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# The Electric Water Level Indicator.

by

F S Rust and L. L. Vincent.

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# - ** INTRODUCTION ** -

## ** The Electric Water Level Indicator.**

The problem of automatically indicating, at a distance, the height of water in a storage basin or open water way is one which chiefly concerns water power plants although it may come up, of course, in many different cases. However, for the intelligent and secure operation of a hydro-electric plant, the necessity of the station attendent or operator having a constant knowledge of the conditions of the water supply, and especially any sudden changes, is imperative. For plants operating with small storage and high head, or with long flumes, it is especially necessary to have a close and accurate knowledge of the conditions. Again, where there is one plant with a limited constant supply of water and no storage, which operates in parallel with a plant which has storage, it is extremely desirable to know the conditions so that the former can run just below the point of overflow, and thus conserve the storage to the best advantage. Hence, it follows that there are but few hydro-electric concerns operating with open waterways which do not spend, sooner or later, some thing on the installation of an indicator.

While such conditions exist, and the problem is of considerable practical importance, it only comes up occasionally, and is looked upon as a mere detail of comparatively little significance, and nothing is said of it. However, when one goes about putting in an arrangement to perform this function, one finds it is not such a simple matter to get good results over even short distances, and at the same time keep within the limits of a reasonable expense.

One has only to stop and consider for a moment to realize that if any arrangement is used, it must be reliable. It would hardly pay to let several hundred K W flow over the spillway, at a time when water was scarce, because of the indicator registering incorrectly. Neither would it be desirable for a peak load station operating on a storage to suddenly drop a large load, thus causing a general disturbance of the system, because of the indicator failing to show the exhaustion of the supply. Yet such a station must have some automatic arrangement or keep a watchman at the reservoir to report conditions, which is, by the way, both expensive and unreliable. Hence, one sees that though a poor system may be better than none, it is at least worth while to look for the best.

Although reliability is essential, no concern will object to the least expense possible in obtaining the desired results. Hence, in working up the problem, we must give due consideration to costs, as well as to reliability.

It is our purpose to look up such schemes as have been employed in this work: work out such other ideas as are suggested; compare the advantages and disadvantages of each in such points as reliability, accuracy, simplicity and cost, and, if possible, choose or devise the best method for certain conditions which are likely to exist. It may be deemed desirable to make laboratoty tests of such methods, and, when feasable, we hope to do this.

In keeping with our purpose we have searched through a great number of technical magazines and references which gave promise of something on the subject, or at least some idea which might be applied. We found only one direct reference, a method suggested by A. H. Redtke in the Western Electrician, April 27 1907. We will discuss it later in detail. We will also discuss a system devised by Mr. E. L. Buker and installed at the Olmsted plant of the Telluride Power Company; also such schemes as depend on a constant potential direct or alternating current; a step-by-step scheme formerly devised by one of the authors; and a scheme in which the Wheatstone bridge principle is applied is worked out by the authors. We have made a study of a number of articles on position-signals such as the Telautograph, used principally for transmission of ranges and azimuths from observers to gunners in the army, the Range finder as used in the navy, telephone apparatus, etc., our purpose being to find such ideas as might be applied advantageiously to the problem at hand.

# *** THEME .***

## - Radtke!s Indicator.-

This system is set forth diagramatically in Plate I. According the the reference, this arrangement consists, essentially, of three electro-magnets, set 120° apart with a sector of a soft iron disc mounted on a shaft at the centre. The shaft should drive a pointer, through a set of gears, over a graduated dial.

The electrical connections are easily followed on the diagram. A terminal of each coil is brought out to a common point and connected to ground thru a closed circuit battery, such as a battery of gravity, or Lelande, cells, while the other terminals are connected each to a line wire. The coils should be wound with a rather large wire in order to get the necessary ampere turns at a low potential. The potential required of the battery will depend on this resistance and that of the line.

At the reservoir the apparatus consists of drum actuated by a float and counterweight, a wiper arm, and a set of contacts. The arm is carried by the drum and wipes over the contacts as the drum revolves. The number of these contacts, the size of the drum and the value of the gear train are determined from the number of readings desired in a given range of water level change. Every third contact is connected together in a group, and a group is connected to one of each of the live conductors. The wiper arm is permanently grounded, so that the circuit is always closed through one magnet, the current being switched from coil to coil as the arm moves. These are the essentials of the system as suggested by Mr. Radtke.

It is supposed that the armature will be dragged around with this shifting field. However, it is not difficult to see that it must fail to do so. At best the lines of force can only be conducted from the outer end of the magnet around to the part O, from whence they must pass to the magnet core again. The distance from the centre to the pole tip must necessarily be considerable, and with the resulting large leakage the field between O and the pole must be weak. Suppose the sector consists of something like 120°, as shown, and the current is switched from $C_1$ to $C_2$; the armature will be dragged into the position shown dotted, from which it cannot be moved by any one of the magnets. Again, suppose the sector small enough to avoid this difficulty, say 60°, then lines which radiate from O in the armature will not find a shorter arc path, hence, the armature will probably not be magnetized, and there will ne force exerted upon it.

This difficulty could be overcome by putting a short crank on the shaft O, placing the magnets farther out, giving each an individual armature and connecting these armatures to the crank; just as some engines are connected up. Or, the addition of a fourth magnet would correct the difficulty. However, this would necessitate a fourth line wire, and in this respect the system is already at a disadvantage.

Granting that the motion can be obtained, the arrangement is unreliable, because any failure to respond to each change at the reservoir, due to failure of battery or poor contact, will cause the instrument to register incorrectly until it is reset by actual observation of the water level.

Farther the number of leads required is sufficient in itself to make the system impractical for use over any but very short distances.

## - Buker's Indicator. -

Mr. Buker's indicator is a very ingenious arrangement in which ordinary incandescent lamps and a three phase 110 volt current supply are used. The lamps are switched about by a set of contacts into such relations that a number of indications considerably in excess of the number of lamps are shown. Plate II shows the diagramatic arrangement, and Plate III shows simplified diagrams of the six different combinations that come about. In Plate IV are listed the indications given by the system. As stated before, the system is in actual use, and it has given very satis factory results during the last four years.

In the station seven lights are mounted on a panel, where the attendant can see them easily. Lamps G and R are green and red respectively, and are 95 volt lamps. X is a blind resistance of the same value. The other five are uncolored 52 volt lamps. At the reservoir a rod carrying four contacts is run up and down a row of five stationary contacts by a float.

It is found that two 95 volt carbon lamps in series on 100 volts will not glow while a 95 volt and a 52 volt will. It will be seen that, in the position shown in Plate II, corresponding to Set B in Plate III. X is shunted by a 52 volt lamp and thus R is in series with it across one phase, while G is in series with it across the other. Thus G, R, and the 52 volt lamps will be lighted, while X, if a lamp, would be dark. The same relation will hold while the contact moves down the scale lighting the five 52 volt lamps in succession. Furthermore, as we move down, the lights are cut in alternately two and one, thus giving ten readings in passing over the five lights. It will be readily seen how thirty readings are thus obtained from the system as shown. There is a slight variation at the points where the shunt is changed from one leg of the line to another, but this is readily seen and of no consequence. A special contact throws in all the 52 volt lamps in parallel to shunt out G when the water gets dangerously low, so that R burns up to full brilliancy.

This system is very successful in giving results; but, obviously, it is at a great disadvantage in the cost of installation. Three phase current must be carried to the reservoir, besides one-sixth as many leads as readings required. In some cases, of course, single phase lighting leads will already be installed in such a way that it will only be necessary to run one extra lead. This was the case at Olmsted. In this instance the pressure-box is 1000 feet from the station and 350 feet above it. A very good pole line was already in, although loaded with a 5000 volt line beside a number of telephone and lighting circuits so that another arm could not be added. A cable was made up of #14 R C copper and hung under the arms. The last 200 feet on the station end was put under ground with other circuits. We would estimate the cost of installation as follows:-

| | |
|---|---|
| 7000 ft. #14 R C wire at 1 1/4¢ per ft. | $87.50 |
| 6 days labor making up cable and stringing same at $3.50 - - - | 21.00 |
| Material in and contacts - - - - - | 6.00 |
| 4 days labor making up and installing same, at$3.50 - | 14.00 |
| 8 lamps at 25 ¢ - - - - - - - - - - - - - - | 2.00 |
| 8 sockets at 35 ¢ - - - - - - - - - - - - - | 2.80 |
| 3 days labor making up Panel and installing same at $3.50 - - | 10.50 |
| 200 feet trench and conduit at$15. - - | 30.00 |
| Total - - - - - - | $173.80 |

The cost of the line is the principal item, and is obviously a serious disadvantage to the scheme. Its operation is dependent on the supply of A.C., which in most cases will be satisfactory. The power consumption is small, and of little consequence around a plant of any considerable size. As to accuracy and reliability, the system will show the changes of water level absolutely correctly so long as current is supplied to it.

## ** The Polarized Indicator.**

In the Polarized System the idea is that if, rises and falls in the water level can be made to send, correspondingly, positive and negative impulses of current through a circuit, we shoul be able to make these impulses add to, or subtract from, the readings shown by an indicating pointer at the other end of the line. To attain this, the principal of the polarized telephone ringer may be applied. The action of this bell is generally known, or a description can be found in any engineer's pocket book. It would, no doubt, be an advantage in every respect to use a mechanism actually taken from one of these bells. We show two possible arrangements in Plates V and VI which employ the mechanism from standard bells. In Plate VII we show the apparatus at the reservoir for sending the impulses, and Plate VIII we show a diagram of the circuit. In the arrangement shown in Plate V, the mechanism from any ordinary ringer is used, except that the coils should be rewound if necessary with larger wire so that a low voltage can be used. Such a bell should cost about $2.75 An extension of light material, M,,is attached to the ringer armature, and the ringer is mounted on a back board so that this bar stands horizontal. W is a toothed wheel of one-eighth inch brass turning on a horizontal shaft O. A pointer is attached to the wheel so that it rotates over a graduated scale. On the shaft are mounted two independent levers; x and y, which carry clicks, c. The stops s, S and R are fixed pieces. The levers x and y are connected to M by small rods d free toslip down through the hole, b, or they should be a flexible connection of some sort.

When the armature is exactly horizontal it is in unstable equilibrium in the permanent magnetic field. the lever, 1, is attached to the armature; and a spring,b, is so arranged as to resist any motion of the armature with an increasing force, thus always returning the armature, and in turn x and y to rest in a horizontal position.

Now suppose we have a current flowing from the line through the coils to the ground, and that a current in this direction causes the left end of the armature to be drawn up. As x moves up, C is pulled in by a small spring and engages a tooth of the wheel, and will move up until it strikes the stop S. The distance s-S should be such that the wheel is advanced one tooth. As soon as the current ceases to flow the click moves back to its normal position. Current in the opposite direction will produce the opposite effect. The stop, S , should prevent the armature touching the pole tip, otherwise it will probably stick. A similar arrangement of click drive is employed in the Strowger Automatic Telephone switchboard, and works very satisfactorily.

Another and perhaps a better arrangement is shown in Plate VI. In this the coil and magnet from a Western Electric Company's loud ringing telephone bell is used. This is a single coil pivoted at O and vibrates horizontally between the pole, N and S, of a permanent magnet. N is very powerful in its action. We would mount the coil behind a toothed wheel, W, with the rod, K, bent to project over the wheel. On this rod and in the plane of the wheel two clicks are mounted loosely. These clicks nominally rest on a guard, G, which keeps them clear of the wheel, and limits their motion so that the wheel is advanced just the pitch of a tooth for each impulse. The coil is attracted oppositely for opposite currents, of course. The spring, h, opposes the motion and brings the coil back to mid position each time. If found necessary, the clicks can be urged toward the coil by a light spring as shown. The moving parts should be made light, and in either type of instrument it will probably be necessary to damp the motion of the wheel by a light felt brake.

The impulses of current and their direction is controlled by the apparatus at the reservoir. We will first describe this apparatus and then show how it controls the current. The apparatus involves a drum D (see Plate VII) actuated by a float and counterweight. On each end of the drum, a ratchet wheel is fixed. Outside of these, on the same shaft, are two discs, A and A', which must be prevented from moving laterally. The disc A carries a click C, which is forced into contact with the ratchet wheel by the spring r. This click is on the inner side. On the outer side are mounted a circle of metal pins ($P_1$, $P_2$, $P_3$etc.) and contacts ($K_1$, $K_2$, $K_3$, etc.).

Note that when the drum, D, rotates counter clockwise, the ratchet, c, will catch and drag the disc around with the drum, while for an opposite rotation of the drum the click plays idly over the teeth. The spring catch, M, prevents any backward rotation of this disc. The disc A' is exactly like A, and since it is turned around it will be rotated for the clockwise movement of the drum. The ratchet wheels are mounted oppositely, of course. For each end there is a brush, B, made of spring brass and pivoted on the frame. This nominally rests on a pin and makes an electrical contact with it. Suppose the brush to be on pin $P_2$ as shown and the disc is made to rotate. B will slip off $P_2$, wipe the contact $K_2$, and stop on $P_3$.

The contact should be made slightly oblique to the plane of the wheel, to insure a good contact; however, not so much as shown in the figure. There must be spring enough in the arm to allow it to move a little laterally in wiping down the contact piece. B falls by the action of gravity.

A diagram of the electrical circuit is shown in Plate VIII. All the pins are connected together and grounded through the brushes *m* and *m*', which must be set so as to clear the contacts $K_1$, $K_2$, etc. All these contacts are connected together and to the single line wire through some sort of a collecting devise. For instance through brushes making contact with the shaft, which would have to be insulated and connected to the line. The battery, consisting of gravity cells, is connected between the brushes B B'. Now suppose again that the brush B is resting on $P_1$, B' will be resting on a pin on the other side, say $P'_3$, and the battery circuit will be normally closed. As A rotates B will fall and wipe $K_2$, thus connecting the positive pole of the battery to the line, while the negative pole is connected to ground through $P'_3$, and a positive impulse will be sent over the line, through the indicating instrument to ground.

When A' rotates a negative impulse will be sent through the circuit in the same manner.

The number of cells which will be required will depend upon the number of turns and resistance in the instrument coils, and also to a more or less extent on the resistance in the line. This brings us to another point. It has been seen that one lead and the ground can be used. Now it is always customary to have a metallic telephone circuit running from the station to the pressure box or reservoir. This can be utilized in addition for the indicator line by splitting the line as shown in Plate XVI, in connection with the Wheatstone Bridge Indicator. This splitting of the line is accomplished by leading the current in at the centre of a highly inductive coil and taking it out again in the same manner. The current splits, half flowing through each side of the line. Thus no difference in potential will be caused between the sides of the line, and the telephone will not be disturbed. The high inductance keeps back the ringing and voice currents while the coils oppose the flow of D C only by their resistance. The value of this resistance will be one-fourth of the sum of both coils since there are two branches of the path. The connection can be made by connecting between the coils of the telephone bells, where the ordinary telephone bells are used at each end of the line, and thus all expense for line is eliminated, and this system becomes practically wireless.

