Tables show that the amount of disturbance, especially of horizontal magnetic force, is nearly the same at widely distant stations.

An attempt has also been made to apply the Gaussian analysis to sudden magnetic disturbances, and, with a view to their application in future work, the values of the Gaussian functions have been obtained for 20 different Observatories, and the numerical equations formed for the elements of magnetic force in three directions mutually at right angles, and also the equation for the magnetic potential in terms of the Gaussian coefficients to the fourth order.

The Tables give the numerical values to be multiplied by the 24 Gaussian coefficients to give the values of the forces X, Y, and Z in the geographical meridian towards the north, perpendicular to the meridian towards the west, and vertically downwards respectively. The equations are also formed and the values obtained in terms of the 24 Gaussian coefficients for X_2, Y_2, and Z_2, X_2 being the horizontal force in the magnetic meridian, Y_2 the horizontal force perpendicular to the magnetic meridian, and Z_2 the vertical force. If then X_2, Y_2, and Z_2 be the observed values of any simultaneous disturbances, they may be at once substituted in the equations, the equations giving the 24 Gaussian coefficients may be solved, and the corresponding change of magnetic potential may be determined.

VII. "On the Measurement of the Heat produced by Compressing Liquids and Solids." By the late Cosmo Innes Burton, B.Sc., F.C.S., Professor of Chemistry, Polytechnic, Shanghai, and William Marshall, B.Sc., F.C.S. Communicated by Professor Thorpe, F.R.S. Received June 10, Read June 18, 1891.

In the year 1885 Messrs. Creelman and Crocket ('Edinburgh Roy. Soc. Proc.,' vol. 13. p. 311), under Professor Tait's supervision, performed a series of experiments on the heat produced by the compression of various substances. Their method was briefly as follows:—For the application of the pressure, the same apparatus which we describe and figure later was used. A thermo-electric junction of insulated nickel and iron wires was fixed between the leather washers and a sufficient length of wire coiled away inside the gun to allow the junction to be drawn out at the top and a specimen attached to it. Among the substances examined were glass, cork, vulcanite, glue, bees'-wax, and paraffin oil, the only pure chemical compounds being chloroform and ether. The following are some of the results obtained. Pressure, about 1 ton on the square inch.

	Rise of temp. per ton.
	°C.
Vulcanite	0·30
Glass	0·12
Cork	0·75
Beeswax	0·83
Chloroform	1·44
Ether	1·80
Paraffin (solid)	0·61
Paraffin oil	1·39

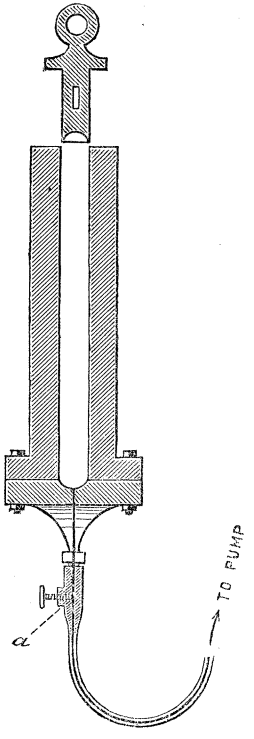
Owing to the unfortunate choice of substances, these results, although of interest as illustrating the application of the method, can have little, if any, general significance. In the year 1888 Mr. Burton performed a similar series of experiments, with the view of gaining some light on the physical constitution of allotropic forms of elementary substances. As the results have not hitherto been published, they are here shortly recorded. The following table gives a *résumé* of the results obtained with the two forms of phosphorus and with several metals. The method was in nearly all particulars the same as that of Messrs. Creelman and Crocket. The powdered substances were strongly compressed in short glass tubes, and the sharp-pointed nickel-iron junction pressed into the powder. The metals were made into little cylinders, and a hole drilled in each, very little larger than the junction. The sample was fixed on the wires and then finely powdered metal packed in, so as to leave the least possible air space. This method proved fairly satisfactory for such metals as could be obtained in ingots, and for very heavy and coherent powders, such as graphite, arsenic, and amorphous phosphorus; but it was, of course, inapplicable to liquids, except water, and almost equally so to light powders, like charcoal.

