

plest power or watt-meter is the Siemens dynamometer, arranged with one series and one shunt-coil; and it indicates at any instant the power which is being supplied or withdrawn from the cells.

An erg-meter, or energy-integrator, can be made in various forms. The one I have here to show is Ayrton and Perry's modification of an eight-day clock. They substitute a fine coil of wire for the bob of the pendulum, and surround this with another larger and thick coil. A current sent in the same direction round two nearly concentric coils, causes the smaller one to move to the center of the large one. Thus, if the pendulum is oscillating, and the clock keeping good time, a current sent round the two coils will cause the clock either to gain or lose, according as the currents are opposed or agree in direction. If the two coils are both in series in the circuit, the gain or loss of the clock will indicate the coulombs passed through. But if the small fine coil is a shunt, while the other is a series, the force acting on the bob will be a function of the power, and the gain or loss of the clock will indicate the energy in some more or less arbitrary way, which can be made simple proportion by empirically adjusting the relations among the parts.

To determine the internal resistance of a battery cell, or of a whole battery, the plan is to measure its electromotive force when driving two different strengths of current, as different as possible and both known. One strength of current is most conveniently zero; the other must be measured, say, by an am-meter in the circuit. A volt-meter, such as the high resistance Wiedemann, is connected to the terminals of the battery, and read. Its indication will be a scrap higher if the current was being supplied by the cells, but lower if the current was being supplied to them. The difference of the indication of the volt-meter, when a current is passing, and when no current is passing, is proportioned to the resistance of the battery, and for a secondary battery cell in good order, the difference is surprisingly small, so much so that an ordinary volt-meter will often fail to detect it. To get the resistance of the battery in ohms, you must divide the difference in the readings of the volt-meter (interpreted into volts) by the strength of the current passing in the main circuit, reckoned in amperes. A moment's interruption is sufficient with a good dead-beat volt-meter, and the current may be immediately switched on again before the disturbance in the circuit has had time to show itself, except indeed where the current is being used for lighting purposes, in which case no tricks may be played unless there are several batteries in multiple arc, and one of them can be disconnected without detriment. This, indeed, is a good plan of connecting batteries, as it allows measurements, examinations, and repairs to go on while the current is being used. The resistance of one of the small sized (half horse-power-hour) cells with nine pair of plates averages 0.002 ohm. Large cells have a still lower resistance, of course, and it is to this extremely low internal resistance that the secondary battery owes much of its great practical value. The current from an ordinary Grove's battery is by no means proportionate to the external resistance of the circuit unless this is high; in other words, the driving power of a cell, or the difference of potential between its terminals, falls off greatly when strong currents are demanded. But a secondary battery, from its enormous area of surface, not only gives a higher E.M.F. than a Grove ever does, but it keeps this two volts difference of potential between its terminals for pretty nearly any reasonable strength of current. Hence the current does within wide limits vary with the external resistance, and the current which such a cell will drive through a piece of thick copper wire is simply tremendous.

I must now say a few words about the uses to which secondary batteries can be applied; and, first of all, for general laboratory purposes they are invaluable. A small gas-engine and shunt-dynamo are necessary to charge them up occasionally, but they then retain their charge for days or weeks, according to the demand made upon them, and they are ready at any moment to produce a current, strong or weak, according to wish. They thus save a deal of trouble in setting up Grove batteries, and, moreover, the current they give is much steadier, for unless they are run to near their falling-off point, their E.M.F. continues very constant, and no compunction is felt at leaving them connected up to the circuit for a long time together—for such a time as would make Grove-cells heat violently and boil over. When they are run down, a few days' charging replenishes them again.

As regards durability, the cells repay cleanliness and attention. I mount them in front of a window, on a slab of thick glass raised above the bench; one can then see all over and through them, the light being reflected from below the glass slab by an inclined bit of looking-glass which can be moved about. It ought also to be possible to get on both sides of the bench, so as to be able to detect and remove any attempt at contact between the plates of a cell.

If a lump of composition tumble out and bridge across from one plate to the next, it can be removed with a paper-knife. Plenty of light, easy access, and clear vision through between the plates of each cell are highly desirable. The glass cells and the slab should also be kept clean, and free from acid splashes and spray, for all this moisture promotes leakage, and causes the cells to lose their charge more rapidly than they would by ordinary and unavoidable local action.