Using 1000 ohm bells the line would offer a resistance of approximately 500 ohms. It follows that the current used must be very small and in this case the relay must be wound with a large number of turns. By actual test we know that 6 volts applied to a bell wound to a 1000 ohms with #36 copper energizes it very markedly. Hence, we might use the bells without rewinding and use from 9 to 12 cells in series.

Note that the circuit is normally closed, hence, a small resistance should be connected in with the batteries to limit the current, say 500 ohms, which would be insignificant, compared with the resistance of the external circuit.

The circumference of the drum D enters in determining the variation in water level that each impulse represents. Hence, we can make the size of A and the number of contacts to suit our convenience; and vary D to suit any particular case. For example, suppose we want an indicator of one inch stops in a five foot flume, or 60 stops. In the drawing we show 15 contacts which we would give a pitch of three inches, making A something over 14.3" in diameter, and the circumference of D would have to be 15 inches.

In the instrument, the number of teeth on W would have to equal the number of readings desired (60 in the above example) in order to use the full 360° of scale. In the above case we would suggest a 12" circumference with one-fifth inch pitch for teeth.

This system was devised a couple of years ago by one of the authors; but has never been tried out. It looks feasable enough, and has some marked advantages. The cost of line is reduced to a minimum or nothing, which would make it especially adapted to signalling over considerable distances. The indicating instrument could be contained in a small case and mounted on the station switchboard where it would be in keeping with other instruments. The cost of the apparatus would not be great, although it lacks considerable of being simple. It is at a disadvantage in that the battery must be located at the reservoir where it may suffer from a lack of attention; and where it will generally be found difficult to keep the battery from freezing. Being a step-by-step instrument, any disturbance in its operation will likely throw it out of step, thus reducing its reliability.

## ** Constant Potential Systems.**

At first sight, it would seem that the simplest possible solution to our problem would be either: to measure the current through a circuit containing a resistance varied with the water level ; or to measure the variable potential drop along a resistance, i.e., the application of the potentiometer principle. The milliammeter or voltmeter, as the case may require, can be had for from $15.00 to $20.00; the rheostat at the reservoir should be installed for somewhat less than this; and with D C, the telephone line can be employed as explained in connection with the Polarized Indicator. Or, in case A C is used only one line lead is required. So either method promises to be both simple and inexpensive,.

However, for a constant relation between current and resistance the applied e.m.f. must have a constant value. In many cases this leads to a difficulty. The percentage error in the reading given will be the same as the percentage variation of the e.m.f. from the value at which the instrument is calibrated. The allowable error will vary with the case, but we would say it should hardly be greater than 20%. Most hydrelectric plants develop A C, and we may find in some cases a supply available at a sufficiently close regulation of voltage. On the other hand, D C machines are only used for exciting the alternators, and their voltage is being continually changed, hance we cannot use current from this source.,

In other cases machine current may not be available at all, such for instance, as in a peak load plant where the station is entirely shut down for a portion of the day.

These considerations led us to an investigation of the constancy of the e.m.f. of batteries under a small constant load, say from 10 to 30 milliamperes, since milliammeters can be had to give full scale reading for the latter current.

We immediately barred secondary cells from our considerations, as being too expensive and as requiring too much attention. While such an arrangement as Mr. Buker's requires no attention whatever for months at a time, the need for very little attention must be a requirement. Another objectionable feature is the well known variation of voltage at each end of the discharge curve of the cell.

We searched through every available treatise on primary cells hoping to find some information that would be useful. We could find no record of tests being made under such conditions as ours. The only tests available were for comparatively large currents, 2 1/2 to 3 1/2 amperes, and for short periods of time. The longest test found was one by A.E.Kennelly for 108 hours (see Cooper's Primary Batteries). Such information was of little value in our case, so we found it necessary to run a test ourselves. We have just finished a 22-day run, the data and results of which are shown in Plates IX to XIV inclusive.

We set up a new gravity cell, using distilled water and copper sulphate crystals, and allowed it to stand short circuited for four days to form zinc sulphate solution before beginning the test. We also set up a new Edison-Lelande cell, and obtained an old gravity cell which was in a run down condition. The e.m.f.'s, specific gravity of the solutions, and the temperature of the room were observed at short intervals. The potential measurements were made by comparison with a standard Clark cell giving 1.019 volts; a first class potentiometer and a sensitive galvanometer being used in the measurements. As shown by the data, the room in which the test was run was of very constant temperature.

We show two curves for each cell; one showing voltage vs time; and the other showing the percent-variation of voltage from day to day, i.e., the per-cent variation based upon the previous day's reading. It will be seen that the new gravity cell built up rapidly during the first four days. We decided that this was due to the low density of the zinc sulphate solution shorted it during the fifth and sixth days, putting it on its regular load to make the measurements. After this the voltage changed more gradually, but continued to rise, having changed one percent in the last four days. No doubt better results would have been obtained, had we set the cell up in the first place with a solution of zinc sulphate instead of depending upon its formation. The highest density reached was 1.035 while Pope tells us it should range 1.11 as a minimum to 1.15 as a maximum. John T Sprague in his book "Electricity" points out that there are various reasons which prevent the e.m.f. being absolutely constant. The activity of the zinc solution always varies with its density. Mixture of the solutions by endosmosis causes a variation, and any deposit of copper on the zinc causes a marked variation - something like .03 volts. These variations are of such extent that good authorities differ by 3% on the voltage of the cell.

In addition there is a considerable temperature variation, with respect to which Sprague says: "Between 32°F. and 52°F. there is a difference of .01 volt, and between 50°F. and 60°F. also .01, and between 60° and 100° about .025 volt. This gives a variation of 4 1/2% within the range of ordinary atmospheric changes.

We are forced to conclude that this source of e.m.f. could only give results of anywhere near the required accuracy under the most favorable conditions, and then would require a greater amount of intelligent care than it is likely to get in such work. The results on the old cell show what may be expected if the zinc solution is allowed to become too dense.

Sprague tells us that this cell is the most successful attempt to obtain constancy under load, hence, we may further conclude that batteries are not adapted to such measurements. We have only to glance at the results from the Lelande cells to see that it is not adapted to our use.

Where a constant potential A C is available, there will usually be several different methods of connection to choose from. One way, of course, would be to take current from the station lighting circuit through the ammeter and resistance in series using a full metallic circuit. However, the station transformers will often have one point of the secondary winding grounded, or at least there will be no objection to grounding it, and then we can take a tap from some point of potential above ground, lead this through the ammeter, thence over a line wire and through the variable resistance to ground at the reservoir, thus requiring but one line lead.

In cases where there is a lighting circuit to the reservoir already installed we have a still simpler arrangement. A resistance having a uniform drop is connected directly across the lighting circuit, a point is moved over this resistance by a float, and a lead is taken from this contact through a voltmeter at the station, and connected to either side of the line. Thus the potential drop shown on the voltmeter will vary with the water level. If no other point on the secondary net work is grounded, we may even dispense with the extra lead by connecting the voltmeter from line to ground at the station and grounding the contact point at the reservoir. The diagrams on Plate XV will make these different arrangements clear.

In all these arrangements the results will be affected by the regulation of the transformer, which in some cases may be as high as 3% where the load varies from zero to full load capacity. Further we must not overlook the condition that in plants transmitting power over some distance it is often found necessary to vary the voltage at the station, often as much as 4%. In the case of the potentiometer method, the results will affected by any change in the line drop from the value existing at the time the instrument is calibrated. Conditions will vary to such an extent in different cases that one can only determine the practicability of the use of A C in any particular case when all the conditions are known.

## ** The Wheatstone Bridge Indicator.**

This system is one,devised by the writers, in which the principle of the Wheatstone Bridge is employed; and from which, we believe, most of the objectionable features of the other methods are eliminated.

The very accurate results given by the Wheatstone Bridge are generally known, since it is constantly used in telephone testing, and in electrical measurements generally. Kempster B. Miller in his "American Telephone Practice" tells us that one reliable manufacturer claims an accuracy attainable of one-fifth of one percent for resistances ranging from 10 to 10000 ohms and as great as one-eighth of one percent for resistances ranging from 100 to 1000 ohms. This of course assumes a sensitive reflecting galvanometer. By using unusually high e.m.f.s (110 volts), Mr. Miller obtained even higher degrees of accuracy for large resistances than those claimed by the manufacturer. The fact that the results are quite independent of fluctuations in the emf used makes the principle especially adapted to our purpose. An increase in the e.m.f. can only increase the accuracy, somewhat, since it will cause a greater potential difference on the galvanometer for a given variation from the conditions for perfect balance, and vice versa.

Our idea is to use the bridge in the station to measure the resistance in the circuit which is varied with the water level. Two of the legs are fixed in value while the third (R) is continuously varied to maintain a balance. Obviously there will be a certain point on R corresponding to each point on the resistance at the reservoir, hence, we may calibrate R to show the height of the water. We have been concerned principally in working out the details for the balancing of the bridge to be done automatically, and the greater part of the following discussion must be in connection with those.

Plate XVI shows a diagram of the electrical connections, Instead of the ordinary galvanometer, we use a specially constructed relay or trigger mechanism based upon the same principle (shown in Plates XVII and XVIII). The method of arranging the variable resistance at the station, and the mechanism for adjusting the balance, are shown in assembly and detail in Plates XIX to XXII inclusive.

The drawings show the relay in such a manner that little needs to be said covering the mechanical details. We show it as being made up with four bar magnets as usually used in telephone magnetos. The air gap is decreased by inserting a soft iron block, and the whole is fastened to a mounting board. C is a coil of wire having knife blade bearings made up as shown and taped to each end. Brackets, which are screwed to the back board, supporting the coil so that it is free to rock on its bearings. The bearing should be so mounted that the centre of gravity of the coil hangs below them, then by mounting a counter weight on the extension, b, the coil can be delicately balanced on the bearings and thus increase the sensitiveness of the relay. The direction in which the coil will rock depends upon the direction of the current. The coil causes a battery contact which makes contact with either of two spring contacts marked "Electro magnet contacts". Leads from these springs run to electro-magnets in the instrument - proper, which will be taken up later.

The sensitiveness of the relay can be increased by cutting the corners of the iron block away, and by moving the springs in close so as to require only a small movement of the coil to make contact. The relay is made up different from the ordinary galvanometer in order to make it more substantial, and give a better way of getting a contact. However, we do not doubt that the necessary sensitiveness can be obtained. We would wind the coil to the dimensions shown with #35 silk covered copper wire giving 600 turns, and a resistance of 176 ohms.

Referring to Plate XIX, the resistance R is wound in solenoid form, consisting of one layer of resistance wire wound on a 1 1/2" wooden cylinder. A contact block shown in detail on PlateXXIIis moved up and down a brass runner, and carries a contact shoe which is pressed against the solenoid by a couple of light coil springs (not shown) between the shoe and the block. This block is actuated by a continuous belt, of fish line say, which is shown dashed in the drawings. This belt runs from the block, over a pulley wheel at the upper end of the solenoid, thence around one groove of a double groove pulley at the bottom, thence through an idler pully, thence through the second groove, and up to the block again. The idler keeps the cord taut and gives a large contact surface, while the double grooves keep the cord from creeping as it would otherwise do.

This double grooved pulley at the bottom is fixed to a toothed wheel, which is attached by a couple of electromagnets through a ratchet mechanism as shown, and thus the motion is given to the contact block.

Leads from the contact springs on the relay run each to one of the magnet coils, thence to the make-and-break contact on the corresponding armature, and thence through a battery of sufficient strength to work the mechanism.

As shown the magnet coils are three inches by one and one-half inches having a winding depth of one-half inch. This will accommodate 780 turns of #20 single cotton covered copper wire, and give a resistance of 1.725 ohms. On 4 gravity cells in series this would give about 2.2 amperes or nearly 1700 ampere turns which we believe would give a sufficient pull to operate the wheel. If not, the applied e.m.f. can be readily increased.

The armatures of the magnets each carry a click which is urged toward the toothed wheel by a spring, but is normally held clear, while the armature is in the lower position, by a stop. Each armature also carries a light spring brass contact which catches under a pivoted contact piece each time the armature falls, thus giving a make-and-break contact.

So long as the bridge is unbalanced, the relay will hold one contact closed, and due to the make-and-break contact the corresponding armature will vibrate, and drive the toothed wheel. The relay must be so connected that the motion will be in a direction to bring about a balance.

All the parts are mounted on a back board, and should be enclosed in a nicely finished case for mounting on the wall. A pointer can be attached to the contact block and extended through a slot in the face of the case, and thus made to move over a scale on the face. The length of the instrument as a whole will be finally determined by the length of the solenoid, which in turn must be long enough to accommodate the required resistance, a resistance wire of sufficient size to withstand the necessary rubbing of the contact being used.

In such cases as it is convenient to furnish an independent lead, the resistance in all the legs should be kept small, say around 1000 ohms, since little is lost in accuracy and the apparatus will be more easily constructed.

However, where we wish to take advantage of the use of a telephone line, we must make the corresponding line resistance (which we have shown to be about 500 ohms), a small part of the total resistance of the leg. Assuming the conditions used in previous discussion, i. e., 60 steps, we will use 100 ohms per step thus giving a total possible resistance in the line of 6500 ohms. We would make R equal 650 ohms and the two fixed resistances 6500 and 650 respectively.

In this case we would make R up with #24 manganin wire (see Foster) which has a diameter of .0201 inches and a resistance of .747 ohms per foot. Its current carrying capacity is 5.8 amperes. With the above arrangement there would never be less than 50 ohms in R, so we would make this up as a separate coil, and wind 600 ohms on the solenoid. This would require 803 feet or 2043 turns on a 1.5 inch cylinder. Allowing 50% for insulation this would require a cylinder 61.4 inches long. The wire should be wound tightly on the cylinder, and at the same time a thread of one-half the diameter of the wire should be wound parallel to it to keep the turns separated. This arrangement gives sufficient room for large and distinct scale, which may be read from a convenient distance.

For winding the other resistances, we may use a still smaller manganin wire, for instance #36 has a resistance of 12 ohms per foot and a carrying capacity of 2 amperes where radiation is free. The least resistance through any branch will never be less than 550 ohms with the conditions assumed above, hence, the current will be small. For example, it could never be greater than .2 ampere with 110 volts applied to the bridge.

