WATER METERS.

Comparative Tests of Accuracy, Delivery, etc.—
Distinctive Features of the Worthington,
Kennedy, Siemens and Hesse Meters.

BY

ROSS E. BROWNE,

MEM. TECH. SOC.

REPRINTED FROM VAN NOSTRAND'S MAGAZINE.

NEW YORK:
D. VAN NOSTRAND, PUBLISHER,
23 MURRAY AND 27 WARREN STREETS.
1885.

PREFACE.

As this brief essay is merely descriptive of certain mechanical devices, it needs no explanation in a preface. As the literature of the subject is undoubtedly too scanty, it needs no apology. We believe hydraulic engineers will be found ready to welcome any addition to the stock of existing information on so practical and important a subject.

Mr. Browne's paper has been supplemented with a few descriptions translated from an article in *Le Génie Civil*, by Ch. André.

WATER METERS.

BY

ROSS E. BROWNE.

WATER METERS.

WITH the purpose of employing a meter for the measurement of water, in connection with some hydraulic experiments conducted at the University of California, the writer instituted a series of tests of a meter invented by Prof. F. G. Hesse. The accuracy, at various rates of delivery, was carefully determined. The results of these experiments, properly tabulated, furnish a correction for the indicated delivery. It is believed that, where the flow is uniform, the possible error in the corrected index reading may be safely placed at ¼ per cent.

The meter is of the class known as *velocity* or *inferential* meters, and is so permanent in its sources of error, as to make it peculiarly adapted to the purpose named.

These experiments led to comparative tests of the Worthington meter. Reliable information was also sought concerning other meters in common use. It is thought that sufficient of interest was developed to warrant this paper, particularly as, in the course of this investigation, it was noted: that no great amount of accurate and systematic information upon this subject is to be found in the available files of our engineering and scientific journals; that the several reports consulted, of engineers and superintendents of water works, while well answering their immediate purposes, do not furnish facts in sufficient detail to guide the independent judgment of one not familiar with the construction of the meters in competition; that very few of the circulars of the American manufacturing companies supply such data as will answer for comprehensive comparison.*

* The circular of the National Meter Co. of New York is exceptionally complete, though there is missing some of the data necessary to warrant the inclusion of their rotary Crown Meter in the list of meters discussed.

It will be attempted to bring forward, as fairly as may be, the distinctive features of two of the principal forms of Piston meter—the Worthington and the Kennedy,—and three forms of velocity meter—the Siemens of English manufacture, the Siemens of German manufacture, and the Hesse meter already mentioned.

The Worthington is widely known in the United States. The Kennedy is one of the most perfect of the meters used in England. The two Siemens meters are probably the most extensively employed in Europe. The Hesse meter has been but recently perfected, and not yet introduced. If undue prominence has been given to the last named meter, the interest of the writer in his special investigation must plead as excuse.

It is to be regretted that this list cannot be made more comprehensive by adding an example of the rotary piston form, such as the Crown. It will be understood that, in speaking of the piston meter, special reference is only intended to the Worthington and the Kennedy.

These meters will be considered in the main with reference to their adaptability to house use, or use in the sale by volume of water under pressure.

This being the purpose of a meter, it should fulfill the following conditions:

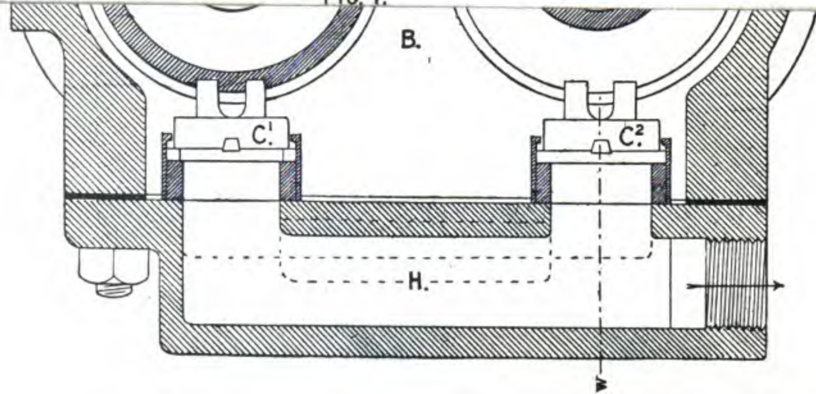
1st. It should register with a suitable degree of accuracy, the quantity of water delivered at every rate of flow, from that of the maximum capacity of the service pipe, to a rate so small as to discourage theft. The admissible error is variously placed at from 2 to 5 per cent.

2d. This degree of accuracy should be reasonably permanent, *i. e.*, the meter should not be subject to any change, seriously affecting its accuracy, by wear, by slight deposition of sediment, etc. Sudden opening and closing of the house faucets should not induce any considerable error of registry.

3d. The introduction of the meter should not materially affect the delivery of the service pipe; *i. e.*, should cause no serious loss of effective head or pressure.

WORTHINGTON METER, 5/8 inch, Scale 1/2.

FIG. I.



4th. The price should be small and the necessary repairs inexpensive.