When cells are stowed away in dirty dark cellars, on wooden shelves, like wine bottles, the leakage must often be considerable, and the cells may get into any state of dilapidation without detection, or attempt at remedy. A light attic, or glass house, with crockery slabs at a convenient height, is a much more suitable place for secondary batteries than a wine cellar.

It is important to be able to detect an incipient flaw in a cell before it has had time to damage the cell perceptibly. A sensitive volt-meter may do this, but an ordinary one will not show any difference for a long time, and if the cell is in series with others, as soon as it begins to run down in E.M.F. the others rush it down to, and past zero, and begin to charge it up wrong way. This reversal is very bad for a cell, besides its very weakening effect upon the main current. It is very important to keep all the cells of a series as exactly alike as possible. A bad short circuit often causes a hissing noise which can be heard with a stethoscope applied to the cell, even when it is not loud enough to call your attention, as it sometimes is. But the most delicate detector of an incipient short circuit is the thermometer. All the cells heat by their proper current, but any abnormal action going on in a cell, whether it be short current or local action, or any other dissipation of energy, must result in heat, and the thermometer is the natural detector of this. Any cell warmer than the others should be examined, and set right, or else replaced.

The lugs and contacts should be wiped clean occasionally

from the acid spray which collects on them, and they may also be recoated with paraffin and shellac. This acid spray is thrown up by the bubbles of gas which rise when the cell is getting full. The hydrogen bubbles throw up largish globules, which bound two or three inches into the air, and fall all over the slab and terminals; but when hydrogen comes off freely, the cell is commonly quite full. The oxygen, which comes off slightly during the greater part of the charging, throws up much more minute globules, which float about as an acid spray, very irritating to the nostrils and very provocative of leakage. The spray may be greatly diminished by a layer of oil spread over the surface, in which the bubbles collect and break in a different way, and it also checks evaporation; but the oil introduces difficulties of its own when the plates have to be lifted out of the cell, though indeed it may be first flooded off. The contacts of the positive plates are very apt to be corroded by the spray and creeping film, together with the peroxidizing action of the current crawling up wet lugs, and they require occasional attention. Unless absolute uniformity of contact is secured, some of the plates will take nearly all the current and get peroxidized to pieces, while the others are nearly idle.

I use pans of very dilute ammonia, or perforated boxes of carbonate, to neutralize the acid spray. The atmosphere is then much improved, and instead of acid films, white crusts of ammonia sulphate collect, which are less harmful, and may be cleared off. Another precaution is always to keep the cells filled with acid above the level of the plates, so that they are completely immersed, else the part above the liquid will be exposed to the influence of non-concentrated acid, from the evaporation of the water out of the acid film covering it. It is important to remember that all these exposed layers of acid are likely to become pretty concentrated, and hence that they may be expected to corrode more rapidly than the mass of the solution.

Another advisable precaution is to stir or agitate the liquid occasionally, more particularly during charging. The bubbles of gas, fortunately, do this to some extent, if the cells are well filled up electrically; but if no such agitation is excited the acid at the bottom of the cell is apt to become very much more concentrated than that at the top. Not that gravity is able to pull down strong acid out of once thoroughly mixed dilute acid. Gravity cannot undo diffusion like this. But it is the acid freshly formed during recharging, by decomposition of the sulphate of lead on both plates—it is this acid which falls to the bottom and accumulates there, frequently corroding the bottoms of the plates.

One great advantage of the present cells over the old flannel-swathed Faure, is that they permit free circulation of the liquid. To make the cells answer various laboratory requirements, I have a sort of resistance-box, made with uncovered spirals of German silver wire, in a stoneware water trough, so that the wires do not melt, and I can then throw in any resistance from a quarter ohm upward, otherwise the current would be frequently too strong. For working a Serrin lamp no extra resistance is necessary, and from eighteen to twenty-two cells work it admirably. Even when one drives the lamp direct from the dynamo, the battery is still connected as a shunt circuit, to act as a regulator and steady the current. Moreover, it has the great advantage of preventing the engine from racing away when one puts out the lamp. A well governed engine, of course, ought not to do this in any case, but I have not found a gas engine behave well when work is thrown on and off it in such an irregular and fitful manner as a lamp is commonly used in a lecture. It is much better for it to be pumping into the cells whenever the lamp is put out. Moreover, one can get a far more powerful current through the lamp in this way than from a small dynamo direct. Another advantage of having the battery connected is, that it will not permit the locking of the carbons, and thus the short circuiting of the field magnets of the shunt dynamo, which is a not infrequent occurrence when a shunt dynamo alone is used to feed an arc lamp.