It is hard to say just what would be the best value of voltage, but ordinarily Wheatstone bridge measurements are made with one or two volts. Where exciter current is available we may take it at a portion of the exciter e.m.f. by taking the drop across a portion of a bridged resistance to apply to the bridge; and draw it through a resistance to work the driving mechanism, and thus do away with batteries. With such an arrangement we believe the system would require little or no attention, if properly made up. Where machine current is not available, six or eight Lelande cells would be the best source of power, since they require no attention after being set up until the elements are exhausted.

Where a water way runs normally nearly full, we would connect the resistances so as to be mostly cut in for this condition, and thus require the smallest current. Obviously they can be made to either increase or decrease with a rise of water by reversing the connections. One end of the solenoid must be connected through the separate 50 ohm coil to the point C, while the contact block is either connected through a flexible lead or through the runner to B.(see Plate XVI).

The relay may either be contained in the case with the other apparatus, or placed at some convenient, out of the way, place.

We have here a system based upon a well known and reliable principle. The mechanical motion is such as we have seen in actual use and we are confident of its satisfactory operation. We are also confident of the trigger motion performing its function as we have designed it. However, if it should fail to do so we have only to change its construction to that of the ordinary galvanometer to make certain of its working. The system is adapted to the use of batteries, and hence, is applicable to all cases. We have taken advantage of the minimum in line cost, and the system can be used over any desirable distance. A telephone circuit of #10 copper has a resistance of approximately 10 ohms per mile and, hence, adds only about 2.5 ohms per mile to our circuit, which is insignificant, even over large distances. However, in taking this advantage, we have introduced the copper resistance of the line, and, hence a source of error due to temperature. All the other parts should be of manganin and so be but little affected by changes of temperature.

The maximum temperature range that we may expect is 40°C. Taking the coefficient of temperature variation for copper to be .0042 and the resistance as 500 ohms the change would amount to about 500 x .0042 x 40 = 84 ohms. This is 1.29% of 6500. However, the instrument could be calibrated, at a time of moderate temperature, and one-half of the 500 ohms would be in the station where it could not be affected by such marked variations, hence, the percent error would be less than one-half the above, that is less than .65%.

It should be noted that the system is liable to the effects of earth currents which might have some effect in long distances.

We cannot see any particular disadvantage in the instrument not being adapted to mounting on the switchboard. Switchboards are usually so designed that it is inconvenient to add anything to them. The instrument has a great advantage in the long scale.

The motion of the contact block can readily be made to show special signals; such, for instance, as flashing a green light at the point of overflow or a red light when the water is dangerously low.

As to the cost of the apparatus it is difficult to form an opinion. The apparatus at the reservoir is of the simplest. As to that in the station, we would estimate from what experience we have had with similar apparatus, that it could be made up for from $25. to $35. including the batteries.

## **CONCLUSION**

## ** Conclusion.**

In deciding upon an indicator for any particular case, we must be guided by the conditions that obtain. We believe we have gone into the subject pretty thoroughly although we have purposely made no mention of the crude mechanical devices, and the many wired electrical devices that may be suggested, and have actually been employed in some cases.

We do not offer Mr. Radtke's scheme even as a possible solution, but include it merely because it shows us how somebody else would attack the problem, and because somebody thought the idea worth publishing.

Mr. Buker has hit upon a scheme which has marked advantages in reliability and accuracy. However, it requires too much line. Good line construction is expensive, and poor line is a constant source of trouble. For cases where there is a constant supply of A C available and where the conditions will allow a low cost of line, this is the system we would choose. This latter condition, however, limits its scope to a few hundred feet at the most.

The constant potential systems are so simple as to be obviously the best, provided an absolutely constant potential could be obtained. We have shown, however, that this is quite impossible.

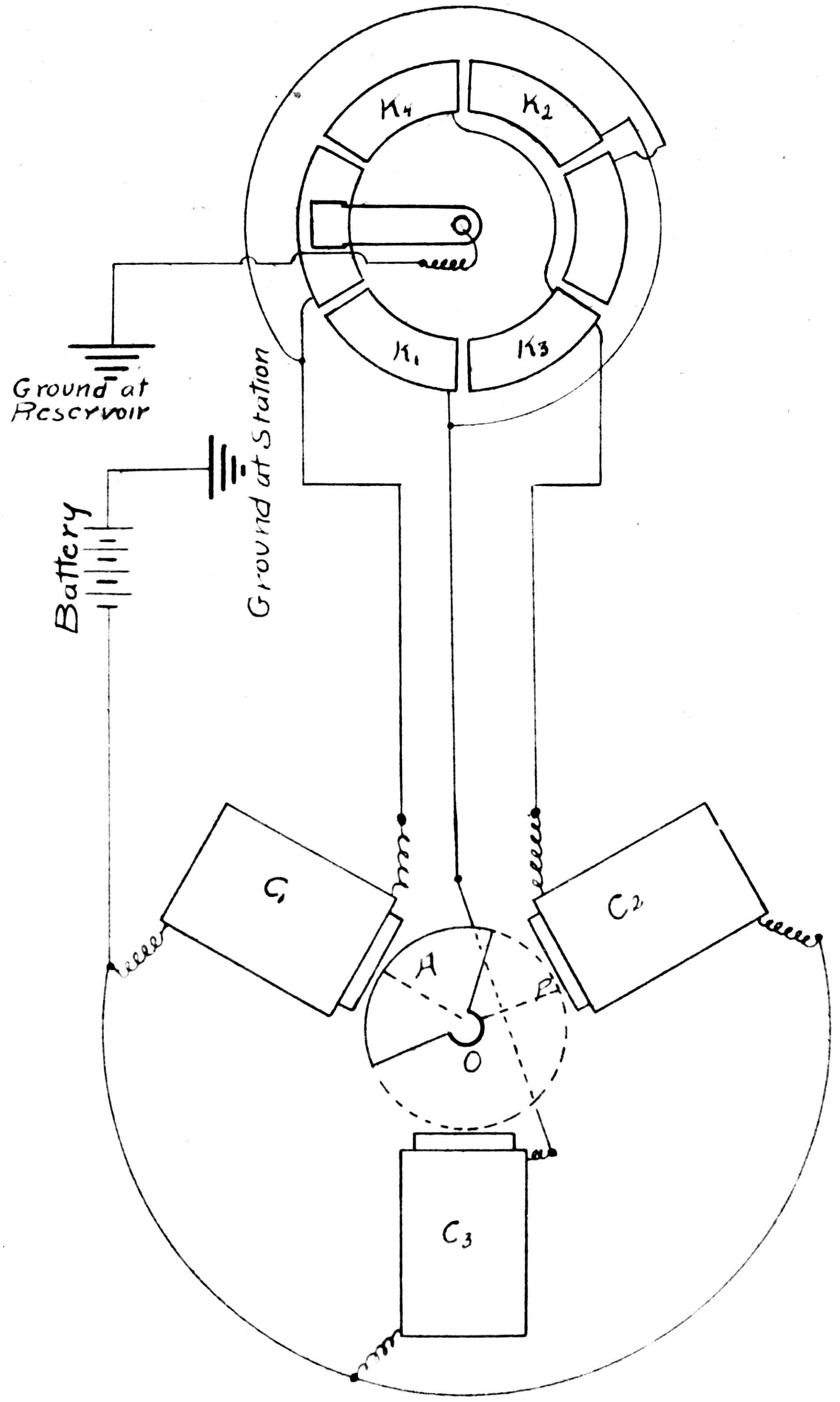
We offer the polarized type as a possible arrangement for use with batteries and for long distances; but we believe we have superseded this idea with a better one, in the Wheatstone bridge type of indicator.

This system is applicable to any set of conditions one can think of, since it may be operated on batteries, and it can be used over indefinite distances. Its cost will compare favorably with any system, and we believe its reliability will. Its action is entirely automatic, and where machine current is available, it will require very little attention or expense to maintain it.

# ** DRAWINGS.**

# * Index to Drawings.*

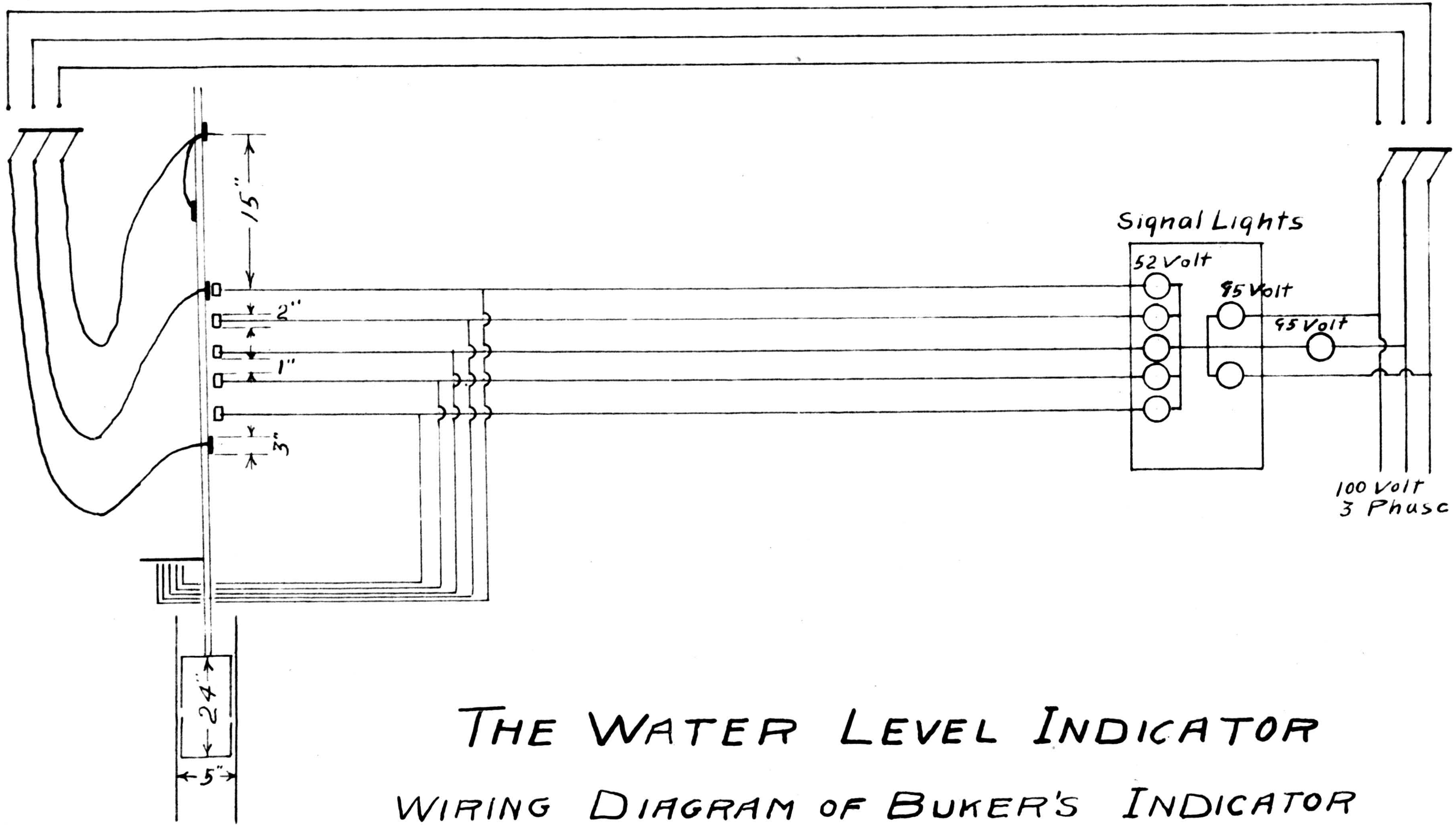
Plate I



THE WATER LEVEL INDICATOR

DIAGRAM OF RADTKE'S INDICATOR

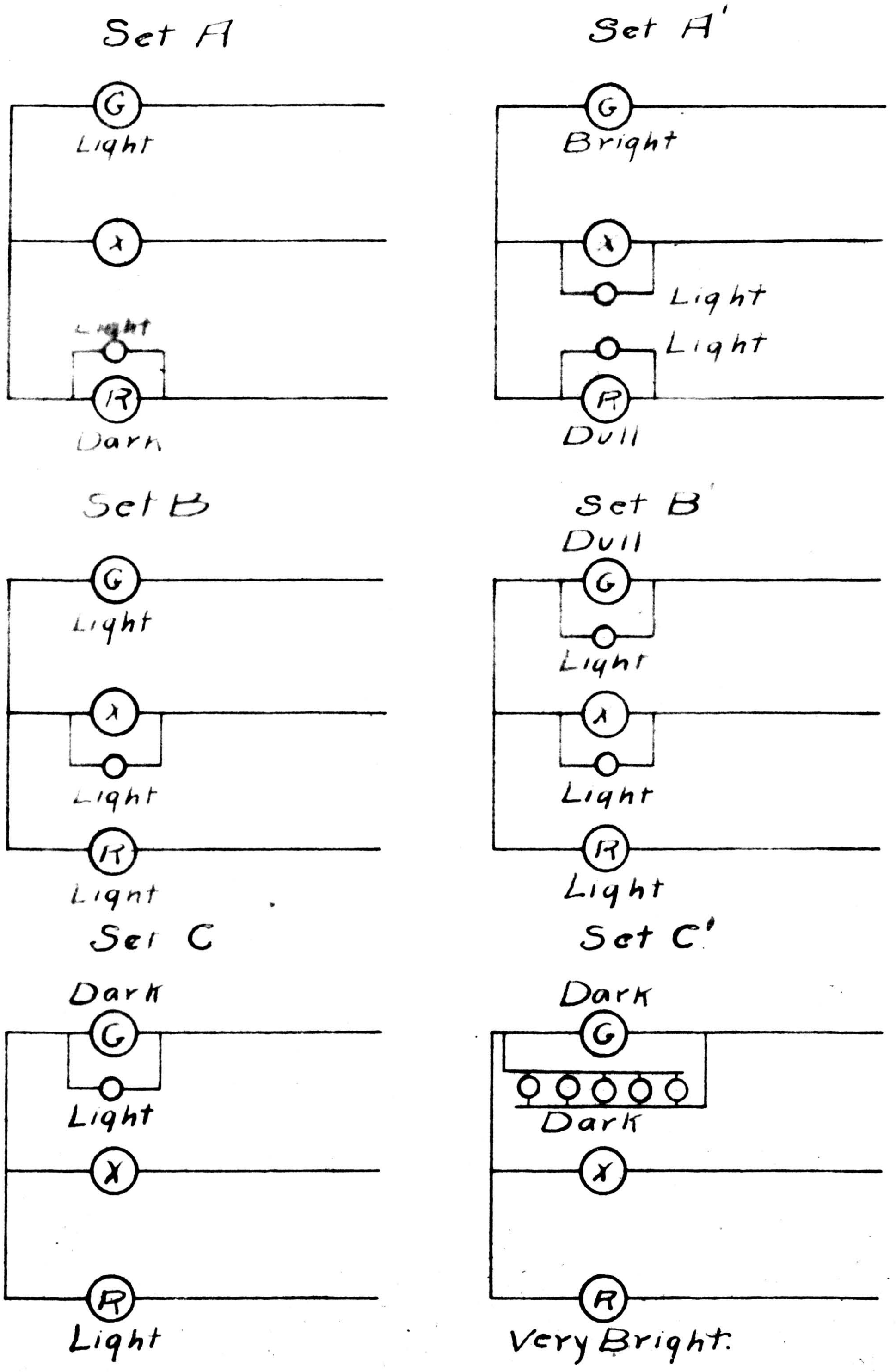
Plate II



THE WATER LEVEL INDICATOR

WIRING DIAGRAM OF BUKER'S INDICATOR

Plate III



THE WATER LEVEL INDICATOR

DIAGRAMS OF THE SIX COMBINATIONS
OF BUKER'S INDICATOR

Plate IV.

