*With the Author's Compliments.*

# UPON THE ELECTRICAL EXPERIMENTS TO DETERMINE THE LOCATION OF THE BULLET IN THE BODY OF THE LATE PRESIDENT GARFIELD;

AND UPON

# A SUCCESSFUL FORM OF INDUCTION BALANCE FOR THE PAINLESS DETECTION OF METALLIC MASSES IN THE HUMAN BODY.

BY ALEXANDER GRAHAM BELL, PH. D.

(A paper read before the American Association for the Advancement of Science, at the Montreal meeting, August, 1882.)

WITH AN APPENDIX.



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# A SUCCESSFUL FORM OF INDUCTION BALANCE FOR THE PAINLESS DETECTION OF METALLIC MASSES IN THE HUMAN BODY.[1]

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The subject of my present paper recalls a time of intense excitement and painful suspense. The long, weary struggle with the untimely death-wound—the prolonged suffering borne so bravely and well by the lamented President Garfield—must still be fresh in every recollection. The whole world watched by his bed-side, and hopes and fears filled every passing hour. No one could venture to predict the end so long as the position of the bullet remained unknown. The bullet might become safely encysted, but, on the other hand, recovery might depend upon its extraction. The search with knife and probe among vital and sensitive tissues could not be otherwise than painful and dangerous; and the thought naturally arose that science should be able to discover some less barbarous method of exploration.

Among other ideas[2] the thought occurred that the bullet might produce some sensible effect in modifying the field of

[1] A preliminary notice relating to this paper was published in the *Comptes Rendus* of the French Academy of Sciences, Oct. 24th, 1881.

[2] See Appendix, note 1.

induction of a coil brought near the body of the President, and that the locality of the bullet might thus be determined without danger to the patient and without pain; for it is well known that induction can be powerfully exerted through the human body without producing any sensation whatever.

*Upon the balancing of Induction.*

The influence that is exercised upon induction by metallic masses has formed the subject of numerous experiments by different investigators; and the principle of balancing the effects of induction on one portion of a circuit by equal and opposite effects produced upon another portion has been utilized in nearly all such investigations.

The earliest form of induction balance for this purpose appears to have been devised in Germany by Prof. Dove,[1] about the year 1841, and a good description of it in the English language may be found in De la Rive's "Treatise on Electricity," (1853 edition, vol. I, pp. 418–433)[2].

Another and superior arrangement for the same purpose is the well-known induction balance of Prof. D. E. Hughes[3].

The Static Induction Balance of J. E. H. Gordon[4] though primarily intended for experiments upon specific inductive capacity, might also, perhaps, be employed in the same class of investigations.

My own attention was directed to the balancing of induction a number of years ago by the disturbing noises produced in the telephone by the operation of telegraphic instruments upon lines running near the telephone conductor.

The difficulty was remedied by using two conductors instead of one, and by so arranging them with reference to the disturbing wires that the currents induced in one of the telephone conductors were exactly equal and opposite to those induced in

[1] Pogg. Ann. vol. liv, pp. 305–335.

[2] A similar apparatus was independently devised in America a number of years ago by Prof. Rowland, of Johns Hopkins University. It is to be regretted that his discovery of the fact that he had been anticipated by Dove prevented Prof. Rowland from completing and publishing his researches.

[3] Phil. Mag., July, 1879, vol. ii, p. 50.

[4] Phil. Trans. for 1879, p. 417,

the other. In this way an induction balance was produced and a quiet circuit secured for telephonic purposes. This method was patented in England in November, 1877, and during the whole winter of 1877–8 I was engaged in London upon experiments relating to the subject.

In the course of these researches I made frequent use of flat spirals of insulated wire, like those employed by the late Prof. Henry[1] in his experiments upon induction.

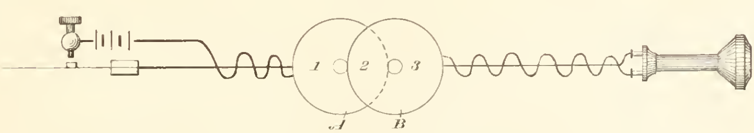
My method was to pass a rapidly interrupted voltaic current through one flat spiral while I examined its field of induction by means of another flat spiral connected with a telephone. The currents induced in the latter coil produced a musical tone from the telephone.

At every point in the field of induction it was found that by turning the plane of the exploring coil a position of silence could be obtained, and another of maximum sound, the two positions making a right angle with one another.

It was also noticed that when a position of silence was established a piece of metal brought within the field of induction caused the telephone to sound. This effect was most marked when the two flat spirals were in close proximity, and were arranged with their planes parallel, as shown in Fig. 1.

When a silver coin, such as a half-crown or florin, was passed across the face of the two coils, the silence of the telephone was broken three times. The instrument emitted a musical tone when the metallic disk passed the points marked 1, 2, and

*Fig. 1.*




3 in the illustration, but the loudest effect was produced when the coin crossed the area marked "2," where the two coils overlapped.

After my return to America I embodied these and other results in a paper "*Upon New Methods of Exploring the Field*

[1] Silliman's Journal, xxviii, 329; xxxviii, 209; xli, 117.

*of Induction of Flat Spirals*," which was read before this association at the Saratoga meeting in August, 1879.

### *Practical Application.*

While brooding over the problem of the detection of the bullet in the body of President Garfield, these experiments made in England returned vividly to my mind. It seemed to me that if the overlapping area "2" of the two coils shown in Fig. 1 could be brought over the seat of the bullet without disturbing the relative positions of the coils, the telephone would probably announce the presence of the bullet by an audible sound.

A crude experiment was at once made to test the idea. A large, single-pole electro-magnet (the core of which was composed of a bundle of fine iron wires) was used in place of coil A (Fig. 1;) and a small coil of fine wire taken from a hand telephone was arranged a little to one side of the pole to represent coil B. The small coil being connected with a telephone, a battery current was passed through the coil of the electro-magnet, and the battery circuit was made and broken by an assistant.

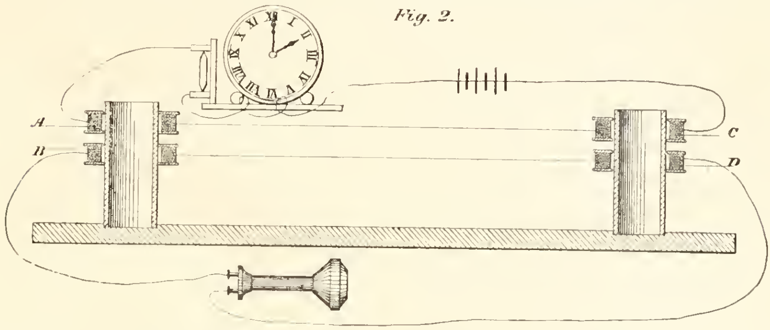
Under these circumstances a much better balance was obtained than could possibly have been anticipated. Upon now bringing a leaden bullet near the small coil, a distinct ticking sound could be heard from the telephone each time the battery circuit was made and broken.

Being absent from my laboratory, and without facilities for proper experiment, I communicated my ideas to Mr. Charles Williams, Jr., of Boston, manufacturer of electrical and telephonic apparatus, who kindly placed the resources of his large establishment at my service; and, at great personal inconvenience, delegated his best workmen to attend to my experiments.

Upon attempting to devise an appropriate form of apparatus for the special purpose in view I saw that there were great practical difficulties in the way of utilizing the arrangement shown in Fig 1, and it occurred to me that the apparatus of Prof. Hughes might perhaps be employed with more advantage as the basis of my experiments. In the ordinary form of

Hughes' induction balance four coils are used, as shown in Fig. 2. Through the agency of a Hughes microphone the ticking of a clock is made to create an electrical disturbance in the voltaic

*Fig. 2.*




circuit containing the two primary coils ( A C) and a corresponding disturbance is produced by induction in the two secondary coils (B D) connected with the telephone. If the connections are so arranged that the currents induced in the telephone circuit by the coils A C are in the same direction, the ticking of the clock is heard very plainly, but if they are in opposite directions no sound is perceived.

In the latter case the action of one primary coil (A) opposes that of the other, (C,) and an electrical balance results. If now a piece of metal is brought near one pair of coils (say A B) the balance is disturbed and the ticking of the clock is audible at the telephone. The arrangement of the coils (A, B, C, D) was the point to be studied, the microphone attachment being of no importance in the combination ; for it is well known that a rheotome to break the primary circuit completely at intervals can be substituted for the microphone with advantage.

It seemed to me that two of the coils (A B) in the Hughes induction balance might be attached rigidly to a wooden handle, so as to be moved over the seat of the bullet without changing their relative positions, and that all the adjustments necessary might be made on the other pair of coils, which need not be moved from their place, and would not therefore be liable to disarrangement. If a single pair of coils were to be used as in Fig. 1, they must be adjustable one upon the other. But if during the course of exploration the coil B (Fig. 1) should be moved from its proper position even to the extent only of a small fraction of a millimetre, the balance would be disturbed and the exploration might have to be stopped in order to adjust the apparatus. These considerations led me to the conclusion that some modification of the Hughes induction balance was most suitable for my purpose, and I immediately commenced the construction of such an apparatus.

### *Suggestions Tested.*

Just at this time I learned from the newspapers that Prof. Simon Newcomb, of Washington, had the idea of using a magnetic needle to indicate by retardation of its rotation the proximity of the bullet in the body of the President, and I telegraphed to Prof. Newcomb the offer of my assistance in carrying on experiments, knowing the comparative difficulty he would experience in having apparatus made in Washington.

At his suggestion I tested the point whether the rotation of a leaden disk and of a leaden bullet underneath a delicately suspended magnetic needle would cause a deflection of the needle. The disk occasioned a deflection, but the bullet produced no sensible effect. I telegraphed the result to Prof. Newcomb, and at the same time took occasion to inform him of the hopeful results I had obtained with the crudely constructed induction balance referred to above.

I was much gratified by his immediate appreciation of the experiment. He telegraphed that he thought an induction balance promised a much more hopeful solution of the problem than his own method, and encouraged me in every way to continue my experiments.

This appreciation determined me to proceed to my laboratory at Washington, where I was accompanied by Mr. Sumner Tainter, who was anxious to assist in such a cause. I learned from Prof. Newcomb that Mr. Geo. M. Hopkins, of Brooklyn, had independently suggested the use of Hughes' induction balance, and had made experiments in Brooklyn, the results of which were published in the New York Tribune on the 11th of July, 1881.[1] Mr. J. Stanley Brown (private secretary of

[1] See Appendix, note 2.

President Garfield) kindly handed to me the letters he had received from Mr. Hopkins,[1] and also a Hughes induction balance like that shown in Fig. 2, which Mr. Hopkins had forwarded to the Executive Mansion for trial.

This apparatus was at once tested in my laboratory, with results slightly better than those I had obtained in Boston.

My Boston apparatus did not give a greater hearing distance than 3 cm., whereas with the Hopkins apparatus I could distinguish effects at a distance of 3.75 cm.

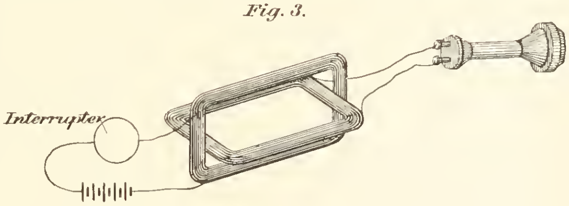
Two of Mr. Hopkins' coils (A B, Fig. 2) were then fastened upon a wooden handle to form an exploring instrument, and the whole apparatus was arranged for immediate use in case of any necessity arising for an experiment upon the President. I set myself in communication with Mr. Hopkins, and requested his assistance and co-operation, and in reply received through Private Secretary Brown the following account of further experiments:

"60 Irving Place, Brooklyn, *July* 16, 1881.

"Mr. J. Stanley Brown:

"Dear Sir: I have made two new instruments on plans differ-"ing from that sent, but they yield no better results. The first "consisted of "two oblong "coils ar-"ranged at "right angles "to each oth-"er, thus:

*Fig. 3.*



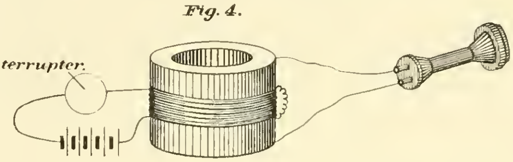

"The outer coil being of coarse wire (No. 18) placed in the "primary circuit, the inner coil being of very fine wire (No. "36) and connected with a telephone. The parallel currents "traversing the wires neutralized each other, and no audible "effects are perceived in the telephone, but on presenting a "metallic body to the instrument upon a line bisecting the "angle between the coils the clicking in the telephone is heard.

"This instrument possesses only one advantage over that "sent, and that is that it requires no adjustment.

[1] See Appendix, notes 3 and 4.

"The other instrument consists of two large coils of very "fine wire (No. 36) placed upon opposite sides of a coil of "coarse wire, (No. 16,) the fine coil being connected so that "the induced currents neutralize each other, thus:

*Fig. 4.*




"I am sorry to be obliged to say of this as of the other, that "it is no more sensitive than the one sent. To produce the "best effects from the instrument which you have it will be "necessary to use all the battery power possible without burn-"ing the coils, and two receiving telephones of the best con-"struction must be used.

"As I stated in the first instance, if the ball is more than "two inches deep, I think it cannot be located by this means.

"If larger coils were used the instrument might be operative "at a greater distance, but the area indicated as containing the "ball would be so large that the result would be indefinite and "without value.

"Hoping that Prof. Bell will be able to succeed, I remain,

"Yours very truly,

"GEO. M. HOPKINS."

Prof. Hughes of London, England, Prof. Trowbridge of Harvard College, Prof. Rowland of Johns Hopkins University, and other authorities were consulted by telegraph as to the best theoretical form of induction balance for the purpose required, while empirical experiments were being carried on under my direction in my laboratory at Washington by Mr. Sumner Tainter; in the electrical work-shop of Davis and Watts, in Baltimore, by Mr. J. H. C. Watts, and in the establishment of Mr. Chas. Williams, Jr., in Boston, by Mr. Thomas A. Gleason. To test the influence of size of coil an instrument was constructed in which the coils were no larger than the bullet for which we sought, (as had been suggested by Prof. Newcomb,)[1] and experiments were also made with the enormous coils used by the late Prof. Henry in his researches upon induction, which

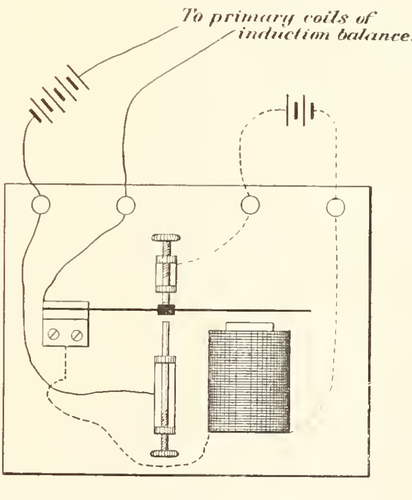
[1] See Appendix, note 5.

were kindly lent to me for the purpose by the Smithsonian Institution, but neither the small nor the large coils produced more satisfactory results than those we had already obtained.