If, however, only a regulator is wanted, and not a store of energy, a set of zinc and lead plates can be easily arranged which will do all that is wanted in the way of regulation; and as the lead gets gradually more and more "formed," the battery will gradually acquire more and more actual storage capacity. The cells were very useful once when the gas-engine was being repaired. I took the dynamo over to a neighboring steam engine, and laid its comparatively full current with spans of common wire to the battery. From the battery thus charged, the powerful occasional currents needed for some magnetic researches then going on were readily obtained. To bring such currents from the distant dynamo would have necessitated the use of very thick and expensive cable, and would in fact have seriously damaged its armature.

The battery thus acted as a transmuter of weak currents into strong ones, and this illustrates on a small scale one of its very important future functions, viz., a receiver of energy transmitted from a distance, as Sir Wm. Thomson has pointed out. Currents generated at a distant station, to be conveyed to a distance, ought not to be strong; they ought to be feeble currents at a high potential. They can be received by a great number of batteries in series, and the batteries so charged can be used for any local purposes, and made to give any reasonable desired current by altering their connections. Moreover, they can be coupled up to a number of independent circuits, so that irregularities in one shall not interfere with the others. The great advantage of a set of batteries as a receiver, over a set of dynamos in series, is that the latter would need such a high internal resistance to give the necessary back E.M.F., whereas a battery, even of small cells, can give 1,000 volts E.M.F. with an internal resistance of only 2 ohms. Hence the waste in heating the receiver is next to nothing. There is another kind of waste, no doubt, for the work got out of a battery can never be anything like that put in. The E.M.F. of charge is about 2.3 or even 2.4 volts, while that of discharge is scarcely above 2; besides this, there is a slight loss or discrepancy between the quantity supplied and that afterward withdrawn. Notwithstanding this waste, they must come into use when made in a satisfactory and quite dependable manner, for their great convenience and steadiness. And when the power at the distant station is water or wind-power, as I doubt not it often will be, waste becomes of secondary importance, and a convenient method of storing is the first consideration.

So plainly is high E.M.F. pointed at as the requisite for the economical transmission of energy, that I cannot help thinking that, in some cases, a use will be found for electrostatic machines as generators instead of dynamos. Not exactly a Holtz machine—which has a high internal resistance, and must dissipate energy, from its use of non-conductors and sparking intervals—but some gigantic form of Thompson's replenisher with metallic contacts. A large

machine is needed to give a current of one ampere, but not outrageously large, and a clear separation of the parts by a millimeter will enable 4,000 volts E.M.F. to be obtained. No great horse-power is here represented, but it would be transmitted by a well insulated wire with very small loss.

In using a waterfall running continuously to light a town for, say, eight hours, batteries are evidently desirable. Three sets might be used, each charging for eight hours—one or other of them always charging, and two of them discharging during the eight hours the light is required. Or two sets would be sufficient if the water-power itself could be used for lighting direct. But the use of three sets of batteries would enable a reasonably distant waterfall to be used, and would, for the eight hours the light is needed, give an actually greater horse-power than the fall itself possesses.

For locomotion in cases where the current cannot easily be supplied to the moving carriage by metallic conduction, as in tram-cars on common streets, batteries carried by the tram-car afford an obvious, and, moreover, an economical form of motive power. It is sincerely to be hoped that electric tram-cars may speedily come to perfection, and that the excessive wear and tear of horseflesh in this monotonous and severe labor may be checked.

