que la réduction du nombre d'éléments.

Le premier pas à faire ensuite dans cette investigation était de trouver quelle est la résistance de fil sur l'électro-aimant qui produit l'effet maximum.

Dans ce but, j'ai choisi une résistance représentée par une ligne de 500 kilomètres, avec perte moyenne de  $2/3$  du courant réel à la terre. Cette perte pouvait être augmentée ou diminuée pour représenter le travail réel d'une ligne aérienne. Après de nombreuses expériences, j'ai trouvé qu'une résistance de 120 kilomètres, ou de 60 sur

chaque bobine, donnerait les meilleurs résultats moyens, en prenant en considération tous les changements qu'une ligne télégraphique réelle doit éprouver pendant différentes périodes de temps.

Il serait trop long de publier ici les courbes nombreuses obtenues à l'aide de ces expériences, mais nous pouvons établir que les courbes moyennes les plus élevées obtenues par différentes pertes, l'ont été constamment avec des bobines ayant chacune une résistance de 60 kilomètres.

Le second pas à faire dans cette recherche était de trouver la forme propre et la grandeur des ames de fer contenues dans les bobines de l'électro-aimant. D'abord, deux qualités très importantes se manifestèrent dans différents barreaux de fer soumis à l'expérience.

J'ai trouvé que des barreaux de fer différents conduisaient plus ou moins le magnétisme produit, et que le résultat total magnétique était directement proportionnel au pouvoir conducteur du barreau de fer. Ainsi, prenons des barreaux de fer doux et des barreaux d'acier, de longueur et de diamètre égaux : en plaçant un aimant naturel à l'une des extrémités du barreau, et en observant la quantité de magnétisme conduite à l'extrémité libre, nous trouverons que le barreau de fer supportera un poids huit fois plus considérable que le barreau d'acier placé dans les mêmes conditions.

De cette manière, nous pouvons constater facilement que le pouvoir conducteur du fer est égal à huit fois celui de l'acier trempé. Placé dans la bobine, le barreau d'acier exigerait un courant huit fois plus considérable pour produire la même quantité de force magnétique à son extrémité libre ; ce qui montre combien il est important de choisir le fer le plus doux. Il y avait une différence de 48 pour 100 en faveur d'un barreau de fer recuit. Toutes

les parties telles que l'armature, etc., devraient donc être parfaitement recuites, parce que la plus petite parcelle de fer écrouï réduit sensiblement les résultats.

Il faut avoir soin également que les fibres du fer soient longitudinales, les résultats étant sensiblement réduits quand elles sont transversales. Pour cette raison, un tube de fer étiré ou un faisceau de fils ont été généralement trouvés préférables pour les Ames. La plus grande différence observée était de 10 à 15 pour 100.

Une autre qualité très importante du fer dont la connexion avec l'électro-magnétisme n'a pas, croyons-nous, été observée jusqu'ici, est le pouvoir d'absorption du magnétisme dans le fer. Cette absorption du magnétisme ou, en d'autres mots, ce en quoi le magnétisme devient latent, est très-remarquable dans différentes espèces de fer, et avec le même fer la quantité absorbée est en raison directe de la masse. Si nous posons une pièce de fer sur un barreau aimanté, nous trouverons que l'aimant supportera un poids moindre qu'auparavant ; et la différence sera exactement proportionnelle à la quantité absorbée par la pièce de fer posée sur l'aimant. Si maintenant nous plaçons une pièce d'acier trempé de même dimension, nous trouverons que la différence des pouvoirs absorbants n'excède pas 1/6, et que le fer n'a absorbé que 1/6 de plus que l'acier trempé, tandis que son pouvoir conducteur est huit fois plus considérable.

L'âme de ces bobines consistait en un tube mince de fer, de 1 centimètre de diamètre, de 6 centimètres de longueur et de 1/4 de millimètre d'épaisseur. Elles avaient été disposées de manière que des tubes d'épaisseurs différentes pussent y être introduits, et par les courbes de force obtenues on verra dans les courbes (3) et (4) que l'effet maximum était atteint avec 1 millimètre 1/2 d'épaisseur.

Ce point atteint, le fer ayant déjà conduit tout le magnétisme engendré aux pôles, l'addition du fer produisait une diminution d'effet due à l'absorption du magnétisme maximum déjà engendré, et de cette manière une certaine quantité qui avait été transportée aux pôles était absorbée dans le fer inutile ajouté.

Cette expérience a été répétée de plusieurs manières avec des âmes de fil de fer fin, de barreaux massifs et de tubes grands et petits, et a donné des courbes (5) qui toutes confirment les résultats obtenus dans les courbes (3) et (4) avec les tubes en fer, ce qui prouve que dès que le maximum de pouvoir conducteur avec une force donnée a été obtenu par une certaine quantité de fer, l'addition d'une nouvelle quantité serait préjudiciable au résultat, une certaine portion du magnétisme induit devenant latent dans le fer inutile.

Pour ce qui est de la longueur des bobines et des barreaux, dans chaque cas l'effet maximum a été obtenu avec une longueur égale à six fois le diamètre du barreau.

Les courbes (6) ont été obtenues avec des bobines de longueurs différentes, ce qui montre qu'après la longueur égale à six fois le diamètre, la résistance à la conductibilité produite par une plus grande longueur diminue l'effet total, malgré l'addition de bobines plus longues et l'effet électro-magnétique produit par le courant dans les bobines plus longues.

Supposons qu'un barreau de fer de plusieurs mètres de long et de 1 centimètre de diamètre, soit garni dans toute sa longueur de bobines séparées, ayant même résistance et qu'une même puissance soit exercée sur chaque bobine, il ne se produira pas plus d'effet aux pôles extrêmes qu'avec une bobine longue seulement de 6 centi-

mètres, à cause de la résistance à la conductibilité du magnétisme engendré.

Ainsi, il est de la plus haute importance, avant de choisir du fer pour l'âme des électro-aimants, d'en essayer la conductibilité en prenant pour étalon de l'acier fondu fortement trempé. Des barreaux de bon fer de diamètre égal et d'une longueur huit fois plus grande devraient supporter le même poids que cet étalon.

Les meilleures conditions pour que des tubes en fer soient transformés en électro-aimants télégraphiques sont que, possédant un diamètre suffisant auprès des bobines, la quantité de fer soit réglée de manière à avoir le maximum de conductibilité avec le minimum d'absorption.

Les résultats de ces expériences montrent que la quantité de même que la qualité de fer dans un électro-aimant qui doit être employé avec une certaine résistance extérieure, devrait être étudiée soigneusement. Pour un électro-aimant donnant les résultats moyens les plus élevés à travers une résistance de 300 à 800 kilomètres, on a trouvé que le poids total de fer dans des âmes reliant le barreau et l'armature devrait être de 80 grammes.