Notwithstanding the demand and the effort made by inventors to meet these desiderata, such marked success has not been attained as to make it a universal custom to sell water by the volume.

In the systems of city supply, there result decided advantages from the employment of the meter. Reckless waste is checked and the consumer is not charged for his neighbors' extravagance. A number of comprehensive articles have been published upon this subject, and a few points only will be reiterated.

It is claimed that nearly one-half of the water consumed in our cities is uselessly wasted. It is doubtful if this lavish consumption is on the whole a sanitary benefit, the waste being in large part the result either of leakage or of willful negligence, and not of a character to effect any proper flushing of closets and sewers. By placing meters near the point where the service pipes enter the premises, and thus making the consumers responsible for such negligence, and for defective plumbing, a wiser use of water is effected. In order to prevent the penurious consumer from pursuing an economy so stringent as to result in certain sanitary evils, it is recommended that a minimum quantity of say 10 or 20 gallons per capita per diem be established, and the consumer charged for this whether he use it or not. The water department of Providence, R. I., makes a minimum charge of $10 per year (equivalent to about 100 gallons per diem) for each meter service. Meters were provided, in Providence, for about one-half the total number of services, and a decided economy effected. The daily consumption at present is about 350 gallons per service, or 25 to 30 per capita—less than one-half the average in American cities.

When the water supply of a city, employing few meters, becomes inadequate to meet the demands of the consumers, two propositions may be entertained: the increasing of the capacity of its water works, and the introduction of meters. It is maintained that in most cases the latter proposition is by far the more economical. As the city grows, it will, from time to time, become necessary to increase the supply; but it is thought much cheaper to keep the meters in repair and maintain water works of double the capacity sufficient without meters.

It seems inevitable that the meter system should rapidly grow in favor with improvement of the present forms of meter. In a few cities their use is already extensive. In London* nearly 40 per cent. of the houses supplied by the various water companies are now provided with meters. In New York and Boston, meters have been introduced into from 5 to 10 per cent. of the services. In Providence, R. I., 50 per cent. In San Francisco 20 per cent. In Oakland 3 or 4 per cent.

THE COMPARISON OF METERS.—A just and comprehensive comparison of the merits of competing meters will frequently involve an extended investigation. If,

* See *London Engineer* of Aug. 1, 1884. For detailed information concerning the U. S. and Canada, see circular of National Meter Co., N. Y.

for instance, the extent and effect of wear and rusting are difficult to estimate, prolonged trial may becomo necessary.

Of the more important considerations in such a comparison, the following are enumerated in an order not pretending to indicate relative importance.

Delivery under various effective heads.

Greatest advisable rate of delivery.

Accuracy of registration at various rates of delivery.

Sensitiveness.

Necessity and difficulty of special adjustment.

Permanence of initial degree of accuracy and sensitiveness.

Liability to obstruction.

Compactness.

Price, both upon the basis of delivery and of greatest advisable effective head.

Expense of repairs, including the consideration of the life of the meter.

Head lost in the meter.—By head lost is understood the difference of the heads in the inlet and the outlet openings. If H is the actual head at the inlet and *h* that at the outlet, then the head lost is $H-h$. The rate of delivery will depend upon this difference of heads, and not upon the actual magnitude of H and h.

In each of the meters described, the law of loss of head is, within a practical limit, roughly the same—the resistance being mainly due to impact and fluid friction, and therefore approximately proportional to the square of the rate of delivery.

This is about the same as the law of loss in a pipe. Hence the loss of head in a meter is fittingly indicated by the length of pipe of given diameter which will cause the same loss. Thus 10 feet of ½-inch pipe, or 30 feet of ⅝-inch pipe, will occasion the same loss as the Worthington ⅝-inch or the Hesse ½-inch meter.

Effective head.—By effective head is understood the actual head necessary to force water through the meter at a given rate. This is equal then to the "head lost" plus the velocity head in the outlet pipe, and will, in the meters mentioned, be very little greater than the "head lost."

Delivery of the meter.—It is customary to designate the size of a meter by the diameter of service pipe for which the inlet and outlet openings are fitted. This classification furnishes no general measure of delivery. When the rate of delivery is approximately the same function of the head lost, in each, it is admissible to adopt a unit and classify the meters accordingly.

The loss in the delivery of a service pipe occasioned by the introduction of a Worthington $\frac{5}{8}''$ or a Hesse $\frac{1}{2}''$ meter, is easily calculated.