A number of motors were exhibited, some lent by the Electrical Power Storage Company, and some by Professors Ayrton and Perry. A De Meritens motor, driven by 18 storage cells, was used to drive a small Siemens dynamo by a strap, the current from this being used to drive another motor, which worked a lathe, or was used to light four small Swan lamps. A Pilsen arc-lamp was shown, working very steadily with the current from the battery, and a number of Swan lamps were also excited, so as to show how entirely any one was unaffected by the turning out of the others, a battery behaving in this respect like a very good compound wound dynamo. Diagrams of the mode of connecting up cells and dynamos for transmission or power and curves representing the charge and discharge of cells, as tested by Dr. Hopkinson and Messrs. Ayrton and Perry, were also exhibited, but it is thought unnecessary to reproduce them here.]

For driving boats electrically, secondary batteries are obviously necessary, because the laying on of a current by a wire is not only inconvenient but impossible. The storage cells will act as ballast, and can be charged while the boat is moored. For swift short voyages, and for pleasure vessels, nothing better than electrical propulsion is likely to be devised. For long voyages and big ships, the weight of secondary batteries would need all the floating power the ship possesses, and perhaps more. The energy consumed in propelling the present Atlantic liners is something almost incredible.

When motors are driven by secondary batteries with very short connecting wire, the question arises, Is high E.M.F. still desirable, as it is when transmission across great distances is concerned, or may powerful currents be now used with advantage? The answer is that, neglecting the resistance of battery and connecting wires, there is neither gain nor loss in using powerful currents, provided the dynamo is properly wound, and has brushes that will not burn up.

But if we do not neglect the resistance of the batteries—a thing we have no right whatever to do—the answer is, that high E.M.F. is of very great advantage. A large number of cells in series, driving a high E.M.F. dynamo at its highest possible speed, and with as small a current as is needed for the power, is by far the most economical arrangement. Now, a screw for a ship has always needed a high speed for economy, and in the old days gearing used to be employed between the steam-engine and the screw, because no high speed engine was sufficiently economical. I understand that slow engines are still the best, but the disadvantages of gearing are so great that high-speed direct-acting engines are always used. But a high-speed is absolutely essential to economy in an electric motor, and no screw, as ordinarily made, would work at such a speed; consequently there is a temptation to use gearing the other way, and to gear down the dynamo to suit the screw. I hope the attempt will be resisted, and high-speed screws made of small size, smooth surfaces, and low pitch, so that the electric motor axle may be coupled direct to the screw shaft. The direct rotatory action of a dynamo used as a motor, as opposed to the oscillating action of a steam-engine, is a great simplifier of mechanism, and will be found extremely convenient.

For all kinds of short transit locomotion, electric power will, probably, prove to be the most suitable, and the improvement in the atmosphere of the Underground Railway, which would result from the adoption of such a means of propulsion, would be far more remarkable than anything which ventilators, whether ornamental or the contrary, are able to effect. In fact, there can be little doubt that the practical development of electrical appliances in the near future will be something extraordinary, and the consequence of this, and of the extensive use of gaseous fuel, will be, I most sincerely hope, and not unreasonably believe, not only the abatement, but the compulsory abolition, of smoke and all other artificial pollution of the atmosphere, and such an improvement in the air of towns as will change them from stifling purgatories into wholesome and refreshing centers of life and work.

THE MOST SENSITIVE GALVANOSCOPE.

By Prof. ERNST VON FLEISCHL.

THE most sensitive galvanoscope is the nerve of a frog. Its superiority over other galvanoscopes depends not so much upon its power of indicating traces of electricity as such, but rather upon its power of showing fluctuations in the strength of currents even of the feeblest intensity, if only they take place with sufficient rapidity.

As the readers of this memoir cannot be supposed to be possessed of a knowledge of anatomical and physiological details, we must first give a description of the position, of the appearance, and the general properties of the nerves and muscles of the frog. The reason why frogs are selected for these experiments is that they are easily procured in our districts; that their tissues, after the death of the frog, retain for some hours their vital properties in a degree not sensibly diminished, and lastly, that a nerve has its course in the hinder extremities of these animals, which possesses suitable dimensions for the experiment, and which is easy to prepare.

Near the lower end of the backbone of these animals the roots of the nerves for the lower extremities issue from two series of apertures in the form of fine white threads. These, after forming a plexus, unite to a thicker cylindrical stem of 1 millimeter in diameter, from which branches are given off in the shape of fine threads. These, under the microscope, appear formed of a number of extremely fine parallel fibers, each from 0.03 to 0.001 millimeter in diameter.