To test battery power, 20 enormous Bunsen elements, which had formerly been used to light the gas at the Capitol, were placed at my disposal by Mr. Rogers, electrician of the Capitol, but while great electro-motive force was evidently of use we derived no advantage from such a battery as this.

To test the influence of speed of interruption, Mr. Marean, Supt. of the Western Union Telegraph Co. in Washington, kindly lent us an electric motor, by means of which we were able, with the aid of a rotating commutator, to obtain interruptions of the primary circuit of all rates up to 600 interruptions per second,[1] and we found that the more rapid the rate of interruption the more distinct was the sound in the telephone. The hearing distance, however, was not proportionately increased. The automatic interrupter, (shown in Fig. 5,) yielding about 100 interruptions per second, gave as good results as any, and was much more convenient. This interrupter was therefore afterwards used exclusively in our experiments.

*Fig. 5.*




The theoretical form of coil suggested by Prof. John Trowbridge[2] was substantially the same as that proposed by Prof. Rowland,[3] and is shown in Fig. 6.

The arrangement was quite sensitive to metal placed in the

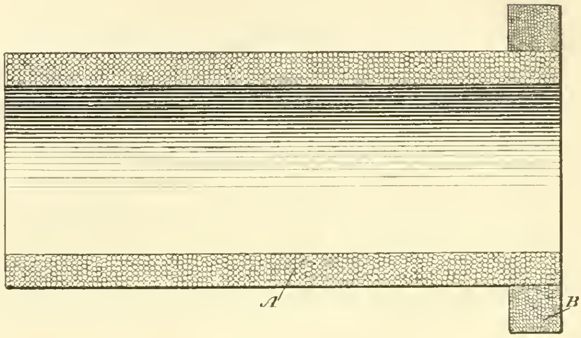
[1] Mr. Sumner Tainter has since made an apparatus operating in a similar manner by means of which he has obtained as many as 4,000 interruptions of the circuit per second.

[2] See Appendix, note 6.

[3] See Appendix, note 7.

interior of the coil, but the hearing distance for a bullet external to the coils was no greater than before.[1]

*Fig. 6.*




Prof. Hughes[2] proposed to have two flat superposed coils wound on a single reel, so that the two coils should form a single one as regards their relative distance ; and Mr. F. T. Bickford, Washington correspondent of the New York Tribune, suggested winding two wires side by side into a single coil, so that the relative distances of the wires from the bullet should be absolutely the same. Mr. Chas. E. Buell[3] and Dr. Chichester A. Bell[4] proposed to determine the depth of the bullet beneath the surface by causing a similar bullet to approach the balancing coils until silence was restored ; the secondary bullet it was presumed would then be at the same distance from the balancing coils as the embedded bullet from the exploring coils.

The results of all the experiments so far made were unsatisfactory. I had tried every thing that had been suggested, but 4 cm. remained the extreme limit of audibility for a bullet like that which had struck the President. Even when such a bullet was flattened by being fired against a board, and was presented with its flat side towards the coils of the explorer—the most favorable mode of presentation—no better result was obtained.

[1] The balance obtained was not quite perfect, and we have since discovered that the insulation of the wires of one of the secondary coils was defective.

[2] See Appendix, note 8.

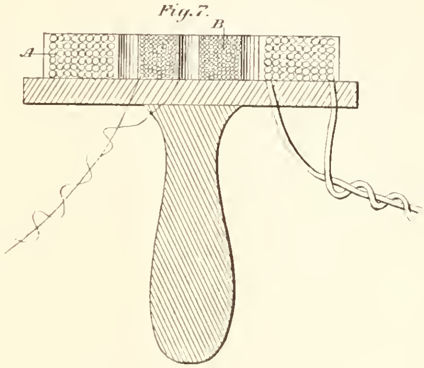
[3] See Appendix, note 9.

[4] See Appendix, note 10.

*Original Experiments.*

In the theoretical arrangement recommended by Profs. Trowbridge and Rowland (Fig. 6) the primary coil A was of smaller diameter than the secondary B. This had given us no better effects than the ordinary form of Hughes' balance, (see Fig. 2,) in which the two coils A B were of equal diameter. We then tried the effect of making the primary coil A of greater diameter than the secondary B, (see Fig. 7,) and in this case we appeared to obtain an increase of hearing distance. Five centimetres (2 inches) was, however, the utmost limit reached, when, on the 19th of July, Mr. J. Stanley Brown and Dr. Woodward visited my laboratory and witnessed some experiments. No difficulty was experienced in detecting a bullet held in the mouth by passing the exploring coil over the cheek; and the presence of a flattened bullet held in the clenched hand was also readily determined. Dr. Bliss, Dr. Reyburn, and Surgeon-General Barnes visited the laboratory next day and expressed themselves as very hopefully impressed by the experiments. These were subsequently repeated in the surgeon's room at the Executive Mansion for the information of Dr. Frank Hamilton and Dr. Agnew, who also seemed favorably impressed.

Fig. 7.




Such opinions from the surgeons in attendance upon the President, and the continued interest shown by Prof. Newcomb, encouraged me to proceed with the experiments.[1]

It was now determined to test the effect of each convolution of the primary coil, so as to arrive empirically at some idea of

[1] I desire specially to express my gratitude to Dr. Frank Hamilton for words of encouragement spoken at a later date when sympathy and encouragement were greatly needed.

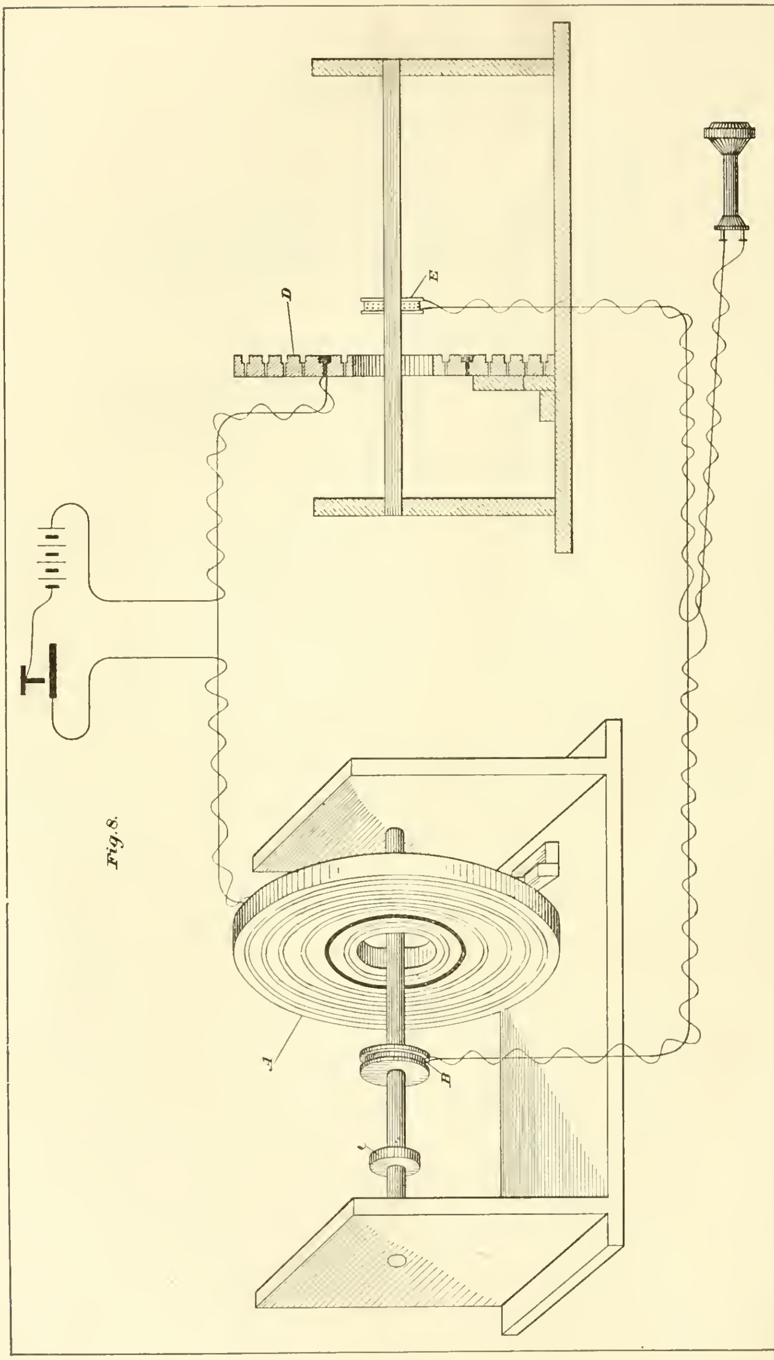


Fig. 8.

the best shape of coil. For this purpose Mr. Tainter constructed the instruments shown in Fig. 8. Circular grooves were turned in two boards, one of which is shown in perspective at A and the other in section at D. An insulated copper wire could be pressed into any of these grooves so as to give the wire an exactly circular shape of known diameter, and the two ends were passed through an orifice in the back of the board, making connection with a similar ring of wire in the other instrument as shown. A small secondary coil (B) of fine wire, which could be moved with moderate friction upon the horizontal rod, was connected to another similar coil, (E,) and to a telephone; and a small brass ring, (C,) which could also be moved along the horizontal rod, was used instead of a bullet to disturb the balance.

In making an experiment with this apparatus the secondary coil (B) was first placed within the primary ring and in the same plane with it, and the balancing coil E was adjusted to produce silence. The brass ring C was then moved along the horizontal rod until the balance was sensibly disturbed and the relative distances of the coils and the brass ring were noted.

Continuing the experiment the coil B was moved a determined distance beyond the plane of A, and the balancing coils again adjusted to silence. The brass ring C was once more caused to disturb the balance, and the new hearing distance was noted. The following are the tabulated results of a series of experiments made on the 19th of July, 1881. The battery employed consisted of six bichromate cells connected in series.

| Diameter of Primary Ring. | Distance Between— | | |
|---|---|---|---|
| | A B | B C | A C |
| *mm.* | *mm.* | *mm.* | *mm.* |
| | 0 | 17 | 17 |
| | 5 | 14 | 19 |
| 30 | 10 | 13 | 23 |
| | 20 | 9 | 29 |
| | 30 | 7 | 37 |
| | 50 | 0 | 50 |
| | 0 | 17 | 17 |
| | 5 | 19 | 24 |
| 50 | 10 | 26 | 36 |
| | 20 | 17 | 37 |
| | 30 | 14 | 44 |
| | 50 | 5 | 55 |
| | 0 | 21 | 21 |
| | 5 | 23 | 28 |
| 81 | 10 | 23 | 33 |
| | 20 | 18 | 38 |
| | 30 | 14 | 44 |
| | 50 | 12 | 62 |
| | 0 | 22 | 22 |
| | 5 | 25 | 30 |
| 113 | 10 | 27 | 37 |
| | 20 | 26 | 46 |
| | 30 | 26 | 56 |
| | 50 | 17 | 67 |

| Diameter of Primary Ring. | Distance Between— | | |
|---|---|---|---|
| | A B | B C | A C |
| *mm.* | *mm.* | *mm* | *mm.* |
| | 0 | 27 | 27 |
| | 5 | 20 | 25 |
| 159 | 10 | 18 | 28 |
| | 20 | 17 | 37 |
| | 30 | 14 | 44 |
| | 50 | 14 | 64 |
| | 0 | 12 | 12 |
| | 5 | 18 | 23 |
| 206 | 10 | 25 | 35 |
| | 20 | 19 | 39 |
| | 30 | 22 | 52 |
| | 50 | 18 | 68 |
| | 0 | 20 | 20 |
| | 5 | 18 | 23 |
| 253 | 10 | 20 | 30 |
| | 20 | 19 | 39 |
| | 30 | 23 | 53 |
| | 50 | 20 | 70 |

These figures show that *the distance from the primary coil* A (Fig. 8) *at which the influence of the brass ring* C *became perceptible increased with the diameter of the primary ring, and that the secondary coil* B *required to be projected considerably beyond the plane of the primary in order to obtain the maximum effect.*

The conclusion seemed a natural one that the degree of projection A B of the secondary coil should proportionally increase with the diameter of the primary ring, but the tabulated figures did not fully justify the inference.

The experiments had necessarily occupied a considerable time, and I thought that the difference between the results that should have been observed, according to the above hypothesis, and those that were actually obtained, might have been due to the gradual exhaustion of the bichromate battery employed and to its polarization, although every care had been taken to preserve its power by removing the carbon and zinc plates from the solution, excepting when an observation was made. To test whether the battery exerted any material influence upon the hearing distance, a further series of experiments was made with the same battery.

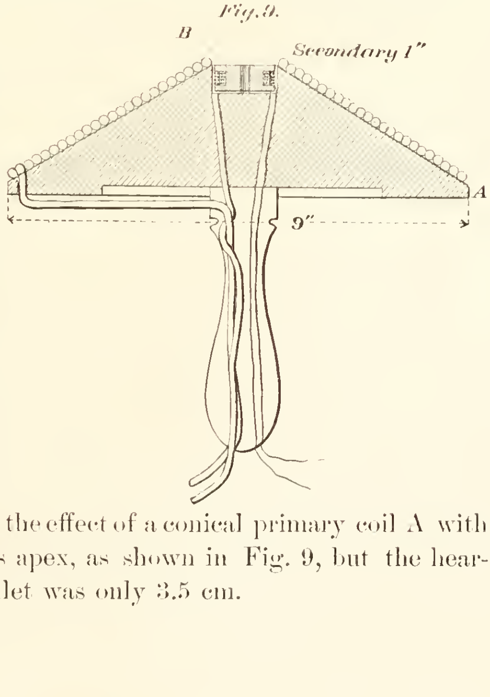
It will be seen by reference to the tabulated statement shown above that the maximum hearing distance B C had been obtained with a primary ring 11.3 cm. in diameter when the distance A B between the primary and secondary coils was one centimetre. This arrangement of the apparatus was therefore adopted throughout the following experiments:

| | | Hearing distance |
|---|---|---|
| 1. Apparatus tried with 1 cell, (bichromate battery)... | (B C, Fig. 8) | = 9 mm. |
| 2. Six cells in series.................. .............. ........... | (B C, Fig. 8) | = 16 mm. |
| 3. Six cells in multiple arc......................................... | (B C, Fig. 8) | = 9 mm. |
| 4. Six cell in two series of 3 each............................. | (B C, Fig. 8) | = 15 mm. |
| 5. Same experiment repeated.................................. | (B C, Fig. 8) | = 13.5 mm. |
| 6. Same experiment repeated by Mr. Tainter........... | (B C, Fig. 8) | = 12.5 mm. |

These experiments proved that battery power *did* exert an influence upon hearing distance, and also that the battery in use was gradually deteriorating.

