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The Photophone

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the age of thirteen, in the year 1804, remaining there eight years, and during the chief part of the time bound books. Now it was in those books, in the hours of the week, that I found the beginning of my philosophy. There were two that especially helped me,—the *Encyclopædia Britannica*, from which I gained my first notions of electricity, and Mrs. Marcet's "Conversations on Chemistry," which gave me my foundation in that science. Do not suppose that I was a very deep thinker, or was marked a precocious person. I was a burly imaginative person, and could believe in the Arabian Nights as easily as in the *Encyclopædia*. But facts were important to me and saved me. I could trust a fact and always cross-examined an assertion. So when I questioned Mrs. Marcet's book by such little experiments as I could find means to perform, and found it true to the facts as I could understand them, I felt that I had got hold of an anchor in chemical knowledge, and clung fast to it. Thence my deep veneration for Mrs. Marcet—first, as one who had conferred great personal good pleasure on me; and then as one able to convey the truth and principle of those boundless fields of knowledge which concern natural things to the young, untaught and inquiring mind. You may imagine my delight when I came to know Mrs. Marcet personally; how often have I cast my thoughts backward, delighting to connect the past and the present; how often, when sending her a paper as a thank-offering, I thought of my first instructress; and such thoughts will remain with me."

Henry wrote on the inside of the cover of Gregory's work the following words: "This book, although by no means a profound work, has, under Providence, exerted a remarkable influence on my life. It accidentally fell into my hands when I was about sixteen years old, and was the first book I ever read with attention. It opened to me a new world of thought and enjoyment; invested things before almost unnoticed with the highest interest; fixed my mind on the study of nature, and caused me to resolve at the time of reading it that I would immediately begin to devote my life to the acquisition of knowledge.—J. H." Each of these philosophers worked with simple instruments, mostly constructed by his own hands, and by methods so direct that he appeared to have an almost intuitive perception into the workings of nature; and each gave great care to the composition of his writings, sending his discoveries into the world clothed in simple and elegant English. Finally each loved science more than money, and his Creator more than either. There was sympathy between these men; and Henry loved to dwell on the hours that he and Bach spent in Faraday's society. I shall never forget Henry's account of his visit to King's College, London, where Faraday, Wheatstone, Daniell and he had met to try and evolve the electric spark from the thermopile. Each in turn attempted and failed. Then came Henry's turn. He succeeded, calling in the aid of his discovery of the effect of a long interpoler wire wrapped around a piece of soft iron. Faraday became as wild as a boy, and, jumping up, shouted, "Hurrah for the Yankee experiment." And Faraday and Wheatstone reciprocated the high estimation in which Henry held them. During a visit to England, not long before Wheatstone's death, he told me that Faraday and he had, after Henry's classical investigation of the induced currents of different orders, written a joint letter to the council of the Royal Society, urging that the Copley medal, "that laurel wreath of science," should be bestowed on Henry. On further consultation with members of the council it was decided to defer the honor till it would come with greater éclat, when Henry had continued farther his researches in electricity. Henry's removal to Washington interrupted these investigations. Wheatstone promised to give me this letter to convey to Henry as an evidence of the high appreciation which Faraday and he had for Henry's genius, but Wheatstone's untimely death prevented this. Both Faraday and he gave much thought to the philosophy of education, and in the main their ideas agreed. I may in this connection be excused from reading abstracts from a letter from Henry soon after he had received the news I had given my son his name. After a playful discussion of the name Joseph, Jo and Josey, he says—what may be news to most of you: "I did not object to Henry as a first name; although I have been sorry that my grandfather, in coming from Scotland to this country, substituted it for Hendrie, a much less common, and, therefore, distinctive name." He then proceeds: "I hope that both his body and mind will be developed by proper training and instruction, that he may become an efficient, wise and good man. I say efficient and wise, because these two characteristics are not always united in the same person. Indeed, most of the inefficiency of the world is due to their separation. Wisdom may know what ought to be done, but it requires the aid of efficiency to accomplish the desired object. I hope that in the education of your son due attention may not only be given to the proper development of both these faculties, but also they will be cultivated in the order of nature; that is, doing before thinking; art before science. By inverting this order much injury is frequently done to a child, especially in the case of the only son of a widowed mother, in which a precocious boy becomes an insignificant man. On examination in such a case it will generally be found that the boy has never been drilled into expertness in the art of language, of arithmetic, or of spelling, of attention, perseverance and order; or, in other words, of the habits of an active and efficient life."

Henry was a man of extensive reading, and often surprised his friends by the extent and accuracy of his information, and by the original manner in which he brought his knowledge before them.