The roots of the nerves proceed from the backbone on each side, in two mutually distinct longitudinal series; the anterior roots more approaching the belly of the animal, and the posterior roots turned more toward the back.

I, first preparation; N₁, nerve; F, red muscular flesh; S, sinew; E, E¹, exciting electrodes; II, second preparation; N₂, nerve; P, f, lower thigh and foot.

By numerous experiments which have been made on the excitability of motor-nerve fibers by electricity, it has been found that they are sensitive neither for static tensions nor for constant currents of whatever intensity, but for fluctuations in the intensity of such currents, of whatever character.

The determining feature for the action of the fluctuations of electric currents is decidedly their abruptness. It is quite possible, *e. g.*, to introduce a current of great intensity into a nerve so gradually that the nerve, and the muscle with which it is connected, are not excited; or the current may be very gradually and slowly removed without producing any visible effect. But the sudden opening or closing, even of a minimum current, is sufficient to excite a nerve, and this sensibility of a nerve, for sudden even though infinitesimal fluctuations of currents constitutes its peculiar value as a galvanoscope.

The fluctuations caused in the wire coils of a Bell tele-

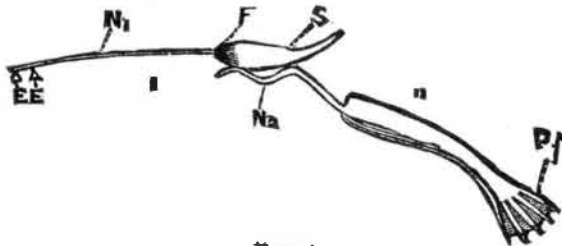


FIG. 1.

phone by the human voice are quite sufficient to set the nerves in a state of excitement. These fluctuations of current furnish, as is well known, a faithful image of the sound-vibrations by which the telephone is excited, and upon this the working of the instrument entirely depends. If, in a graphic representation of the movement of the air-molecules in a sound-wave, there occur portions of the curve which rise or fall with exceptional abruptness, these portions of the sound-curve correspond to abrupt positive or negative fluctuations in the currents which circulate in the telephone wire, and these fluctuations are especially well adapted to act upon the living nerve.

If the two ends of the wire of a telephone are connected by the hip-nerve of a frog, laid bare, but left in connection with the muscle which it supplies, the latter will contract when abruptly rising or falling portions occur in the sound-waves which act upon the telephone. Professor E. Du Bois Reymond has given this experiment an elegant form, utilizing the different form of the curves corresponding to the sounds of different vowels in the following manner: If the word "lie" is spoken with a moderately strong voice into a telephone connected with the prepared nerves, the muscle lies at rest, as no abrupt curves occur in this sound. But if, with a voice no louder than before, the word "jump" is spoken into the telephone, the muscle is thrown into such violent contraction that, along with the nerve, it springs away from the ends of the wires to which it had been applied. (The word "jump" is the nearest approach which we can find to a monosyllabic translation of the original German word "ruck" so as to contain the same vowel. It will be better to pronounce "lie" as if written "lee," and to give "jump" with the close sound of the u, as in bull).

Another experiment, in which not merely the nerve, but the muscles themselves, are traversed by the current, is the following: Place upon a large copper plate a smaller zinc plate, and upon the latter a leech. This animal soon begins to creep away from the zinc, raising the anterior part of its body and bringing down its head upon a part of the copper surface. As soon as this is touched a Daniell element is closed, the current of which passes suddenly through the body of the leech. Its muscles then contract and raise the head away from the copper plate. The interruption of the current again causes an irritation, and the animal retreats still further. The same scene recurs, after a short time, with the same result, so that it appears as if the leech was held to the zinc plate by enchantment.

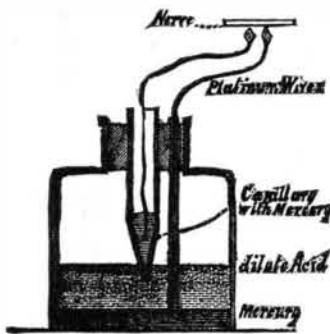


FIG. 2.