I concluded, therefore, that if the battery power had remained constant, the hearing distance might not only have been proportional to the diameter of the primary ring, but, in order to attain the maximum effect, the projection of the secondary coil beyond the plane of the primary might also have been found to increase in like proportion.

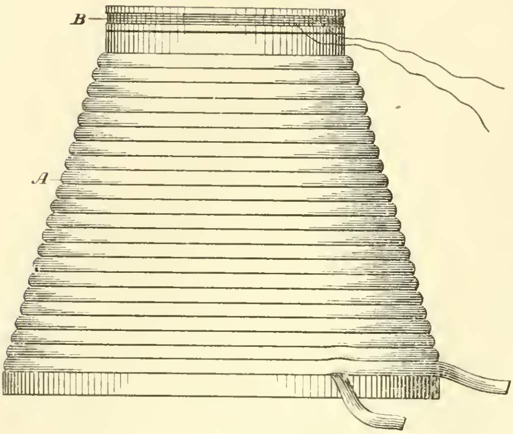
*Fig. 9.*




This led me to try the effect of a conical primary coil A with the secondary B at its apex, as shown in Fig. 9, but the hearing distance for a bullet was only 3.5 cm.

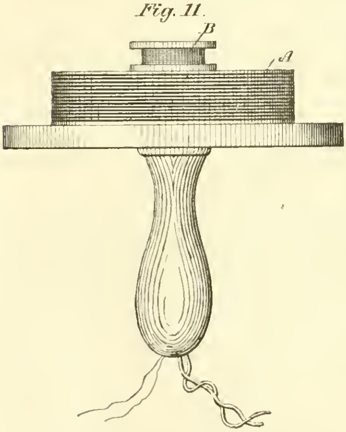
Singularly enough Mr. J. H. C. Watts, in Baltimore, had independently arrived at a very similar form of coil, and with the instrument shown in Fig. 10 he had obtained at one time a hearing distance of 7.5 cm., (or 3 inches,[1]) but from some cause not ascertained he was unable subsequently to reproduce the effect.

*Fig. 10.*




The final form of apparatus adopted as the result of the above experiments is shown in Fig. 11. With this arrangement and a battery of six bichromate elements freshly set up, we were always sure of a hearing distance of at least 5 cm., although after the battery had been in use for some time the hearing distance hardly exceeded 4 cm.

*Fig. 11.*




The following are the dimensions of the coils A B (Fig. 11) and their resistance:

| | | |
|---|---|---|
| Coil A...... | External diameter | 7 cm. |
| | Internal diameter | 4.5 cm. |
| | Depth | 2.4 cm. |
| Wire used, No. 23, (cotton covered.) Resistance, 2 ohms. | | |
| Coil B...... | External diameter | 2.3 cm. |
| | Internal diameter | 8 mm. |
| | Depth | 8 mm. |
| Wire used, No. 36, (silk covered.) Resistance, 75 ohms. | | |

[1] See Appendix, note 11.

The face of the coil B projected beyond the face of coil A 4 mm.

The balancing coils were made as nearly as possible the duplicates of A and B. The resistance of the coil of the telephone employed was 75 ohms.

### *Influence of Battery Power.*

The following experiments were made with this apparatus (Fig. 11) on July 20th, 1881, to test the influence of battery arrangements upon the hearing distance of a leaden bullet.

I. *Series of experiments with a bichromate battery which had previously been in use for a few minutes.*

| | Hearing distance of leaden bullet as observed by— | |
|---|---|---|
| | A. G. Bell. | S. Tainter. |
| | *cm.* | *cm.* |
| 1 cell | 2.4 | 2.6 |
| 2 cells in series | 3.3 | 3.5 |
| 3 cells in series | 3.7 | 4.1 |
| 4 cells in series | 3.7 | 4.0 |
| 5 cells in series | 4.0 | 4.1 |
| 6 cells in series | 4.3 | 4.4 |
| 6 cells in multiple arc | 2.6 | 2.9 |
| 6 cells in two series of 3 each | 3.8 | 3.7 |
| 6 cells in three series of 2 each | 4.3 | 4.0 |

II. *Series of experiments with a Leclanché battery of twenty cells which had been set up for about one month. It had been kept normally upon open circuit, and had only been occasionally used.*

| | Hearing distance. |
|---|---|
| 20 cells in series | 3.3 cm. |
| 20 cells in 10 series of 2 each | 3.6 cm. |
| 20 cells in 5 series of 4 each | 4.1 cm. |
| 20 cells in 2 series of 10 each | 3.0 cm. |

Although the battery appeared to be in good condition, a close inspection showed that the connections were dirty, and that one of the zinc wires was half broken through.

The defective cell was now removed from the circuit, and the connections of all the other cells cleaned and tightened.

III. *The following experiments were then made with the Leclanché cells united in series:*

| No. of cells. | Hearing distance. | No. of cells. | Hearing distance. |
|---|---|---|---|
| | *cm.* | | *cm.* |
| 1 | 2.7 | 11 | 3.8* |
| 2 | 2.8 | 12 | 4.2 |
| 3 | 3.0 | 13 | 4.2 |
| 4 | 3.3 | 14 | 4.2 |
| 5 | 3.3 | 15 | 4.3 |
| 6 | 3.5 | 16 | 4.2 |
| 7 | 3.6 | 17 | 4.2 |
| 8 | 3.8 | 18 | 4.2 |
| 9 | 4.0 | 19 | 4.2 |
| 10 | 3.8* | | |

These results are graphically represented in Fig. 12.

It will be observed that the hearing distance was carried nearly one-third as far again as at first, simply by increasing the number of cells employed without any other change in the arrangement. It will also be noticed that the apparatus requires to be adjusted to complete silence in order to obtain the maximum effect.

As a general result of all our experiments with voltaic batteries, we find that *it is advisable to use a battery possessing great electro-motive force and slight internal resistance, and to connect the cells in series.*

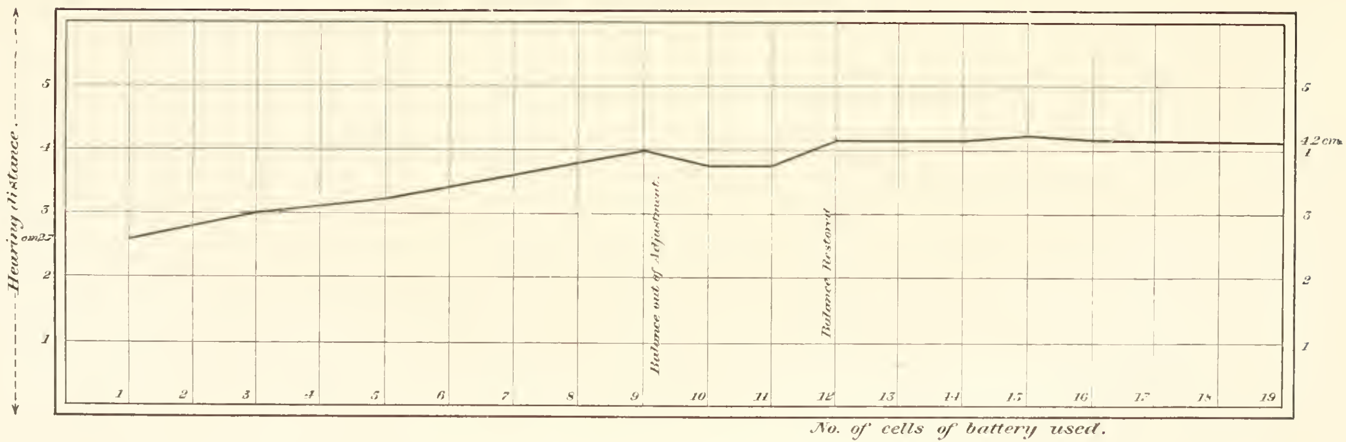
## *Experiments upon Living Subjects.*

On the 22d of July an experiment was made at the request of Dr. Bliss upon the person of Lieut. Simpson, who had carried a bullet in his body for many years.

When the exploring instrument (Fig. 11) was passed over the lieutenant's back a sonorous spot was found, but the indications were too feeble to be implicitly relied upon. Imagination very easily conjures up a feeble sound like that observed,

* Balance not quite perfect.

Fig. 12.


Hearing distance.
5
4
3
cm2.5
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Balance out of Adjustment.
Balance Restored
4.2 cm
No. of cells of battery used.

but a number of experiments by different observers seemed to indicate that in this case there was an external cause for the sound—probably the presence of a very deeply-seated bullet. The results of this experiment were communicated to Dr. Bliss in a letter dated July 23d, 1881.[1]

On the 25th of July Prof. Rowland visited me at Washington, and suggested the use of a condenser in the primary circuit. I had previously discussed this idea with Mr. Tainter, but, not having a condenser at hand, we had been unable to make any experiment. After our conversation with Prof. Rowland, however, we were so impressed by the importance of the point that we obtained a condenser next morning, and found it to produce not only a different quality of sound when the bullet approached the coils, but also to increase the hearing distance of the instrument shown in Fig. 11 at least one centimetre.

On the evening of the same day (July 26th) our apparatus was carried to the Executive Mansion, and an experiment made upon the person of the President.[2]

From some cause then unknown a balance could not be obtained, and the results were therefore uncertain and indefinite. It was discovered afterwards that a mistake had been made in the mode of connecting the condenser. The latter should have been connected at E F, (Fig. 13,) whereas it was placed at E G, thus influencing only one, instead of both, of the primary coils.

With the condenser properly arranged experiments were tried on July 29 and 30 on three soldiers from the Soldiers' Home who had been wounded during the civil war, namely, John Teahan, Asa Head, and John McGill.

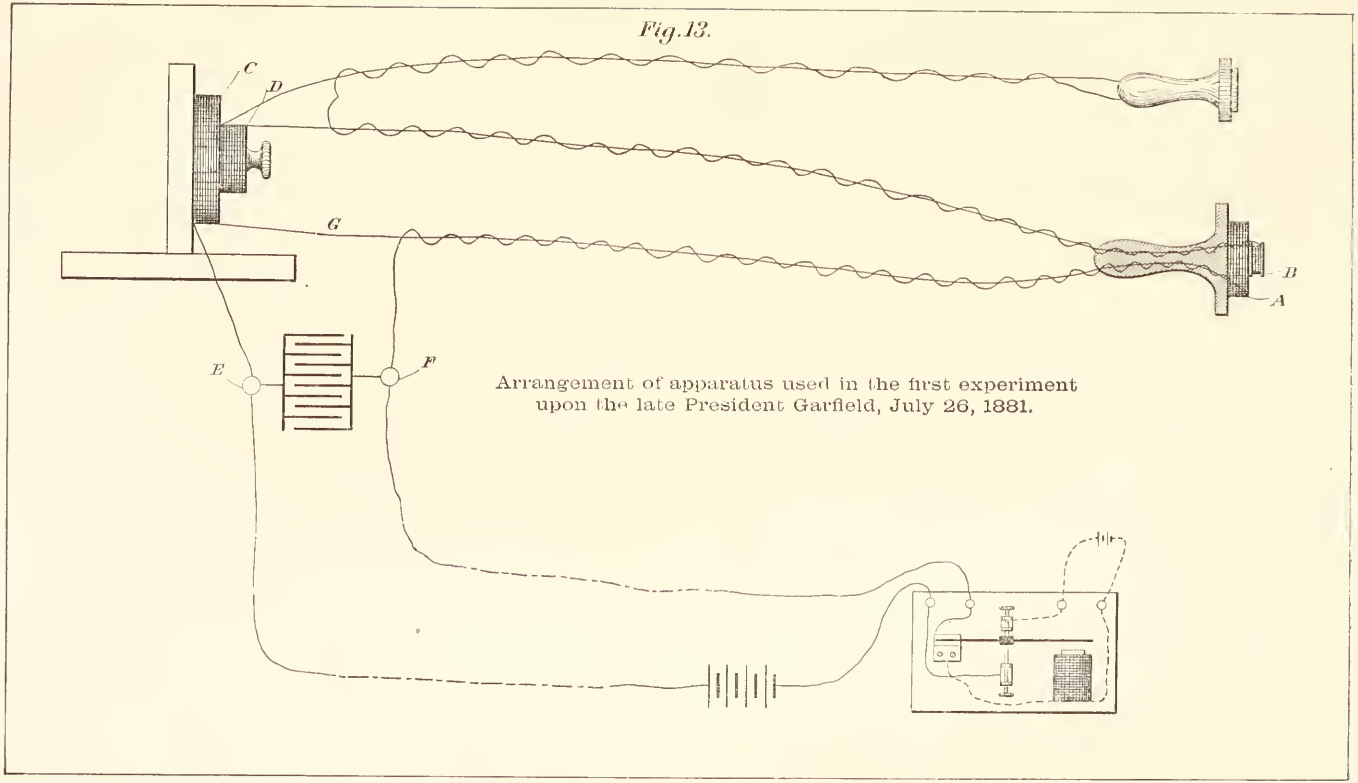
In the case of John Teahan no results were obtained. In the case of Asa Head, who had a buckshot in the cheek, loud and well-marked sounds were heard in the telephone; and in the case of John McGill, who was supposed to carry a bullet in his back, no results were obtained.

Further efforts were then prosecuted for the improvement of the apparatus.

[1] See Appendix, note 12.

[2] See Appendix, note 13.

Fig. 13.



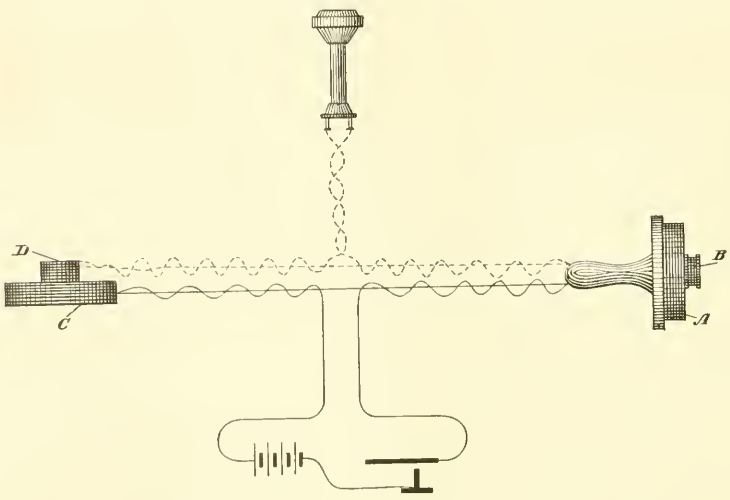

Arrangement of apparatus used in the first experiment upon the late President Garfield, July 26, 1881.