Suppose for example the $\frac{5}{8}$-inch service pipe to have a length of 100 feet; also 5 elbows each equivalent, in loss of pressure occasioned, to 5 feet of pipe; also one service cock, together with minor obstructions equivalent to 25 feet of pipe. The equivalent length of pipe, of diameter, $d=\frac{5}{8}$ inch, is $l_1=150$ feet $=1800$ inches. After introduction of meter $l_2=(150+30)$

$\times 12 = 2{,}160$ inches. Weisbach's formula gives

$$v = \sqrt{\frac{2gH}{1 + \lambda\frac{l}{d}}}$$

wherein H will be the effective head in the main, v the velocity in the service pipe, and λ a coefficient $= .02$ for such velocities as are here involved. If v_1 represents the velocity before, and v_2 after the introduction of the meter

$$\frac{v^2}{v^1} = \sqrt{\frac{d + \lambda\, l_1}{d + \lambda\, l_2}} = \sqrt{\frac{\frac{5}{8} + .02 \times 1{,}800}{\frac{5}{8} + .02 \times 2{,}160}} = 0.914$$

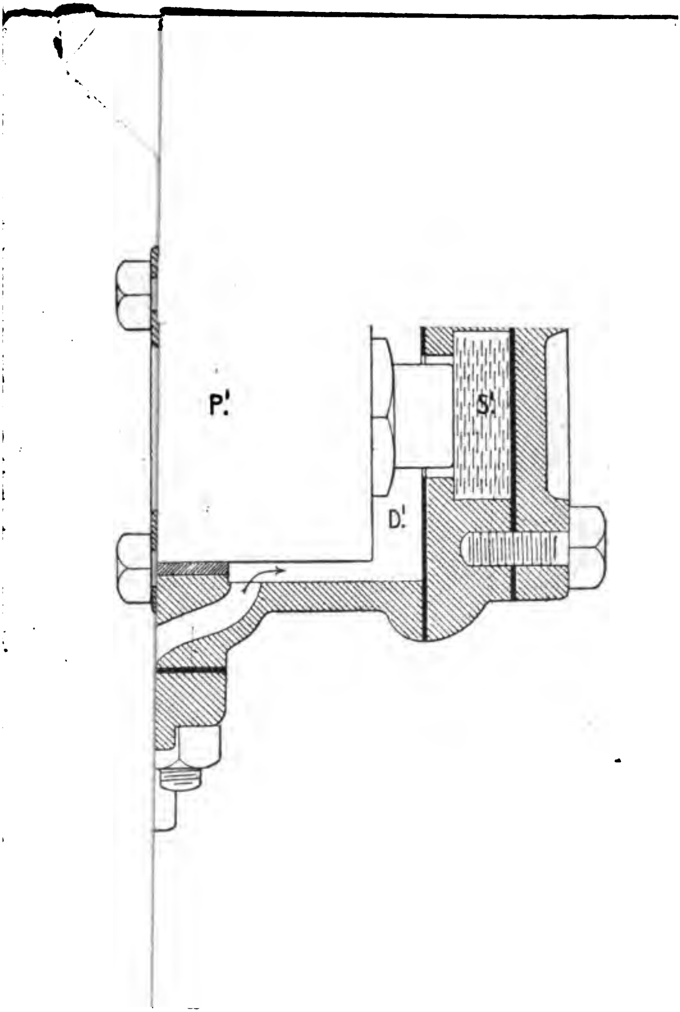
In other words, the meter would occasion, in the case given, a loss: in delivery of service pipe, of about 9%; in effective head back of the faucet, of about $1.00 - (0.914)^2 = 16\%$; in the kinetic energy or capacity for work, of about $1.00 - (0.914) = 24\%$.

Greatest Advisable Rate of Delivery—When a meter is taxed beyond a certain point it will be seriously damaged. A practical limit in rate of delivery is therefore fixed upon, and this should govern the selection. In addition to this limit in rate of delivery, the corresponding effective head should be given. The allowable effective head in the oscillating piston meters is small, in the rotary piston meters considerably greater, in the velocity meters very high. Where a high head is at hand, and the capacity of the service pipe is great, an oscillating piston meter of large size should be used, whereas it is safe to introduce a comparatively small velocity meter.

Sensitiveness.—The rate of delivery necessary to cause motion of the dial hands, or the greatest quantity per minute which may pass without causing registration, will be taken as an inverse measure of the sensitiveness of the meter.

The head lost and accuracy of a meter, are conveniently illustrated by means of curves.

Curves of head lost (see diagram).—These were obtained by plotting on suitable scales, in a rectangular co-ordinate system, the rates of delivery as abscissæ, and the corresponding heads lost as ordinates.