The nerves of the frog are so sensitive to currents that if, in preparing them, they are simultaneously touched with a steel forceps and steel scissors, and if these instruments are accidentally brought into direct metallic contact, a movement is observed in the muscles, caused by the extremely feeble current proceeding from the two instruments, which, though both formed of steel, have surfaces not absolutely electromotorically equivalent. If a nerve in connection with a muscle is placed upon a piece of metal, such as a coin, and if the nerve and the coin are touched simultaneously with another piece of metal, a violent movement ensues each time on contact, but the muscle remains at rest as long as the current produced in this manner circulates constant in the nerve.

Nerves and muscles are well known to be electromotive tissues, *i. e.*, currents emanate from them which circulate both in the nerve and in the muscle from any artificial transverse section to the natural surface. In the muscle the sinew to which its fibers are attached behaves like an artificial transverse section. These currents can be easily shown by means of the sensitive galvanoscope which a nerve-muscle galvanoscope affords. In a freshly killed frog the hip nerves on one side are prepared in connection with the

lower part of the thigh and the foot. The one end is cut off just where it issues from the vertebral column. On the other side of the frog the great muscle of the calf of the leg is laid bare by taking off the skin. If the former preparation is held by its lower end in the hand, and allowed to fall with the bare nerve across the muscle, so as to touch both at points of its red surface, and also at points of the white iridescent sinew, the preparation is thrown into very perceptible movement. The experiment succeeds better if a wound is made in the second muscle, and if the nerve is allowed to fall in such a manner that one part of it may come in contact with the natural surface, and another part may touch the inner surface of the wound.

An experiment which shows the extraordinary sensitiveness of the frog nerve to electrical currents, even of the lowest intensity, if they only arise or disappear with sufficient rapidity, is the following: as is well known, if mercury is placed in a cylindrical tube, open above and below but tapering downward conically, to a capillary degree of fineness, it comes into equilibrium at a certain point. The higher the column of mercury the farther it penetrates into the tapering lower end of the tube, the smaller is the transverse section of its lower end, and the greater is the curvature of the lower surface, until at last, as the height of the mercurial column is continually increased, the mercury reaches the extremity of the tapering capillary and issues in minute drops. As long as the mercury does not flow out the column may be considered as held in equilibrium by the equality of the two forces which act upon it in opposite directions. The one force is gravitation; the opposing force is the surface-tension of the meniscus.

If the lowest part of the capillary tube below the mercury is filled with dilute sulphuric acid, and the capillary tube is plunged into a small vessel, likewise containing dilute sulphuric acid with mercury at the bottom, and if this mercury is connected with one polar wire, and the mercury in the tube with the other polar wire, of a battery or other source of electricity, a displacement of the lower end of the mercurial column is occasioned by the action of the current.

If such a small capillary electrometer is constructed, say of a bottle five centimeters in height, with a little mercury poured into the bottom, and a conical glass tube as above described is passed through the neck and secured by means of a cork, so that its lower end plunges into dilute sulphuric acid, which forms a layer above the mercury, and if it is charged with mercury, and its lowest part, into which the mercury does not penetrate, with dilute sulphuric acid, and if the mercury at the bottom of the bottle is connected with an insulated wire which rises up out of the bottle, while the mercury in the tube is connected with another wire, and the ends of these wires, projecting out of the bottle, are brought in contact with the nerve of a freshly-prepared nerve and muscle, the muscle is thrown into a convulsive movement as often as the slightest agitation of the bottle occurs.

Such an agitation sets the mercury, and consequently the meniscus which forms its lower boundary, into a slight oscillation. With every change of the form or the position of the lower meniscus, a current is produced. But in consequence of the inertia of the masses which have to be set in motion, and the extreme brevity of the time within which the equal and opposite fluctuations of the currents pass off, none of the instruments used by physicists to detect currents are sufficiently sensitive for their indication. These feeble and transitory currents, nevertheless, excite the nerve of a frog most violently. It is merely necessary to set the bottle, as above described, upon an ordinary, firm table, and then to touch the top of the table with the finger, or to drop a small grain of shot upon it from a trifling height, in order to set the frog-nerve in movement. The author hence concludes that for very feeble currents, beginning or ceasing suddenly, the living frog-nerve is the most delicate of all galvanoscopes.—*Internat. Zeitschrift Elect. Ausstellung Wien.*

FIRING OF THE MULTICHARGE GUN.