Not only was he well versed in those subjects in which one might naturally suppose him proficient, but in departments of knowledge entirely distinct from that in which he gained his reputation as an original thinker. Although without a musical ear he had a nice feeling for the movement of a poem, and was fond of drawing from his retentive memory poetic quotations apt to the occasion. He was a diligent student of mental philosophy, and also took a lively interest in the progress of biological science, especially in following the recent generalization of Darwin; while the astonishing development of modern research in tracking the history of prehistoric man had for him a peculiar fascination. Yet with all his learning, reputation and influence, Henry was as modest as he was pure. One day, on opening Henry's copy of Young's *Lectures on Natural Philosophy*—a book which he has studied more than any other work of science—I read on the fly-leaf, written in his own hand, these words:—

"In Nature's infinite book of secrecy  
A little I can read."—*Shakespeare*.

And did he not read a little "in Nature's infinite book of secrecy?" And did he not read that little well? May we all read our little in that book as modestly and as reverently as did Joseph Henry.

## THE PHOTOPHONE.

BY ALEXANDER GRAHAM BELL.

In bringing before you some discoveries made by Mr. Sumner Tainter and myself, which have resulted in the construction of apparatus for the production and reproduction of sound by means of light, it is necessary to explain the state of knowledge which formed the starting point of our experiments. I shall first describe the remarkable substance selenium, and the manipulations devised by various experiments: but the final result of our researches has evidenced the class of substances sensitive to light-vibrations, until we can propound the fact of such sensitiveness being a general property of all matter. We have found this property in gold, silver, platinum, iron, steel, brass, copper, zinc, lead, antimony, German silver, Jenkin's metal, Babbitt's metal, ivory, celluloid, gutta percha, hard rubber, soft vulcanized rubber, paper, parchment, wood, mica and silvered glass; and the only substances from which we have not obtained results are carbon and thin microscopic glass. We find that when a vibratory beam of light falls upon these substances they emit sounds,—the pitch of which depends upon the frequency of the vibratory change in the light. We find farther that, when we control the form or character of the light-vibration on selenium, and probably on the other substances, we control the quality of the sound and obtain all varieties of articulate speech. We can thus, without a conducting wire as in electric telephony, speak from station to station, wherever we can project a beam of light. We have not had opportunity of testing the limit to which this photophonic influence can be extended, but we have spoken to and from points 273 meters apart; and there seems no reason to doubt that the results will be obtained at whatever distance a beam of light can be flashed from one observatory to another. The necessary privacy of our experiments hitherto has alone prevented any attempts at determining the extreme distance at which this new method of vocal communication will be available. I shall now speak of selenium.

In the year 1817 Berzelius and Gottlieb Gahn made an examination of the method of preparing sulphuric acid in use at Gripsholm. During the course of this examination they observed in the acid a sediment of a partly reddish, partly clear brown color, which, under the action of the blow-pipe gave out a peculiar odor, like that attributed by Klaproth to tellurium. As tellurium was a substance of extreme rarity, Berzelius attempted its production from this deposit; but he was unable, after many experiments, to obtain further indications of its presence. He found plentiful signs of sulphur mixed with mercury, copper, zinc, iron, arsenic and lead, but no trace of tellurium. It was not in the nature of Berzelius to be disheartened by this result. In science every failure advances the boundary of knowledge as well as every success, and Berzelius felt that, if the characteristic odor that had been observed did not proceed from tellurium, it might possibly indicate the presence of some substance then unknown to the chemist. Urged on by this hope he returned with renewed ardor to his work. He collected a great quantity of the material, and submitted the whole mass to various chemical processes. He succeeded in separating successively the sulphur, the mercury, the copper, the tin and the other known substances whose presence had been indicated by his tests:—and after all these had been eliminated, therestill remained

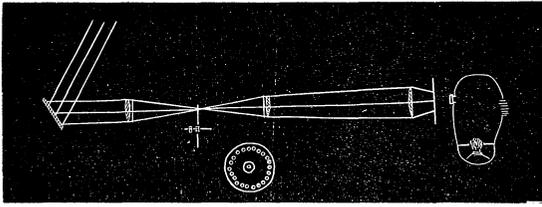


FIG. 1.

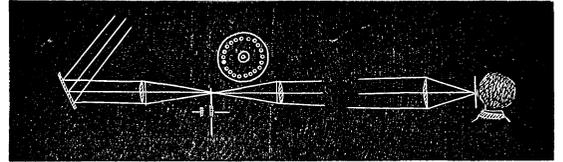


FIG. 6.

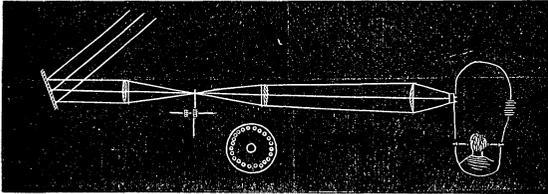


FIG. 2.