The figures in column 2, showing the amount of heat produced by a uniform pressure of about 300 atmospheres, or 2 tons, on the square inch, seemed to indicate that in metals the heat produced by compression varied inversely as the atomic weight. The difference in the heat given out by the two kinds of phosphorus is remarkable, and may possibly be held to indicate a wide difference in molecular weight.

The results were not sufficient, either in number or accuracy, to warrant the statement of any such law as that above mentioned, but they were of quite sufficient interest to induce us to take up the subject once more, using a larger number of substances and more accurate methods.

Substance.	Rise of temperature on applying pressure, 300 atmos., deg. cent.	Fall of temperature on suddenly releasing pressure, deg. cent.	Specific heat.	Atomic weight.
Graphite	0·318	0·257	0·188	12
Yellow phosphorus....	0·532	0·408	—	—
„ „ 2nd	0·955	0·912	0·200	31
Amorphous phosphorus	0·290	0·239	0·170	31
Zinc	0·261	0·221	0·0932	65
Arsenic.....	0·261	0·248	0·076	75
Cadmium	0·285	0·293	0·0548	112
Tin	0·277	0·264	0·054	118
Antimony.....	0·248	0·191	0·051	120
Lead.....	0·305	0·368	0·0315	206
Bismuth	0·251	0·230	0·0305	210
Water.....	0·290	0·201	1·000	—

Fig. 1.—Section of "Gun."



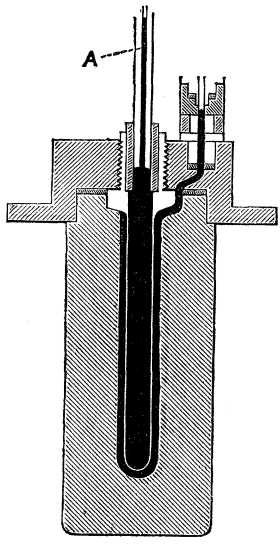
Description of Apparatus and Experimental Methods.

The compression apparatus used in all these various series of experiments was one originally constructed for testing the effect of pressure on thermometers. Its construction is shown in fig. 1. The cylinder, called "the gun," is of wrought iron, about 16 inches long and 4 inches diameter, with a bore of 1 inch. It is fixed vertically, and the lower end is flanged and closed by a very thick flange plate, bolted upon soft leather washers, and drilled to admit water from the pump. The pump-barrel consists of a steel ingot, $1\frac{3}{4}'' \times 6''$, drilled with a hole $\frac{1}{4}$ inch diameter; in this works a plunger, with a steel cup at the lower end, through a stuffing-box and cup leather. The stroke of the pump is about $2\frac{1}{2}$ inches, and it is moved by a handle nearly 3 feet long, with a leverage of about 10 to 1. The upper end of the gun is closed by a solid plunger, turned to fit very accurately, and rendered water-tight by means of a steel cup, turned to a very thin, knife-like edge, slightly belled out, so as to press against the sides of the gun. When pressure comes upon the cup, the sides expand sufficiently to form an almost perfectly tight joint. The plunger is held in position by a key fitting into a hole cut through the sides of the gun and through the plunger or ram. The cup is filled with tallow or lard to avoid leaving an air space inside the gun. The connexion to the pump is formed by a solid-drawn copper tube with a steel connecting piece, which is screwed upon a washer of soft copper.

For measuring the pressure, a compression gauge, designed by Professor Tait, and used by him in his experiments on the "Challenger" thermometers, was employed. It is represented in fig. 2. Essentially it consists of a steel tube, about 5 inches long, $\frac{1}{2}$ inch in diameter, and $\frac{1}{20}$ inch thick, filled with mercury, and bearing a glass capillary, A. This tube is enclosed in a steel vessel communicating with the pump by a solid-drawn copper tube. The pressure is measured by the rise of the mercury in the tube A. The gauge in the first instance was graduated by means of air manometers, and was afterwards compared with an Amagat mercury gauge. Its indications have been found extremely constant. The long bulb contains an inner bulb, which nearly fills up the whole space, leaving only a thin shell of mercury, which is very little affected by temperature. This gauge marked 22·35 mm. per ton pressure. The amount is small, and the reading cannot be said to be very accurate, but no other gauge could be obtained equally trustworthy and which required so very small a bulk of water—a matter of great importance, as will be perceived on referring to the description of the experiments given below.