Alors, il a été fait des expériences dans le but de trouver la meilleure forme à donner à l'armature pour utiliser le maximum d'effet produit aux pôles de l'électro-aimant. Des armatures de toutes les formes possibles ont été adaptées au même électro-aimant et essayées avec la même résistance de ligne et le même nombre d'éléments. Il serait trop long d'énumérer les nombreuses expériences ainsi faites; mais on pourra voir dans les courbes (8) quelques-uns des effets les plus distincts.

Ces armatures agissaient directement sur les pôles comme dans l'aimant du relais Morse, et l'on verra que

le maximum d'effet a été obtenu avec un barreau de 3 millimètres d'épaisseur, de 1 centimètre de large, et de 4 centimètres de long.

Le même phénomène de conductibilité et d'absorption a été observé en différentes armatures. Quand l'armature était trop mince, la résistance à la conductibilité était trop grande; quand l'armature était trop épaisse, le magnétisme induit devenait latent, et une portion était en conséquence perdue pour l'effet pratique.

Dans les courbes (7) et (8), on verra le maximum et le minimum sur des armatures d'épaisseurs différentes.

Des expériences ont été faites ensuite avec l'addition des pièces saillantes ou pièces de pôle à l'électro-aimant (fig. 10). Dans ce cas, les résultats ont été exactement les mêmes que dans les expériences précédentes avec la même longueur d'armature, mais ceux obtenus en raccourcissant les armatures différaient tout à fait. *Totalmente*

On sait depuis longtemps que les pôles vrais d'un aimant sont situés à peu de distance de l'extrémité; mais il n'a encore été fait aucune tentative d'utiliser cette propriété dans la construction et le travail des électro-aimants. [L'objet que l'on se proposait dans les expériences précédentes par l'addition de pièces de pôle était d'obtenir les pôles vrais agissant directement sur l'armature; mais, ainsi que nous l'avons annoncé, cette disposition ne nous a présenté aucun avantage.]

Je me déterminai alors à faire coïncider le pôle vrai de l'armature avec celui de la pièce de pôle, en raccourcissant l'armature. Les résultats de ces expériences furent plus heureux, la force croissant rapidement à mesure que les pôles vrais s'approchaient l'un de l'autre, et diminuant quand cette coïncidence était dépassée. [On verra dans les courbes (9) avec quelle rapidité cette force croît, de

nême que l'effet produit diminue quand on a dépassé ce point.

La figure 11 représente un aimant naturel; les lignes pointées, le maximum et le minimum d'effet sur ce barreau.

La figure 12 représente les pièces de pôle sur l'électro-aimant avec une longue armature; les lignes pointées montrent que les pôles vrais ne coïncident pas.

La figure 13 montre la courte armature donnant le maximum d'effet avec les pôles vrais coïncidant.]

L'armature ainsi raccourcie devient excessivement sensible et rapide dans son action. Elle travaille avec un effet constant, malgré une variation de courant beaucoup plus considérable qu'il n'est possible avec les arrangements ordinaires d'armatures. La sensibilité à de faibles courants de l'électro-aimant ainsi disposé est très-remarquable, un élément étant amplement suffisant pour mettre en mouvement le télégraphe imprimant à sa vitesse ordinaire de 120 révolutions de la roue des types, cinq lettres par révolution, ou 600 lettres par minute, à travers une résistance de 1,000 kilomètres, avec une perte à la terre des  $\frac{2}{5}$  du courant total. *perdita*

Avec une courte résistance, une petite pièce de zinc et une pièce de cuivre placées sur la langue excitent l'aimant parfaitement réglé à 600 contacts par minute, à travers une résistance de 1000 kilomètres. Avec une résistance de 300 kilomètres, une pièce de monnaie d'or et une pièce d'argent dans l'eau produisent un courant suffisant pour donner les mêmes effets.

Les expériences montrent qu'avec une résistance et une pile données, et une perte à la terre, telle que l'arrangement ordinaire de l'armature, comme dans le Morse, où un galvanomètre très-sensible n'accuse pas le plus

léger passage de courant, par un simple changement d'armatures, l'instrument fonctionne parfaitement et donne de fortes indications d'un courant d'une force suffisante pour être utilisée en pratique, même quand celle de la pile serait réduite de moitié.

Ainsi en soignant la construction des électro-aimants et l'ajustement des pôles vrais des armatures, une ligne télégraphique pourrait aisément fonctionner quand le courant, par les pertes sur la ligne, serait devenu trop faible pour les dispositions usitées auparavant.

Les résultats pratiques mentionnés ici ont été obtenus par l'application de ces principes à mon télégraphe imprimant, qu'ils ont rendu très-sensible à de faibles courants, en même temps qu'ils donnent la facilité de travailler sans réglage avec une série de 1 à 100 éléments.

L'aimant du relais Morse, construit d'après ces lois, serait, à mon avis, beaucoup plus sensible qu'auparavant; mais alors même les importants résultats mentionnés ici ne pourraient pas être obtenus en agissant à une certaine distance sur l'armature, avec le minimum de force seulement, tandis que dans l'appareil imprimant, l'armature étant contre les pôles à l'état de repos, on obtient toujours de cette façon le maximum de force.

Les résultats de ces expériences ne sont pas des déductions purement théoriques obtenues des lois énoncées dans les expériences, ce sont des lois appliquées pratiquement dans mon appareil imprimant, tel qu'il fonctionne sur les lignes les plus importantes et les plus longues de l'administration télégraphique de France.

D. E. HUGHES.

*Expériences sur les Electroaimants, par G. C. Hughes.*

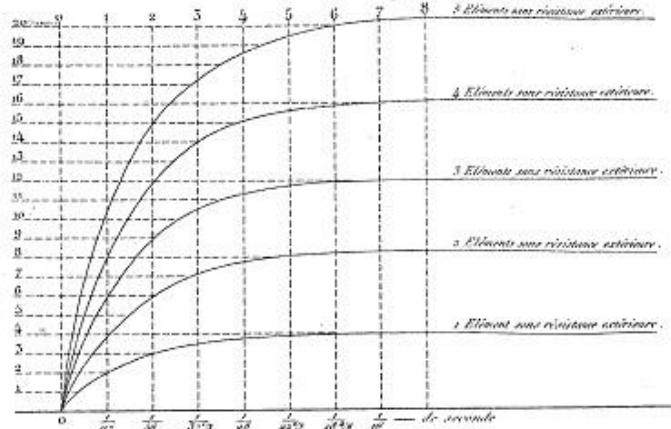


Fig. 1.