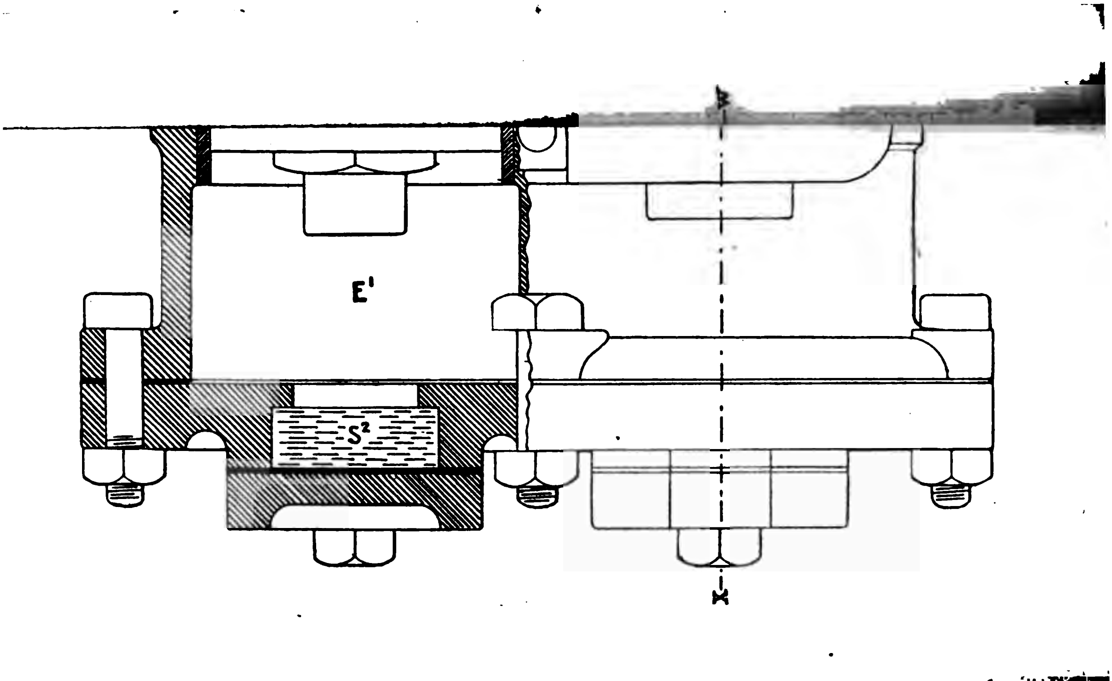
P!
S!
D!

Curves of Registry (see diagrams).—By recording the measurement of the actual quantity delivered, and the reading of the index, under various rates of flow, the data is obtained for plotting a curve which will illustrate the effect of the change in rate of delivery upon the accuracy of registration. The curves given were obtained by plotting the rates of delivery as abscissæ, and the corresponding per cent. registered of the actual quantity delivered as ordinates.

Upon the basis of the considerations enumerated, a comparison of the meters selected has been instituted. A statement of this comparison will be preceded by a detailed description of each meter concerned.

Piston Meters.—In the piston meters mentioned, the oscillating pistons displace a quantity of water each stroke. The measure of the quantity delivered, is, in the Worthington the number of strokes, in the Kennedy the approximate distance traveled by the piston. The degree of accuracy for the various rates of delivery, will depend in the Worthington upon the differences in length of stroke, the piston leakage, the action of the valves, &c. In the Kennedy there is a dependency upon, but slight differences in the length of stroke, upon leakage, etc. These and similar meters are frequently termed *volume* or *positive* meters, in contradistinction to *velocity* or *inferential* meters. No assumption of advantage is authorized by such a distinction. The approximate volume is registered in either case, and there is no general difference in the directness of transmission from the measuring part to the index.

Description of the Worthington Piston Meter (see Figs. 1, 2, 3, 4_a 4_b)—Letters of reference refer to the same parts in the different figures. In this meter two piston plungers are closely fitted in parallel cylinders. By means of two slide valves, the water is admitted under pressure into the chamber at one end of each plunger alternatively, while connection is made between the chamber at the other end and the discharge pipe. Thus the piston


X
X
E^1
S^2

in moving, displaces the volume escaping through the discharge pipe. The arrangement is such that the strokes of the two plungers alternate, the valve actuated by the one admitting the pressure to the other. The displacement, (area of piston times length of stroke) multiplied by the number of strokes will give approximately the volume of water delivered. The indexing apparatus is arranged to move the dial hands once every fourth stroke, 3 such movements registering $\frac{1}{10}$ cubic foot in the $\frac{5}{8}$-inch meter.

The water enters through opening A into chamber B. In the position of plungers shown, the water then passes through port *a* (of valve C^1), channels *b* and *c* into chamber D^1. Plunger P^1 is moved to the left, forcing the water of chamber D^2 through channels *d*, *e*, ports *f* and *g* into outlet H. In the last third of the stroke, valve C^2 is shifted to the left, establishing communication between chambers B and E^2, through port *k* and channels *l* and *m*—and at the same time connecting chamber E^1 with outlet H

FIG. 4a.