The wires of the thermo-electric junction are introduced by placing

Fig. 2.—Section of Gauge.



them between two broad washers of thick soft leather, and screwing these as tightly as possible between the flanges at the lower end of the gun. The leathers were prepared by soaking in warm lard *in vacuo*, as recommended by Professor Andrews. The arrangement was found to hold pressure extremely well, if the bolts were tightened up each day before beginning the experiments. As it was necessary that many of the liquids used should be completely protected from water, we were obliged to choose wires for the junction which could be sealed through glass. After experiments with a large number of different pairs of metals, beginning with pure platinum and going up to 33 per cent. of iridium, specimens of commercial platinum and an alloy of platinum with 10 per cent. of iridium were selected. Strange to say, nearly the same current was obtained from a junction of two different samples of 10 per cent. iridium.

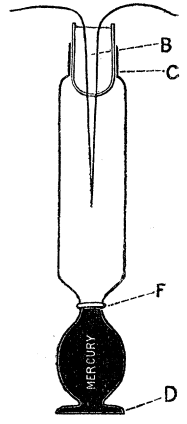
The platinum wire was of about No. 24 B.W.G., the alloy wire of 0″·029 diameter. The latter resembled steel in its properties, being very hard and elastic. Its thickness was a disadvantage, because it increased the mass of the junction and caused a sensible time to elapse before the wires attained the temperature of the liquid during the experiments. The wires were welded to form the junction and hammered thin and flat in order that the contact with the substance under trial might be as perfect as possible. A length of about 3 feet of the double wires was coiled into a spiral spring inside the gun, so that the junction end could be drawn out at the top either for

graduation or to allow the substance to be changed. The wires were insulated by drawing them through fine india-rubber tubing of the kind known as vein tubing. This arrangement proved very objectionable in practice, as the oil and grease off the inside of the gun attacked the rubber and ultimately perforated it, permitting contact with the metal sides of the gun.

Naturally, after this occurred, the results became perfectly irregular and worthless, and the whole apparatus had to be taken to pieces in order to renew the insulation. This was done by stripping off the bad pieces of india-rubber and then covering the whole length of each wire with a double thickness of narrow silk ribbon wound on and whipped over with thread. After the renewal of the insulation there was not a single defective result, and the readings vary within remarkably narrow limits, as will be seen by reference to the tables. The outer or cold junction of the thermo-electric apparatus was immersed in a large wooden tub of cold water, the temperature of which changed but little from day to day, and might be regarded as perfectly uniform during the performance of any experiments.

The apparatus for containing the liquids which were subjected to compression is represented in fig. 3. The wires of the junction are

FIG. 3.—Section of Tube.



fixed into a hollow glass stopper, B, which was ground to fit the tube C. This tube carried a slight flange at D, to which a disc of soft black rubber could be tightly wired. This rubber disc served to close the end of the tube and at the same time allowed perfectly free communication of pressure from the outside to the inside of the apparatus. A loop of thick copper wire was twisted round the neck of the tube to furnish a handle by which it could be drawn out of the gun. In

order to prevent liquids like chloroform or bisulphide of carbon coming in contact with the india-rubber, the tube was filled up to the neck F with clean dry mercury. Twelve tubes were provided, all of which fitted to the same stopper, in order to prevent loss of time in changing substances. The mercury was poured away and a fresh rubber cap wired on for each experiment.

The galvanometer used was of the dead-beat pattern, by White, of Glasgow, of 642 turns and 1·242 ohms resistance. It was placed on a slate shelf about 20 feet distant from the compression apparatus, and it was not at all affected by the movements of the pump handle or by any other part of the mechanism. The scale of the galvanometer was graduated in arbitrary divisions of nearly 2 cm. in length, these being divided into tenths; these small divisions could again be read to quarters. As one large division on the scale corresponded very nearly to 1 degree centigrade, the temperature readings are very accurate. In order to have all substances as nearly as possible at the same temperature, a large covered vessel was sunk in the water-tub which contained also the cold junctions, and in this vessel the bottles of substances were placed the day before, along with mercury and clean tubes ready for use. The suction tube of the pump also drew its supply from the same source.