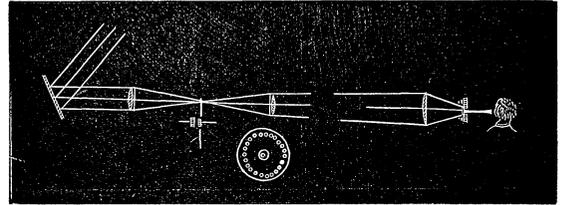


FIG. 7.

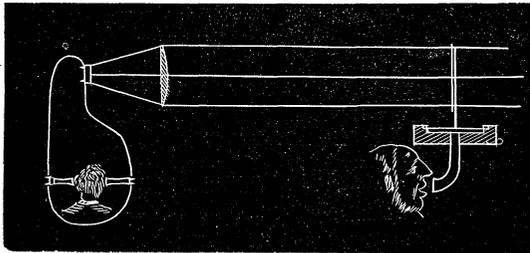


FIG. 3.

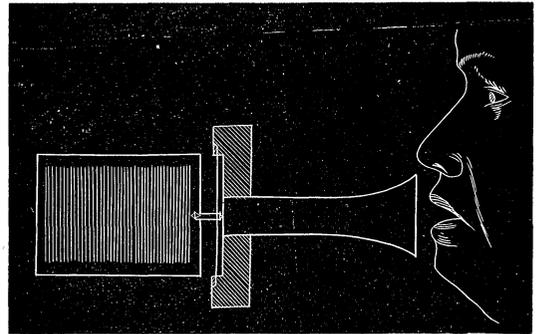


FIG. 8.

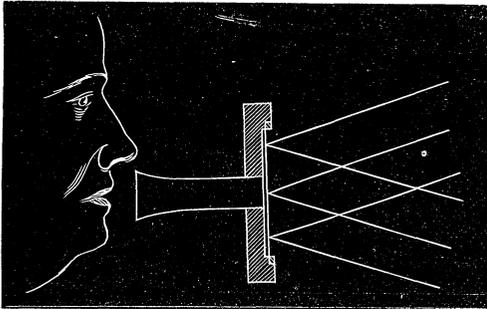


FIG. 4.

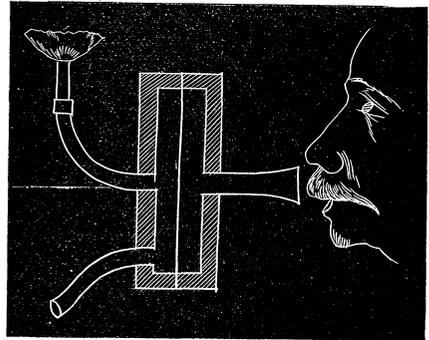


FIG. 9.

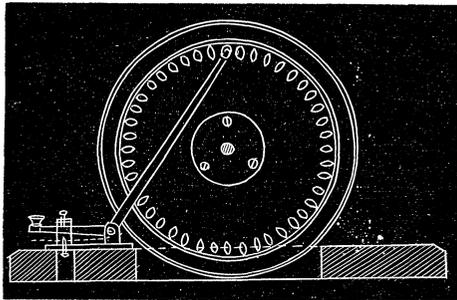


FIG. 5.

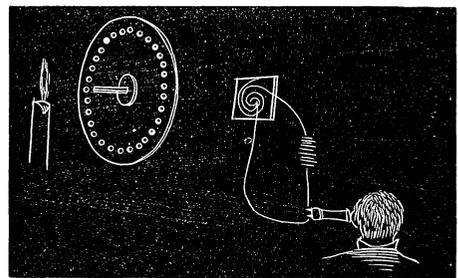


FIG. 10.

ILLUSTRATING PAPER ON PHOTOPHONE.

By ALEXANDER GRAHAM BELL.

1—The Interposition of Hard Rubber Plate. 2—The Light passed through openings in rapidly revolving diaphragm and reflected in selenious recesses. 3—Application of figure four. 4—Action of Voice on thin Plate of Silvered Mica. 5—Application of Morse system of Telegraphy to Photophone. 6—Listening directly to Receiving Plate. 7—Another form of Receiver. 8—One of the first forms, Voice passed through Slits. 9—Direct Action of Voice on Gas Flame. Action of Candle Light on selenius received.