*Further Experiments to Improve Apparatus.*

Our attention had hitherto been directed chiefly to modifications of the exploring instrument. We now investigated the effect, upon the hearing distance, of the coils used to obtain a balance.

The following experiments, made July 29, 1881, bear upon the point:

Fig. 14.




Exp. 1. (See Fig. 14.) Resistance of primary A of exploring instrument, 2 ohms; resistance of primary C of balancing coils, also 2 ohms; resistance of exploring secondary B, 140 ohms; and of balancing secondary D, 120 ohms.

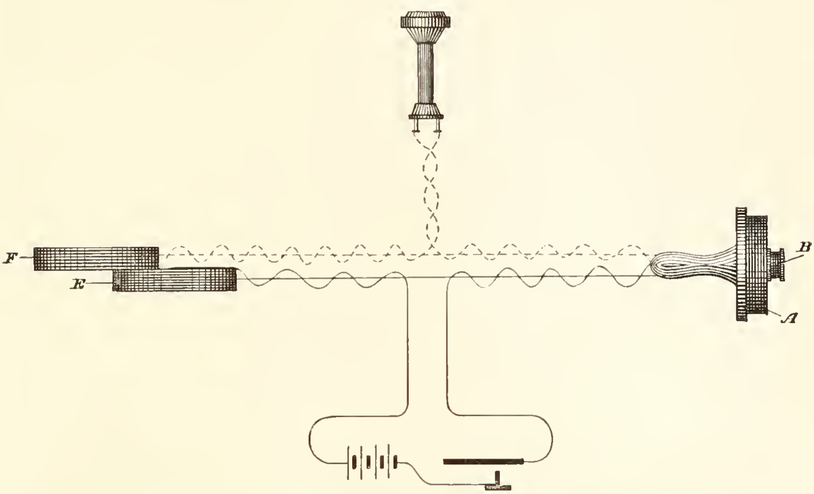
Result: Hearing distance of bullet from explorer A B, 3.5 cm. Hearing distance from balancing coils C D, also 3.5 cm.

Exp. 2. (See Fig. 15.) Same exploring coils as in Exp. 1, but balancing coils consisted of a flat primary, E—resistance, 5.30 ohms; and flat secondary, F—resistance, 83 ohms. The adjustment was made by sliding the secondary coil upon the primary until a position of silence was obtained.

Result: Hearing distance from explorer A B, 1.5 cm. Hearing distance from E F, 3 cm.

As a general result of our experiments we found that *every* *increase in the resistance of the balancing coils (especially the primary) reduced the hearing distance of the exploring instru-*

*Fig. 15.*




*ment*, and it became therefore desirable to do away with this source of resistance as much as possible.

*Return to Original Form of Apparatus.*

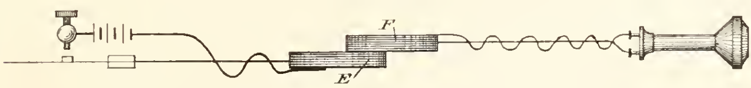
This led us back to the original form of apparatus that had first occurred to me, (see Fig. 1,) in which a single pair of coils was employed. A few other experiments, made July 29, 1881, will show the importance of the point attained.

Exp. 3. The two flat coils E F used in experiment 2 were arranged as in Fig. 16, so as to form a balance by themselves.

Result: Hearing distance, 7 cm.

In all these experiments the battery used consisted of four cells, (Leclanché.)

*Fig. 16.*



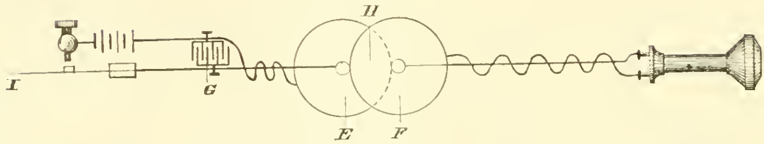

Exp. 4. The same coils used in Exp. 3 were tried again, as shown in Fig. 16, but with a battery of eight cells, (Leclanché.)

Result: Hearing distance, 8.7 cm., or nearly $3\frac{1}{2}$ inches—a result quite unprecedented in our experiments.

The following are the dimensions of the coils E F:

| | | | |
|---|---|---|---|
| Coil E...... | External diameter.................. | 10 | cm. |
| | Internal diameter.................. | 2.5 | cm. |
| | Depth................................ | 1 | cm. |
| | Wire used, No. 23, (silk-covered.) | | |
| Coil F...... | External diameter.................. | 10 | cm. |
| | Internal diameter.................. | 2.5 | cm. |
| | Depth................................ | 1 | cm. |
| | Wire used, No. 28, (silk-covered.) | | |

*Fig. 17.*




Exp. 5. The same coils E F, used in Exps. 2, 3, and 4, were tried once more with a battery of six large bichromate elements, and with a condenser, G, in the primary circuit as shown in Fig. 17.

Result: Hearing distance 13 cm., or more than 5 inches.

This great increase in hearing distance seemed to be chiefly due to the condenser, for upon disconnecting it the hearing distance was little more than 9 cm., but further experiments proved that other causes also contributed to the result.

Exp. 6. When the condenser was in circuit and the leaden bullet close to the coils (arranged as in Fig. 17) the sound produced by the telephone was a musical note whose pitch was the same as that normally produced by the vibration of the reed of the interrupter. Mingled with this tone could be distinguished a number of feebler tones of very much higher pitch. Upon withdrawing the bullet gradually from the coils the fundamental sound became fainter, and one of the high upper-partial tones gradually acquired prominence; and at a distance of about 8 or 9 cm. the fundamental could no longer be distinguished, but the high tone persisted, and was clearly audible up to a distance of 13 cm. The effect was very striking, and when the bullet was moved to and fro parallel to the plane of the coils E F at a distance of about 10 cm., the telephone emitted a shrill whistling sound each time the sensitive area (II) was passed.

It was noticed that other metals, such as iron, brass, and copper, did not seem to reinforce this high tone to any great extent, but brought out the fundamental at every distance where an effect was produced.

Exp. 7. The condenser G (Fig. 17) was removed from the circuit and the leaden bullet held about 4 or 5 cm. from the coils E F. The fundamental tone was heard, and the characteristic upper-partial could also be distinguished, but it was only faintly audible. Upon now suddenly replacing the condenser the high upper-partial tone was instantly reinforced as if by a resonator.

Exp. 8. The rheotome employed to interrupt the primary circuit (which had been placed in a distant room) was found to be vibrating badly. The reed I of the instrument (see also Fig. 5) was rattling against its contact pieces, thus producing an impure sound, and I could distinguish amongst the upper-partials the tone that had been reinforced by the condenser. Upon screwing up the contact pieces so as to improve the vibration I could no longer distinguish the particular upper-partial referred to, and upon returning to the room in which the coils E F (Fig. 17) were placed I could no longer detect the effects noted above in Exps. 6 and 7, and the hearing distance did not exceed 9 cm.

*The peculiar effects obtained with the arrangement shown in Fig.* 17 *thus seemed to depend* (1) *upon a particular kind of vibration of the reed of the interrupter, producing a certain high upper-partial or overtone,* (2) *upon the use of a condenser acting as a sort of electrical resonator for this tone, and* (3) *upon the use of the metal lead.*

Mr. Marean, of Washington, kindly lent me a number of condensers used by the Western Union Telegraph Co., and we found, upon connecting them with the coils E F, as shown in Fig. 17, and, holding a leaden bullet near the coils, that each condenser reinforced a high upper-partial of different pitch. We arranged the condensers so that they could be successively introduced into the circuit with great rapidity. The effect was very curious, and sounded somewhat like a Scotch air played upon the bag-pipes. The low hum of the fundamental could be heard continuously, like the drone of the bag-pipe, while the higher tone changed its pitch with each change of condenser.

*The pitch of the high tone reinforced seemed to depend upon the electro-static capacity of the condenser employed*, but the exact relation between the two has not been ascertained. In experiments 5, 6, 7, 8, and the subsequent experiments described above, the battery employed consisted of six pairs of carbon and zinc plates of large area placed in a solution of bichromate of potash containing sulphuric acid.

The effects noted above were not produced satisfactorily when the battery was much run down, nor were they obtained with a Leclanché battery which had been set up for some time, but which appeared to be in good condition.

*It is evidently necessary in order to produce this characteristic high tone to use a battery possessing considerable electromotive force and slight internal resistance.*

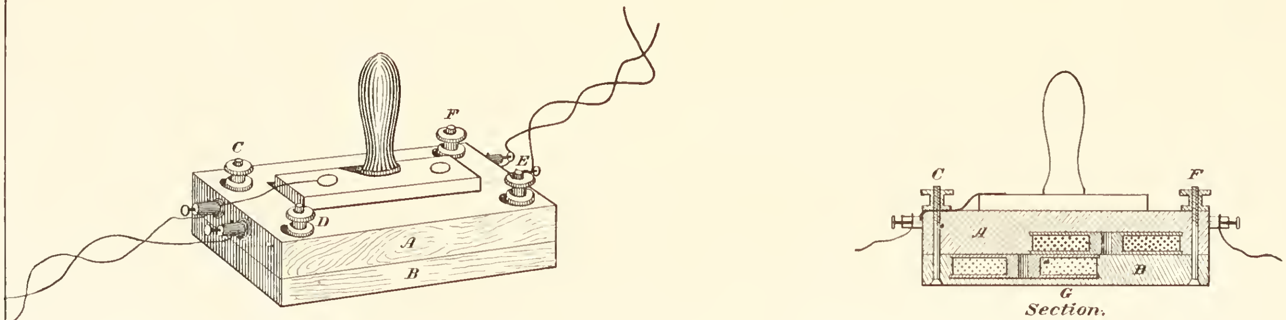
Our experiments had reached this stage when, on Saturday, the 30th of July, 1881, I was requested to make another trial upon the person of the President at the evening dressing of the wound.

At this time, however, we had no exploring instruments completed excepting one or two like that shown in Fig. 11; for it will be understood that the promising results noted above had been obtained from coils that were simply placed upon a table and adjusted by hand.

We immediately proceeded to the Executive Mansion with the apparatus shown in Fig. 13, prepared to make a trial, if it was deemed advisable; but upon learning of the results of our later experiments the surgeons resolved to postpone any further trial until we could arrange the coils (Fig. 17) in a portable form.

By forced exertions the coils were arranged that same night in a wooden case, as shown in Fig. 18. This case consisted essentially of two oblong blocks A B. A shallow circular recess

Fig. 18




Apparatus used in the second experiment upon
the late President Garfield, August 1st, 1881.

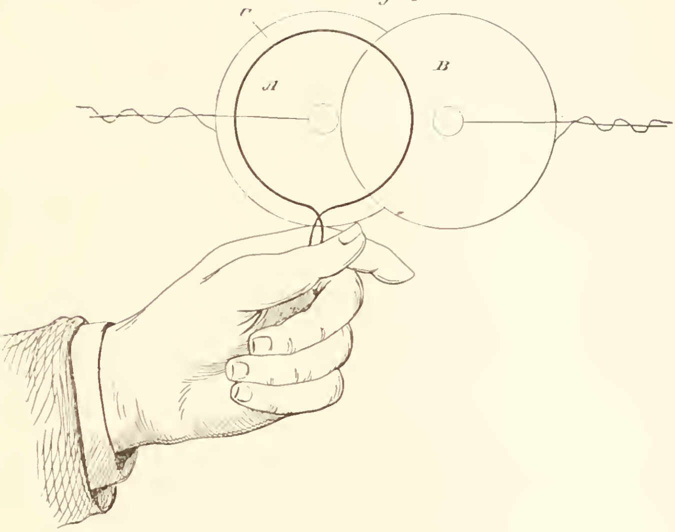
was turned out in each block for the reception of one of the coils, and the two blocks were held together by four pins of ebonite, C, D, E, F, which passed up through slots in the upper block and were secured by ebonite thumb-screws.

When the instrument was completed I found to my great distress that a balance could not be obtained by any adjustment of the apparatus. There was a position of minimum sound, and the telephone responded to a bullet presented to the central part G of the instrument; but the hearing distance did not exceed 3 or 4 cm., whereas we had obtained with the same coils before the construction of the wooden case a perfect balance and a hearing distance of 13 cm.

After numerous unsuccessful experiments had been made to ascertain the cause of the difficulty it occurred to me that if two adjoining convolutions in one of the coils, made contact at any point, a circuit of low resistance would be formed, (a single ring of wire, in fact,) in which the induced currents might circulate without reaching the telephone connected with the apparatus. I had previously measured the resistance of the coils without discovering any defect, but when I considered the large number of convolutions in each coil it seemed possible that a defect of this kind might exist which could not be discovered by a Wheatstone Bridge, excepting by very delicate and accurate observations. To test whether a short-circuited convolution would produce effects analagous to those observed, a piece of copper wire was bent into an annular form and the ends connected together. On bringing this metallic ring near a pair of coils, (A, B, Fig. 19,) properly adjusted to silence, the balance was loudly disturbed. The copper ring (C) was held as shown in Fig. 19, and the balance could not then be restored by any adjustment of the coils. A position of minimum sound was all that could be obtained, and the hearing distance was enormously reduced. This was *prima facie* evidence of the nature of the defect.

The coils (Fig. 18) were then removed from their case, but a cursory examination revealed no defect. Upon trial, however, (being arranged, as formerly, in Fig. 17,) a balance could not be obtained, and the hearing distance was only about 4 cm. The defect was thus definitely located in the coils themselves.

*Fig. 19*




Upon close examination it was noticed that the outside convolutions of the primary coil were slightly frayed at one part, but it appeared hardly possible that so great a defect could be due to so apparently slight a cause. However, to test the matter, I removed the outside layer of wires and then tested the coils again.

Result : The defect had vanished—a perfect balance was obtained, and the hearing distance was again 13 cm.[1]

The coils were then replaced in their case and the completed instrument tested. The lower wooden block B (Fig. 18) was

[1] These experiments have revealed the cause of the extreme difficulty always experienced in obtaining a perfect balance with coils of fine wire. I have recently used an Induction Balance to test the condition of the helices that were employed in these researches, and have discovered that in a large percentage of cases the insulation was defective. It is possible that some of the results described in this paper (especially of the earlier experiments) may have been vitiated by errors due to defects in the coils that were not suspected at the time. A defect of insulation that is quite immaterial for ordinary purposes may be absolutely fatal to the success of an Induction Balance. Indeed, so much care is required in this respect that it is extremely difficult to obtain coils that are perfectly suitable for an apparatus intended to search

adjusted by hand as nearly as possible to the position of silence, and then the thumb-screws C, D, E, F were tightened.