J. R. HASKELL, inventor of the multicharge gun, lately led a party of gentlemen down to Sandy Hook to witness the experimental firing of this new war implement. The gun is a mass of iron 25 feet long, weighing 25 tons, looking like a section of a mast with four tumors in line upon its under side. The tumors indicate the pockets for the explosion of supplemental charges of powder, which are the distinctive features of this gun. The bore is 6 inches in diameter, and the pockets are each 22 inches in depth, their greatest diameter 11½ inches, the width of each opening into the bore 4 inches, and angle of inclination toward the muzzle of the gun 55 degrees. The entire interior of the gun, bore and pockets, is of steel, over which is a mass of iron.

In the bottom of each pocket, and about a foot back from the muzzle, pressure gauges are introduced. There are two kinds, the Rodman and the "crushing," and, though the best yet discovered, neither possesses anything more than relative accuracy, and both are subject to great errors. Both are based upon the effect of pressure on a soft metal—copper. The Rodman gauge determines the pressure by the depth to which a piston forces a knife blade into a copper disk of determined density. In the other, the compressibility, lengthwise, of a cylinder of copper one-half inch long and one-quarter inch in diameter, inclosed in an air tight chamber beneath a piston which is acted upon by the pressure of the gases in the gun, affords the required indication of force exerted upon it. It is this latter kind that is used in the multicharge gun. The delicacy of the reading of the information it imparts may be inferred from the fact that its compression under 19,000 pounds of pressure is only one-eighth of one-thousandth of an inch, and under 20,600 pounds only three-fourths of one-thousandth. Unfortunately, it is not possible, whatever the care exercised in preparing it, to obtain copper of such absolute uniformity of molecular construction as will give always accurate results.

The theory of this invention is the gradual accumulation of power by a succession of charges exploded as the shot passes along the bore. In the old fashioned gun a single charge of powder does all the work, and the strain upon the breech is enormous, the pressure in the single charge gun running from 33,000 to 50,000, 60,000, and sometimes over 100,000 pounds per square inch. In the multicharge system, a small charge of slow burning powder in the breech overcomes the inertia of the shot, the velocity of which, after its start, is easily accelerated by the successive explosions of subsequent discharges of quicker burning powder, fired in the pockets by the gas of the breech charge following the shot.

The velocity of expansion of gunpowder gas is 7,000 feet per second, and it would be impossible for it to move any projectile with even an approximate speed. The instant that the throat of the pocket is uncovered by the passage of the shot, the gas in its rear, with a pressure of say 15,000 pounds

to the square inch, surrounds every grain of powder in the pocket, converting it instantly into more gas, at an increased pressure, and in like manner flashes the contents of the next pocket, and so on until the combined power of all the powder in the breech and the four pockets has been utilized to keep up the speed of the projectile.

The inventor claims that it will give to projectiles greatly increased velocities when fired with full charges; increased range in proportion to the greater velocity, and power to penetrate four calibers of four times the diameter of the bore through armor plates, with pressures very much less than in ordinary or single charge guns. This is a gain over the old system of about 50 per cent. in velocity and range and 100 per cent. in penetration.

There seems to be no limit to the amount of powder which can be effectively burned, which is not true of the old system. In all single charge guns a certain quantity of powder, variable according to the caliber of the gun, produces the maximum result, and any addition to that amount decreases the velocity of the shot, because the extra powder is thrown out unburned, and is just so much extra weight to be moved in addition to the projectile.

The term "velocity" is apt to be misleading to the ordinary mind. A high velocity is occasionally produced by the one charge guns, but velocity of itself has no effect on the mind of an ordnance expert. It is mere fancy work, and not such as is done in actual service, to get an excessively high velocity by firing an unusually large charge of powder behind an uncommonly light shot. A great velocity imparted to a heavy projectile produces the most effective work on an armor plate, and that is precisely what the multicharge gun is destined to accomplish. It is a difficult matter to draw comparisons between this and other guns, because the data are so dissimilar as to weight of shot, charge and quality of powder, etc. This gun, in the thirteenth round, threw a shot of 109 pounds with a velocity of 1,735 feet, which is equal to 2,300 feet velocity with the 68 to 75-pound shot usually fired in single charge six inch guns, and the pressures in the multicharge gun were maintained at about 20,000 pounds to the square inch. The service charge of powder in the ordinary six inch gun is 34 pounds behind a shot weighing from 68 to 75 pounds. If a shot weighing as much as that used in this multicharge gun in this series of trials were used in a single charge gun of six inches caliber the charge would either have to be reduced, with consequent reduction of velocity, or the pressure would run up to a dangerous point. In a report of the Secretary of War there is one instance at least approximate. A six inch steel gun of Krupp's manufacture was fired with a projectile of 112 pounds, which is about 60 per cent. heavier than that used in service, producing a velocity of 1,676 feet per second under a pressure of 40,320 pounds to the square inch. In the thirteenth round a projectile weighing 109 pounds was given a velocity of 1,735 feet per second with a pressure of about 20,000 pounds and in the nineteenth round was given to an 111 pound shot a velocity of 1,832 feet per second under about the same pressure.