# PRESSURE BOX SIGNAL CIRCUIT.

## Water Heights Indicated by Signals in Station.

-----------oooooo$oooooo-----------

| Signal. | | Elevation. | Remarks. |
|---|---|---|---|
| Green | 1 | 493.00' | -1.2'Overflow |
| " | 1-2- | 492.85' | -1.05' " |
| " | 2 | 492.70' | .90' " |
| " | 2-3- | 492.55' | .75' " |
| " | 3 | 492.40' | .60' " |
| " | 3-4- | 492.25' | .45' " |
| " | 4- | 492.10' | .30' " |
| " | 4-5- | 491.95' | .150' " |
| " | 5 | 491.80' | -Overflow Level. |
| G. R. | 5-1(G.Brighter) | 491.65' | -3 ft. Storage. |
| " | 1(Same Brilliancy) | 491.50' | -2.85' " |
| " | 1-2- | 491.35' | -2.70' " |
| " | 2 | 491.20' | -2.55' " |
| " | 2-3- | 491.05' | -2.40' " |
| " | 3 | 490.90' | -2.25' " |
| " | 3-4- | 490.75' | -2.10' " |
| " | 4 | 490.60' | -1.95' " |
| " | 4-5- | 490.45' | -1.80' " |
| " | 5 | 490.30' | -1.65' " |
| " | 5-1-(R.Brighter) | 490.15' | -1.50' " |
| Red | 1 | 490.00' | -1.35' " |
| " | 1-2- | 489.85' | -1.20' " |
| " | 2 | 489.70' | -1.05' " |
| " | 2-3- | 489.55' | .90' " |
| " | 3 | 489.40' | .75' " |
| " | 3-4- | 489.25' | .60' " |
| " | 4 | 489.10' | .45' " |
| " | 4-5- | 488.95' | .30' " |
| " | 5 | 488.80' | .15' " |
| " | (Very Bright) | 488.65' | Danger Level. |

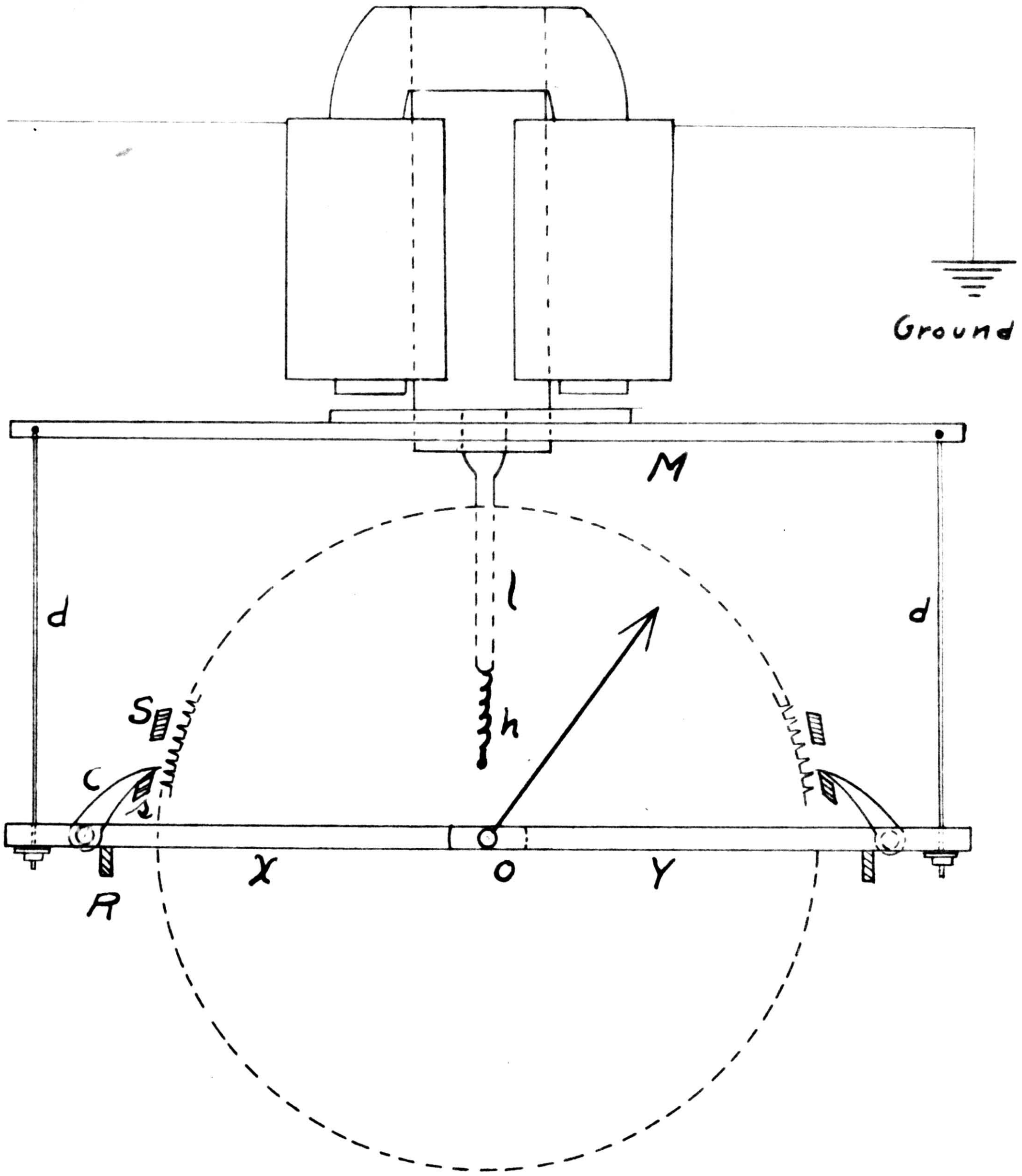
(SIGNED) Earl L. Buker,

Approved_____________

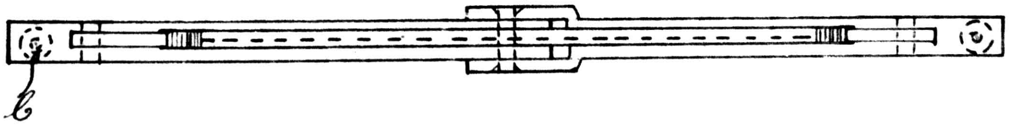
Oct. 1 1906.

4-5-09.