The balance now obtained was not quite perfect, but by striking the lower block B a few smart blows with a wooden mallet we were able to reduce the arrangement to complete silence.

The instrument was then in such a sensitive condition that it could scarcely be moved without affecting the balance. Upon gently swaying it backwards and forwards a pulsation of sound was heard at every swing.

When the motion was carefully made, so that it was always in the same plane, no pulsations were observed. They only occurred when the inclination of the coils was changed.

This defect was found to be due to the bulging of the thin portion G of the wooden case (Fig. 18) under the weight of the enclosed coil, and the simple pressure of a finger on this portion of the case disturbed the balance. The movement of the lower coil when the instrument was swayed about must have been inconceivably small, but on account of the extreme sensitiveness of the arrangement it produced a perceptible effect upon the balance.

The pulsating sound did not seem to interfere with the detection of a bullet held in the clenched hand, nor did it seem to affect the hearing distance. I therefore despatched a mes-

out a bullet imbedded in the body. I now make it a rule to test every helix used in Induction Balance experiments by bringing it up to a system of balanced coils like that shown in Fig. 17.

1. If the helix is perfect the balance is not disturbed until the terminals of the coil are connected.

2. If there is a break in any of the convolutions the balance is not disturbed, even when the terminals are connected.

3. If a convolution is short-circuited the balance is disturbed, even though the terminals are not connected, and the sound produced is the fundamental of the rheotome employed to interrupt the primary circuit.

4. If the insulation is defective the balance is disturbed, although the terminals are not connected, and a peculiar spluttering effect is noticed like that produced by a series of sparks.

I propose to apply this method practically as a means of testing the condition of the helices used in the construction of Induction Coils and those employed in the manufacture of telephones.

senger to the Executive Mansion, (Sunday morning, July 31st,) with a note for Dr. Bliss,[1] to let him know that the instrument was in a condition to be used, should any necessity arise for an immediate experiment. At the same time I informed him that the apparatus in its present form was very crudely constructed, and that I hoped to improve it very greatly in the course of a few days. On Sunday afternoon (July 31st) we sent to the Soldiers' Home for John McGill, upon whom we had experimented the previous day without results, (using the apparatus shown in Fig 11.)

Upon trying the new instrument (Fig. 18) we had no difficulty in finding a sonorous spot in his back, at the place where the bullet was always supposed to be.

This result was at once communicated to Dr. Bliss,[2] and in reply we were requested to make the experiment upon the person of the President next morning.

On Monday morning (August 1st, 1881) we accordingly removed our apparatus to the Executive Mansion.

### *The Late President Garfield.*

During the former experiment (July 26) a sudden sonorous effect had been observed upon passing a point near the spot where the surgeons suspected the bullet to be lodged, but I had been unable to verify this by a second observation, although the exploring instrument (A B, Fig. 13) was repeatedly passed over the same place. The sound had been so loud and well marked that I believed at the time it must have been caused by a sudden irregularity in the vibration of the reed of the rheotome used to interrupt the primary circuit, for the arrangement (as explained above, p. 20) was not perfectly balanced, and any irregularity of this kind would, under these circumstances, have affected the telephone. At the same time the coincidence was remarkable that the exploring instrument should have been at that very time so near the suspected seat of the ball, and this led to the thought that perhaps after all the bullet had been the

[1] See Appendix, note 15.

[2] See Appendix, note 14.

cause of the sound. I felt confident that the new instrument (Fig. 18) would at once decide the question, for the extreme hearing distance of the former apparatus (Fig. 13) was only 6 cm.. and the apparatus shown in Fig. 18 was so superior in this respect that if the sound had really been due to the bullet we should obtain with the new instrument distinct and well-marked effects. When the new explorer (Fig. 18) was passed over the suspected spot nothing was heard excepting a slight pulsating sound as the instrument was moved to and fro. This was evidence to me that the former sound had been of accidental origin, whether the bullet was there or not. With the view of eliminating any error of observation caused by the pulsations due simply to the movement of the instrument, I lifted the latter (without changing the inclination of the coils) to a height of about 50 centimetres above the body of the President, and moved it to and fro in as nearly as possible the same way I had done at the lower elevation.

I presumed that if the pulsations heard were due simply to the movement of the instrument, they should occur with equal strength at the two elevations; but if any portion of the sonorous effect was due to the influence of the bullet, the pulsations at the two elevations would be different in intensity. I was struck by the fact that, although the sonorous pulsations were very feeble, they were sensibly louder when the instrument was close to the surface of the body than when it was raised. Continuing the exploration, I found a considerable area over which similar effects were noticed, but upon carrying the instrument towards the back of the President, the difference between the pulsations produced at the two elevations grew less and less, and finally could not be distinguished.

The difference in the loudness of the sound at the two elevations was so slight that it probably would not have been noticed by an ear unaccustomed to listen to feeble effects, and I feared that the general expectation that the bullet would be found in that part of the body might have led me to imagine a difference that did not exist. For the purpose of eliminating as far as possible any personal error, I requested Mr. Sumner Tainter (who was the only other person present whose ear had been sufficiently trained to be reliable in such an emergency) to repeat the experiments and let me know the result. Upon our return to my laboratory we compared notes, and I found that his observations tallied with mine. He declared he could not obtain a distinctly localized effect, but stated that he had observed a reinforcement of the pulsation over an area of at least two inches in the neighborhood of the spot to which his attention had primarily been directed, and that he was convinced that the bullet was within that area.

It appeared reasonably certain that the area of feeble sound was due to some external cause, and was not simply an effect of expectancy. In the absence of any other apparent cause for the phenomenon I was forced to agree in the conclusion that it was due to the presence of the bullet, and I so stated in my report to the surgeons.[1] I was by no means satisfied, however, with the results obtained, for no such effects had been observed before in our experiments with bullets. I tried to reproduce the effects by moving the instrument (Fig. 18) at different distances over a bullet, but in every case where an effect was produced the sound was quite sharply localized. I thought that perhaps the body of the patient might have affected the result, and so experimented upon a bullet buried in a piece of meat, but no difference of effect was noted. This led me to fear that the extensive area of feeble sound might have been due to some extensive area of metal that was unsuspected at the time, and I proceeded to the Executive Mansion next morning (August 2) to ascertain from the surgeons whether they were perfectly sure that all metal had been removed from the neighborhood of the bed. It was then recollected that underneath the horse-hair mattress on which the President lay was another mattress composed of steel wires.

Upon obtaining a duplicate, the mattress was found to consist of a sort of net of woven steel wires, with large meshes. The extent of the sonorous area having been so small, as compared with the area of the bed, it seemed reasonable to conclude that the steel mattress had produced no detrimental effect.[2]

[1] See Appendix, note 16.

[2] The death of President Garfield and the subsequent *post-mortem* examination, however, proved that the bullet was at too great a distance from the surface to have affected our apparatus.

I was unable to continue experiments with the steel mattress, as just at this time I was obliged to leave Washington on account of illness in my family. Although I was unable for a long time afterwards to carry on personally Induction Balance experiments, the investigations were ably continued under my direction by Mr. Thomas Gleason, in the establishment of Mr. Charles Williams, Jr., in Boston.

*Experiments Continued in Boston.*

Mr. Tainter forwarded from Washington drawings of an improved apparatus he had designed to remedy the defects of the instrument shown in Fig. 18, in which the case, adjusting screws, &c., were all to be composed of ebonite.

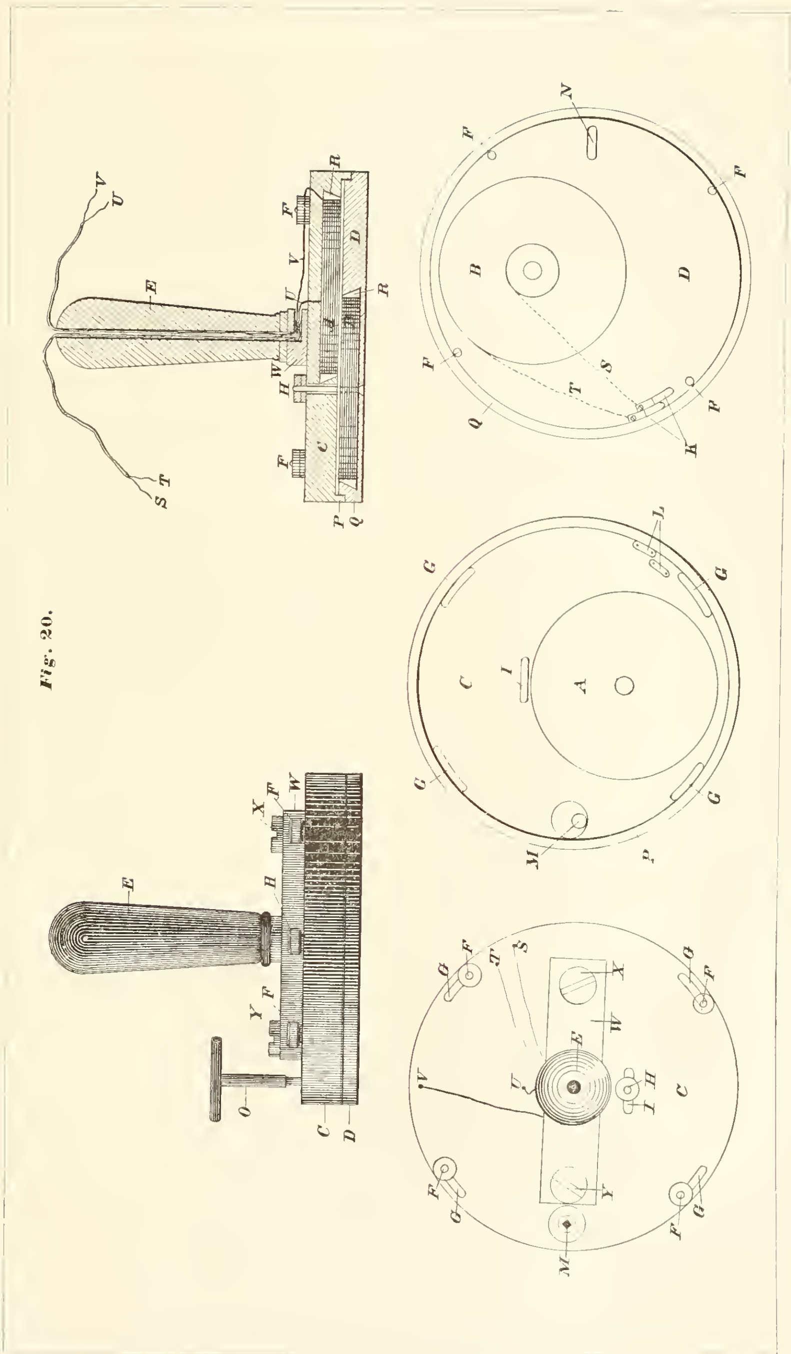
Mr. Gleason constructed for me a number of such ebonite instruments differing slightly from one another in detail, and the apparatus shown in Fig. 20 combined the different points that had been approved.

The two coils A B were eccentrically arranged in two circular disks of ebonite, C D, and the adjustment was obtained by means of an ebonite key O, like the key used for tuning pianos, which turned a cam M pivoted in the upper disk and working in a slot N in the lower disk.

In order to prevent any movement of the coils, excepting that produced by the adjusting-key O, each coil was placed in a recess turned out in its ebonite disk, the edges of which were bevelled as shown at R. Paraffine was then poured in so as to fill up each recess. But this alone did not prevent a slight pulsation of sound when the instrument was swayed from side to side, and a very slight pressure of the finger on the thin portion of the ebonite plate under the coil B was sufficient to destroy the balance.

This was remedied by strengthening this portion by means of a rod of ebonite, which passed up through the centre of the coil and through a slot I, in the upper ebonite plate, and was clamped firmly after the adjustment of the instrument by an ebonite thumb-screw H. This, however, increased the difficulties of adjustment. When the coils were adjusted to silence, then the tightening of the thumb-screw H disturbed

Fig. 20.

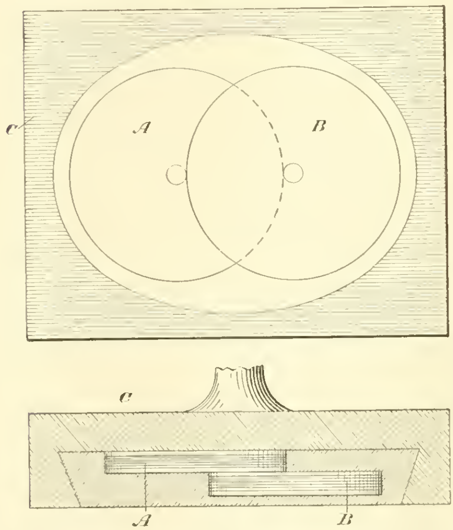


the balance; and if the thumb-screw H was tightened first, then the adjustment could only be made by a series of jerks, on account of friction. In practice we found it best to adjust the instrument *almost to silence*, and then the tightening of the thumb-screw H completed the balance.

This was the form of apparatus at which we had arrived at the time of the death of President Garfield.

The difficulty of adjusting the coils led me ultimately to the idea of the apparatus shown in Figs. 21, 22, 23, 24, which is the most practical form of the instrument yet devised.

*Fig. 21.*



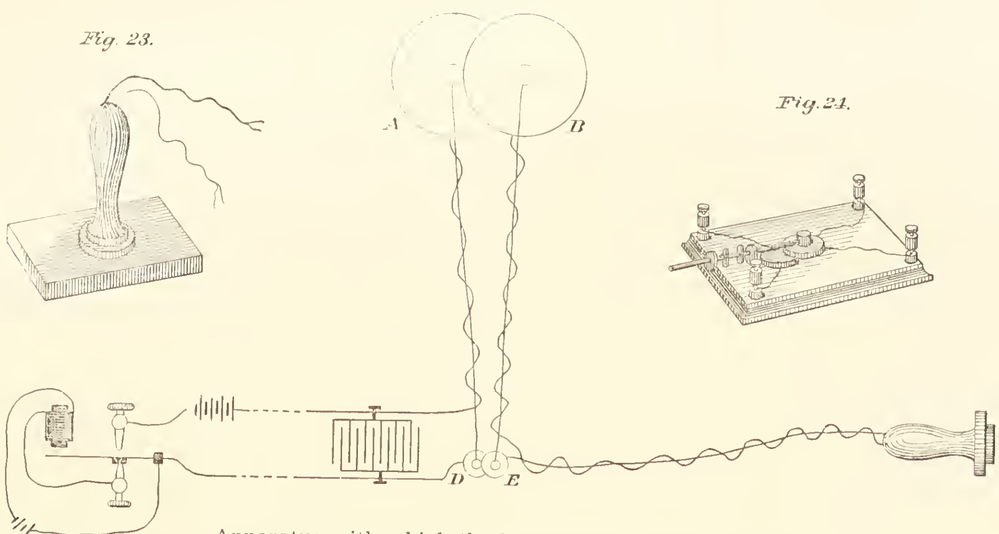

The two exploring coils A B (Fig. 21) are arranged as shown, in a recess turned out in a single block of wood C.