After the gun had been filled with water taken from the tub, a tube filled with clean mercury to the neck E, and with the substance to be compressed up to C, was then brought up to the stopper and well pressed home, care being taken that no air bubble should be left in inserting the stopper. The wires were arranged on opposite sides of the tube, which was then pressed down on the spiral spring formed by the coiled wire inside the gun, and the ram inserted. The discharge valve at fig. 1 was opened, the ram pressed home and secured by its key. Pressure was usually applied and blown off two or three times to prove that everything was in good condition. As little or no air space was left in any part of the apparatus, the pressure rose very rapidly, two strokes of the pump usually sufficing.

When the galvanometer was steady, its zero point was noted and pressure immediately applied, an operation which took about two seconds. As the apparatus could never be made perfectly tight, it was always necessary to continue pumping slowly, watching the gauge so as to maintain the pressure as nearly as possible constant till the galvanometer became steady, when the reading was taken and pressure immediately relaxed.

As soon as the galvanometer was again steady a new zero was taken, pressure applied again, and so on, usually ten times. If the results appeared to agree satisfactorily the ram was removed from the gun, and the tube drawn up and carefully examined to see that no leakage had taken place. It was then set aside, a clean tube

taken, and the cycle of operations repeated. In this way three to four substances per hour could be finished, from ten to fifteen observations being taken for each. The limits of accuracy are found in the measurement of pressure, which cannot be said to be quite satisfactory, and in the impossibility of maintaining the pressure perfectly constant till the galvanometer can be read. The error due to the last-named cause is less than might be expected, because the pressure varies rapidly about the point at which it should be maintained, and the galvanometer does not follow the small and quick rises and falls of pressure. In comparing the results among themselves the actual amount of pressure is not of so great importance as the fact that, as nearly as the gauge would read, it was the same in every case, viz., 2·6 tons on the sq. in. = 388 atmospheres.

In order to show the degree of accuracy for this work, the full figures for one substance are here quoted from the experiment book:—

Substance taken, butyric acid. Pressure, 2·6 tons.

Zero point.	Reading.	Deflection.	Rise of temp.
17·0	11·8	5·2	5°·23
17·7	12·5	5·2	5·23
18·1	13·1	5·0	5·03
18·6	13·3	5·3	5·33
18·8	13·7	5·1	5·13
19·0	13·7	5·3	5·33
18·9	13·65	5·25	5·28
19·1	13·9	5·2	5·23
19·1	13·8	5·3	5·33
19·3	14·1	5·2	5 23
		5·205	
Average deflection			
„ rise of temperature		5°·235	

When the individual figures vary so little among themselves it will easily be seen that the average of ten such observations must differ extremely little from the truth.

At the end of each day's work the junction was graduated to ascertain what deflection of the galvanometer corresponded to a degree centigrade. The graduation was performed in the following manner:—The junction was drawn out of the gun and dipped in a beaker of cold water from the tub to find its zero. As soon as the galvanometer had been read the junction was transferred to a beaker of warm water which was kept rapidly moving by means of a stream of air, and the temperature and the galvanometer were read as nearly as possible at the same moment; the junction was then again placed

in cold water to give a zero and re-transferred to warm water at a different temperature. Care was taken that the greatest temperature difference between the cold and hot water should cause a deflection slightly in excess of the largest caused by compression. The average of four or five such observations is taken as the deflection corresponding to 1° C. The same thermometer was used throughout for all these temperature readings. It was a "fixed zero" by Hicks, graduated in 0°·1 C., and could be read accurately to 0°·01.

To secure the greatest possible uniformity of conditions in all these experiments, every preparation was completed and all substances collected before a single compression was made. The whole of the final observations were thus compressed into a few days, and it was possible to maintain every part of the apparatus practically unchanged during that time.

The Results.

The following table sets forth all the results obtained with liquid specimens, together with such data as may probably be useful in arriving at general conclusions.