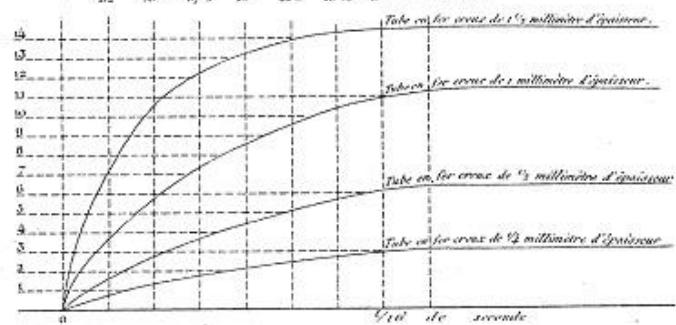


Fig. 3.

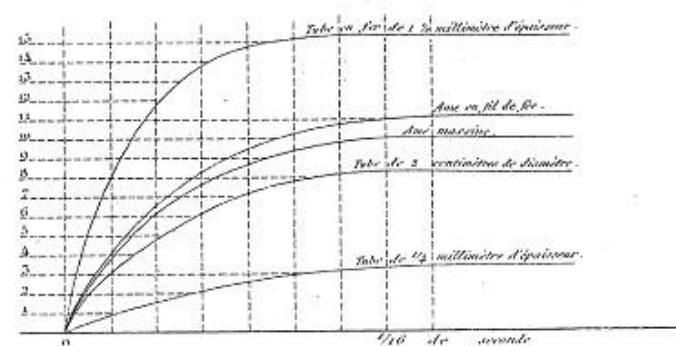


Fig. 5.

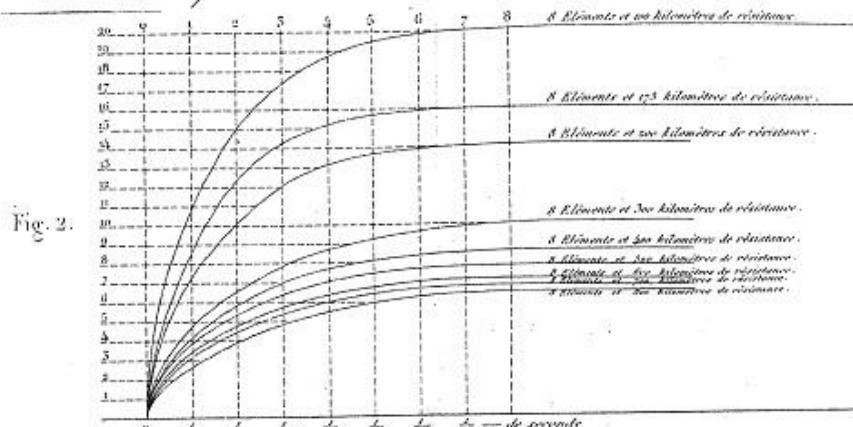


Fig. 2.

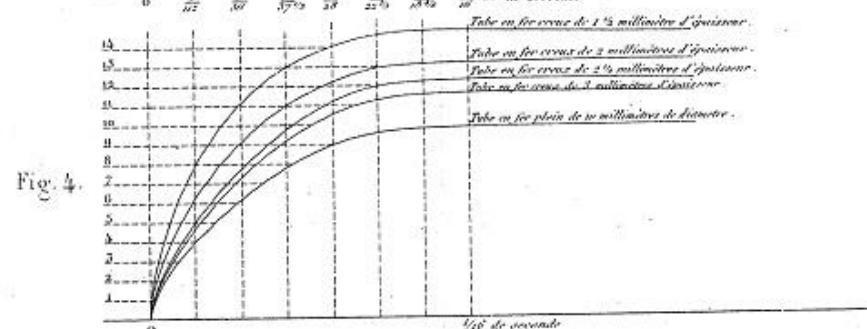


Fig. 4.

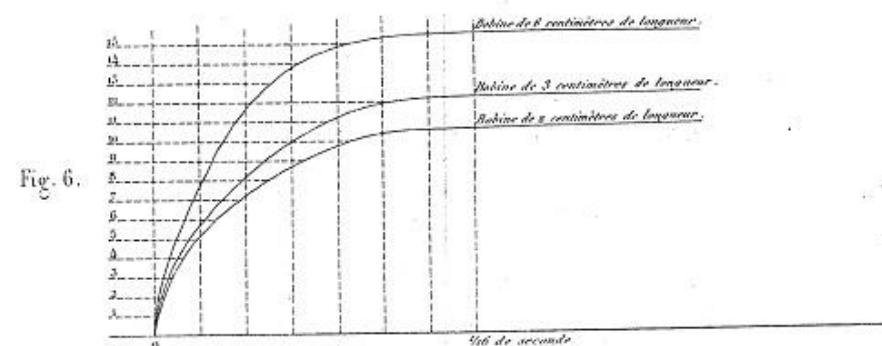


Fig. 6.

Fig. 7.

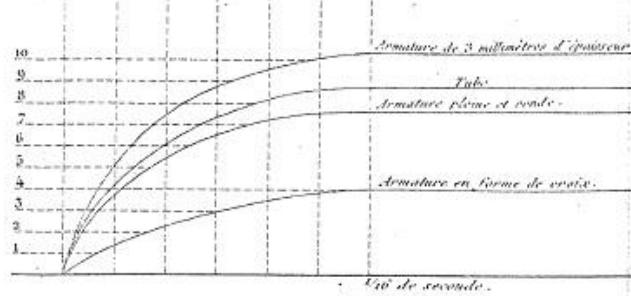


Fig. 8.

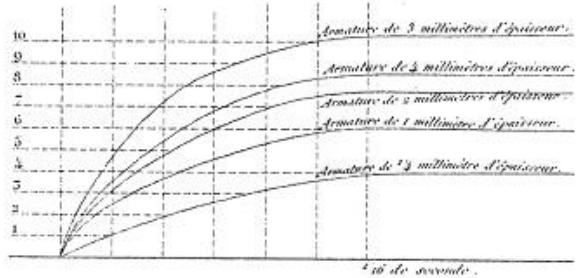


Fig. 9.

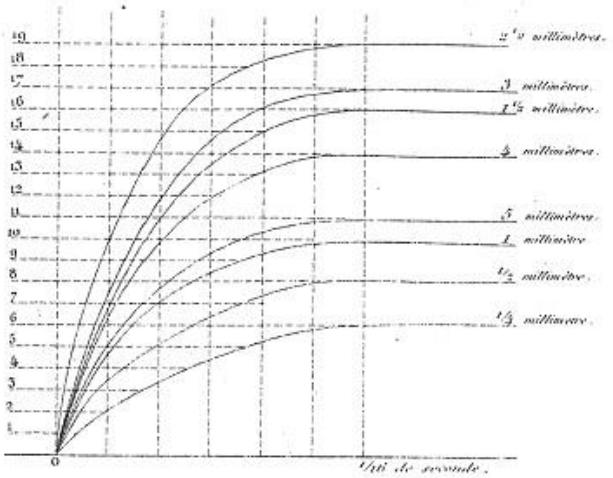


Fig. 10.