The coils are temporarily connected with a telephone, battery and rheotome in the manner shown in Fig. 1, so that they may be adjusted by hand to form a balance. When they have been arranged in their position of silence the hollow in the block of wood C (Fig. 21) is filled with melted paraffine. Upon cooling, the two coils are found immovably fixed in one solid cake of paraffine.

As a matter of practice it is found impossible to fix the coils in this way exactly in their position of silence; but by means of two other very small coils, D E, (Fig. 22,) of insignificant resistance, forming a sort of fine adjustment external to the explorer, a perfect balance is easily obtained. In this instrument the swaying of the coils A B produces no effect upon the balance.

The completed arrangement is shown in plan in Fig. 22, and the explorer and balancing coils are shown separately in perspective in Figs. 23 and 24.

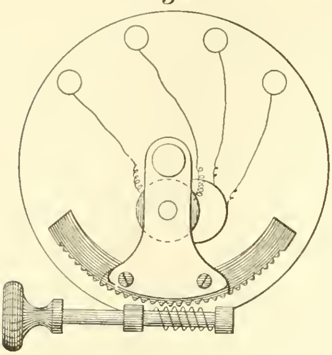
*Fig. 23.* *Fig. 22.* *Fig. 24.*




Apparatus with which the location of the bullet in the
body of Col. Clayton was discovered, Oct. 7th, 1881.

On account of the small size and slight resistance of the balancing coils we were enabled to make the adjustable parts of the balancer of metal without practical interference with the sensitiveness of the exploring instrument, and this gave us the power of making very delicate adjustments of the balancing coils.

*Fig. 25.*

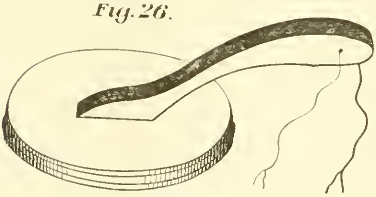


We found it advisable, however, to avoid placing metal over the sensitive area of the coils as had been done in the instrument shown in Fig. 24.

In the balancing apparatus shown in Fig. 25, (which is the most perfect one yet constructed,) the lever to which the upper coil is attached is made of hard rubber.

In Fig. 26 is shown the most convenient form of case yet devised for holding the exploring coils.

*Fig. 26.*



By invitation of Dr. Frank Hamilton experiments were made at his office in New York October 7, 1881, the instruments used being those shown in Figs. 22, 23, 24.

As this was the first successful application of the Induction Balance to the discovery of the situation of a ball in the body the position of which was previously unknown, I may be pardoned for entering somewhat into detail.

I shall quote from the *Medical Gazette*,[1] of New York, an account of the experiments written by one of the witnesses:

" *The First Successful Application.*

" On Friday, Oct. 7, by invitation, several medical gentle-
" men,[2] including the writer, met Prof. Bell at the house of

[1] See *Medical Gazette*, Oct. 15, 1881, pp. 347-349.

[2] " The following are the names of the medical gentlemen who were present,
" each one of whom verified personally the results and declared his entire

" Dr. Frank H. Hamilton, in this city, for the purpose of wit-
" nessing the practical application of his improved instrument.

" The first person subjected to experiment was General " Calvin E. Pratt, judge of the supreme court of the State of " New York, and who is now a resident of Brooklyn. General Pratt, at the battle of Gaines' Mills, June, 1862, this " being the second day of the famous seven days' retreat across " the peninsula, received a ball in his left cheek, which penetrated through the nares and was lodged in the right antrum. " Its presence at this time was recognized by his surgical attendant, Dr. Damainville, and its exact position has been " known from that day until this, it having given rise at times " to much pain and suffering.

" General Pratt has been seen by Dr. Hamilton and Dr. " Damainville occasionally from that time forward, and they " have from time to time urged upon him the necessity of its " removal. General Pratt, however, was anxious to know " whether Prof. Bell's instrument would indicate its presence " at the same point as declared by his surgeons.

" The results of the experiment were conclusive and entirely " satisfactory to General Pratt, the response being heard distinctly, but rather feebly, by every person present in the " room. The feebleness of the response was supposed to be " due to the fact that, owing to its situation and the peculiar " form of the instrument containing the induction coils, it was " impossible to bring the centre of its surface very near the " site of the ball, the ball being situated very near the depression at the ala of the nose."

" The next patient was Col. B. F. Clayton, who received a " wound at the battle of Cedar Mountain, Virginia, Aug. 9, " 1862.

" The missile was supposed to be an Enfield rifle ball, and " the wound was supposed to be mortal by the medical director " of General Banks' staff and his assistants. The ball passed " through the sternal end of the left clavicle, and was supposed " to have lodged in the muscles under the superior angle of the " corresponding scapula. The injury was followed by complete " paralysis of the left arm, continuing for a period of six months; " and his arm has never yet been completely restored to its normal condition. He suffers a great portion of his time from " pains in the arm, shoulder, and portions of the back.

" satisfaction with every experiment that was made: J. C. Hutchinson, J. " G. Johnson, and J. G. Allen, of Brooklyn; Elias Marsh, of Patterson, N. J.; " Nathan Bozeman, J. H. Hunter, G. Durant, F. Delafield, L. Damainville, " W. M. Chamberlain, J. H. Girdner, Frank H. Hamilton, and E. J. Bermingham, of New York."

"Several small fragments of bone escaped through a fistu-
"lous orifice formed near the seat of the original wound.

"About eighteen months later an abscess opened on the front "of the chest below the fifth rib and to the left of the sternum. "Through this sinus his surgeon was able to carry a probe up-"wards and backwards towards the top of the shoulder several "inches, and which sinus was supposed then to communicate "with the seat of the ball on the back.

"Pleural adhesions were recognized by the medical attend-"ants as having occurred in the upper part of the left thoracic "cavity. He has been troubled occasionally ever since the "injury with cough, expectoration, and violent palpitations of "the heart. A suspicion has even been entertained that the "fistulous canal which remained open a period of eighteen "months, and then became permanently closed, communicated "with the bronchial tubes, but at no time was a suspicion en-"tertained by him or his medical attendants that the ball was "not lodged in the back and there closely encysted.

"We are disposed to mention as an evidence of Col. Clay-"ton's loyalty and faithfulness as a soldier that within six "months of the receipt of the injury, and while the wound was "still discharging pus and blood, he returned to active duty "with his regiment and remained in the field until the close of "the war.

"In the presence of the gentlemen assembled Col. Clayton "exposed his chest, and Prof. Bell proceeded to move the coils "across that portion of his back where the ball was supposed "to be situated, the colonel indicating the point underneath "the superior angle of the scapula as that which had been fixed "upon by himself and all the surgeons who had examined him "as its exact seat. Although being buried underneath the "scapula, they had not been able to verify their diagnosis by "the sense of touch. Repeated examinations were made over "this region without any response both by Prof. Bell and sev-"eral of the gentlemen who were present.

"The instrument was then moved in every direction across "the back and shoulders with the same result. There was an "evident feeling of disappointment on the part of Prof. Bell "and all the gentlemen present, for no one entertained a doubt "up to this moment that the situation of the ball was known "and correctly stated by Col. Clayton.

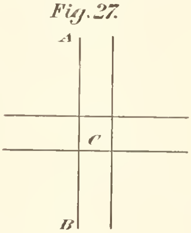
"It was not until the lapse of half an hour, and a thorough "examination on the part of Prof. Bell to determine if there "was not some imperfection in the working of the apparatus, "that it was suggested to move the instrument along the front "of the chest.

"This was done by Prof. Bell, and immediately he exclaimed: "'I have found it!' And such was evidently the fact, as was "verified by the personal examination through the telephone "by every gentleman present. The response when the instru- "ment was moved over the seat of the ball was loud and dis- "tinct, and left no room for doubt."

After all the visitors present had had the opportunity of verifying my discovery of the sonorous spot on the chest of Colonel Clayton, experiments were made to determine as accurately as possible the exact position of the ball.

The exploring instrument (Fig. 23) was first held over that part of the chest where the maximum sound was obtained. The instrument was then moved slowly towards the left until the sound could no longer be perceived. The position of the centre of the instrument was noted, and a vertical line (A B, Fig. 27) was drawn with ink upon the skin through that point. This line indicated the boundary of the sonorous area towards the left. The experiment was then repeated by moving the instrument from the point of maximum sound towards the right, and also upwards and downwards, giving us the four boundary-lines shown in the diagram. (Fig. 27.) The bullet was thus located within a square, C, of about one inch.

*Fig. 27.*



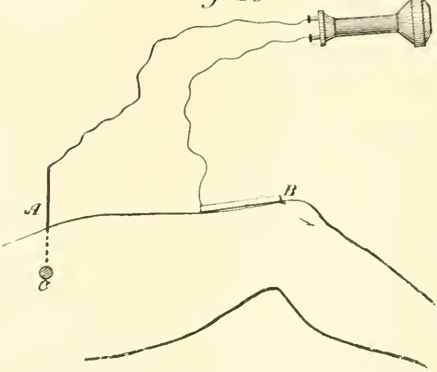

"The exact situation of the ball," as described in the *Medical Gazette*, "was found to be within the thorax, probably "in immediate contact with the inner surface of the ribs, the "point being a little to the left of the sternum, between the "third and fourth ribs, and two or three inches above the cica- "trix on the front of the chest, where the sinus, long since "closed, had evacuated itself, and in a direct line from this "cicatrix towards the left shoulder, which indicated the line of "the track of the original sinus."

*Experiments with Needles.*

During my absence from Washington and from all conveniences for experimenting personally with Induction Balance apparatus, I devised a method of verifying the indications of the Induction Balance and of ascertaining the exact depth at which a bullet lies beneath the surface. This method was communicated through Dr. Woodward to the surgeons in attendance on President Garfield, and it was made the subject of a special paper presented to the French Academy of Sciences Nov. 7, 1881.

This method, although involving extremely slight pain, would ordinarily be used only as a preliminary to an operation for the extraction of a bullet. The arrangement is shown in Fig. 28. A fine needle A is connected to one terminal of a telephone, and the other terminal makes contact with a plate B, preferably of the same material as that composing the needle. Place this metallic plate B against the surface of the patient's skin and thrust the needle into that portion of the body where the bullet is believed to be lodged. When the point of the needle makes contact with the surface of the bullet C a galvanic battery will be formed naturally within the body, the two poles of which are respectively the leaden bullet C and the metallic plate B. Under these circumstances a click will be heard from the telephone each time the bullet is touched by the needle. This has been verified by experiments upon bullets buried in a joint of meat. The click, though feeble, is unmistakable.

*Fig. 28.*



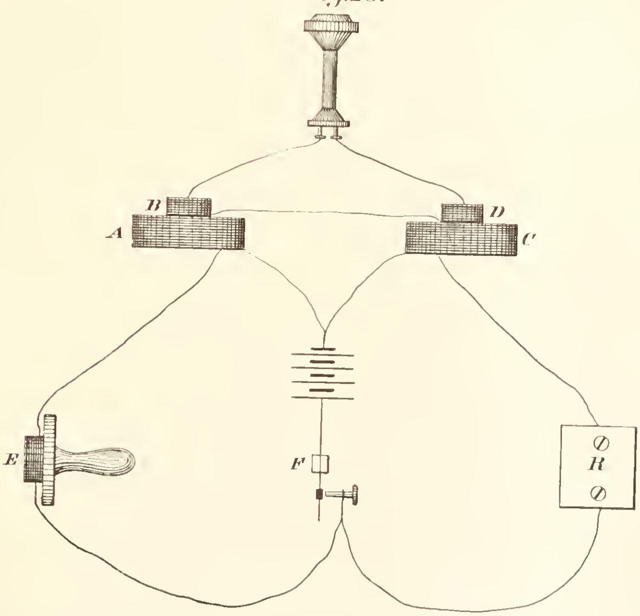

I have no doubt that this method of exploration alone, without the Induction Balance, would prove of great service upon a field of battle, where the employment of complicated apparatus is impossible. Mr. Thomas Gleason has recently communicated to me the particulars of an experiment he witnessed, in the course of which this method was tried upon a living subject. The surgeon who conducted the experiment was unable to obtain any response from the Induction Balance employed, although from certain indications apparent to the sense of touch he believed that the bullet was located in the part of the body submitted to experiment.

To verify his supposition a needle connected as above (Fig. 28) was thrust into contact with the hard substance perceived, but no response was made by the telephone. The surgeon, however, believing that the bullet had been found, etherized his patient and proceeded with an operation, but discovered, when too late, that the bullet was not there.

### *Further Modifications of Induction Balance.*

I sailed for Europe early in October, 1881, and have had no opportunity since of continuing my researches until quite recently. While I was in Europe, however, Mr. Sumner Tainter devised a new kind of Induction Balance which deserves men-

*Fig. 29.*




tion here. The results obtained with this apparatus in its present form (Fig. 29) are not to be compared with those produced by the best instruments described above, but there are undoubtedly great possibilities of future development.

The important feature is that the exploring instrument E consists of *a single coil*, so that there is no possibility of any part of the explorer getting out of adjustment. All the adjustments are made upon the stationary part of the apparatus.

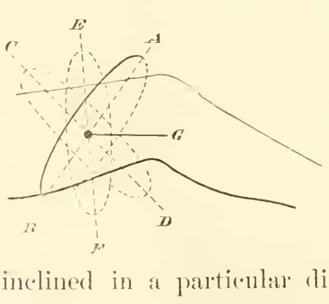
The current of the battery is divided between two equal circuits. One of the primary circuits contains the coil A and the exploring coil E, and the other circuit the coil C and a rheostat R. Coils A and C are exactly similar; and if the resistance introduced at R is equal to the resistance of the exploring coil E, an acoustic balance can be obtained by the adjustment of the secondary coils B D upon the primaries A C; but if the resistance introduced at R is different from that at E, Mr. Tainter states that no balance is possible.

When the apparatus is adjusted to silence the approach of a bullet to the coil E destroys the balance.

Although the great object of the researches that have been brought before you to-day has been to find that arrangement of balance which will detect a bullet at the greatest distance from the coils of the explorer, it must not be forgotten that in every case the instrument is more sensitive to the presence of a bullet placed *inside* the exploring coils than to one exterior to them. When, therefore, we seek the location of a bullet in one of the limbs, it may be advisable to use an annular coil large enough to slip easily over the leg or arm, as the case may be.