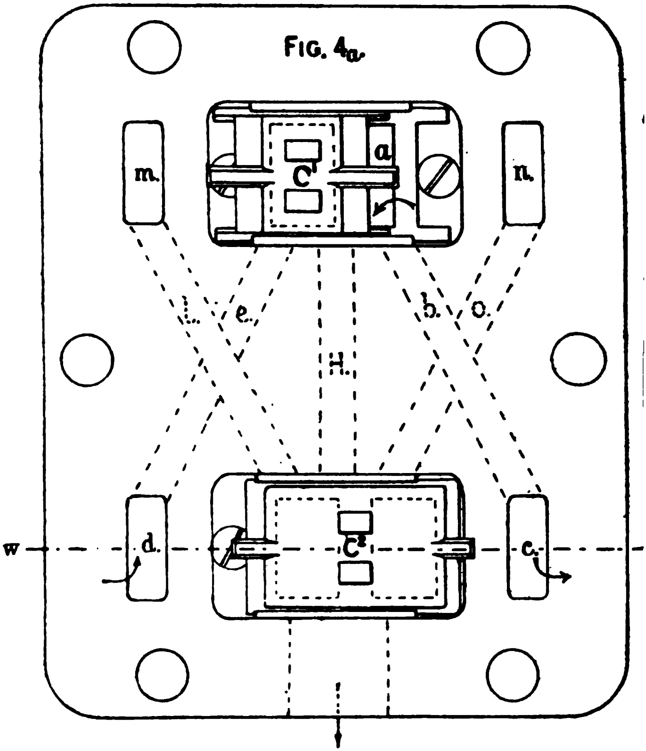
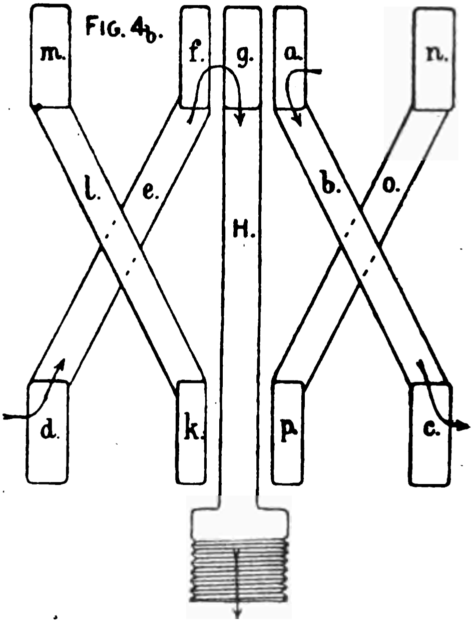


FIG. 4b.



through channels *n* and *o* and port *p*. Plunger P^2 is moved to the right, shifting, in the last third of its stroke, valve C^1, and thus establishing communication between chambers B and D^2 through port *f* and channels *e* and *d*.

The pistons are brought to rest at the end of the stroke by rubber seatings S^1, S^2.

Piston P_1 imparts a reciprocating motion to lever L, which, in combination with the movable pawl M, ratchet-wheel W, stationary pawl N, and index gear R, causes the dial hand U to register for each four plunger strokes (single strokes) $\frac{1}{30}$ of a cubic foot.

Fig. 1 is a section through *uv* (see Figs. 2 and 3).

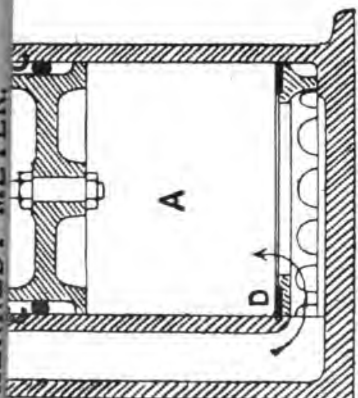
Fig. 2 is a section through *wx* (see Figs. 1, 2 and 4_a).

Fig. 3 is a view from below with base plate (Fig. 4_a) removed, showing the walls of chamber R partly in section.

Fig. 4_a is a top view of the base plate, showing valves, ports, etc.

Fig. 4_b is a plan of the valve ports,

KENNEDY METER.



M. Co., Kilmarnock, Scotland.

channels and outlet, showing how channel *o* passes under channel *b*, channel *e* under channel *l*, etc.

*Description of the Kennedy Piston Water Meters** (see Figs. 5, 6, 7).—The measuring cylinder (A) forms the base of the meter, and is fitted with a piston (B) made of vulcanite. The piston is made to move perfectly water-tight and almost free from friction, by means of a solid cylindrical ring (C) of pure "Para" rubber, which rolls between the body of the piston and the internal surface of the cylinder. Each end of the cylinder is fitted with an india rubber seating (D), on which the piston will form a water-tight joint, if back pressure should force it to either end of the cylinder; undue pressure is thus prevented from being thrown on the piston roller.

The piston rod (E), after passing through a stuffing box (F) in the cylinder cover (G), is attached to a rack (H) which

---

* Description and figures are taken with but slight changes from the circular of the Kennedy Patent W. M. Co., Kilmarnock, Scotland.

gears into a pinion (K) fixed on the shaft (L). The shaft is turned in reverse directions, actuating the reversing and indexing gear (M) as the piston moves up and down. The rack is kept in gear and guided in a vertical line by an anti-friction roller, which is carried on a stud projecting from one of the shaft-bearing brackets. The cock-key (P), which directs the water alternately above and below the piston, is placed in the same axial line as the shaft, and is fitted with a duplex lever (Q), which is actuated by a weighted lever (R) carried loosely on the shaft, and caused to fall alternately on each arm of the duplex lever. The weighted lever, after reversing the key, falls on a buffer (S) faced with india rubber, which, yielding before it and traveling in the same curve, gradually brings it to rest.