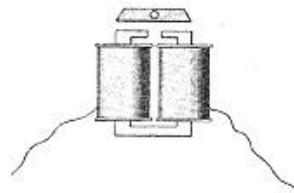


Fig. 11.



Fig. 12.

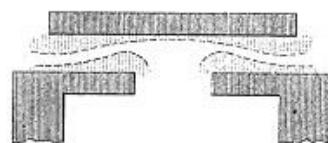
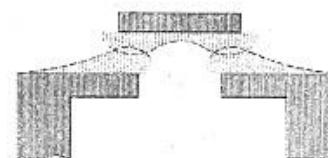


Fig. 13.



May 9, 1878.

Sir JOSEPH HOOKER, K.C.S.I., President, in the Chair.

The Presents received were laid on the table and thanks ordered for them.

The following Papers were read :—

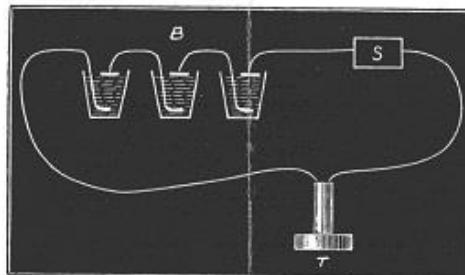
- I. "On the Action of Sonorous Vibrations in varying the Force of an Electric Current." By Professor D. E. HUGHES.  
Communicated by Professor HUXLEY, Sec. R.S. Received May 8, 1878.

The introduction of the telephone has tended to develop our knowledge of acoustics with great rapidity. It offers to us an instrument of great delicacy for further research into the mysteries of acoustic phenomena. It detects the presence of currents of electricity that have hitherto only been suspected, and it shows variations in the strengths of currents which no other instrument has ever indicated.

It has led me to investigate the effect of sonorous vibrations upon the electrical behaviour of matter. Willoughby Smith has shown that the resistance of selenium is affected by light, and Börnstein has led us to believe that many other bodies are similarly affected. We know also that the resistance of all bodies is materially influenced by heat. Sir William Thomson and others have shown that the resistance to the passage of currents offered by wires is affected by their being placed under strains, and, inasmuch as the conveyance of sonorous vibrations induces rapid variations in the strains at different points of a wire, I believed that the wire would vary in its resistance when it was used to convey sound. To investigate this I made a rough-and-ready telephone, with a small bar magnet four inches long, half the coil of an ordinary electro-magnet, and a square piece of ferro-type iron, three inches square, clamped rigidly in front of one pole of the magnet between two pieces of board. When using the pendulum beats of a small French clock, or the voice, as a source of sound, I found this arrangement supplied me with an extremely delicate *phonoscope* or sound detector.

All the experiments detailed in this paper were made with the simplest possible means, and no apparatus of any kind constructed by a scientific instrument maker was employed. The battery was a simple Daniell's cell, of Minotto's form, made by using three common tumblers, a spiral piece of copper wire being placed at the bottom of each glass and covered with sulphate of copper, and the glass being

then filled with well-moistened clay and water. A piece of zinc as the positive element was placed upon the clay. Insulated wires were attached to each plate, and three of these cells were joined in series. All experiments were made on a closed circuit, the telephone being used as a phonoscope to detect variations in the current and the consequent reproduction of sound. The apparatus, or materials experimented upon, were used in the same way as the transmitter of the speaking telephone of Bell. The attached sketch will make this clear.



B is the battery, S the source of sound or material examined, T the telephone or phonoscope.

I introduced into the circuit at S a strained conductor—a stretched wire—listening attentively with the telephone to detect any change that might occur when the wire was spoken to or set into transverse vibrations by being plucked aside. Gradually, till the wire broke, the strain was varied, but no effect whatever was remarked except at the moment when the wire broke. The effect was but momentary, but invariably at the moment of breaking a peculiar "rush" or sound was heard. I then sought to imitate the condition of the wire at the moment of rupture by replacing the broken ends and pressing them together with a constant and varying force by the application of weights. It was found that if the broken ends rested upon one another with a slight pressure of not more than one ounce to the square inch on the joints, sounds were distinctly reproduced although the effects were very imperfect.

It was soon found that it was not at all necessary to join two wires endwise together to reproduce sound, but that any portion of an electric conductor would do so even when fastened to a board or to a table, and no matter how complicated the structure upon this board, or the materials used as a conductor, provided one or more portions of the electrical conductor were separated and only brought into contact by a slight but constant pressure. Thus, if the ends of the wire terminate in two common French nails laid side by side, and are separated

from each other by a slight space, were electrically connected by laying a similar nail between them, sound could be reproduced. The effect was improved by building up the nails log-hut fashion, into a square configuration, using ten or twenty nails. A piece of steel watch chain acted well. Up to this point the sound or grosser vibrations were alone produced, the finer inflections were missing, or, in other words, the *timbre* of the voice was wanting, but in the following experiments the *timbre* became more and more perfect until it reached a perfection leaving nothing to be desired. I found that a metallic powder such as the white powder—a mixture of zinc and tin—sold in commerce as "white bronze," and fine metallic filings, introduced at the points of contact, greatly added to the perfection of the result.

At this point articulate speech became clearly and distinctly reproduced, together with its *timbre*, and I found that all that now remained was to discover the best material and form to give to this arrangement its maximum effect. Although I tried all forms of pressure and modes of contact, a lever, a spring; pressure in a glass tube sealed up while under the influence of strain, so as to maintain the pressure constant, all gave similar and invariable results, but the results varied with the materials used. All metals, however, could be made to produce identical results, provided the division of the metal was small enough, and that the material used does not oxidize by contact with the air filtering through the mass. Thus platinum and mercury are very excellent and unvarying in their results, whilst lead soon becomes of such high resistance, through oxidation upon the surface, as to be of little or no use. A mass of bright round shot is peculiarly sensitive to sound whilst clean, but as the shot soon become coated with oxide this sensitiveness ceases. Carbon again, from its surface being entirely free from oxidation, is excellent, but the best results I have been able to obtain at present have been from mercury in a finely divided state. I took a comparatively porous non-conductor, such as the willow charcoal used by artists for sketching, heating it gradually to a white heat and then suddenly plunging it in mercury. The vacua in the pores, caused by the sudden cooling, become filled with innumerable minute globules of mercury, thus, as it were, holding the mercury in a fine state of division. I have also tried carbon treated in a similar manner with and without platinum deposited upon it from the chloride of platinum. I have also found similar effects from the willow charcoal heated in an iron vessel to a white heat, and containing a free portion of tin, zinc, or other easily vaporized metal. Under such conditions the willow carbon will be found to be metallized, having the metal distributed throughout its pores in a fine state of division. Iron also seems to enter the pores if heated to a white heat without being chemically combined with the carbon as in graphite, and, indeed, some of the best results have been

obtained from willow charcoal containing iron in a fine state of division.