Plate V



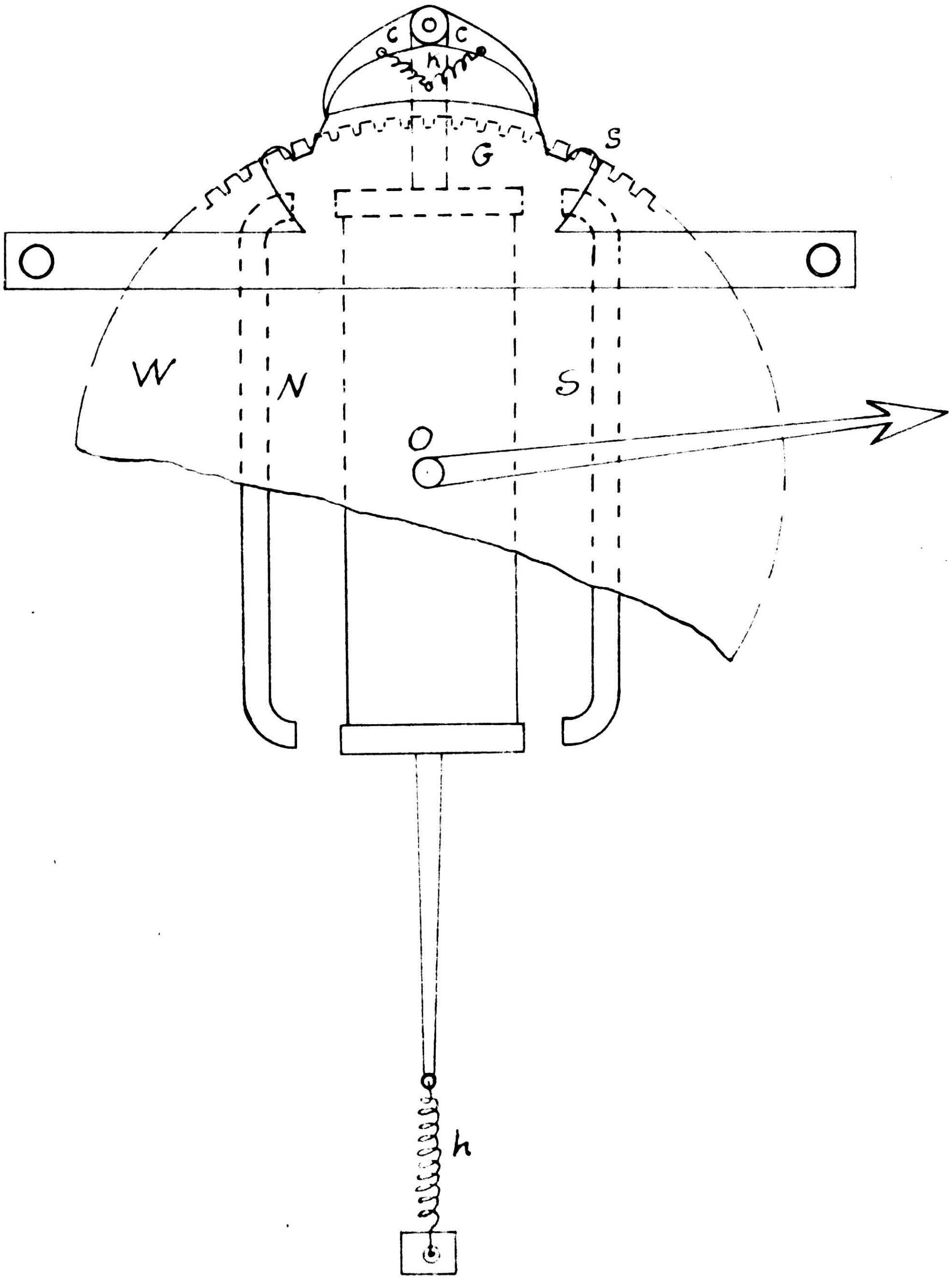
Bottom View of Wheel & Ratchets



THE WATER LEVEL INDICATOR

POLARIZED TYPE: STATION INSTRUMENT

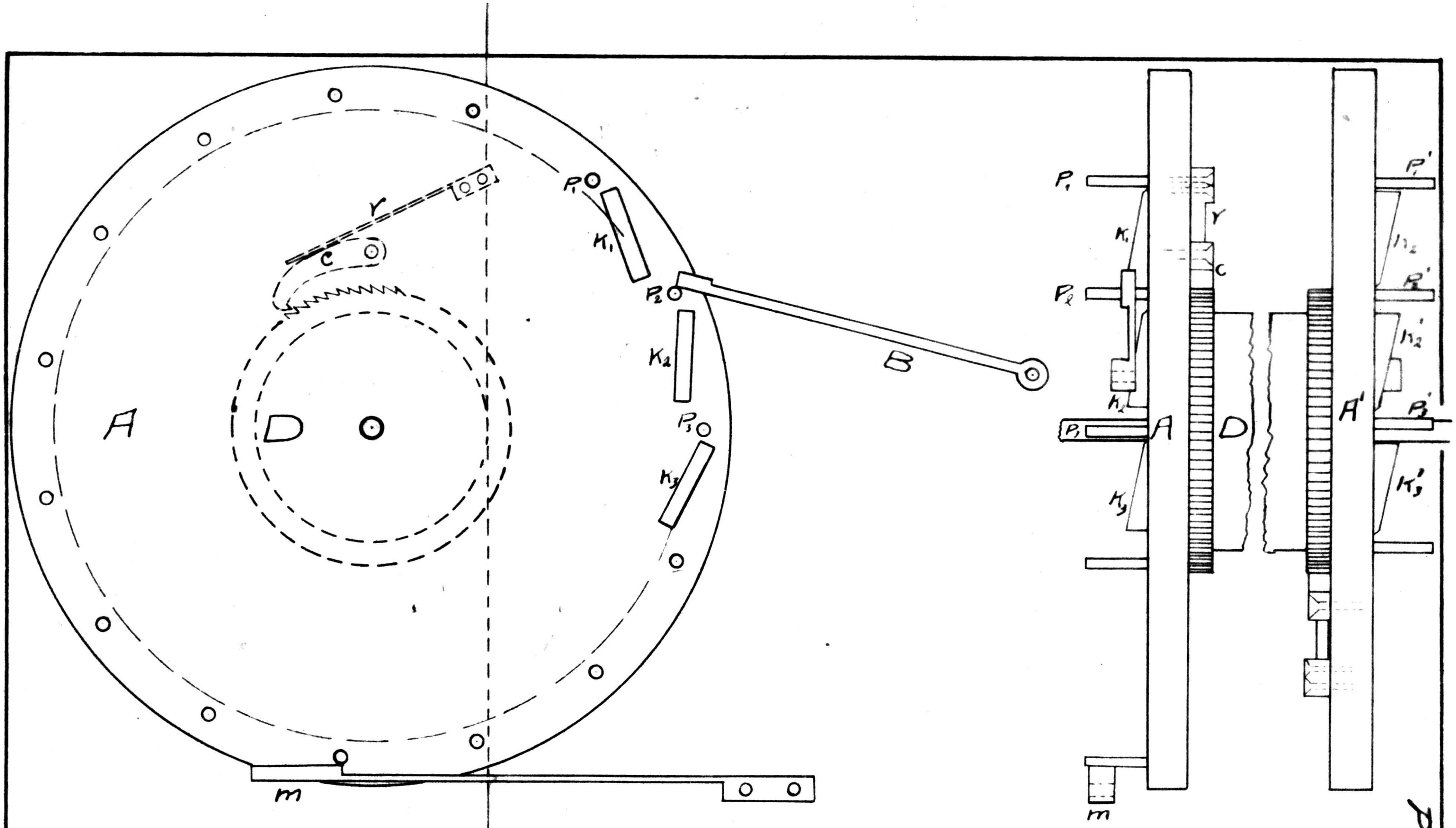
Plate VI



THE WATER LEVEL INDICATOR

POLARIZED TYPE: STATION INSTRUMENT

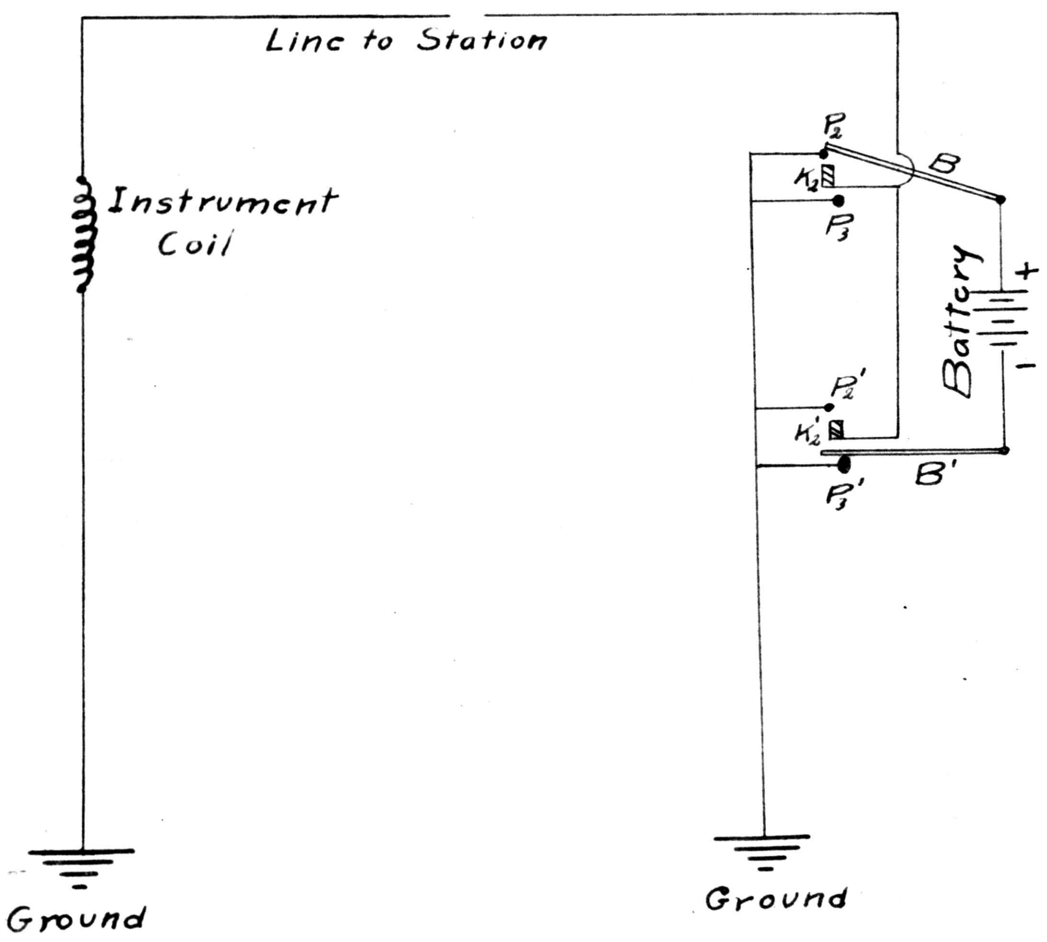
Plate VII



THE WATER LEVEL INDICATOR

POLARIZED TYPE: INSTRUMENT AT RESERVOIR

Plate VIII



# THE WATER LEVEL INDICATOR

## POLARIZED TYPE OF INDICATOR WIRING DIAGRAM

Plate IX.

## Voltage Test of Gravity Cell.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5/5 | 5 P M | 1.000 | .774 | | | | |
| 5/6 | 5 P M | 1.000 | .856 | .082 | 10.620 | 24°C | |
| 5/7 | 10 A M | .790 | .865 | .009 | 1.0520 | 22°C | 1.005 |
| 5/7 | 4 P M | .250 | .874 | .009 | 1.040 | 22°C | 1.005 |
| 5/8 | 11 A M | 1.290 | .874 | .000 | .000 | 21°C | 1.005 |
| 5/9 | 10 P M | .960 | .890 | .016 | 1.830 | 21°C | 1.008 |
| 5/10 | 10 A M | .500 | .928 | .038 | 4.270 | 21°C | 1.008 |
| 5/10 | 10 P M | .500 | .926 | -.002 | -0.215 | 21°C | 1.011 |
| 5/11 | 11 A M | .542 | .943 | .017 | 1.835 | 21°C | .000 |
| 5/12 | 9 A M | .917 | .956 | .013 | 1.380 | 21°C | 1.021 |
| 5/12 | 12 P M | .625 | .968 | .012 | 1.255 | 22°C | 1.022 |
| 5/13 | 2 P M | .584 | .968 | .000 | 0.000 | 21°C | 0.000 |
| 5/13 | 11 P M | .333 | .969 | .001 | 0.103 | 21°C | 1.026 |
| 5/14 | 10 A M | .542 | .973 | .004 | 0.413 | 21.5° | 1.025 |
| 5/14 | 11 P M | .500 | .974 | .001 | 0.103 | 21°C | 1.030 |
| 5/15 | 10 P M | .940 | .972 | -.002 | -0.203 | 20°C | 1.025 |
| 5/16 | 10 A M | .500 | .974 | .002 | 0.203 | 19°C | 1.024 |
| 5/16 | 11 P M | .452 | .978 | .004 | 0.412 | 20°C | 0.000 |
| 5/17 | 12 M | .542 | .978 | .000 | 0.000 | 21°C | 1.029 |
| 5/17 | 10 P M | .417 | .980 | .002 | 0.202 | 21.5° | 0.000 |
| 5/18 | 8 A M | .417 | .980 | 0000 | 0.000 | 21.5° | 0.000 |
| 5/18 | 11 P M | .625 | .982 | .002 | 0.203 | 21°C | 1.031 |
| 5/19 | 11 P M | 1.000 | .985 | .003 | 0.306 | 21°C | 0.000 |
| 5/20 | 2 P M | .584 | .986 | .001 | 0.101 | 21°C | 0.000 |
| 5/21 | 10 A M | .832 | .986 | .000 | 0.000 | 21°C | 1.0325 |
| 5/21 | 12 M | .584 | .987 | .001 | 0.101 | 21°C | 0.000 |
| 5/23 | 10 A M | 1.410 | .992 | .005 | 0.507 | 21°C | 1.032 |
| 5/24 | 2 P M | 1.165 | .991 | -.001 | -0.101 | 21°C | 1.035 |
| 5/26 | 10 P M | 2.330 | .998 | .007 | 0.707 | 21°C | 0.000 |
| 5/28 | 10 P M | 2.000 | .992 | -.006 | -0.602 | 21°C | 1.040 |

Note. Where no determinations of specific gravity was made we have filled the blank spaces in that column in the table with zeros.

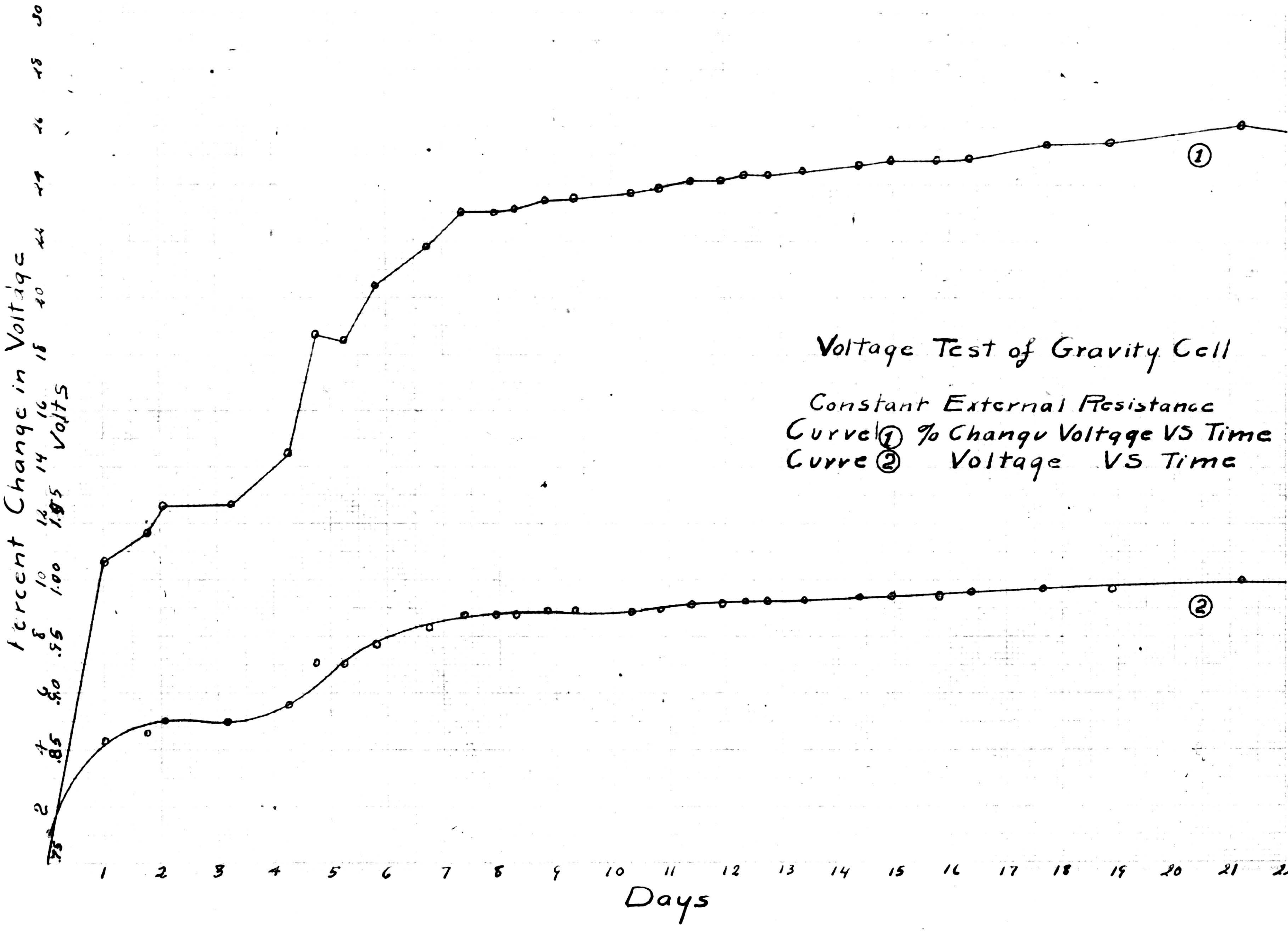

Voltage Test of Gravity Cell
Constant External Resistance
Curve ① % Change Voltage VS Time
Curve ② Voltage VS Time
①
②
Percent Change in Voltage
Volts
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
.75 .85 .90 .95 1.00 1.05
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Days

Plate X

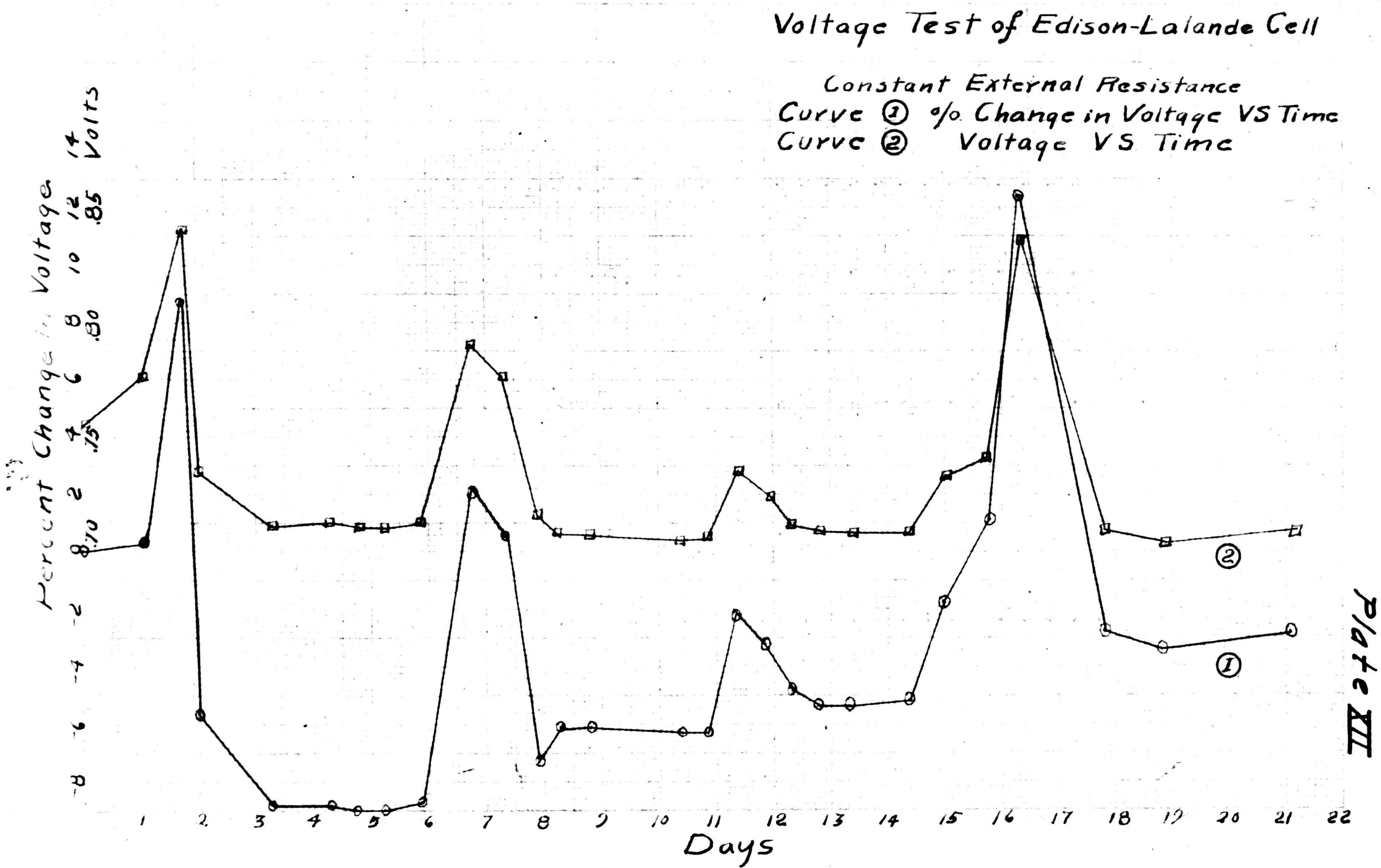
## Plate XI.