Substance.	Formula.	No. of observations.	Rise of temp. in deg. cent.	Maximum variation in deg. cent.
Hydrocarbons—				
Amylene	C_5H_{10}	11	10·00	0·6
Benzole	C_6H_6	10	6·43	0·8
Alcohols—				
Methyl alcohol	CH_4O ...	12	6·54	0·35
Ethyl „	C_2H_6O ...	14	4·60	0·8
Propyl „	C_3H_8O ...	10	6·23	0·35
Isobutyl alcohol.....	$C_4H_{10}O$ ..	20	5·90	0·5
Tertiary butyl alcohol .	$C_4H_{10}O$ ..	—	—	—
Amyl alcohol	$C_5H_{12}O$ ..	15	5·41	0·65
Capryl alcohol.....	$C_8H_{18}O$ ..	10	4·28	0·2
Allyl alcohol	C_3H_6O ...	10	4·65	0·2
Aldehydes —				
Aldehyde	C_2H_4O ...	10	8·98	0·75
Paraldehyde	$(C_2H_4O)_3$.	11	5·86	0·45
Benzoic aldehyde	C_7H_6O ...	10	5·00	0·2
Acids—				
Formic acid	CH_2O_2 ...	10	3·95	0·1
Acetic „	$C_2H_4O_2$ ..	10	4·71	0·4
Butyric „	$C_4H_8O_2$ ..	10	5·19	0·2
Ethereal salts—				
Methyl formate	$C_2H_4O_2$ ..	11	6·29	0·6
Ethyl „	$C_3H_6O_2$ ..	11	6·52	1·2
Methyl acetate.....	$C_3H_6O_2$ ..	10	7·13	0·5

Substance.	Formula.	No. of observations.	Rise of temp. in deg. cent.	Maximum variation in deg. cent.
Ethereal salts (*cont.*)—				
Ethyl acetate	$C_4H_8O_2$	10	7·11	0·4
Propyl „	$C_5H_{10}O_2$	10	6·58	0·2
Isobutyl „	$C_6H_{12}O_2$	10	6·65	0·3
Amyl „	$C_7H_{14}O_2$	10	5·91	0·4
Ethyl oxalate	$C_6H_{10}O_4$	10	5·31	0·2
Ethyl carbonate	$C_5H_{10}O_3$	10	5·92	0·3
Acetoacetic ether	$C_6H_{10}O_3$	10	5·00	0·3
Ethers—				
Ether	$C_4H_{10}O$	11	7·77	0·3
Amyl ether	$C_{10}H_{22}O$	10	5·69	0·2
Halogen derivatives—				
Chloroform	$CHCl_3$	10	8·19	0·35
Carbon dichloride	CH_2Cl_2	10	5·85	1·1
Carbon tetrachloride	CCl_4	10	7·76	0·5
Monochlorethane	C_2H_5Cl	11	8·19	0·7
Acetyl chloride	C_2H_3ClO	10	7·71	0·3
Dichloracetic acid	$C_2H_2Cl_2O_2$	10	4·17	0·3
Propyl chloride	C_3H_7Cl	10	8·54	0·7
Isobutyl chloride	C_4H_9Cl	12	7·60	0·9
Monochlorbenzole	C_6H_5Cl	10	6·46	0·45
Ethyl bromide	C_2H_5Br	10	9·09	0·5
Propyl „	C_3H_7Br	10	5·49	0·5
Isobutyl „	C_4H_9Br	10	5·37	0·65
Amyl „	$C_5H_{11}Br$	10	5·11	0·35
Monobrombenzole	C_6H_5Br	10	5·76	0·4
Bromtoluole	C_7H_7Br	10	5·00	0·4
Ethyl iodide	C_2H_5I	11	7·98	0·4
Isobutyl iodide	C_4H_9I	10	6·64	0·35
Unclassified—				
Acetone	C_3H_6O	10	7·36	0·5
Acetic anhydride	$C_4H_6O_3$	10	5·38	0·3
Carbon disulphide	CS_2	10	8·27	0·4
Inorganic—				
Water	H_2O	10	0·303	0·05
Sulphuric acid	H_2SO_4	10	1·96	0·15
Mercury	Hg	10	0·829	0·05

Remarks.

Ethyl Alcohol.—Readings not very trustworthy on account of defective insulation.