Pine charcoal treated in this manner (although a non-conductor as a simple charcoal) has high conductive powers, due to the iron; and from the minute division of the iron in the pores, is a most excellent material for the purpose.

Any one of these preparations confined in a glass tube or a box, and provided with wires for insertion in a circuit, I call a "transmitter."

Reis, in 1860, showed how, by the movement of a diaphragm, intermittent voltaic currents could be transmitted, agreeing in exact number with the sonorous waves impinging on the diaphragm, and thus reproducing music at a distance by causing an electro-magnet to vibrate in unison with the diaphragm; and, with an iron diaphragm, Graham Bell showed how the vibrations of that diaphragm in front of a polarised electro-magnet could similarly induce magneto-currents, corresponding in number, amplitude, and form, with the sonorous vibration, and thus reproduce all the delicacies of the human voice. Edison and others have produced variations in the strengths of a constant current by causing the diaphragm to press directly upon some elastic conductor, such as carbon, spongy platinum, &c., the varying pressure upon these materials varying the resistance of the circuit, and consequently the strength of current flowing. Graham Bell and others have produced the same effect, by causing the vibrations of the diaphragm to vary the electromotive force in the circuit. It will be seen, however, that in the experiments made by myself, the diaphragm has been altogether discarded, resting as it does upon the changes produced by molecular action, and that the variations in the strengths of the currents flowing are produced simply and solely by the direct effect of the sonorous vibrations.

I have found that any sound, however feeble, produces vibrations which can be taken up by the matter interposed in the electrical circuit. Sounds absolutely inaudible to the human ear affect the resistance of the conductors described above. In practice, the effect is so sensitive, that a slight touch on the board, by the finger nail, on which the transmitter is placed, or a mere touch with the soft part of a feather, would be distinctly heard at the receiving station. The movement of the softest camel hair brush on any part of the board is distinctly audible. If held in the hand, several feet from a piano, the whole chords—the highest as well as the lowest—can be distinctly heard at a distance. If one person sings a song, the distant station, provided with a similar transmitter, can sing and speak at the same time, and the sounds will be received loud enough for the person singing to follow the second speech or song sent from the distant end.

Acting on these facts, I have also devised an instrument suitable for magnifying weak sounds, which I call a *microphone*. The microphone,

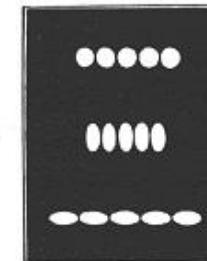
in its present form, consists simply of a lozenge-shaped piece of gas carbon, one inch long, quarter inch wide at its centre, and one-eighth of an inch in thickness. The lower pointed end rests as a pivot upon a small block of similar carbon; the upper end, being made round, plays free in a hole in a small carbon-block, similar to that at the lower end. The lozenge stands vertically upon its lower support. The whole of the gas carbon is tempered in mercury, in the way previously described, though this is not absolutely necessary. The form of the lozenge-shaped carbon is not of importance, provided the weight of this upright contact piece is only just sufficient to make a feeble contact by its own weight. Carbon is used in preference to any other material, as its surface does not oxidise. A platinum surface in a finely-divided state is equal, if not superior, to the mercurised carbon, but more difficult and costly to construct. I have also made very sensitive ones entirely of iron.

The best form and materials for this instrument, however, have not yet been fully experimented on. Still, in its present shape, it is capable of detecting very faint sounds made in its presence. If a pin, for instance, be laid upon or taken off a table, a distinct sound is emitted, or, if a fly be confined under a table-glass, we can hear the fly walking, with a peculiar tramp of its own. The beating of a pulse, the tick of a watch, the tramp of a fly, can thus be heard at least a hundred miles distant from the source of sound. In fact, when further developed by study, we may fairly look for it to do for us, with regard to faint sounds, what the microscope does with matter too small for human vision.

It is quite evident that these effects are due to a difference of pressure at the different points of contact, and that they are dependent for the perfection of action upon the number of these points of contact. Moreover, they are not dependent upon any apparent difference in the bodies in contact, but the same body in a state of minute subdivision is equally effective. Electrical resistance is a function of the mass of the conductor, but sonorous conduction is a function of the molecules of matter. How is it therefore that a sonorous wave can so affect the mass of a conductor as to influence its electrical resistance? If we assume a line of molecules, we know that a sonorous wave is accompanied by alternate compressions and rarefactions. If we isolate the part under compression from the part under dilatation we vary the dimensions of the mass, and we alter its electrical resistance. In any homogeneous conductor of finite dimensions the effect of the one will exactly compensate for the effect of the other, and we get no variation of current, but if we break up this homogeneous conductor into a series of minute subdivisions without actually breaking their electrical continuity we destroy this neutralizing influence, and we render evident the effect of sonorous vibrations in varying the dimensions of

the mass of the conductor, and therefore in varying its electrical resistance, for we reduce the length of a portion of the conductor to a fraction of the length of a sonorous wave. Molecular action alone explains to me all the effects produced. Size or shape does not affect them. A piece of willow charcoal, the size of a pin's head, is quite sufficient to reproduce articulate speech. I regard the action as follows:—If we have two separate conductors joined simply by contact this contact offers a certain resistance. Now we can vary or lessen the resistance by increasing the pressure, thus bringing more points in contact or closer proximity. Now, as I employ a constant pressure on the contact, which is exactly under the same influence of the vibrations as the points of contact, more points or closer proximity can only be obtained through the molecular swelling or movement of the contact points.

If we assume a line of molecules at the point of contact of the minute masses of conducting matter in their neutral condition to be arranged thus:—



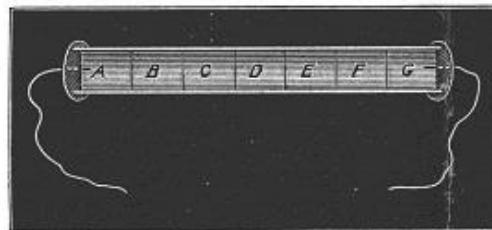
they will appear thus under compression:—

and thus under dilatation:—

In the former case the electrical resistance would be less, and in the latter case more than in the normal condition. Hence we should get variation in their electrical resistance, and thus sonorous waves could vary the strength of an electric current, and the variations of the electric current can be made to reproduce sonorous vibrations. These, however, would only produce the result in a certain line, say horizontal; but those perpendicular, while producing the same result, would be a half vibration behind, and thus if two contacts, the one horizontal and the other perpendicular, were on the same piece of charcoal and the conducting line joined to both, we should have interference. The contrary takes place as the more contacts we have, and the more varied their direction on the same, the louder and purer the sound becomes. Hence there is no interference, and consequently the whole mass must swell and diminish equally in all directions at the same instant of time.