In Mr. Tainter's arrangement the exploring coil E (Fig 29) might simply be a large ring consisting of a number of convolutions of thick wire which could be slipped over the limb, or the ring might consist of two coils, forming one side of a Hughes' Induction Balance.

*Fig. 30.*

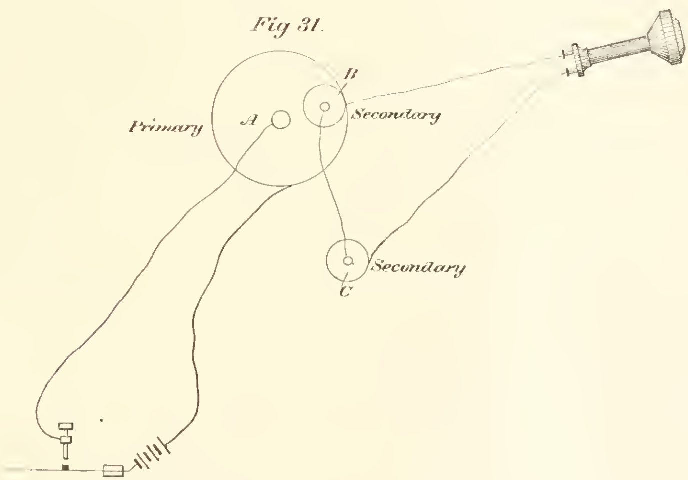



In either case the loudest sound will be produced when the bullet is in the plane of the ring, and its exact location should be deduced from three observations. Suppose, for instance, that with the ring inclined in a particular direction the maximum sound is obtained when the ring occupies the position A B. (Fig. 30.)

We know then that the bullet is in that plane. Now, incline the ring in some other direction and explore again. Let the position of maximum sound be now C D. We know then that the bullet is somewhere on the straight line formed by the intersection of the planes A B and C D. It is only necessary then to make a third observation with the apparatus so inclined that the plane of the ring cuts this straight line, for instance, the position E F. The point of intersection of the three planes G is then the exact point occupied by the bullet.

I shall conclude this paper by the description of an experiment made in Newport, R. I., a few days ago. The results are so unprecedented in my experience that I feel they cannot be received as implicitly reliable until the experiments have been repeated and verified.

*Fig 31.*




I had arranged upon a table three coils, (as shown in Fig. 31.) The large flat primary coil A was connected with a battery of four Bunsen elements and an interrupter, as shown, and the two small secondaries of fine wire, B C, were connected with a telephone.

The secondary B was moved about on the primary A until a position of silence was obtained. Upon bringing a leaden bullet near C the balance was disturbed and a distinct sound produced from the telephone. There is nothing very strange about this when we know that the distance between A and C was only 15 centimetres, so that C was well within the field of induction of A; but what did seem extraordinary was that the approach of the large steel blade of a penknife to the coil C produced no effect! The iron diaphragm of a hand telephone brought close up to the coil C produced no sensible disturbance of the balance, whereas a small disk of lead produced quite a marked effect. A disk of copper the size of a telephone diaphragm also produced a good effect, but the sound was not sensibly louder than that due to the small leaden disk. A diaphragm of zinc occasioned a feeble, but distinct, disturbance of the balance. It is unfortunately the case that in all the forms of induction balance described above lead gives the poorest effect of all metals. If people would only make their bullets of silver or iron there would be no difficulty in finding them in any part of the body! In the apparatus shown in Fig. 31, however, it seems (unless subsequent experiments should reveal some fallacy) that we have an arrangement which is sensitive to lead and not to iron, or, at all events, which is more markedly influenced by lead than iron.

It is hardly necessary to state that when the coil C was removed to a considerable distance from the primary A no effect was produced by the approach of metal to the coil C.

I have in this paper brought before you an outline of a labor of love pursued through many anxious days and sleepless nights. However imperfect or disappointing may be the results so far achieved, they are sufficiently encouraging to enable us to look forward with confidence to the attainment of still greater perfection.

I hope to continue these researches in the future; and certainly no man can have a higher incentive to renewed exertion than the hope of relieving suffering and saving life.

# APPENDIX.

NOTE 1.—Another mode of painless exploration suggested itself to my mind at this time, based upon the fact that a leaden bullet is much more opaque to light than the substances composing the human body.

I was aware of the fact that the ingenious M. Trouvée, of Paris, had, by means of his polyscope, produced a light inside a living fish, and was thus enabled in the dark to see the anatomical structure of the fish as it swam about in a vessel of water.

M. Trouvée had himself shown me a modified form of this apparatus for the illumination of the interior of the human stomach, and I understood him to say that when the instrument was used the body of the patient could be seen in the dark, faintly illuminated, like a Chinese lantern, and that the extent and location of tumors in the stomach could be detected on account of their great opacity.

It occurred to me that leaden bullets were certainly more opaque than tumors, and that a painless method of exploration might be based upon the observations of M. Trouvée.

It would evidently be impracticable, in the great majority of cases, to introduce into the stomach any illuminating apparatus; but if the light of a properly protected incandescent platinum spiral, introduced into the stomach, could produce effects visible from the outside—that is, if this feeble light could penetrate through the substance of one-half of the body—then why should not the intense light of an electric arc, or of a lime light, penetrate the whole body from one side to the other so as to produce similar effects?

The most feasible plan that occurred to me was to place an electric lamp at one end of a long opaque tube, and to apply the other end closely against the skin of the patient. The interior of the tube between two plate-glass diaphragms could be filled with a saturated solution of alum, or some other highly-absorbent transparent substance, so as to obstruct the passage of heat rays.

Of course, the whole apparatus was to be so arranged that no light from the lamp could escape into the room to interfere with the experiment.

Under these circumstances, the body of the patient, or at least a portion of it, should, in a dark room, appear self-luminous; and it seemed possible that the shadow of an imbedded bullet might be projected upon the skin. The track of the bullet might also, perhaps, be discernible as an illuminated streak either more or less bright than the surrounding surface.

These considerations led me to try a number of experiments, which proved that the method was feasible where the bullet was very near the surface of the body. On account of the great and irregular refraction of light in passing through the tissues of the body, I doubt whether the shadow of a deeply-seated small bullet could be distinguishable upon the skin, unless, indeed, a very brilliant light emanating from a single point could be safely produced inside the body.

The following experiments bearing upon the subject were made in Boston July 6th, 1881, with the assistance of Mr. Wm. Schuyler Johnson:

*Experiment* 1.—Mr. Johnson placed in his mouth a glass cylinder containing a spiral of platinum wire, which was rendered incandescent by the passage of an electrical current. He also held in his cheek a small leaden bullet.

In a dark room the effect was very striking. The cheek appeared semi-transparent, and the location of the bullet was detected at a glance by a shadowy spot upon the skin.

*Experiment* 2.—A metallic glove button (not more than 4 or 5 mm. in diameter) was attached to the glass cylinder by a few turns of black thread passed round the cylinder.

In this case the effect, although not so marked as in the former experiment, was quite discernible, and a faint shadowy streak could be seen crossing the cheek, caused by the shadow of the black thread tied round the cylinder.

NOTE 2.—*Letter from Mr. George M. Hopkins, published in the New York Tribune, July* 11, 1881.

LETTERS FROM THE PEOPLE—THE BULLET FIRED BY GUITEAU.

*A suggestion that the Induction Balance be used to discover its position in the President's body.*

*To the Editor of the Tribune:*

SIR: The attempt upon President Garfield's life and the present condition of the sufferer have called forth the nation's deepest sympathies, and elicited very many suggestions as to the methods of promoting his comfort and assuring his recovery.

As one crisis after another has passed hope has risen, and the people wait with earnest desire for the last danger to pass away.

The attending and consulting surgeons state that it is impossible to predict the final result of the shot without locating the ball.

With all deference to the several methods proposed, I desire to suggest a method of ascertaining the position of the missile which will be painless and harmless, and which, in my experiments under conditions analagous to those under which it might be practised in the present instance, has proved successful. I refer to the use of the Induction Balance—a most delicate electrical instrument for detecting the presence of metals—a modified form of which could be easily applied in this case with a reasonable expectation of success. This instrument consists of two short glass cylinders, around each of which are wound two parallel coils of fine insulated copper wire.

One coil of each pair is included in a battery circuit, in which there is a clock microphone. The other pair is placed in a closed circuit with a receiving telephone. The two glass cylinders, with their encircling coils, may be widely separated.

The induction set up in the secondary or telephone circuit is balanced by the reversal of one of the secondary coils, and so adjusted that the induction in one of the secondary coils exactly balances or neutralizes the induction in the other, so that when the ear is applied to the receiving telephone no sound is heard.

Now, by placing ever so small a piece of metal in one of the glass cylinders, the electrical balance is disturbed and the clock on the microphone is heard to tick loudly, thus indicating the presence of metal, and the same is true if the coil be placed in the vicinity of a piece of metal.

It occurred to me to try the effect of a lead bullet upon the instrument, placing it at different distances, and separating it from the coil by insulating material. The result exceeded my anticipations, as with a set of coils that were by no means sensitive I was able to locate the bullet with the coils raised a vertical distance of nearly two inches. With more sensitive apparatus it is more than probable that the bullet might be located, even though distant several inches, by passing a pair of coils over the President's back and abdomen; and by comparative tests the depth of the bullet might be ascertained.

GEORGE M. HOPKINS.

BROOKLYN, *July* 10, 1881.

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NOTE 3.—*Letter from Mr. G. M. Hopkins to Private Secretary Brown, enclosing printed description of Hughes' Induction Balance.*

OFFICE OF THE SCIENTIFIC AMERICAN, NO. 37 PARK ROW,
NEW YORK, *July* 11*th*, 1881.

MR. J. STANLEY BROWN,
*Executive Mansion, Washington, D. C.:*

MY DEAR SIR: I send herewith a full description of the Induction Balance as promised in my note of yesterday. I will send the apparatus for trial if desired.

I am certain that the bullet can be located with it if it is not too deeply seated.

Please advise Dr. Bliss.

Very respectfully,
GEO. M. HOPKINS,
*Of the Scientific American.*

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NOTE 4.—*Letter from Mr. Geo. M. Hopkins to Private Secretary Brown accompanying the Hughes' Induction Balance apparatus he forwarded to the Executive Mansion for trial.*

60 IRVING PLACE, *July* 13*th*, 1881.

MR. J. STANLEY BROWN:

DEAR SIR: I give below a few suggestions in regard to the use of the Induction Balance sent herewith.

Very respectfully,
GEO. M. HOPKINS.

Suggestions: Connect A to A, B to B, &c., as marked on the wires. Strength of current used, 15 or 20 volts.

A strong current extends the influence. Use the clock interrupter, and place a drop of mercury in the vulcanite cup to make connection.

The coils are now adjusted to "silence," but will probably have to be re-adjusted on their arrival in Washington; as a $\frac{1}{100}$ inch movement of one of the coils will throw it out of adjustment, it will be seen that the adjustment is a matter of great nicety. Two telephone receivers should be employed, and the most acute sense of hearing is required to distinguish the ticking when the ball is two inches distant from the coils.

The shorter instrument is intended for application to the patient should it be considered sufficiently sensitive to warrant the experiment.

As a preliminary experiment pass the Induction Balance over the pocket containing coins, keys, &c.; also over buttons, buckles, &c., attached to the garments.

Lead is the poorest of all metals to locate with this instrument. If the ball were of iron it could be readily found at a distance of 3 or 4 inches.

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NOTE 5.—*Telegram from Prof. Newcomb.*

EXECUTIVE MANSION,
WASHINGTON, D. C., *July 13th*, 1881.

To Prof. A. G. BELL,
*Care of Chas. Williams*, 109 *Court st., Boston, Mass.:*

Perhaps small core for coil no larger than bullet, with very fine wire, might give best effect. Shall telegraph to Rowland to know best theoretical form. Telegraph me or Brown, care Executive Mansion, what train you take.

S. NEWCOMB.

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NOTE 6.—*Telegram from Prof. John Trowbridge.*

BAR HARBOR, MAINE, *July 16th.*

To Secretary BROWN,
*White House, Washington, D. C., for Prof. Bell:*

Make resistance of secondary coils equal to telephone. Put large number of turns of wire on primary and secondary coils. Primary coils long compared with width. Put secondary coils around middle of primary coils.

JOHN TROWBRIDGE.

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NOTE 7.—*Telegram and letter from Prof. Rowland to Prof. Newcomb.*

HUNTER, N. Y., *July 14th*, 1881.

To Prof. SIMON NEWCOMB,
*Executive Mansion, Washington, D. C.:*

Telegram just received. Make cores four inches long, with six layers of number twenty wire; diameter an inch and one-half. Make outer coil half an inch wide and half an inch thick, of finest wire, and slip over inner coil at its end.

H. A. ROWLAND.

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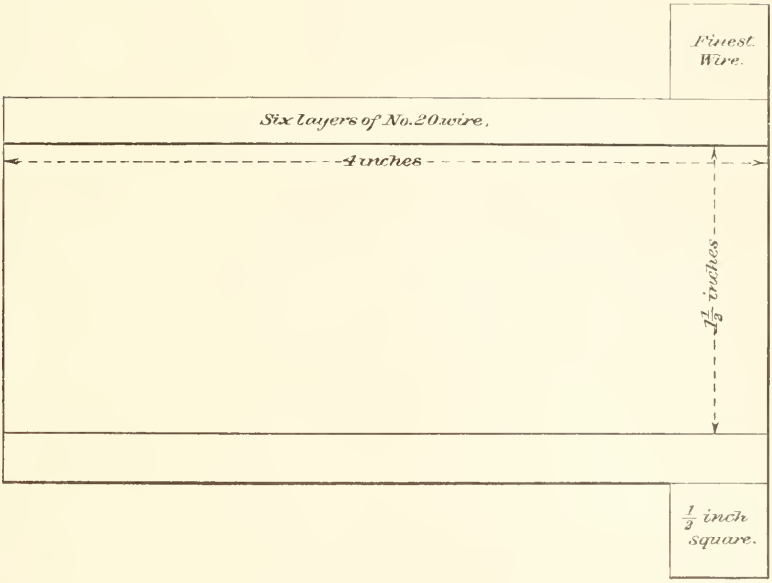
*Letter following above telegram.*

HUNTER, *July* 14, '81.

Prof. NEWCOMB:

DEAR SIR: When your telegram arrived I had gone to the Hotel Kaaterskill, about ten miles from here, to stay over night. The telegram was sent back to the office to be sent to me, and my friends thought that I had received it; but the stupid man here simply kept it and would not send it, because he had no authority to send it further.