Instead of projectiles two diameters in length, weighing from 68 to 75 pounds, we are firing now shot that are three diameters in length and weigh 109 to 111 pounds. Before we get through we will be firing shots four diameters in length, weighing 155 pounds, from our multicharge gun, at a velocity sufficient to penetrate 24 inches of solid wrought iron, or the armor of any war vessel that floats. No single charge gun could throw that shot, but would burst in starting it, in all probability.

Mr. Haskell threw open the breech of the gun, and the reporter peered through the long tube. It was as carefully finished as the interior of any sporting rifle, with fifteen grooves 6-100 inch deep and one twist in twelve feet. The breech merited and received special admiration. It is entered and retracted by an interrupted screw, hinged to throw aside for the introduction of the shot, gas check wad, and breech charge, and double locked by a simple and ingenious device that works almost instantaneously. The work upon it is as fine as that upon the mechanism of a good watch, and it can be operated with surprising celerity by the men accustomed to handling it. Mr. A. G. Sinclair, master mechanic, superintended the loading of the gun. Mr. Sanborn, who has official charge of all the powder, aided him. Mr. Sanborn has gray hair and beard, but stood in the storm quite unconcerned, in his check shirt sleeves. "Haven't you anything under that shirt?" Major McKee asked him in a tone of astonished curiosity. "Got my hide," replied the old fellow placidly. Four other men assisted those three. There didn't seem to be any too many of them. The big steel plugs containing the pressure gauges were firmly screwed into the bottoms of the pockets. Then, one by one, four other steel plugs, with handles on them like those on hand organs, were unscrewed on the upper side of the gun and taken out. Into each aperture thus made was thrust a long copper funnel, through which the charges of powder were poured from tin cans into the pockets, 18 pounds in each, after which the organ-handle trimmed plugs were quickly screwed into place again. Into the pocket nearest the breech was put powder in grains as big as peas; into the second pocket grains half as large; into the third grains not more than quartered peas in size; and in the fourth pocket ordinary musket powder was used. These gradations in size were made because the finer powder grains are the more quickly they burn, and it is desirable to have a rapidity of gas development in the bore of the gun proportionate to the constantly and swiftly accelerating speed of the moving projectile. When the pockets were charged the breech was thrown open, and, through a copper shield, or guide, to carry it accurately into place, a conical shot—iron, banded with copper to take the rifling—weighing 110 pounds, having been daubed with grease and plumbago, was shoved into place, and solidly rammed to the shoulder at the end of the breech chamber, where it must begin to be compressed to take the rifling. Behind it was fitted a gas check wad, composed of disks of sole leather and copper, and greased like the shot. Last of all was slid into place a coarse flannel bag holding 15 pounds of powder in hexagonal grains as big as hickory nuts. Then the breech was closed and locked, a cannon primer, with electric wires attached, was shoved into a small central hole in the breech, and Capt. Starring ordered everybody into the bomb-proof.

There were eighteen men in that bombproof, which is a subterranean construction of enormous timbers, over which many feet of sand and gravel are heaped. The reporter fired the big gun, by permission of Major McKee. To do so he simply had to press a little ivory button in a box on the wall. There was a dull roar, nothing like so loud as had been expected by those who now heard it for the first time. But the recoil of the steel and iron mass from that shot was four and a half feet. Of the two frames of electric wires, 100 feet apart, between the muzzle of the gun and the heavy barricade backed with sand which catches and saves the