Tertiary Butyl Alcohol.—Readings exceedingly irregular. On taking out the tube it was found that the substance had solidified. Melted on standing.

Paraldehyde.—On keeping on the pressure after attaining the maximum deflection, a further deflection was observed due to the

crystallising of the substance. The crystals melted rapidly at the temperature of the room.

Monochlorethane.—The whole apparatus was cooled to 0° C. for this series of observations.

Propyl Bromide and Isobutyl Bromide.—A slight "kick" of the galvanometer image in the opposite direction to that indicating a rise of temperature was observed on the first stroke of the pump.

Iodides.—The free iodine was extracted by shaking with mercury.

Carbon Disulphide.—The temperature rose slowly to within a degree of maximum; then there was a sudden rise to maximum, succeeded by a rapid fall.

Looking merely at the rise of temperature produced by pressure, it is impossible to deduce any general laws from these figures. We find that, as a rule, in comparable series, the higher the molecular weight, the less the rise of temperature. This is best seen in the cases of the series of acetates and the halogen substances; but there are several perfectly distinct exceptions—such as the fatty acids—which come in the inverse order to that stated. It is worthy of note that these exceptional series all contain large proportions of oxygen.

We would draw special attention to the effect of pressure on paraldehyde and tertiary butyl alcohol, both of which are caused to solidify at temperatures above their normal melting point. We think it probable that all substances which follow the ordinary law of expansion by heat could be solidified by pressure if tried at temperatures not far from their melting point. The apparatus which we used serves extremely well for observing the course of events in such cases.

When a liquid which does not solidify is compressed, the image on the galvanometer scale travels almost steadily and rapidly to a point at which it remains fixed for a few seconds; it then begins to move back towards zero, as the substance is cooled by the water outside the compression tube. In the two cases mentioned above (paraldehyde and tertiary butyl alcohol) the behaviour of the galvanometer was entirely different, indicating a rapid rise of temperature on application of the pressure, and then a continuous slow increase as long as the pressure was maintained constant. The method of closing the gun by means of a ram renders it easy to remove and inspect a substance within half a minute after letting off the pressure, so that there is not time for the crystals to melt.

Experiments with Solids.

A number of specimens of metals were prepared and tested, with the results given in tabular form below. Of each metal two small

ingots were prepared and filed flat on one face, so that they could be tied one on each side of the flat junction, which was used without any tube. It is difficult in this way to secure at all a satisfactory contact between the sample and junction, and we are of opinion that the method originally used as described in the beginning of the paper will prove more trustworthy. The rise of temperature in metals is so small that, to obtain a readable deflection, it would be necessary to use a more sensitive junction than can be made of platinum-iridium alloys, as the galvanometer cannot be made much more sensitive without becoming too slow to permit of true readings. Considerable care was taken to secure specimens of metals in a state of approximate purity, but, the results having proved of so little value, the methods used need not be here described.

	Rise of temp. °
Aluminium	0·181
Magnesium	0·181
Zinc	0·062
Silver	0·047
Tin	0·125

Several other metals were tried, but the deflection was too slight to allow of accurate observation.

Notwithstanding the large amount of work involved in these experiments, study of the results shows but too clearly that this research can only be regarded as preliminary. Many interesting problems present themselves for solution, of which we think the following are worthy of mention :—

1. The effect of pressure in causing solidification should be followed up and tested with different substances at temperatures little removed from their melting point. In the case of tertiary butyl alcohol it may be noted that, though the crystals formed were too small to be clearly distinguished, they appeared to be of a different habit from those formed under ordinary circumstances.

2. The effect of temperature in causing differences in the amount of heat developed. It might be necessary to compare the substances at different temperatures so as to have them all in the same physical state.

3. The relation of compressibility to heat of compression.

This is but an indication of the few out of the many lines of research suggested by the work we have done. Some of these seem to afford good hope of yielding new knowledge of the constitution of matter.

In conclusion, we wish to record our gratitude to the Government Grant Committee of the Royal Society for affording us the means of

carrying out this research; and also to Professor Tait for allowing us the use of his laboratory and his valuable apparatus, without which these results could not have been obtained.