I have telegraphed back a reply. The dimensions should probably be about as follows:




Of course, the two must be precisely alike, and the induction coefficients of one should be made to vary by a screw, which would move one of the secondary coils nearer to or further from the end of the primary.

Yours truly,

HENRY A. ROWLAND.

P. S.—For these dimensions a telephone with many turns of fine wire in its coil would be best.

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NOTE 8.—*Communications with Prof. D. E. Hughes, of London, England.*

(*a.*) *Cablegram to Mr. Preece, Superintendent Postal Telegraph, London, England.*

WASHINGTON, *July* 15*th*, 1881.

TO PREECE,
*London:*

Can Hughes suggest form of Induction Balance to locate leaden bullet in President? If so, cable at my expense.

GRAHAM BELL.

*(b.) Telegraphic reply to above.*

WHITNEY,
*Washington, D. C.:*

Preece says to Graham Bell, Washington: "Interesting and hopeful letter from Hughes with diagrams sent you to-day."

W. GREEN,
*Pres. West. Union Telegraph Co.*

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*(c.) Note from Mr. Preece enclosing letter from Prof. Hughes.*

GENERAL POST OFFICE, LONDON, ENGLAND, 19 *July*, 1881.

MY DEAR BELL: The enclosed very interesting letter from Hughes will enable you to make some experiments, which I trust will result in success.

Yours, sincerely,

W. H. PREECE.

Prof. ALEXANDER GRAHAM BELL,
*Washington, D. C.*

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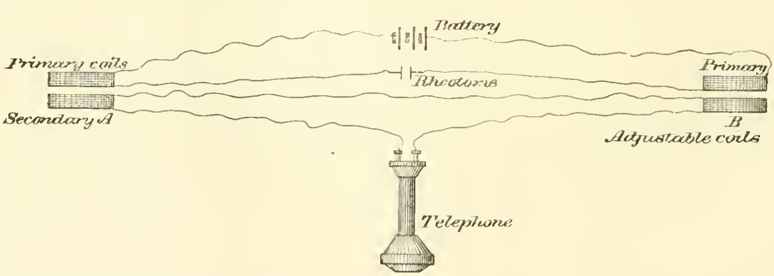
*(d.) Prof. Hughes to Mr. Preece.*

108 GT. PORTLAND STREET, W. LONDON, *July 18th*, 1881.

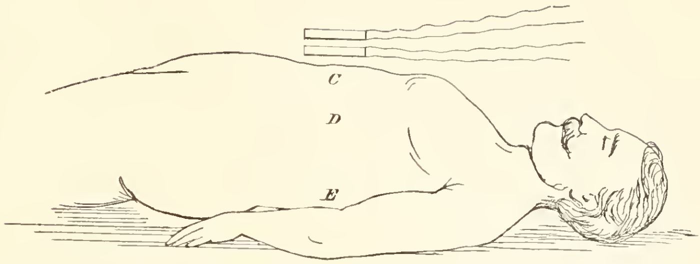
DEAR PREECE: In reply to yours of to-day enclosing telegram from Prof Graham Bell, I believe a specially-constructed Induction Balance could be made to locate the leaden bullet in President Garfield, provided the ball was nearer to one side of his body than the other.

Suppose we have two flat superposed coils on a single reel, so that these two coils form a single one as regard their relative distance: these coils, if connected with the usual adjusting coils of my balance, could be reduced to silence; then, on moving these coils near a metallic body, sounds would be




heard. Thus the only difference would be instead of as usual taking the metallic body to the coils upon a fixed table, we take the coils to a fixed body in which we suppose metal, such as a bullet, to be hid.

Now, suppose we take the coils A and move it over a body with a bullet, thus:




If bullet near C, we should hear it when coils just above it; at E, when the coils were below; but if bullet in the centre of the body, then we should have equal or probably no indications.

All this could be most easily done and with some results if the bullet had been of copper or silver, but lead has such a high resistance and gives, consequently, very feeble tones.

We can easily hear a copper penny at some inches distant from the coils, but lead requires that it should not be more than one or two inches distant; consequently, more sensitive coils would be required or a larger battery.

I think the experiment a hopeful one, and above all that the coils are easily made, and simple experiments could be first made to find a bullet in a mass of cotton, &c.

The microphone is invaluable as a probe for bullets. I made the first for Sir Henry Thomson to find out stone in bladder. But it is even more applicable to bullets. It consists of a simple hammer and anvil microphone adjusted upon the handle of the ordinary probe. The instant this probe touches any hard substance a loud, sharp click is heard in the telephone. The smallest shot can thus be heard, and there is a very distinctive tone between when the probe strikes a bone or bullet. This instrument is well known to surgeons, so I need not say more about it.

If you write to Prof. Bell, please enclose this, as I should be pleased to hear of his success.

Sincerely yours,

D. E. HUGHES.

W. H. Preece, F. R. S.

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Note 9.—*Letter from Mr. Charles E. Buell to Col. Rockwell.*

Col. Rockwell:

Dear Sir: Please suggest for me that in an electrical test to locate the bullet it will only be done with certainty by obtaining a balance, which can be done as follows: When the loudest tick is obtained by placing the inducing coil in the vicinity of the imbedded bullet, then move another bullet of equal size towards the other coil of the bridge until a balance is had and no tick is audible, when the imbedded bullet will be known to be a like distance from its respective coil.

CHARLES E. BUELL,
*Electrical Engineer, New Haven, Conn.*

Note 10.—*Note from Dr. Chichester A. Bell.*

N. Y. Central R. R., between Syracuse and Buffalo,
*July 16th*, 1881.

Dear A. G. B.: If your coils are symmetrically arranged, should it not be possible to balance the effect of a bullet on one side by a bullet placed in a corresponding position on the other?

Probably you have thought of this before, but, if not, it may be worth a three-cent stamp.

Yours, truly,
CHICHESTER A. BELL.

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Note 11.—*Note and telegram from Mr. J. H. C. Watts.*

Balto., *July 21st*, 1881.

Prof. A. Graham Bell,
1221 *Conn. Ave., Washington, D. C.:*

Am working hard at our problem. Succeeded in reaching full three inches last night, but owing, I think, to my battery weakening somewhat, can hardly reach so far now. Won't you please advise me how you are getting along, and oblige,

Yours, very truly,
J. H. C. WATTS.

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*Telegram.*

Baltimore, *July 23d*, 1881.

Prof. A. G. Bell,
*Washington, D. C.:*

Have been unable to obtain satisfactory results since first trial, and probably yours is at least as good as mine.

J. H. C. WATTS.

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Note 12.—*Letter to Dr. Bliss.*

Volta Laboratory, 1221 Connecticut avenue,
Washington, D. C., *July* 23, 1881.

Dr. Bliss,
*Executive Mansion:*

My Dear Sir: You were kind enough to suggest that preliminary experiments should be made with the Induction Balance upon the person of Lieutenant Simpson, whose address you gave me. I accordingly communicated with the lieutenant, and he came to my laboratory last night in company with Dr. Stanton.

The new instruments we had hoped to use were not complete, so we had to content ourselves with the apparatus you tested the other day.

Upon passing the coils over the back of the lieutenant, it was found that at one spot a feeble sound made its appearance—too feeble, however, to be entirely satisfactory as evidence of the presence of a ball. I find that very feeble sounds like that heard are easily conjured up by imagination and expectancy, but the following facts seem to indicate that in this case the sound was due to an external cause—probably to the presence of a very deeply-imbedded bullet:

1. The sound, although it could not always be distinguished, uniformly appeared, when audible, *at the same spot.*

2. It was heard independently by Mr. Tainter, Dr. Stanton, and myself at the same spot. (If I recollect rightly, the lieutenant himself also located the sound, but my father could hear nothing.)

3. A blindfold test was then made. Mr. Tainter closed his eyes and turned away while the coils were moved over different parts of the lieutenant's back. The moment the sonorous spot was covered Mr. Tainter declared he could hear the sound. We are to repeat the experiments with our new instruments as soon as they are completed, and I shall report progress.

Yours, truly,

ALEXANDER GRAHAM BELL.

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NOTE 13.—*Letter to Dr. Bliss.*

WASHINGTON, *July 27th*, 1881.

DR. BLISS:

MY DEAR SIR: Permit me to make a few remarks upon the value of the indications of the Induction Balance in determining the location of a lead bullet imbedded in the human body.

*Positive deductions concerning the location of the ball can only be safely made from positive indications of its presence. Negative indications may mean anything.*

For instance: If we hear a sound from the telephone connected with the balance every time the exploring coil is passed over a certain part of the body, this may be taken as proof positive that a metallic mass is to be found in the neighborhood of the sonorous spot. If, on the other hand, we fail to obtain audible effects, we are not entitled to conclude that the bullet is absent from the part explored, or that it is imbedded at a greater distance below the surface than the penetrating distance of the instrument used, for the bullet may be within any part of the area explored and close to the surface without affecting the balance if it is flattened, and if it is so located that the plane of its face is nearly perpendicular to the plane of the face of the exploring coil.

A few words may not be out of place here concerning the experiment made last night upon the person of the President.

Before entering the President's room, I applied the telephone to my ear, and heard a peculiar spluttering sound which it was found impossible to extinguish by any adjustment of the coils. I satisfied myself, however, that the arrangement was in a sensitive condition, by holding near it a flattened bullet. The hearing distance appeared to be about 4 cm. When the exploring coil was passed over the back of the President near the spine, no definite pulsation of the sound was heard; but when the coil was first passed over a portion of the front part of the abdomen near the right side, I heard at one point a sharp and sudden reinforcement of the sound. Upon moving the coil backwards and forwards a number of times over the same spot, I was unable to verify the observation. I should state here that, when a perfect balance is not obtained, it is not safe to place reliance upon a single observation of a pulsation in the sound, as a similar effect might be caused by an accidental irregularity in the vibration of the instrument used to interrupt the electrical current.

The sound heard was distinct and well marked, but it would not be safe to conclude that it was due to the presence of the bullet, unless the effect could be reproduced a number of times and always at the same spot.

I think I mentioned to you that it was discovered yesterday morning that the application of a tin-foil "condenser" to the Induction Balance markedly influenced the hearing distance, increasing it in our experiments by about one centimetre.

A condenser was therefore connected to the arrangement used last night, but it has since been found that the condenser was only connected to one side of the balance, instead of to both. This mistake is enough to account for the difficulty experienced in adjusting the coils so as to obtain an acoustic balance, and for the observed reduction in the hearing distance.

If it is of importance to locate the bullet at once, I would recommend an immediate repetition of the experiment with the condenser properly arranged.

Whatever other results might be obtained, I feel sure we could, at all events, settle immediately whether the sound I heard was due to the presence of the bullet or was an accidental phenomenon.

If it is not important to locate the bullet at the present time, it might be well to postpone a repetition of the experiment, so as to give Mr. Tainter and myself more time to improve our apparatus.

Yours, truly,

ALEXANDER GRAHAM BELL.

NOTE 14.—*Letter to Dr. Bliss.*

VOLTA LABORATORY, 1221 CONNECTICUT AVENUE,
WASHINGTON, D. C., *July* 31, 1881.

MY DEAR DR. BLISS: I write to let you know that my new form of Induction Balance gives brilliant promise of success. The indications with a flattened bullet are well marked and distinct at a distance of three inches, and audible effects can even be distinguished at five inches, but beyond three inches silence and the greatest attention are requisite. Effects are produced at about two inches, when the bullet is held with its edge towards the instrument—a position that gave no results with our former apparatus.

Altogether I feel very much encouraged. The apparatus in its present form is a very clumsy affair, the surface that would be applied to the person of the President measuring seven inches by four. I hope to reduce the size of the apparatus very greatly in a day or two. In the meantime, should any necessity arise for an experiment upon the President, we have much better chances of success than at any previous time.

Yours, very truly,

ALEXANDER GRAHAM BELL.

NOTE 15.—*Letter to Dr. Bliss.*

VOLTA LABORATORY, 1221 CONNECTICUT AVENUE,
WASHINGTON, D. C., *July* 31, 1881.

DR. BLISS,
*Executive Mansion:*

DEAR SIR: We have made experiments this evening upon the person of Private John McGill, an old soldier, who was wounded at the battle of Gaines' Mill, in 1862, and who still carries the ball that shot him.

I found no difficulty in finding a sonorous spot in his back, where undoubtedly the bullet lies imbedded.

Mr. Tainter also located the bullet in the same place. Upon pressing with the fingers upon the spot a lump could be felt between two of the ribs. We experimented upon this same man yesterday, using a similar form of Induction Balance to that we tried upon the person of the President the other day, but could obtain no indications.

The new form of Induction Balance is so sensitive that a new difficulty is introduced by the effects produced by large metallic masses—for instance, gas lustres, iron fire-places, &c.

I think also that the earth's magnetism affects the result. We shall investigate these causes of disturbance to-night.

Yours, sincerely,
ALEXANDER GRAHAM BELL.

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NOTE 16.—*Report to the surgeons published in the daily papers Aug.* 2, 1881.

VOLTA LABORATORY, 1221 CONN. AVE.,
WASHINGTON, D. C., *Aug. 1st,* 1881.

*To the Surgeons in attendance upon President Garfield:*

GENTLEMEN: I beg to submit for your information a brief statement of the results obtained with the new form of Induction Balance in the experiments made this morning for the purpose of locating the bullet in the person of the President. The instrument was tested for sensitiveness several times during the course of the experiments, and it was found to respond well to the presentation of a flattened bullet at a distance of about four inches from the coils.

When the exploring coils were passed over that part of the abdomen where a sonorous spot was observed in the experiments made on July 26th a feeble tone was perceived, but the effect was audible a considerable distance around this spot. The sounds were too feeble to be entirely satisfactory, as I had reason to expect from the extreme sensitiveness of the instrument a much more marked effect. In order to ascertain whether similar sounds might not be obtained in other localities I explored the whole right side and back below the point of entrance of the bullet, but no part gave indications of the presence of metal, except an area of about two inches in diameter, containing within it the spot previously found to be sonorous. The experiments were repeated by Mr. Tainter, who obtained exactly corresponding results. We are therefore justified in concluding that the ball is located within the above-named area.

In our preliminary experiments we found that a bullet like the one in question when in its normal shape produced no audible effect beyond a distance of two and a half inches, while the same bullet, flattened and presented with its face parallel to the plane of the coils, gave indications up to a distance of five inches. The same flattened bullet, held with its face perpendicular to the plane of the coils, produced no sound beyond a distance of one inch. The facts show that, in ignorance of the actual shape and mode of presentation of the bullet to the exploring instrument, the depth at which the bullet lies beneath the surface cannot be determined from our experiments.

I am, gentlemen, yours truly,

ALEXANDER GRAHAM BELL.