### Voltage Test of Edison-Lalande Cell.

| | | | | | | |
|---|---|---|---|---|---|---|
| 5/5 | 5 P M | ..754 | | | | 1.240 |
| 5/6 | 5 P M | .775 | .001 | .1342 | 24°C | 1.236 |
| 5/7 | 10 A M | .841 | .066 | 8.520 | 22°C | 1.285 |
| 5/7 | 4 P M | .735 | -.106 | -14.430 | 22°C | 0.000 |
| 5/8 | 11 P M | .712 | -.023 | -3.130 | 21°C | 0.000 |
| 5/9 | 10 P M | .712 | .000 | 0.000 | 21°C | 0.000 |
| 5/10 | 10 A M | .710 | -.002 | -.281 | 21°C | 0.000 |
| 5/10 | 10 P M | .710 | .000 | 0.000 | 21°C | 0.000 |
| 5/11 | 11 A M | .712 | .002 | 0.281 | 21°C | 0.000 |
| 5/12 | 9 A M | .790 | .078 | 10.990 | 21°C | 1.276 |
| 5/12 | 12 P M | .777 | -.013 | -1.645 | 22°C | 0.000 |
| 5/13 | 2 P M | .716 | -.061 | -7.860 | 21°C | 0.000 |
| 5/13 | 11 P M | .708 | .008 | 1.130 | 21°C | 0.000 |
| 5/14 | 10 A M | .708 | .000 | 0.000 | 21.5°C | 0.000 |
| 5/14 | 10 P M | --- | --- | --- | 21°C | 1.280 |
| 5/15 | 10 P M | .705 | -.425 | -.425 | 20°C | 0.000 |
| 5/16 | 10 A M | .705 | .000 | .000 | 19°C | 1.285 |
| 5/16 | 11 P M | .733 | 3.970 | 3.970 | 20°C | 0.000 |
| 5/17 | 12 M | .725 | -1.090 | -1.090 | 21°C | 0.000 |
| 5/17 | 10 P M | .712 | -1.795 | -1.795 | 21.5°C | 0.000 |
| 5/18 | 8 A M | .708 | -.562 | -.562 | 21.5°C | 0.000 |
| 5/18 | 11 P M | .707 | -.143 | -.143 | 21°C | 0.000 |
| 5/19 | 11 P M | .709 | .283 | .283 | 21°C | 0.000 |
| 5/20 | 2 P M | .733 | 3.400 | 3.400 | 21°C | 0.000 |
| 5/21 | 10 A M | .749 | 2.180 | 2.180 | 21°C | 0.000 |
| 5/21 | 12 M | .834 | 11.35 | 11.350 | 21°C | 1.290 |
| 5/23 | 10 A M | .708 | -15.10 | -15.100 | 21°C | 0.000 |
| 5/24 | 2 P M | .703 | -.760 | -.760 | 21°C | 0.000 |
| 5/26 | 10 P M | .707 | .570 | .570 | 21°C | 0.000 |
| 5/28 | 10 P M | .782 | 1.060 | 1.060 | 21°C | 0.000 |

Note. Where no specific gravity was determined we have filled the blank spaces in that columnin the table with zeros.

**Plate XII**



Voltage Test of Edison-Lalande Cell

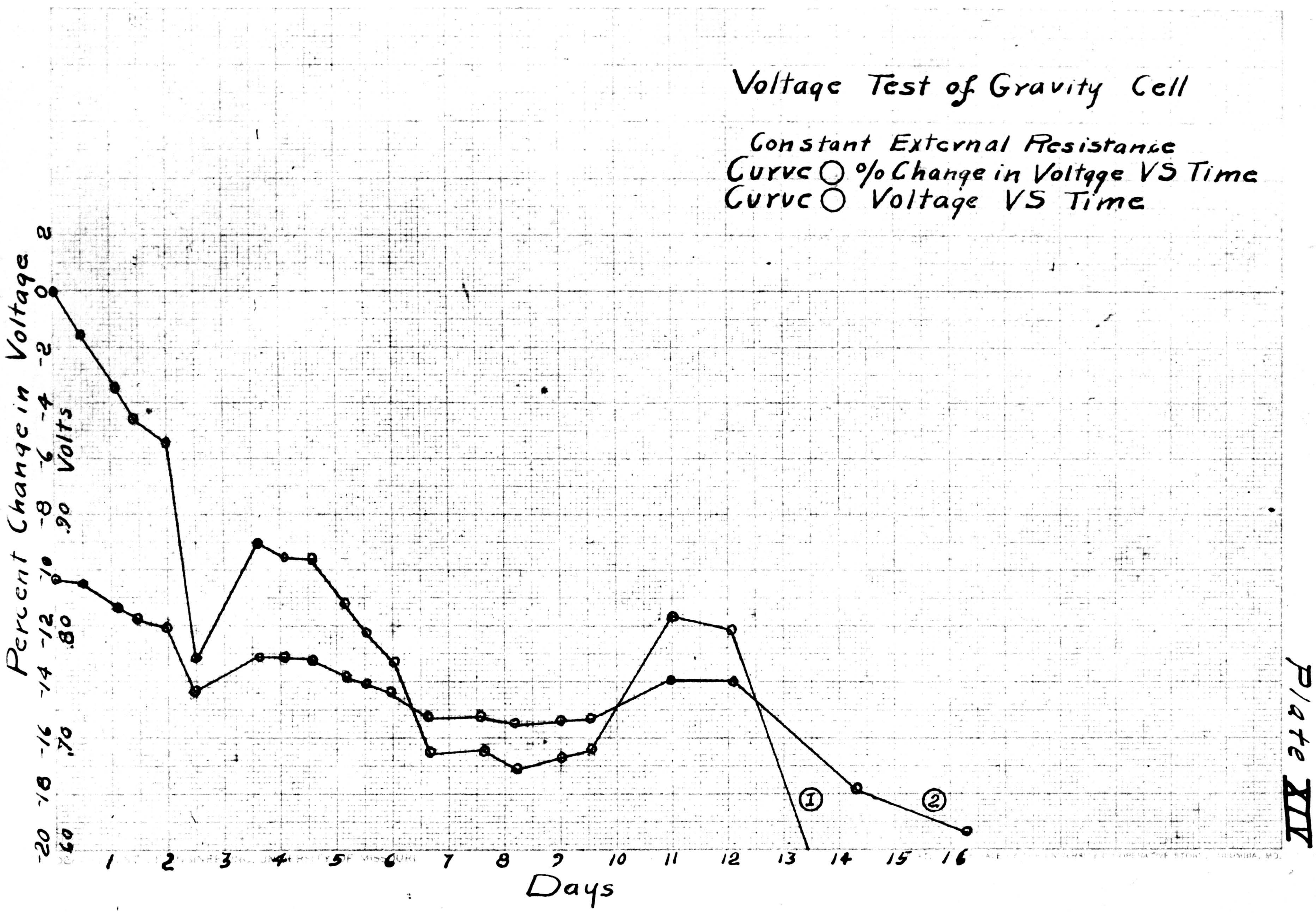
Constant External Resistance
Curve ① % Change in Voltage VS Time
Curve ② Voltage VS Time

## Plate XIII.

## Voltage Test of Gravity Cell.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5/12 | m 9 A M | .6 | .843 | | | 21°C | 1.226 |
| 5/12 | 12 P M | .625 | .830 | -.013 | -1.540 | 21°C | 1.225 |
| 5/13 | 2 P M | .584 | .815 | -.015 | -1.810 | 22°C | ---- |
| 5/13 | 11 P M | .333 | .806 | -.009 | -1.110 | 21°C | - - |
| 5/14 | 10 A M | .542 | .798 | -.008 | - .992 | 21.5 | 1.235 |
| 5/14 | 11 P M | .5000 | .740 | -.058 | -7.840 | 21°C | - - |
| 5/15 | 10 P M | .940 | .771 | .031 | 4.190 | 20°C | - - |
| 5/16 | 10 A M | .500 | .767 | -.004 | - .520 | 19°C | 1.255 |
| 5/16 | 11 P M | .542 | .767 | .000 | .000 | 20°C | - - |
| 5/17 | 12 M | .542 | .754 | -.013 | -1.750 | 21°C | - - |
| 5/17 | 10 P M | .417 | .747 | -.007 | - .930 | 21.5 | - - |
| 5/18 | 8 A M | .417 | .740 | -.007 | - .940 | 21.5 | - - |
| 5/18 | 11 P M | .625 | .717 | -.023 | -3.110 | 21°C | 1.255 |
| 5/19 | 11 P M | 1.000 | .718 | .001 | 1.400 | 21°C | - - |
| 5/20 | 2 P M | .584 | .713 | -.005 | - .696 | 21°C | - - |
| 5/21 | 10 A M | .832 | .716 | .003 | .420 | 21°C | - - |
| 5/21 | 12 M | .584 | .719 | .003 | .421 | 21°C | 1.250 |
| 5/23 | 10 A M | 1.410 | .753 | .034 | 4.730 | 21°C | - - |
| 5/24 | 2 P M | 1.165 | .750 | .003 | - .398 | 21°C | - - |
| 5/26 | 10 P M | 2.330 | .656 | .094 | -12.500 | 21°C | - - |
| 5/28 | 10 P M | 2.000 | .615 | -.041 | -6.250 | 21°C | 1.240 |

Plate XIV



Voltage Test of Gravity Cell

Constant External Resistance
Curve ○ % Change in Voltage VS Time
Curve ○ Voltage VS Time