VIII. "On the Changes evoked in the Circulation and Respiration by Electrical Excitation of the Floor of the 4th Ventricle." By W. G. SPENCER, M.S., Assistant-Surgeon to the Westminster Hospital. Communicated by Professor HORSLEY, F.R.S. Received June 15, 1891.

(Abstract.)

The object of the research was to connect more closely clinical signs with pathological changes in the medulla by localising in the floor of the 4th ventricle the "centres" which influence the circulation and respiration.

The author commences his paper with a full account of the work of previous observers upon the medulla in relation to the circulation and respiration.

The research differs from preceding ones in the use of the electric current to excite without injury the floor of the ventricle, in avoiding puncture and incision of the medulla, in employing complete anæsthesia with ether without at the same time impeding respiration.

The floor of the 4th ventricle was accurately measured in each experiment, so that the distance from the calamus scriptorius and from the middle line of each point was known before it was excited. The experiments were performed on cats, dogs, and monkeys, the records of the changes which took place being divided into those affecting respiration, the rate of the heart, and the blood-pressure respectively.

By adding together the results obtained for each point in all the experiments on animals of the same species, conclusions have been arrived at for each species, and a comparison is then made of the three species of animals.

The conclusions drawn from the experiments, aided by the facts detailed in the historical retrospect, are as follows:—

(1.) *Inspiration.*—The part of the floor of the 4th ventricle which, when excited, caused an increase in the normal inspiratory impulses descending to the thorax lies along the middle line, extending for 2 mm. on either side.

(2.) *Expiration.*—The part of the floor of the 4th ventricle which, when excited, caused an increase in the normal expiratory impulses descending to the thorax lies along the lateral part of the ventricle, 2 to 3 mm. from the middle line.

FIG. 1.—Section of "Gun."

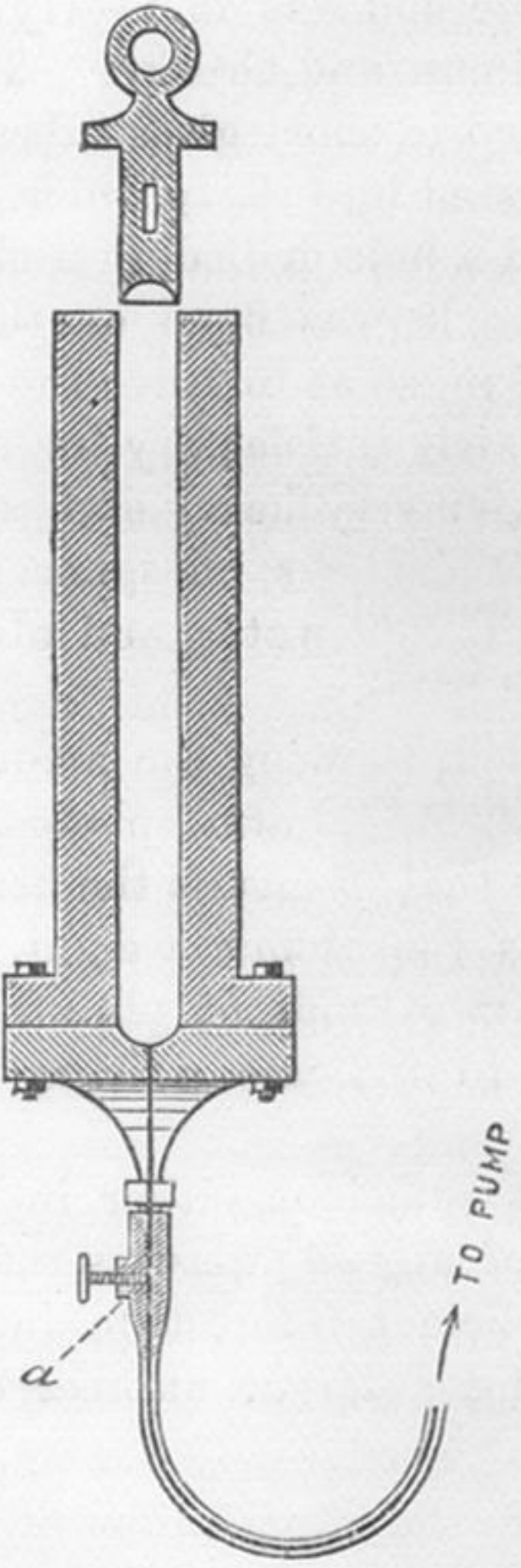


FIG. 2.—Section of Gauge.