a residue which proved upon examination to be what he had been in search of—a new elementary substance. The chemical properties of this new element were found to resemble those of tellurium in so remarkable a degree that Berzelius gave to the substance the name of "Selenium," from the Greek word *selene*, the moon—"tellurium," as is well known being derived from *tellus*, the earth. Although tellurium and selenium are alike in many respects, they differ in their electrical properties; tellurium being a good conductor of electricity, and selenium, as Berzelius showed, a non-conductor. Knox discovered, in 1837, that selenium became a conductor when fused; and Hittorff, in 1852, showed that it conducted, at ordinary temperatures, when in one of its allotropic forms. When selenium is rapidly cooled from a fused condition, it is a non-conductor. In this, its vitreous form, it is of a dark-brown color, almost black by reflected light, having an exceedingly brilliant surface. In thin films it is transparent, and appears of a beautiful ruby red by transmitted light. When selenium is cooled from a fused condition with extreme slowness, it presents an entirely different appearance, being a dull lead color, and having throughout a granulated or crystalline structure, and looking like a metal. In this form it is perfectly opaque to light, even in very thin films. This variety of selenium has long been known as "granular" or "crystalline" selenium, or, as Regnault called it, "metallic" selenium. It was selenium of this kind that Hittorff found to be a conductor of electricity at ordinary temperatures. He also found that its resistance to the passage of an electrical current diminished continuously by heating up to the point of fusion, and that the resistance suddenly increased in passing from the solid to the liquid condition. It was early discovered that exposure to sunlight hastens the change of selenium from one allotropic form to another; and this observation is significant in the light of recent discoveries.

Although selenium has been known for the last sixty years it has not yet been utilized to any extent in the arts, and it is still considered simply as a chemical curiosity. It is usually supplied in the form of cylindrical bars. These bars are sometimes found to be in the metallic condition; but more usually they are in the vitreous or non-conducting form. It occurred to Willoughby Smith that, on account of the high resistance of crystalline selenium, it might be usefully employed at the shore-end of a submarine cable, in his system of testing and signalling during the process of submersion. Upon experiment, the selenium was found to have all the resistance required—some of the bars employed measuring as much as 1400 megohms—a resistance equivalent to that which would be offered by a telegraph wire long enough to reach from the earth to the sun! But the resistance was found to be extremely variable. Experiments were made to ascertain the cause of this variability. Mr. May, Mr. Willoughby Smith's assistant, discovered that the resistance was less when the selenium was exposed to light than when it was in the dark.

In order to be certain that temperature had nothing to do with the effect, selenium was placed in a vessel of water, so that the light had to pass through from one to two inches of water in order to reach the selenium. The approach of a lighted candle was found to be sufficient to cause a marked deflection of the needle of the galvanometer connected with the selenium, and the lighting of a piece of magnesium wire caused the selenium to measure less than half the resistance it did the moment before.

These results were naturally at first received by scientific men with some incredulity, but they were verified by Sale, Draper, Moss and others. When selenium is exposed to the action of the solar spectrum, the maximum effect is produced, according to Sale, just outside the red end of the spectrum, in a point nearly co-incident with the maximum of the heat rays; but, according to Adams, the maximum effect is produced in the greenish-yellow or most luminous part of the spectrum. Lord Rosse exposed selenium to the action of non-luminous radiations from hot bodies, but could produce no effect; whereas a thermopile under similar circumstances gave abundant indications of a current. He also cut off the heat-rays from luminous bodies by the interposition of liquid solutions, such as alum, between the selenium and the source of light, without affecting the power of the light to reduce the resistance of the selenium; whereas the interposition of these same substances almost completely neutralize the effect upon the thermopile. Adams found that selenium was sensitive to the cold light of the moon, and Werner Siemens discovered that, in certain extremely sensitive varieties of selenium, heat and light produced opposite effects. In Siemens's experiments, special arrangements were made for the purpose of reducing the resistance of the selenium employed. Two fine platinum wires were coiled together in the shape of a double flat spiral in the zig-zag shape, and were laid upon a plate of mica so that the discs did not touch one another. A drop of melted selenium was then placed upon the platinum-wire arrangement, and a second sheet of mica was pressed upon the selenium, so as to cause it to spread out and fill the spaces between the wires. Each cell was about the size of a silver dime. The selenium cells were then placed in a paraffine bath, and exposed for some hours to a temperature of 210° C., after which they were allowed to cool with extreme slowness. The results obtained with these cells were very extraordinary; in some cases the resistance of the cells, when exposed to light, was only one-fifteenth of their resistance in the dark.