The tube transmitter, which I exhibit this evening, consists of an exterior glass tube two inches long and one quarter of an inch in

diameter. In it are four separate pieces of willow charcoal, each one quarter of an inch long, and two terminals of the same material. The terminals are fastened in the tube, and connect exteriorly with the line and interiorly with the four loose pieces, thus:—



Here A is made to press on B, C, D, E, F, and G, until the resistance offered to the electrical current is about one-third that of the line upon which it is to be employed. It may be attached to a resonant board by the ends A or G. If the result was simply due to vibrations, we should have A and B making greater contact at a different time from F and G, and consequent interference. If it was a simple shaking or moving of B, C, D, E, and F, it could produce no change, as if B pressed more strongly on C, it would be less on A, and also if the tube was attached by the centre we should have no effect; but if the effect is due to a swelling or enlargement of B, C, D, E, F, it would make no difference where it is attached to the resonant board, as is actually the case. Again reduce the pressure of A upon B, &c., until they are not in contact, and no trace of current can be perceived by shaking the tube. The instant the sonorous vibrations pass in the tube there is electric contact to a remarkable degree, which could only have taken place by the molecules enlarging their sphere under the influence of the sonorous vibrations.

It is impossible to say what can be the applications or the effects of the discovery which I have had the honour of bringing before the Royal Society, for the whole question has been studied with crude materials, and scarcely sufficient time has elapsed to enable me to consider its ultimate uses. I do not desire to assert that there is anything in what I have brought forward that is superior to or equal to other transmitters used for telephony. It is as loud and far more sensitive than any I have yet heard, and it may be increased by multiplication of transmitting contacts in quantity or intensity; the loudness is at present limited by the capability of the receiver. The materials at my disposal, and the arrangement of them, have not yet been sufficiently studied. I only wished to show that it is possible to transmit clear and intelligent articulate speech, and to render audible

sounds which have hitherto been inaudible by the mere operation of sonorous vibrations upon the conducting power of matter.

My warmest thanks are due to Mr. W. H. Preece, electrician to the Post Office, for his appreciation of the importance of the facts I have stated, and for his kind counsel and aid in the preparation of this paper.

I do not intend to take out a patent, as the facts I have mentioned belong more to the domain of discovery than invention. No doubt inventors will ere long improve on the form and materials employed. I have already my reward in being allowed to submit my researches to the Royal Society.

## II. "Note on the Minute Anatomy of the Thymus." By HERBERT WATNEY, M.A., M.D. Cantab. Communicated by Dr. KLEIN, F.R.S. Received April 8, 1878.

The thymus is composed of lobes, lobules, and follicles.

Each follicle consists of a cortical and a medullary portion; the medullary parts of two neighbouring follicles are often united; and at one point, therefore, the medullary portion may extend through the cortex of the follicle; in some follicles the medullary portion may be found in the form of two or more islands situated in the interior of the follicle.

The follicle is composed (a) of a reticulum of nucleated cells, and (b) of cells; the reticulum forms an adventitia to the blood-vessels.

The cells forming the reticulum in the cortical part of the follicle consist of a disk-shaped nucleus, a cell body very little larger than the nucleus, and of very long, fine, branching processes.

The reticulum of the medullary portion is composed of cells with coarse, short processes; the body of the cell is more than twice, or even three times, as large as the nucleus, and contains one, or at times, two nuclei; in places, large protoplasmic masses are met with, forming part of the reticulum composed of two or three cells united together. There are also found in the medullary portions, in certain states of the thymus, connective tissue trabeculae.

The cells are of four kinds:—

(1.) Small cells, resembling the lymph cells of a follicle of a lymphatic gland. Staining fluids act differently on these cells in the cortical and in the medullary parts of the follicle.

(2.) Large granular cells of various sizes; many of them have long processes by which, in some cases, they are attached to the trabeculae and to the blood-vessels: these cells contain one or two nuclei, and help to form (partly by a process of vacuolation) the concentric corpuscles of the thymus.

*Miscellaneous Notes.*

§ 183. The following notes of salts which have not yet been fully examined may be useful.  
 Cyanide of Potassium, as a cryogen, gives a temperature of  $-21^{\circ}1$ . The cryohydrate forms at  $-33^{\circ}$ , with a carbonic-acid and-ether cryogen. Compare § 170.

Oxalate of Sodium forms a cryohydrate at  $-1^{\circ}7$  C.

Employed as cryogens, the following temperatures were obtained from the corresponding salts:—

Chloride of cadmium . . . .	$-8^{\circ}3$ C.
" nickel . . . .	$-10^{\circ}35$
Citrate of sodium . . . .	$-11^{\circ}3$
Acetate of calcium . . . .	$-11^{\circ}8$
Chloride of cobalt . . . .	$-15^{\circ}35$
" manganese . . . .	$-28^{\circ}0$

Those of these bodies which evolve heat on mixture with water would, when cooled, depress the temperature more. Thus the chloride of manganese scarcely showed signs of a cryohydrate at  $-40^{\circ}$  C.

Formate of Sodium, as a cryogen, gives  $-14^{\circ}3$ . A concentrated solution becomes semisolid at  $-14^{\circ}$ , but does not become opaque or completely solid in a salt-ice cryogen ( $-22^{\circ}$ ).

Tannic Acid, as a cryogen, gives  $-1^{\circ}5$ .

Sulphurous Acid gives a cryohydrate at  $-1^{\circ}5$ .

Boracic Acid, as a cryogen, gives  $-0^{\circ}8$ . The cryohydrate forms at  $-0^{\circ}71$ .

Arsenious Acid.—The cryogen stands at  $-6^{\circ}3$ ; the cryohydrate formed at  $-6^{\circ}5$ . Two samples of the melted and liquid cryohydrate were sealed hermetically. After two or three days it was found that a considerable quantity of a fine white powder had exhibited itself.

[To be continued.]

*V. On the Physical Action of the Microphone.*

By Prof. HUGHES.\*

IN the paper read on the 9th of May before the Royal Society, I gave a general outline of the discoveries I had made, the materials used, and the forms of microphone employed in demonstrating important points. I have made a great number of microphones, each for some special purpose, varying in form, mechanical arrangement, and materials. It

\* Communicated by the Physical Society, having been read June 8, 1878.

would require too much time to describe even a few of them; and as I am anxious in this paper to confine myself to general considerations, I will take it for granted that some of the forms of instrument and the results produced are already known.

The problem which the microphone solves is this—To introduce into an electrical circuit an electrical resistance, which resistance shall vary in exact accord with sonorous vibrations so as to produce an undulatory current of electricity from a constant source, whose wave-length, height, and form shall be an exact representation of the sonorous waves. In the microphone we have an electric conducting material susceptible of being influenced by sonorous vibrations; and thus we have the first step of the problem.