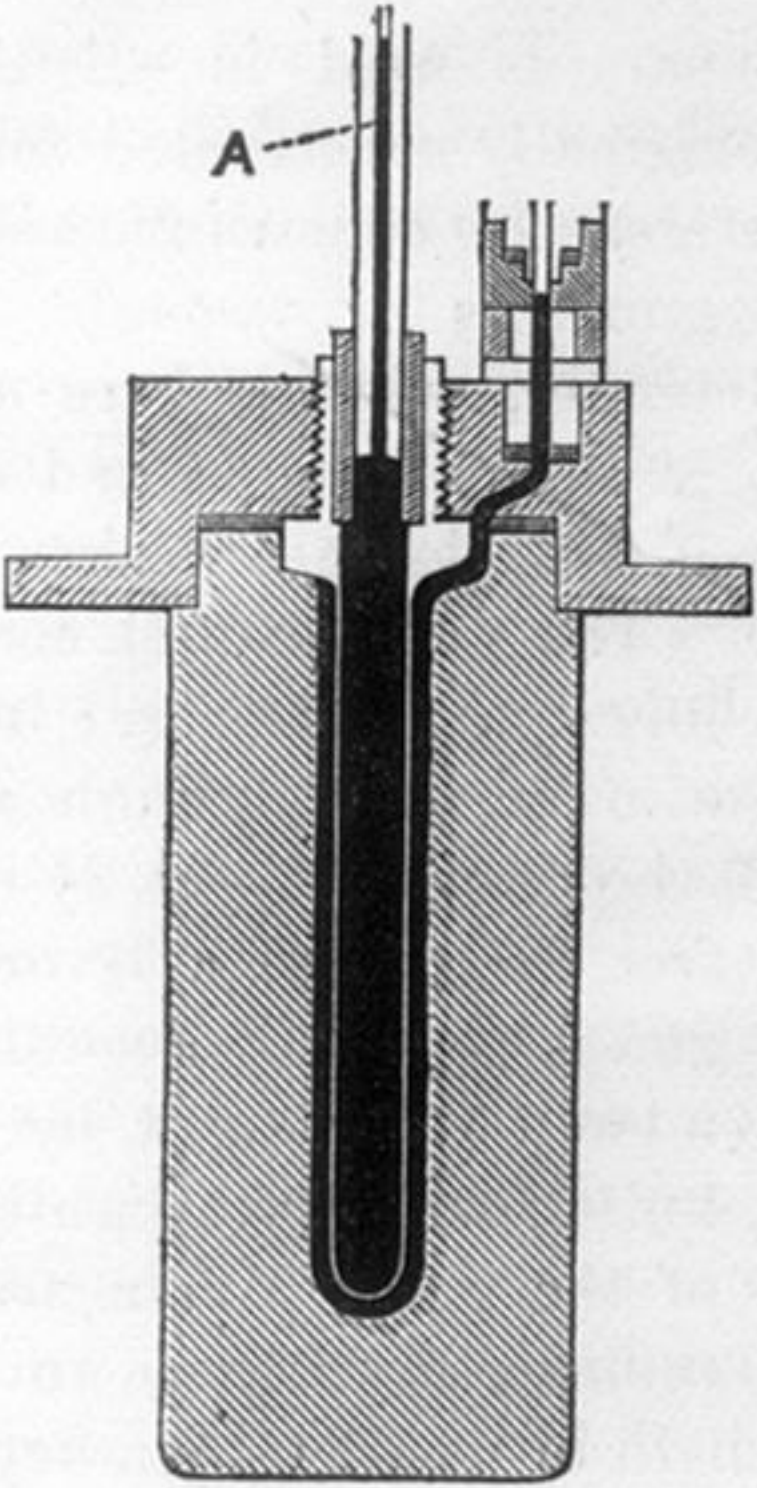


FIG. 3.—Section of Tube.