Without dwelling farther upon the researches of others, I may say

that the chief information concerning the effect of light upon the conductivity of selenium will be found under the names of Willoughby Smith, Lieutenant Sale, Draper and Moss, Professor W. G. Adams, Lord Rosse, Day, Sabini, Dr. Werner Siemens and Dr. C. W. Siemens. All observations by these various authors had been made by means of galvanometers; but it occurred to me that the telephone, from its extreme sensitiveness to electrical influences, might be substituted with advantage. Upon consideration of the subject, however, I saw that the experiments could not be conducted in the ordinary way for the following reason: The law of audibility of the telephone is precisely analogous to the law of electric induction. No effect is produced during the passage of a continuous and steady current. It is only at the moment of change from a stronger to a weaker state, or vice versa, that any audible effect is produced, and the amount of effect is exactly proportional to the amount of variation in the current. It was, therefore, evident that the telephone could only respond to the effect produced in selenium at the moment of change from light to darkness, or vice versa; and that it would be advisable to intermit the light with great rapidity, so as to produce a succession of changes in the conductivity of the selenium, corresponding in frequency to musical vibrations within the limits of the sense of hearing. For I had often noticed that currents of electricity, so feeble as to produce scarcely any audible effects from a telephone when the circuit was simply opened or closed, caused very perceptible musical sounds when the circuit was rapidly interrupted, and that the higher the pitch of sound the more audible was the effect. I was much struck by the idea of producing sound by the action of light in this way. Upon farther consideration it appeared to me that all the audible effects obtained from varieties of electricity could also be produced by variations of light acting upon selenium. I saw that the effect could be produced at the extreme distance at which selenium would respond to the action of a luminous body, but that this distance could be indefinitely increased by the use of a parallel beam of light, so that we could telephone from one place to another without the necessity of a conducting wire between the transmitter and receiver. It was evidently necessary, in order to reduce this idea to practice, to devise an apparatus to be operated by the voice of a speaker, by which variations could be produced in a parallel beam of light, corresponding to the variations in the air produced by the voice.

I proposed to pass light through a large number of small orifices, which might be of any convenient shape, but were preferably in the form of slits. Two similarly perforated plates were to be employed. One was to be fixed and the other attached to the centre of a diaphragm actuated by the voice, so that the vibration of the diaphragm would cause the movable plate to slide to and fro over the surface of the fixed plate, thus alternately enlarging and contracting the free orifices for the passage of light. In this way the voice of a speaker could control the amount of light passed through the perforated plates without completely obstructing its passage. This apparatus was to be placed in the path of a parallel beam of light, and the undulatory beam emerging from the apparatus could be received at some distant place upon a lens, or other apparatus, by means of which it could be condensed upon a sensitive piece of selenium placed in a local circuit with a telephone and galvanic battery. The variations in the light produced by the voice of the speaker should cause corresponding variations in the electrical resistance of the selenium employed: and the telephone in circuit with it should reproduce audibly the tones and articulations of the speaker's voice. I obtained some selenium for the purpose of producing the apparatus shown; but found that its resistance was almost infinitely greater than that of any telephone that had been constructed, and I was unable to obtain any audible effects by the action of light. I believed, however, that the obstacle could be overcome by devising mechanical arrangements for reducing the resistance of the selenium, and by constructing special telephones for the purpose. I felt so much confidence in this that, in a lecture delivered before the Royal Institute of Great Britain, upon the 17th of May, 1878, I announced the possibility of hearing a shadow by interrupting the action of light upon selenium. A few days afterwards my ideas upon this subject received a fresh impetus by the announcement made by Mr. Willoughby Smith before the Society of Telegraph Engineers that he had heard the action of a ray of light falling upon a bar of crystalline selenium, by listening to a telephone in circuit with it.

It is not unlikely that the publicity given to the speaking telephone during the last few years may have suggested to many minds in different parts of the world somewhat similar ideas to my own.

Although the idea of producing and reproducing sound by the action of light, as described above, was an entirely original and independent conception of my own, I recognize the fact that the knowledge necessary for its conception has been disseminated throughout the civilized world, and that the idea may therefore have occurred to many other minds. *The fundamental idea, on which rests the possibility of producing speech by the action of light, is the conception of what may be termed an undulatory beam of light in contradistinction to a merely intermittent one.* By an undulatory beam of light, I mean a beam that shines continuously upon the selenium receiver, but the intensity of which upon that receiver is subject to rapid changes, corresponding to the changes in the vibratory movement of a particle of air during the transmission of

a sound of definite quality through the atmosphere. The curve that would graphically represent the changes of light would be similar in shape to that representing the movement of the air. I do not know whether this conception had been clearly realized by "J. F. W.," of Kew, or by Mr. Sargent, of Philadelphia; but to Mr. David Brown, of London, is undoubtedly due the honor of having distinctly and independently formulated the conception, and of having devised apparatus—though of a crude nature—for carrying it into execution. It is greatly due to the genius and perseverance of my friend, Mr. Sumner Tainter, of Watertown, Mass., that the problem of producing and reproducing sound by the agency of light has at last been successfully solved.