Plate XV

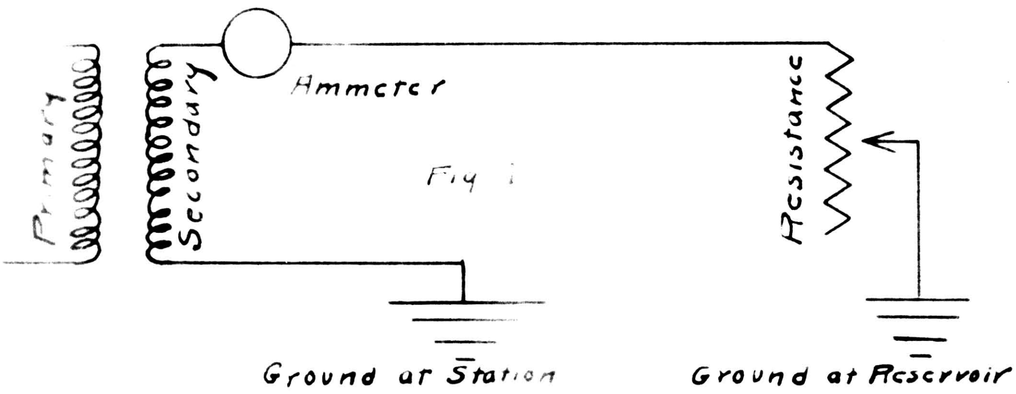


Fig 1

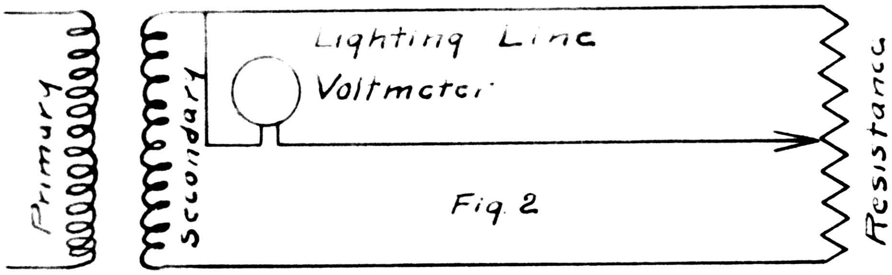


Fig. 2

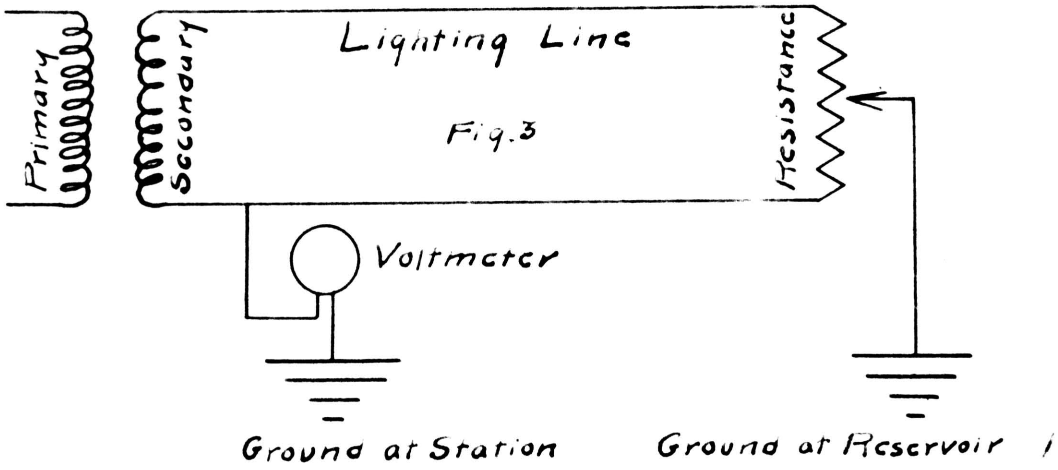
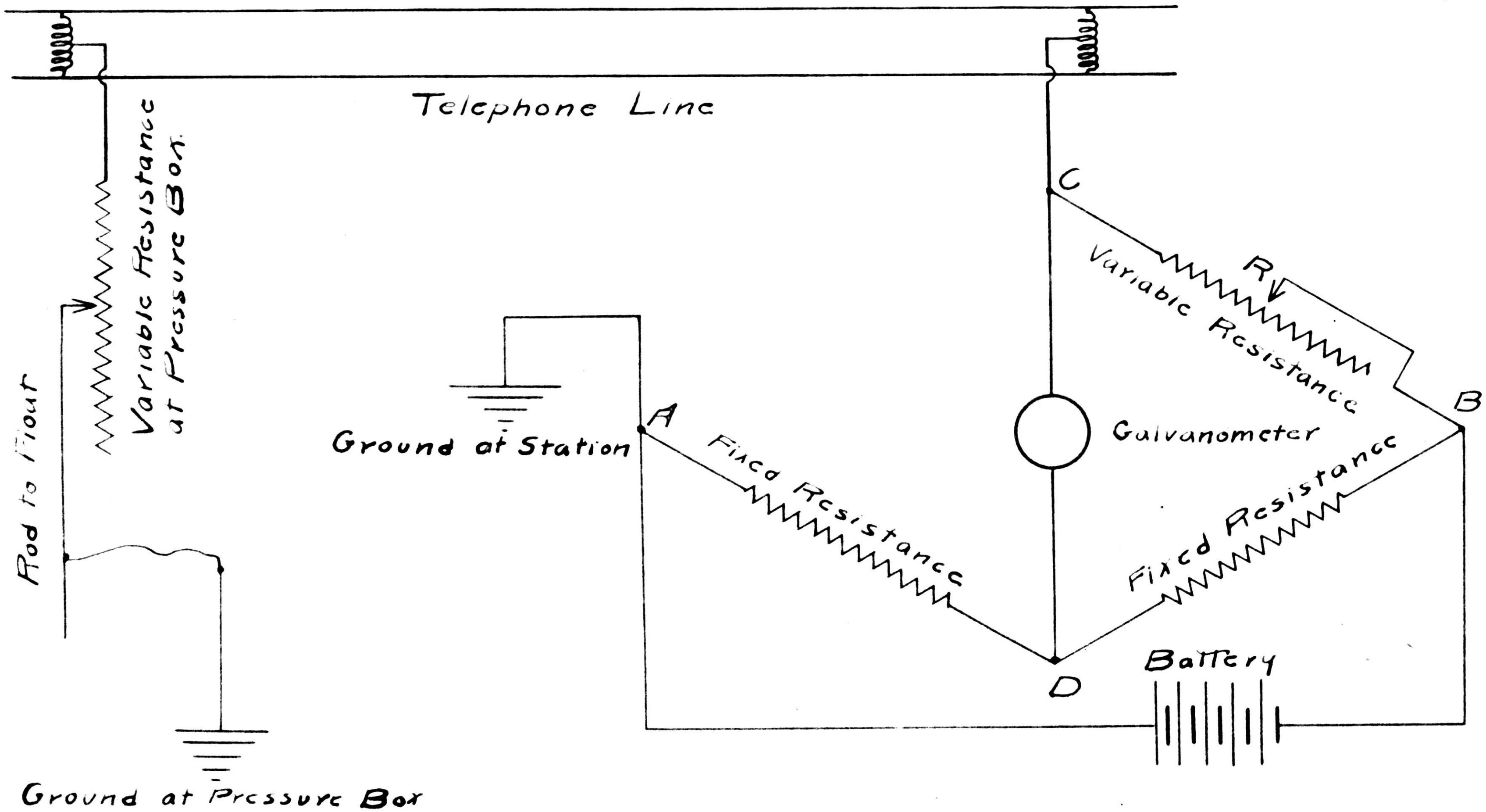