The second step is one of the highest importance: it is essential that the electrical current flowing be thrown into waves of determinate form by the sole action of the sonorous vibrations. I resolved this by the discovery that when an electric conducting matter in a divided state, either in the form of powder, filings, or surfaces, is put under a certain slight pressure, far less than that which would produce cohesion and more than would allow it to be separated by sonorous vibrations, the following state of things occurs. The molecules at these surfaces being in a comparatively free state, although electrically joined, do of themselves so arrange their form, their number in contact, or their pressure (by increased size or orbit of revolution) that the increase and decrease of electrical resistance of the circuit is altered in a very remarkable manner, so much so as to be almost fabulous.

The problem being solved, it is only necessary to observe certain general considerations to produce an endless variety of microphones, each having a special range of resistance.

The tramp of a fly or the cry of an insect requires little range but great sensitiveness; and two surfaces, therefore, of chosen materials under a very slight pressure, such as the mere weight of a small superposed conductor, suffice; but it would be unsuitable for a man's voice, as the vibrations would be too powerful, and would, in fact, go so far beyond the legitimate range that interruptions of contact amounting to the well-known "make and break" would be produced.

A man's voice requires four surfaces of pine charcoal, as is described in my paper to the Royal Society, six of willow charcoal, eight of boxwood, and ten of gas-carbon. The effects, however, are far superior with the four of pine than with either the ten of gas-carbon or any other material as yet used. It should be noted that pine wood is the best resonant material we possess; and it preserves its structure and quality

when converted into the peculiar charcoal I have discovered and described.

It is not only necessary to vary the number of surfaces and materials in accordance with the range and power of the vibrations, but these surfaces and materials must be put under more or less pressure in accordance with the force of the sonorous vibrations. Thus for a man's voice the surfaces must be under a far greater pressure than for the movements of insects. Still the range of useful effect is very great, as the boxes which I have specially arranged for man's voice are still sensitive to the tick of a watch.

In all cases it should be so arranged that a perfect undulatory current is obtained from the sonorous vibrations of a certain range. Thus, when speaking to a microphone transmitter of human speech, a galvanometer should be placed in the circuit, and, while speaking, the needle should not be deflected, as the waves of + and - electricity are equal, and are too rapid to disturb the needle, which can only indicate a general weakening or strengthening of the current. If the pressure on the materials is not sufficient, we shall have a constant succession of interruptions of contact, and the galvanometer-needle will indicate the fact. If the pressure on the materials is gradually increased, the tones will be loud but wanting in distinctness, the galvanometer indicating interruptions; as the pressure is still increased, the tone becomes clearer, and the galvanometer will be stationary when a maximum of loudness and clearness is attained. If the pressure be further increased, the sounds become weaker though very clear; and as the pressure is still further augmented the sounds die out (as if the speaker were talking and walking away at the same time) until a point is arrived at where there is complete silence.

When the microphone is fixed to a resonant board, the lower contact should be fixed to the board, so that the sonorous vibrations act directly on it. The upper contact, where the pressure is applied, should be as free as possible from the influence of the vibrations, except those directly transmitted to it by the surfaces underneath; it (the upper surface) should have its inertia supplemented by that of a balanced weight. This inertia I find necessary to keep the contact unbroken by powerful vibrations. No spring can supply the required inertia; but an adjustable spring may be used to ensure that the comparatively heavy lever shall duly press on the contacts.

The superposed surfaces in contact may be screwed down by an insulated screw passing through them all, thus doing away with the lever and spring; but this arrangement is far

more difficult to adjust, and the expansion by heat of the screw causes a varying pressure. It is exceedingly simple, however, easily made, and illustrates the theoretical conditions better than the balanced lever I have adopted in practice.

In order to study the theoretical considerations, and that with the most simple form of microphone freed from all surrounding mechanisms, let us take a flat piece of charcoal 2 millims. thick and 1 centim. square, and, after making electrical contact by means of a copper wire on the lower surface, glue that to a small resonant board or, better for the purpose of observation, to a block of wood 10 centims. square. Upon this superpose one or more similar blocks of charcoal, the upper surface in communication with a wire, the lowermost surface resting flat, or as nearly so as possible, on the lower block.

The required pressure is put on the upper block; and while in this state the two may be fastened together with glue at the sides, or, better, by an insulated screw. The pressure can then be removed, as the screw or glue equally preserves the force. Let the lower piece be called A and the upper B: when we subject this board to sonorous vibrations, we cannot imagine an undulatory movement of the actual wavelength in such a mass, that is a length comparable with the real wave-length of the sonorous wave, which may be several feet. Nor can we imagine a wave of any length without admitting that the force must be transmitted from molecule to molecule throughout the entire length: thus any portion of a wave, of which this block represents a fraction, must be in molecular activity. The lower portion of the charcoal A, being part of the block itself, has this molecular action throughout, transmitting it also to the upper block. How is it that the molecular action at the surfaces of A and B should so vary the conductivity or electrical resistance as to throw it into waves in the exact form of the sonorous vibrations? It cannot be because it throws up the upper portion, making an intermittent current, because the upper portion is fastened to the lower, and the galvanometer does not indicate any interruption of current whatever. It cannot be because the molecules arrange themselves in stratified lines, becoming more or less conductive, as then surfaces would not be required—that is, we should not require discontinuity between the blocks A and B; nor would the upper surface be thrown



up if the pressure be removed, as sand is on a vibrating glass. The throwing-up of this upper piece B when pressure is removed proves that a blow, pressure, or upheaval of the lower portion takes place : that this takes place there cannot be any doubt, as the surface, considered alone (having no depth), could not bodily quit its mass. In fact, there must have been a movement to a certain depth; and I am inclined to believe, from numerous experiments, that the whole block increases and diminishes in size at all points, in the centre as well as the surface, exactly in accordance with the form of the sonorous wave. Confining our attention, however, to points on A and B, how can this increased molecular size or form produce a change in the electrical waves? This may happen in two ways:—*first*, by increased pressure on the upper surface, due to its enlargement; or, *second*, the molecules themselves, finding a certain resistance opposed to their upward movement, spread themselves, making innumerable fresh points of contact. Thus an undulatory current would appear to be produced by infinite change in the number of fresh contacts. I am inclined to believe that both actions occur: but the latter seems to me the true explanation; for if the first were alone true, we should have a far greater effect from metal powder, carbon, or some elastic conductor, such as metallized silk, than from gold or other hard unoxidizable matter; but as the best results as regards the human voice were obtained from two surfaces of solid gold, I am inclined to view with more favour the idea that an infinite variety of fresh contacts brought into play by the molecular pressure affords the true explanation. It has the advantage of being supported by the numerous forms of microphone I have constructed, in all of which I can fully trace the effect.