The first point to which we devoted our attention was the reduction of the resistance of crystalline selenium within manageable limits. The resistance of selenium cells employed by former experimenters was measured in millions of ohms, and we do not know of any record of a selenium cell measuring less than 250,000 ohms in the dark. *We have succeeded in producing sensitive selenium cells measuring only 300 ohms in the dark, and 155 ohms in the light.* All former experimenters seemed to have used platinum for the conducting part of their selenium cells, excepting Werner Siemens, who found that iron and copper might be employed. We have also discovered that brass, although chemically acted upon by selenium, forms an excellent and convenient material; indeed, we are inclined to believe that the chemical action between the brass and selenium has contributed to the low resistance of our cells by forming an intimate bond of union between the selenium and brass. We have observed that melted selenium behaves to the other substances as water to a greasy surface, and we are inclined to think that when selenium is used in connection with metals not chemically acted upon by it, the points of contact between selenium and the metal offer a considerable amount of resistance to the passage of a galvanic current. By using brass we have been enabled to construct a large number of selenium cells of different forms. The mode of applying the selenium is as follows: The cell is heated, and, when hot enough, a stick of selenium is rubbed over the surface. In order to acquire conductivity and sensitiveness, the selenium must next undergo a process of annealing.

We simply heat the selenium over a gas stove and observe its appearance. When the selenium attains a certain temperature, the beautiful reflecting surface becomes dimmed. A cloudiness gradually extends over it, somewhat like the film of moisture produced by breathing upon a mirror. This appearance gradually increases, and the whole surface is soon seen to be in the metallic, granular or crystalline condition. The cell may then be taken off the stove, and cooled in any suitable way. When the heating process is carried too far, the crystalline selenium is seen to melt. Our best results have been obtained by heating the selenium until it crystallizes, and continuing the heating until signs of melting appear, when the gas is immediately put out. The portions that had melted instantly re-crystallize, and the selenium is found upon cooling to be a conductor, and to be sensitive to light. The whole operation occupies only a few minutes. This method has not only the advantage of being expeditious, but it proves that many of the accepted theories on this subject are fallacious. Our new method shows that fusion is unnecessary, that conductivity and sensitiveness can be produced without long heating and slow cooling; and that crystallization takes place during the heating process. We have found that on removing the source of heat immediately on the appearance of the cloudiness, distinct and separate crystals can be observed under the microscope, which appear like leaden snow-flakes on a ground of ruby red. Upon removing the heat, when crystallization is further advanced, we perceive under the microscope masses of these crystals arranged like basaltic columns standing detached from one another, and at a still higher point of heating the distinct columns are no longer traceable, but the whole mass resembles metallic pudding-stone, with here and there a separate snow-flake, like a fossil, on the surface. Selenium crystals formed during slow cooling after fusion present an entirely different appearance, showing distinct facets.

We have devised about fifty forms of apparatus for varying a beam of light in the manner required, but only a few typical varieties need be shown. The source of light may be controlled, or a steady beam may be modified at any point in its path. The beam may be controlled in many ways. For instance, it may be polarized, and then affected by electrical or magnetic influences in the manner discovered by Faraday and Dr. Ker. The beam of polarized light, instead of being passed through a liquid, may be reflected from the polished pole of an electro-magnet. Another method of affecting a beam of light is to pass it through a lens of variable focus. I observe that a lens of this kind has been invented in France by Dr. Cusco, and is fully described in a recent paper in "La Nature;" but Mr. Tainter and I have used such a lens in our experiments for months past. The best and simplest form of apparatus for producing the effect remains to be described. This consists of a plain mirror of flexible material—such as silvered mica or microscopic glass. Against the back of this mirror the speaker's voice is directed. The light reflected from this mirror is thus thrown into vibration corresponding to those of the diaphragm itself.

In arranging the apparatus for the purpose of reproducing sound at a distance, any powerful source of light may be used, but we

have experimented chiefly with sunlight. For this purpose a large beam is concentrated by means of a lens upon the diaphragm mirror, and, after reflection, is again rendered parallel by means of another lens. The beam is received at a distant station upon a parabolic reflector, in the focus of which is placed a sensitive selenium cell, connected in a local circuit with a battery and telephone. A large number of trials of this apparatus have been made with the transmitting and receiving instruments so far apart that sounds could not be heard directly through the air. In illustration, I shall describe one of the most recent of these experiments. Mr. Tainter operated the transmitting instrument, which was placed on the top of the Franklin schoolhouse in Washington, and the sensitive receiver was arranged in one of the windows of my laboratory, 1325 L street, at a distance of 213 metres. Upon placing the telephone to my ear I heard distinctly from the illuminated receiver the words: "Mr. Bell, if you hear what I say, come to the window and wave your hat." In laboratory experiments the transmitting and receiving instruments are necessarily within earshot of one another, and we have therefore been accustomed to pooling the electric circuit connected with the selenium receiver, so as to place the telephones in another room. By such experiments we have found that articulate speech can be reproduced by the oxy-hydrogen light, and even by the light of a kerosene lamp. The loudest effects obtained from light are produced by rapidly interrupting the beam by the perforated disk. The great advantage of this form of apparatus for experimental work is the noiselessness of its rotation, admitting the close approach of the receiver without interfering with the audibility of the effect heard from the latter; for it will be understood that musical tones are emitted from the receiver when no sound is made at the transmitter. A silent motion thus produces a sound. In this way musical tones have been heard even from the light of a candle. When distant effects are sought another apparatus is used. By placing an opaque screen near the rotating disk the beam can be entirely cut off by a slight motion of the hand, and musical signals, like the dots and dashes of the Morse telegraph code, can thus be produced at the distant receiving station.