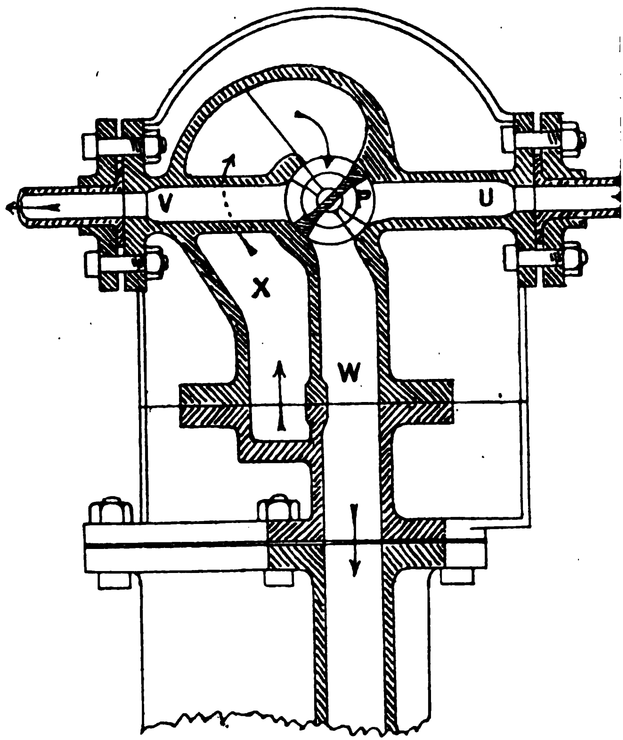
Fig. 5 is a side section through the center shaft, cock-key, and piston.

Fig. 6 is a front section of cock-key (P) and water passages (U, inlet, and V outlet).

Fig. 7 is a horizontal section through line UV.

The meter is shown in the position of having nearly completed its upward stroke. The water enters at the inlet (U), and is directed by the cock-key down the passage (W) to the bottom of the cylinder, forcing up the piston, which presses the water (which on the previous down-stroke entered above the piston,) up through the passage (X), passing behind passage (V), and is directed by the cock-key into the outlet passage (V). When the piston has moved up a little farther, the bob (weighted lever R) will pass its point of unstable equilibrium and fall on the key arm (arm of duplex lever Q) which it will send down until it is stopped by the buffer box (S). The key will then be at right angles to its position as shown in Fig. 6. The water will then be directed from U down X into the top of the cylinder, forcing the piston down, while the water admitted below during the last stroke is forced up the passage W and out by the outlet V. When the piston has arrived

FIG. 6.



KENNEDY METER.

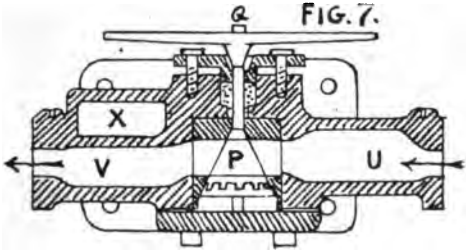


FIG. 7.

near the bottom of the cylinder, the lifter will have lifted the bob from the left side of the buffer-box and raised it to the point of unstable equilibrium; from there it will have fallen on the right hand key-arm, and have brought back the cock-key to its former position, ready to begin another upward stroke.

It is unnecessary to illustrate here the method of converting the reciprocating motion of the shaft (L) into the circular motion (in one direction) of the index wheels (M), and thus causing to be registered a quantity approximately proportional to the distance traveled by the piston.*

* A ratchet is interposed between the pinion and the registering gear, and the degree of approximation in

VELOCITY METERS.—In the velocity meters of the Siemens system a small wheel is driven by the passing water, and the number of revolutions is the measure of the quantity delivered. The frictional resistance, offered by the journals of the wheel spindle and the registering apparatus, cause important modifications of the velocity of the wheel. The Hesse meter practically overcomes the objectionable influence of this resistance, but it will be shown that, even if it could be wholly avoided, perfect accuracy of registration would not thereby be effected.

*Description of the "English" Siemens Velocity Water Meter** (see Figs. 8, 9). —Of the Siemens system there are two important forms, the one manufactured by Guest & Chrimes of Rotherham, England, and the other by Siemens & Halske of Berlin. The former will be termed the "English" Siemens, and the latter the "German" Siemens.

---

indicating the "length of piston travel" depends upon the number of teeth in the ratchet.

* Description, in the main, and figures taken from the circular of Guest & Chrimes.

It will be seen from the figure of the English Siemens meter, that the water passes, as indicated by the arrows, from the inlet pipe through a funnel, into a small reaction wheel, or Barker's mill (H), (constituting the measuring drum,) causing it to revolve. The water then passes on to the outlet pipe. The motion imparted to the measuring drum is communicated to the index, and thus a quantity proportional to the number of revolutions of the drum, registered.

Fig. 8 is a perspective view of the drum or measuring medium (H), showing the adjusting or regulating vanes *a a a*, and curved water ways *b b b*.

Fig. 9 is a section of the meter, filter and unions complete. A is the inlet. C and E are filters for the purpose of preventing foreign substances from passing into the drum H. The motion of this drum is retarded and suitably regulated by the vanes *a a a*. J is an oil-box for the purpose of lubricating the spindle K. N is the outlet. O is the spindle of the drum, with screw Q attached for the purpose of giving motion to the wheels of the dial work R. S S is an oil chamber for the purpose of lubricating and protecting the dial wheels from the action of the water, etc.