I have been very much struck by the great mechanical force exerted by this uprising of the molecules under sonorous vibrations. With vibrations from a musical box 2 feet in length, I found that one ounce of lead was not sufficient on a surface of contact 1 centim. square to maintain constant contact; and it was only by removing the musical box to a distance of several feet that I was enabled to preserve continuity of current with a moderate pressure. I have spoken to forty microphones at once; and they all seemed to respond with equal force. Of course there must be a loss of energy in the conversion of molecular vibrations into electrical waves; but it is so small that I have never been able to measure it with the simple appliances at my disposal. I have examined every portion of my room—wood, stone, metal, in fact all parts—and even a piece of india-rubber: all were in molecular move-

ment whenever I spoke. As yet I have found no such insulator for sound as gutta-percha is for electricity. Caoutchouc seems to be the best; but I have never been able by the use of any amount at my disposal to prevent the microphone reporting all it heard.

The question of insulation has now become one of necessity, as the microphone has opened to us a world of sounds, of the existence of which we were unaware. If we can insulate the instrument so as to direct its powers on any single object, as at present I am able to do on a moving fly, it will be possible to investigate that object undisturbed by the pandemonium of sounds which at present the microphone reveals where we thought complete silence prevailed.

I have recently made the following curious observation:—A microphone on a resonant board is placed in a battery-circuit together with two telephones. When one of these is placed on the resonant board, a continuous sound will emanate from the other. The sound is started by the vibration which is imparted to the board when the telephone is placed on it; this impulse, passing through the microphone, sets both telephone-disks in motion; and the instrument on the board, reacting through the microphone, causes a continuous sound to be produced, which is permanent so long as the independent current of electricity is maintained through the microphone. It follows that the question of providing a *relay* for the human voice in telephony is thus solved.

The transmission of sound through the microphone is perfectly duplex; for if two correspondents use microphones as transmitters and telephones as receivers, each can hear the other, but his own speech is inaudible; and if each sing a different note, no chord is heard. The experiments on the deaf have proved that they can be made to hear the tick of a watch, but not, as yet, human speech distinctly; and my results in this direction point to the conclusion that we only hear ourselves speak through the bones and not through the ears.

However simple the microphone may appear at first glance, it has taken me many months of unremitting labour and study to bring to its present state through the numerous forms each suitable for a special object. The field of usefulness for it widens every day. Sir Henry Thompson has succeeded in applying it to surgical operations of great delicacy; and by its means splinters, bullets, in fact all foreign matter, can be at once detected. Dr. Richardson and myself have been experimenting in lung- and heart-diseases; and although the application by Sir H. Thompson is more successful, I do not doubt that we shall ultimately succeed. There is also hope that

deafness may be relieved. For telephony articulation has become perfect, and the loudness increased. Duplex and multiplex telegraphy will profit by its use; and there is hardly a science, where acoustics has any direct or indirect relation, which will not be benefited. And I feel happy in being able to present this paper on the results obtained by a purely physical action to such an appropriate and appreciative body as the Physical Society.

In conclusion, allow me to state that throughout the whole of my investigations I have used Prof. Bell's wonderfully sensitive telephone instrument as a receiver, and that it is owing to the discovery of so admirable an appliance that I have been enabled to commence and follow up my researches.

*VI. On a Cause for the Appearance of Bright Lines in the Solar Spectrum.* By RAPHAEL MELDOLA, F.R.A.S., F.C.S., &c.\*

IN July 1877 Professor Henry Draper showed that oxygen and (probably) nitrogen are present in the sun's atmosphere, the spectral lines of these gases appearing as bright lines in the solar spectrum.

The photograph accompanying Professor Draper's paper † shows that the oxygen-lines are bright, although not conspicuously so, upon a less-luminous background.

The discoverer of this most important fact in solar chemistry does not offer any complete explanation of the exceptional behaviour of the lines of these elements, but remarks that "it may be suggested that the reason of the non-appearance of a dark line may be that the intensity of the light from a great thickness of ignited oxygen overpowers the effect of the photosphere, just as, if a person were to look at a candle-flame through a yard thickness of ignited sodium-vapour, he would only see bright sodium-lines and no dark absorption-lines. Of course such an explanation would necessitate the hypothesis that ignited gases such as oxygen give forth a relatively large proportion of solar light."

The oxygen-spectrum referred to in the above-mentioned paper is the well-known "line spectrum" seen when powerful disruptive sparks pass through the gas. Dr. Schuster\* has recently succeeded in obtaining a second or "compound" spectrum of oxygen†, the fundamental lines of which he has

\* Communicated by the Author.

† Nature, vol. xvi. p. 364, August 30, 1877.

‡ Nature, vol. xvii. p. 148, December 20, 1877.

shown with considerable certainty to be present as dark lines in the solar spectrum.

Since the publication of Professor Draper's discovery, I have given much attention to the consideration of a cause for the apparently anomalous brightness of the oxygen-lines; and in the present paper I venture to advance an explanation which has recommended itself as being worthy of notice, not only because it offers a reconciliation of the known solar spectrum with the generally accepted views of the constitution of the sun's atmosphere, but likewise because it furnishes a suggestive hypothesis for the attack of many other obscure problems in solar physics.

1. I shall throughout this paper consider it to be established that the gaseous envelopes surrounding the sun succeed each other in the following order, commencing with the lowest:—

1. Photosphere.
2. Reversing layer.
3. Chromosphere.
4. Coronal atmosphere.

I also assume the truth of the hypothesis, first advanced by Johnstone Stoney\*, who showed, from purely theoretical considerations, that in the sun's atmosphere the various elements must extend to heights which are, broadly speaking, inversely as their vapour-densities. This view has, in my belief, been substantially confirmed by subsequent observation. Thus nitrogen and oxygen, having the respective densities 14 and 16 ( $H=1$ ), would extend to a great height in the solar atmosphere, rising above sodium, calcium, and magnesium, and having exterior to them the unknown substance giving the D<sub>3</sub> line (helium), hydrogen, and the element giving the coronal line "1474."

2. Two suppositions can be made concerning the sun's temperature. In the first place, it may be assumed that the temperature is so enormously elevated that no chemical compound is anywhere capable of existing in his atmosphere; in other words, dissociation may be considered to be complete. In the next place, it may be supposed that the temperature falls off sufficiently at some region of the outer portion of the sun's atmosphere for certain chemical combinations to take place.

3. Let us first assume that the temperature of the sun is so

\* Proc. Roy. Soc. xvi. p. 25, and xvii. p. 1; Phil. Mag. August 1868; Monthly Notices Roy. Astr. Soc. Dec. 1867; Lockyer, Phil. Trans. 1873, vol. ccliii. p. 265.