We have made experiments, with the object of ascertaining the nature of the rays that affect selenium. For this purpose we have placed in the path of an intermittent beam various absorbing substances. Professor Cross has been kind enough to give me his assistance in conducting these experiments. When a solution of alum, or bisulphide of carbon, is employed the loudness of the sound produced by the intermittent beam is very slightly diminished; but a solution of iodine in bisulphide of carbon cuts off most, but not all, of the audible effect. Even an apparently opaque sheet of hard rubber does not entirely do this. When the sheet of hard rubber was held near the disk interrupter the rotation of the disk interrupted what was then an invisible beam, which passed over a space of about twelve feet before it reached the lens which finally concentrated it upon the selenium cell. A faint but perfectly perceptible musical tone was heard from the telephone connected with the selenium. This could be interrupted at will by placing the hand in the path of the invisible beam. It would be premature, without further experiments, to speculate too much concerning the nature of these invisible rays; but it is difficult to believe that they can be bent rays, as the effect is produced through two sheets of hard rubber containing between them a saturated solution of alum. Although effects are produced as above shown by forms of radiant energy which are invisible, we have named the apparatus for the production and reproduction of sound in this way "*The Photophone*," because an ordinary beam of light contains the rays which are operative.

It is a well-known fact that the molecular disturbance produced in a mass of iron by the magnetizing influence of an intermittent electrical current can be observed as sound by placing the ear in close contact with the iron. It occurred to us that the molecular disturbance produced in crystalline selenium by the action of an intermittent beam of light should be audible in a similar manner without the aid of a telephone or battery. Many experiments were made to verify this theory without definite results. The anomalous behavior of the hard rubber screen suggested the thought of listening to it also. This experiment was tried with extraordinary success. I held the sheet in close contact with my ear, while a beam of intermittent light was focussed upon it by a lens. A distinct musical note was immediately heard. We found the effect intensified by arranging the sheet of hard rubber as a diaphragm, and listening through a hearing-tube. We then tried crystalline selenium in the form of a thin disk, and obtained a similar but less intense effect. The other substances which I enumerated at the beginning of my address were now successively tried in the form of thin disks, and sounds were obtained from all but carbon and thin glass. We found hard rubber to produce a louder sound than any other substance we tried, excepting antimony, and paper and mica to produce the weakest sound. *On the whole, we feel warranted in announcing as our conclusion that sounds can be produced by the action of a variable light from substances of all kinds, when in the form of thin diaphragms.* We have heard from interrupted sunlight very perceptible musical tunes through tubes of ordinary vulcanized rubber, of brass and of wood. These were all the materials at hand in tubular form, and we have had no opportunity since of extending the observations to other substances.

I am extremely glad that I have the opportunity of making the first publication of these researches before a scientific society, for it is from scientific men that my work of the last six years has received its earliest and kindest recognition. I gratefully remember the encouragement which I received from the late Professor Henry at a time when the speaking telephone existed only in theory. Indeed, it is greatly due to the stimulus of his appreciation that the telephone became an accomplished fact. I cannot state too highly also the advantage I received in preliminary experiments on sound vibrations in this building from Professor Cross, and near here from my valued friend Dr. Clarence J. Blake. When the public were incredulous of the possibility of electrical speech, the American Academy of Arts and Sciences, the Philosophical Society of Washington and the Essex Institute of Salem recognized the reality of the results and honored me by their congratulations. The public interest, I think, was first awakened by the judgment of the very eminent scientific men before whom the telephone was exhibited in Philadelphia; and by the address of Sir William Thomson before the British Association for the Advancement of Science.

At a later period, when even practical telegraphers considered the telephone as a mere scientific toy, Professor John Pierce, Professor Eli W. Blake, Dr. Channing, Mr. Clarke and Mr. Jones, of Providence, R. I., devoted themselves to a series of experiments for the purpose of assisting me in making the telephone of practical utility; and they communicated to me, from time to time, the result of their experiments with a kindness and generosity I can never forget. It is not only pleasant to remember these things and to speak of them, but it is a duty to repeat them, as they give a practical reputation to the often repeated stories of the blindness of scientific men to unaccredited novelties, and of their jealousy of unknown inventors who dare to enter the charmed circle of science. I trust that the scientific favor which was so readily accorded to the telephone may be extended by you to this new claimant—the telephone.