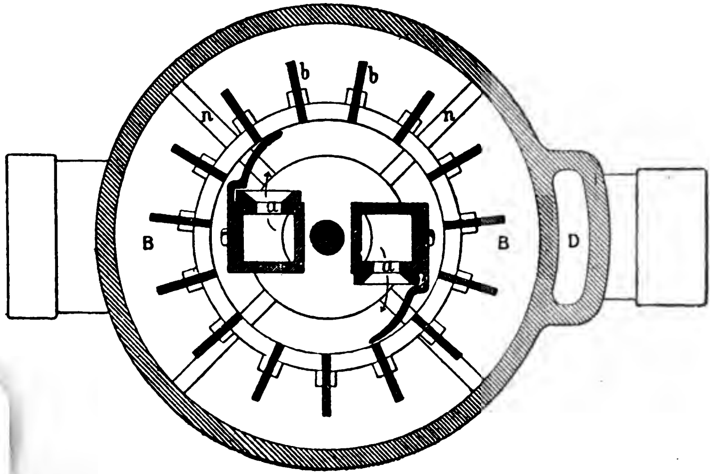
*Description of the "German" Siemens Velocity Water Meter** (see Figs. 10, 11). —This meter differs from the "English" Siemens in so far as the motor is concerned, a small pressure wheel taking the place of the reaction wheel.

The water having entered the meter through the inlet pipe U, passes through the openings *a a a a*, in the brass casing A, and coming in contact with the buckets *b b b b*, imparts motion to the wheel. The water then escapes through openings *c c*, and finally discharges into the outlet pipe V.

* The figures are taken from a valuable article, on the subject of water meters, in the German "*Civilingenieur*" of the year 1875, by B. Salbach, Kgl. Baurath at Dresden. At the instigation of the City Council of Dresden, an exhaustive set of tests were made of twelve "meters of the most modern construction"—among these the Kennedy, the "English" and the "German" Siemens. Further reference will be made to this article.

SCALE 1/2.

FIG. 13.



The manner in which the motion is imparted to the wheel is transmitted to the index, is the same as in the "English" Siemens. In order to keep out the coarse sediment, the water is made to pass through a screen before entering the meter. For the purpose of regulating the velocity of the wheel, four small openings *e e e e* are bored into casing A, in a direction opposed to the motion of the wheel; and by closing or enlarging these, the velocity of the wheel may be increased or reduced.

The stationary ribs *d d* counteract in part the tendency of the water to rotate.

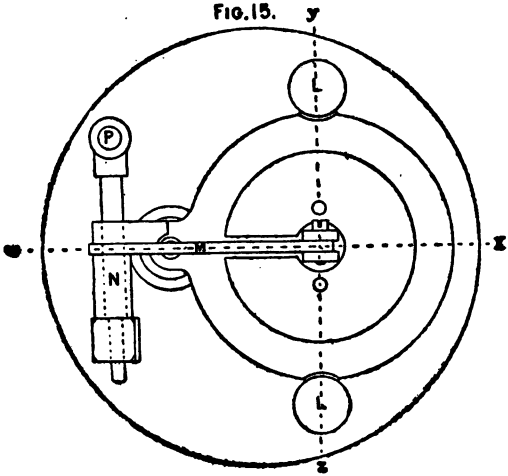
Description of the Hesse Velocity Water Meter (see Figs. 12, 13, 14, 15, 16, 17, 18).—The water from the inlet pipe enters channel A (Fig. 12), passes through openings *a a* (Figs. 12, 13), and striking the buckets *b b* (Figs. 12, 13), imparts motion to the measuring wheel—a pressure wheel similar in character to that of the "German" Siemens. The water passes then from the wheel chamber B into chamber C, mainly through valve opening *d* (Fig. 12), and in part through chamber *e*, opening *f*, chamber *g*, and conical tube *h* (Figs. 16, 17), and is finally discharged through chamber D into the outlet pipe.

The motion of the measuring wheel is transmitted to the worm wheel H (Figs. 16, 17), by means of the endless screw F (Fig. 16), which is attached to the upper end of the wheel spindle G (Figs. 12, 16). This worm wheel, in revolving, interrupts intermittently the direct flow of that portion of the water which passes through chamber *g*. In the position of the worm wheel shown in (Fig. 16), the solid arm of the wheel (the cause of this interruption) is just passing the openings *f* and *h*, hence direct flow through these openings is just beginning. During the interval of direct flow the action is comparable to that of the jet pump, causing the pressure in chamber *g* to fall below that in chamber C. The interruption of the direct flow causes the pressure to rise above that in chamber C.