Fig. 3

# THE WATER LEVEL INDICATOR

## DIAGRAMS OF CONSTANT POTENTIAL SYSTEMS

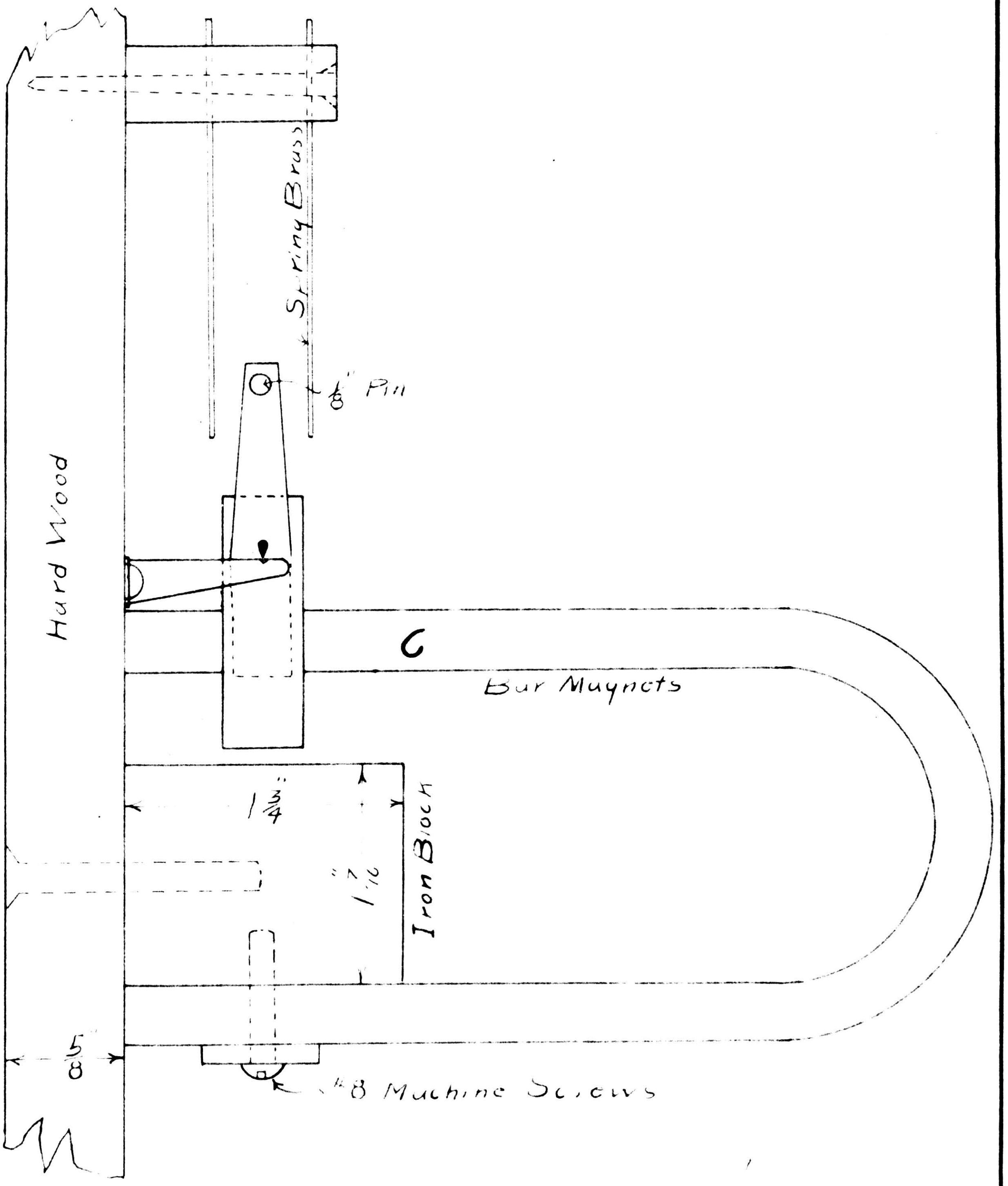
Plate XVI



# THE WATER LEVEL INDICATOR

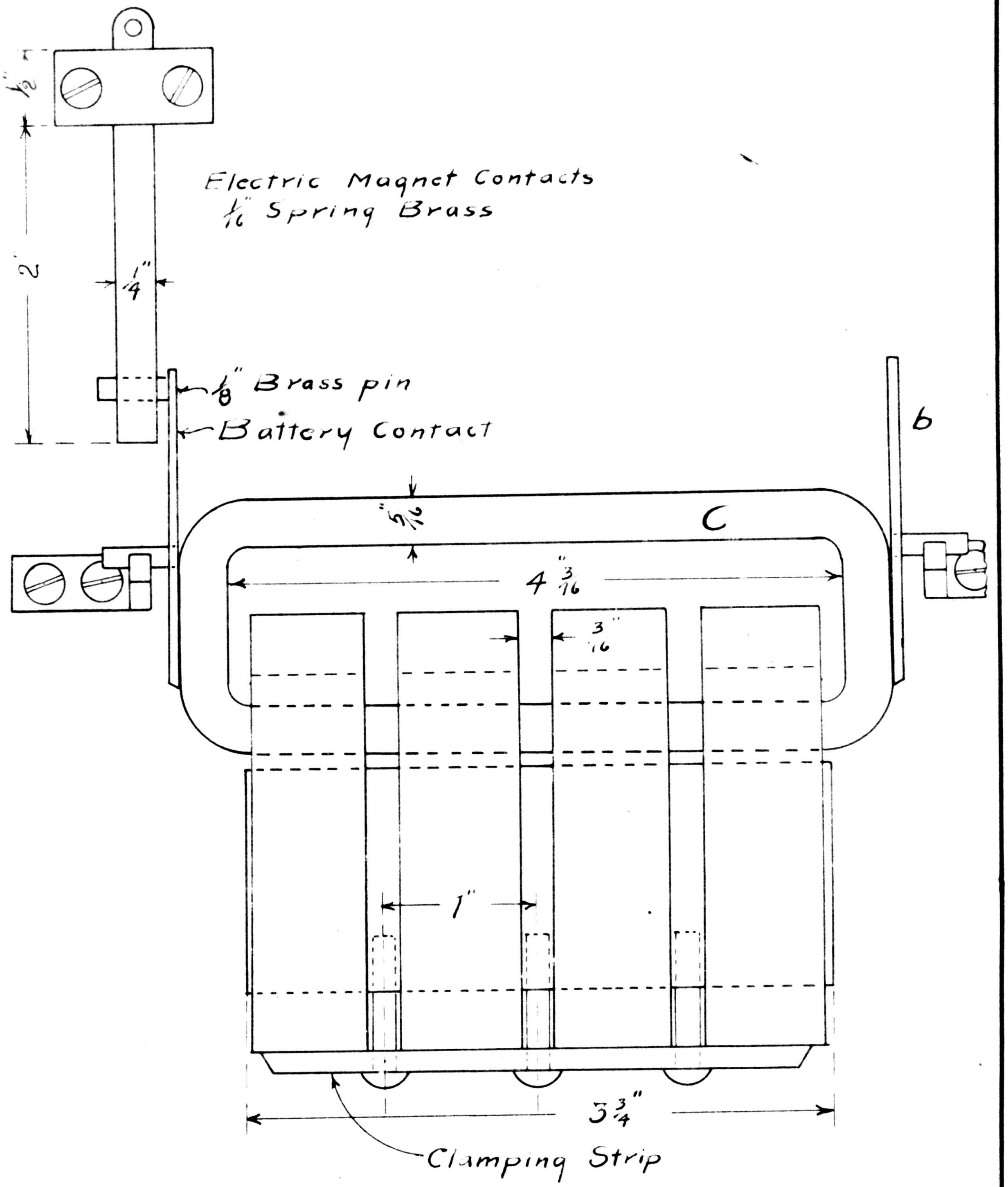
## WHEATSTONE BRIDGE TYPE OF INDICATOR
## WIRING DIAGRAM

Plate XVII



# THE WATER LEVEL INDICATOR

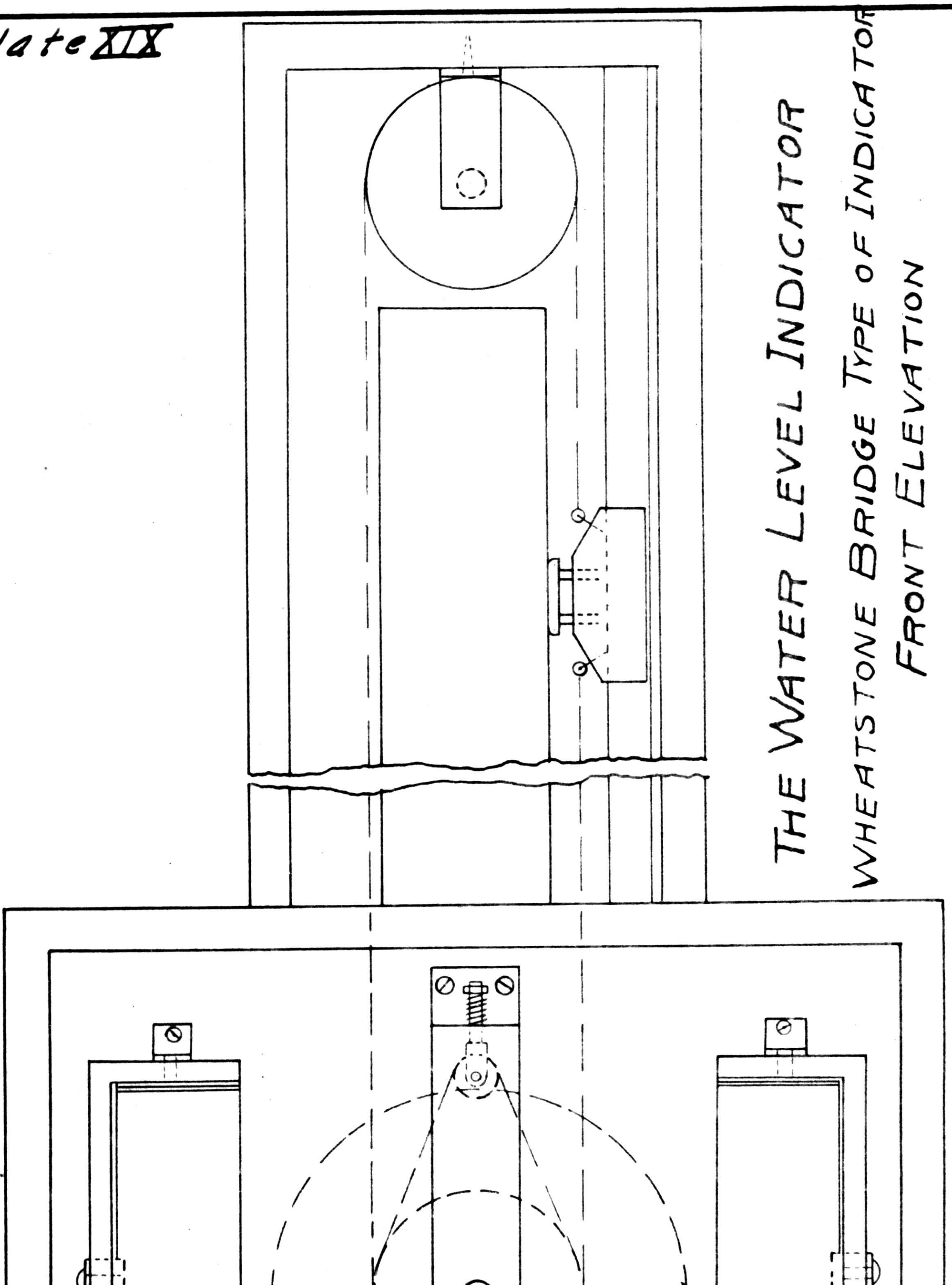
WHEATSTONE BRIDGE TYPE OF INDICATOR
SIDE ELEVATION OF RELAY



# THE WATER LEVEL INDICATOR

## WHEATSTONE BRIDGE TYPE OF INDICATOR
## FRONT ELEVATION OF RELAY

Plate XIX

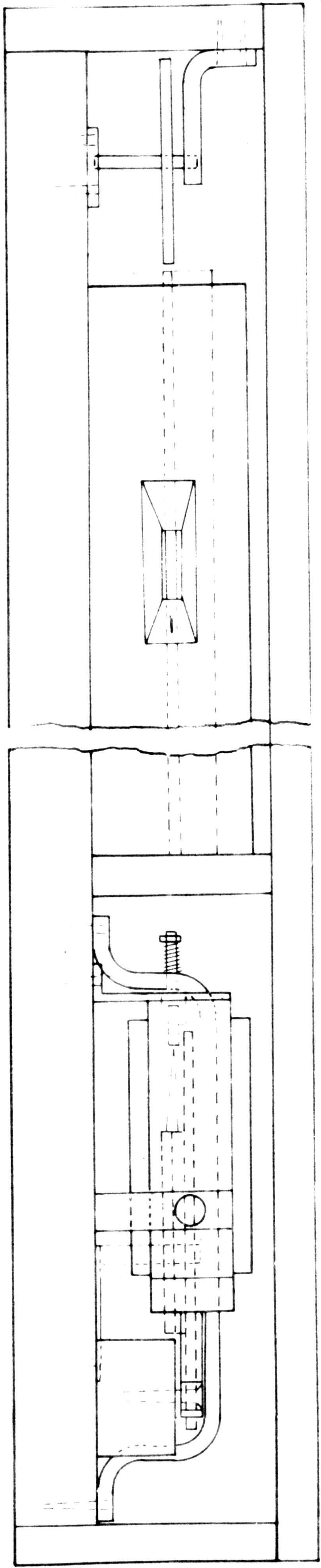


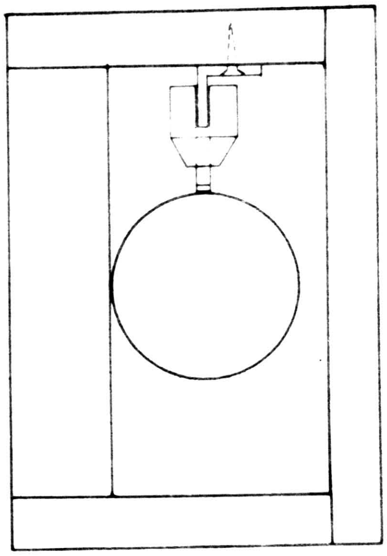
THE WATER LEVEL INDICATOR

WHEATSTONE BRIDGE TYPE OF INDICATOR

FRONT ELEVATION

*Plate XX*

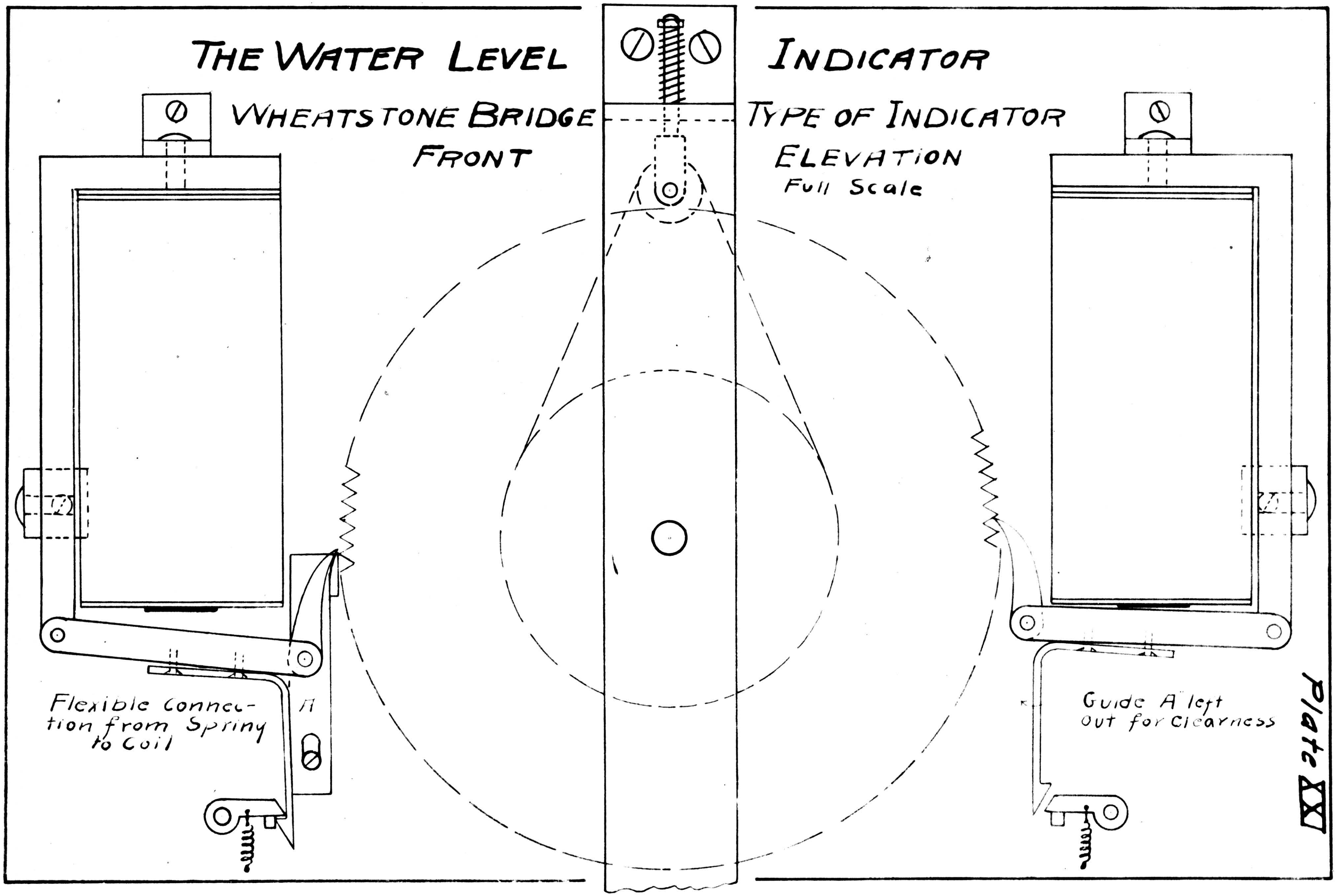




THE WATER LEVEL
INDICATOR
WEATSTONE BRIDGE
TYPE OF INDICATOR
SIDE ELEVATION

Plate XX

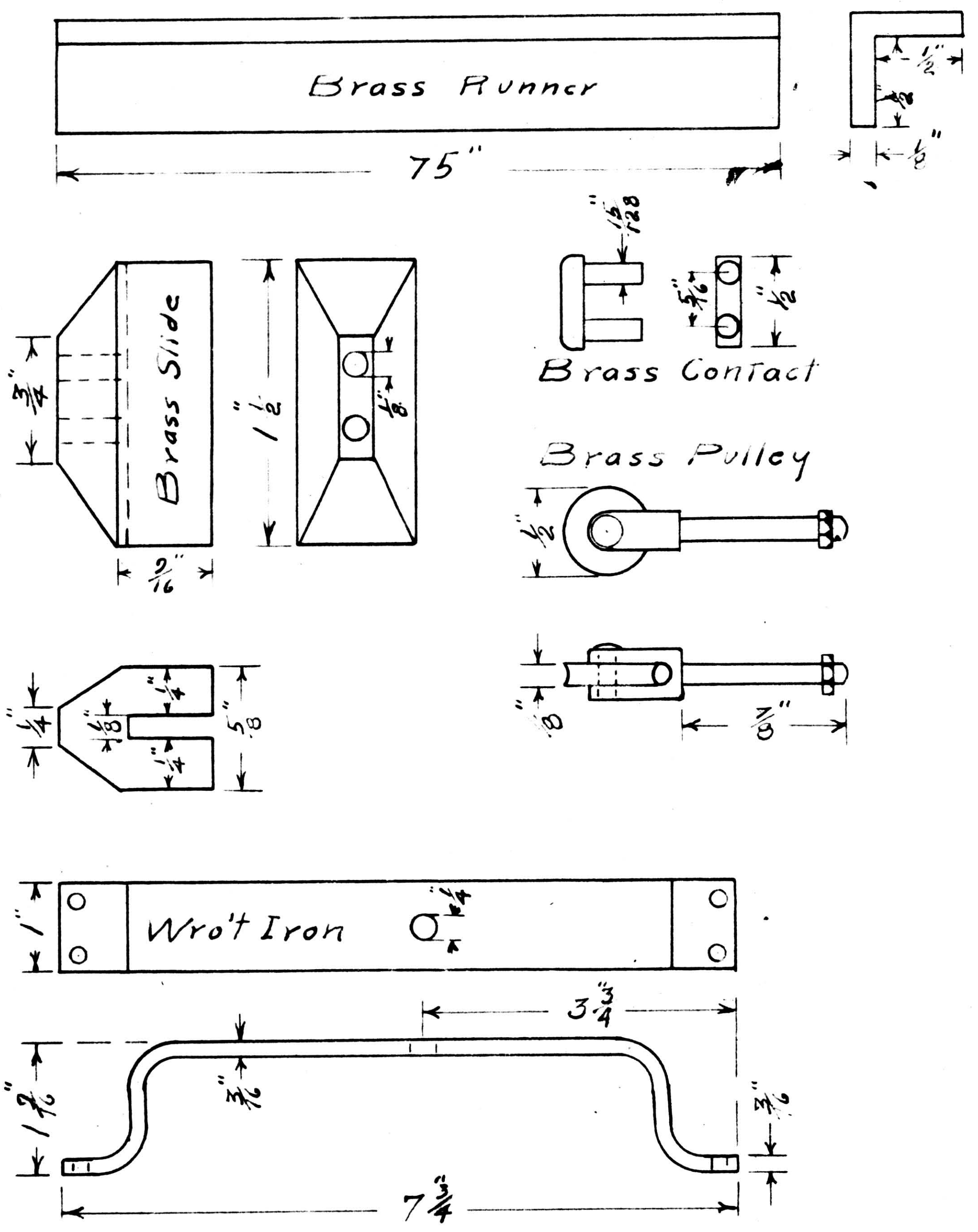
# THE WATER LEVEL INDICATOR



WHEATSTONE BRIDGE
FRONT

TYPE OF INDICATOR
ELEVATION
Full Scale

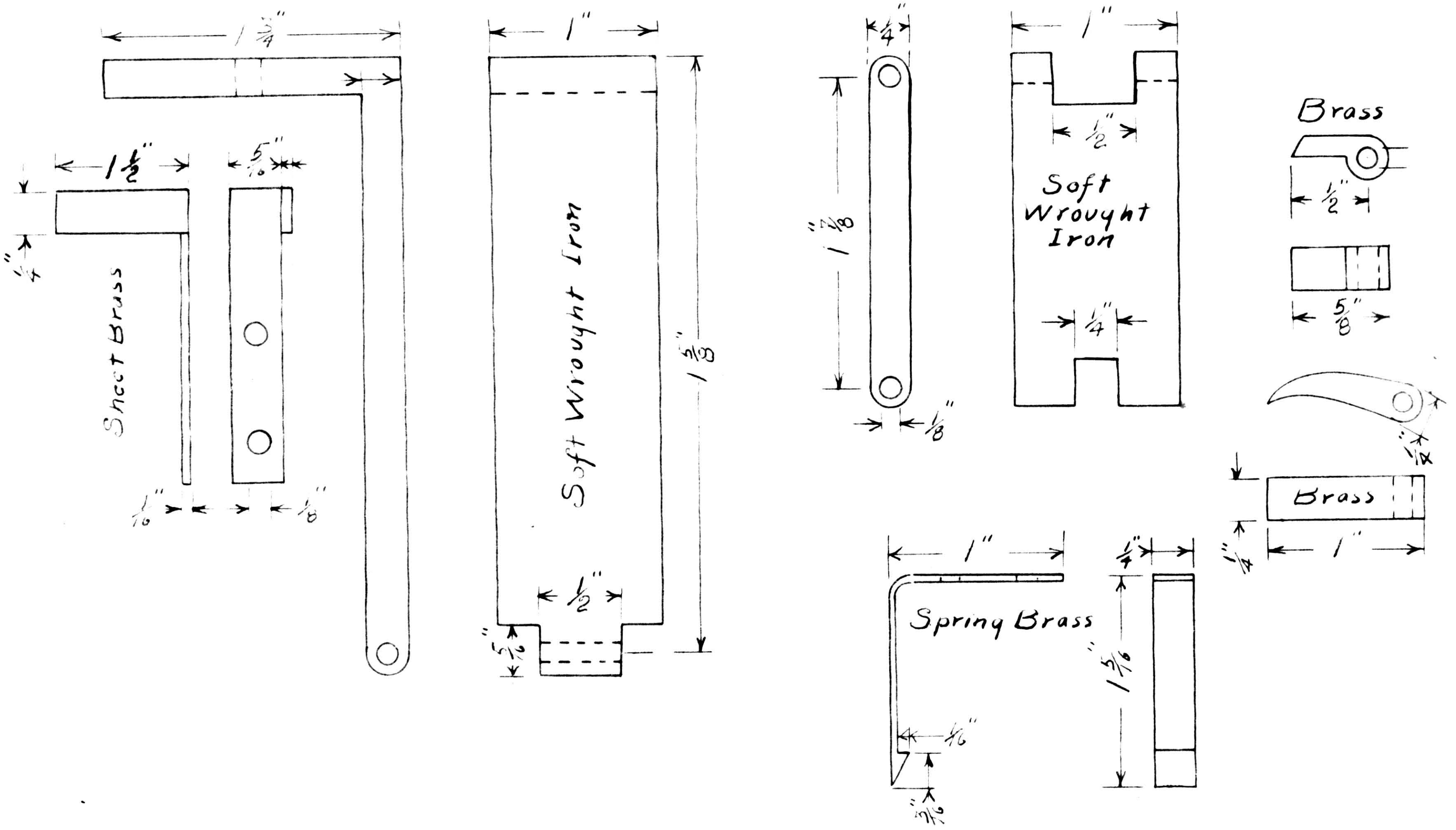
Plate XXII



# THE WATER LEVEL INDICATOR

## WHEATSTONE BRIDGE TYPE OF INDICATOR DETAILS.

Plate XXIII



# THE WATER LEVEL INDICATOR

## WHEATSTONE BRIDGE TYPE OF INDICATOR
## DETAILS

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