#### PLAN OF THE CEREBRO-SPINAL NERVOUS SYSTEM.

BY S. V. CLEVENGER, M. D.

(Abstract from the paper (B 41) read before the American Association for Advancement of Science, Boston, August 28th, 1880).

The great French and German cerebral anatomists Luys and Meynert had endeavored to declare the architecture of the human brain from a multitude of microscopic sections, but so intricate were the relationship of fibres, nerve-cells, arteries, veins, connective tissue, etc., that it was at once seen to be necessary to study lower animal life anatomically and physiologically before the plan could be determined. Luys did nothing in this direction, while Meynert went as far as the brains of small mammals. Spitzka has carried the scrutiny still farther. The scheme of Meynert started with the upper part of the cerebrum as the seat of consciousness and, working downward, his "projection systems" ended in the periphery.

The nerve fibres composing the cerebrum and cerebellum were mainly considered. The presence of a multitude of nerve-cells and ganglia dispersed throughout this region was unaccounted for, and as these were of undoubted importance and all well known to anatomists, it was seen by pathologists that these schemes were insufficient.

No scheme can be correct which ignores any part of the nervous organization, or excludes any form of life as anomalous. The conclusion I have reached, is that the sympathetic system of vertebrata corresponds to the general nervous distribution of invertebrata above protozoa, presiding over the nutritive functions. The vaso-motor has been differentiated from the sympathetic distribution, whose office is to produce the vermicular motions of the intestines. Differentiation proceeds dorsally because that portion of the animal which is in most constant contact with the changing molecular motion of the environment would be precisely the portion to give origin to the higher series of nerve divisions. The endoderm, after the gastrula, stage re-

mains under control of the sympathetic system. The so-called cerebral ganglia of Vermes, are homologous with the spinal segments which afterwards become coalesced in the vertebrata. This is the second system to be developed and *Amphioxus* has not acquired the third or cerebral system proper. In *Trigla Adriatica*, the third system series may be seen developed dorsally upon the second or spinal cord. This third system is the intervertebral ganglia. *Fusion of several of the higher intervertebral ganglia produces the cerebellum*, and accounts for the co-ordinating function of that organ. The several cerebral lobes, the tubercula quadrigemina, mammillary eminence, Gasserian ganglion, olfactory lobe, olivary body, etc., are hypertrophied or atrophied (as the case may be) intervertebral ganglia. Projection systems and commissures, as the callosal, make their appearance in exact accordance with laws operative in the lower series.

The three systems develop gradually, and it may be said, commissurally one upon the other, and this scheme appears to account satisfactorily for physiological and pathological phenomena.

In addition to its publication in the proceedings of the Association, the paper will be produced in full, in the *American Journal of Nervous and Mental Disease*, for October, 1880.

#### ANCIENT AGRICULTURAL IMPLEMENTS OF STONE.

BY HON. WILLIAM McADAMS, OF OTTERVILLE, ILLS.

In the rich, alluvial soil about the mouths of the Missouri and Illinois rivers are found many of these ancient stone implements used by the Mound-builders in their rude agriculture. Mr. McAdams exhibited a fine collection of these implements.

They are all chipped from flint, or a hard silicious limestone, and some of them beautifully made. Some are nearly a foot in length and six inches wide at the broader end.

Some are made to be fastened to handles, like our modern spades. Others resemble our modern hoes, having a deep, lateral notch, to facilitate the fastening to a handle. Some of these stone hoes are made with such ingenuity as to have been effective implements.

Mr. McAdams also exhibited stone implements which evidently were made to fasten to some kind of stock to be pulled through the ground like a plow. As these ancient people had no domestic animals for this purpose, it is probable that manual force was used to perform the work. The broad cutting edge of these stone implements was highly polished from long use by the attrition of the soil.

Mr. McAdams had found these implements of agriculture in the ancient graves associated with pottery, some of which contained carbonized corn. Cobs in a carbonized state were found, and the speaker is of the opinion that these ancient people lived principally on corn and vegetables, which they cultivated to a considerable extent.

The paper elicited much interest in the association.

A very interesting report addressed to the committee of public health in France by M. Wurz, describes a process for retaining the green coloring of vegetables which is generally destroyed by boiling. It consists in the use of an excess of chlorophyll obtained from spinach (*spinacia oleracea*) which holds in its cells a large amount of coloring matter. A watery solution of this rendered alkaline by soda, is added to the boiling vegetable which is slightly acidulated with hydrochloric acid. The chemical result is common salt and a deposit of coloring matter on the organic tissue. There cannot now be any possible temptation for the unwarrantable dyeing of preserved vegetables by salts of copper or the employment of adulterants for obtaining that vivid coloring so attractive to the epicure.