The alternating high and low pressures in chamber *g*, thus induced by the slow

rotation of the worm wheel, cause the cap K of the bellows-like rubber diaphragm E (Figs. 12, 16, 17) to rise and fall accordingly. The number of such pulsa-

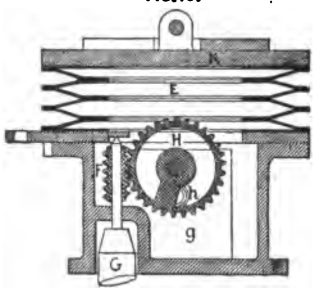
FIG. 15.



tions or strokes is directly proportional to the number of rotations of the measuring wheel. The length of the stroke is limited by the heads of set screws LL (Figs. 12, 16, 17).

This reciprocating motion of the cap K is transmitted and converted into the circular motion of the gear wheels of the index, through lever M, rock-shaft N,

FIG. 16.



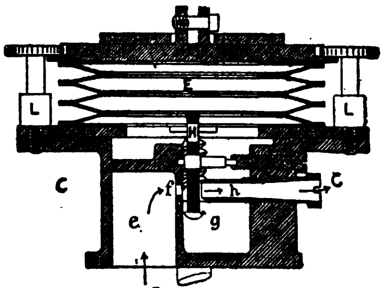
shaft P, lever R, pawl S, and ratchet wheel T (Figs. 12, 14, 15).

The dial hands are thus made to register a quantity, which is directly proportional to the number of revolutions of the measuring wheel. The measuring wheel is made of hard rubber of specific gravity 1.2, and with the cork attachment (U*)

* The cork attachment is unnecessary, as the weight of the wheel in water is sufficiently small without it.

has the same weight as an equal volume of water. There is then so little pressure upon the journals of the spindle G, that the frictional resistance offered is

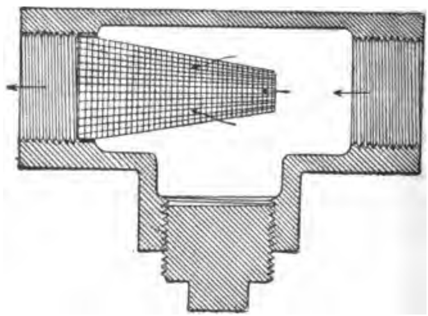
FIG. 17.



exceedingly small. The worm wheel H rests loosely in its bearings, offering but little resistance to rotation. Since in 38 revolutions of the measuring wheel, but one revolution is given to the worm wheel, the work and hence the effective resistance is minute. The frictional resistance due to the periodic pressure upon the journals of the worm wheel, as the arm passes opening *f*, was found by experiment to be very small.

When the meter is delivering water at rates above three or four gallons per minute, the valve J is lifted, but the difference of pressures in chambers B and

FIG. 18.



C is far greater than that needed to operate the bellows. When the rate of delivery is small, the valve is seated, and the entire quantity is forced through chamber *g*, insuring the action of the bellows.

The alternate rise and fall of pressure

in chamber *g*, furnish an abundant surplus of power to provide against undue resistance in the stuffing box X (Fig. 12), and all differences due to the character of the workmanship, and to wear or corrosion of the parts of the registering apparatus.

The measuring wheel does not supply the power expended in moving the registering apparatus, hence the unavoidable changes in the latter do not affect the accuracy of the meter. This points to the distinctive feature of the Hesse meter.

m, *m*, and *n*, *n* (Figs. 12, 13) are stationary ribs provided for the purpose of checking in part the rotation of the water in chamber B, and offering additional resistance to the motion of the wheel. Such resistance diminishes the detrimental influence of the solid friction, and causes almost immediate stoppage of the wheel in case the water is suddenly shut off.

The meter tested is provided with connections for $\frac{1}{2}$ inch pipe. Openings *aa* have $\frac{9}{32}$ inch diameter. Valve opening *d* has $\frac{5}{8}$ inch diameter. Weight of valve J is 0.16 lb. Entire weight of meter is 21.4 lbs.

Fig. 12 is a vertical section through *st* (see Fig. 14).

Fig. 13 is a horizontal section through *uv* (see Fig. 12).

Fig. 14 is a top view of the meter with the dial box removed, showing the dials, etc.

Fig. 15 is a top view of that portion of the registering apparatus contained in chamber C (see Fig. 12).

Fig. 16 is a vertical section of the bellows-like diaphragm, etc., taken through *wx* (see Fig. 15).

Fig. 17 is another vertical section of the same through *yz* (see Fig. 15).

Fig. 18 is a section of the screen or filter which is interposed between the meter and the inlet pipe.

The material used in constructing the meter is shown by the manner of shading the sections. It may be found advantageous to make a different selection for some of the parts. The meter will not serve for the delivery of hot water without radical changes in the material.

The Kennedy and the Siemens Curves (see diagrams) were obtained from the experiments of Mr. Salbach (see foot note), who used such curves as a means of comparison.

The volume of water delivered was measured in an accurately constructed tank. The loss of head was given by the difference of the readings of two large quicksilver manometers, the one communicating with the inlet, and the other with the outlet pipe immediately adjacent to the meter.

Tests were made under mean heads* of about 45 and 150 feet. The change of mean head had no material effect upon the curves of registry of these meters, excepting in the case of the "German" Siemens meter II, which gave better results under the greater head, and even this was doubtless due to cleaning of the meter in the interval. The effect upon

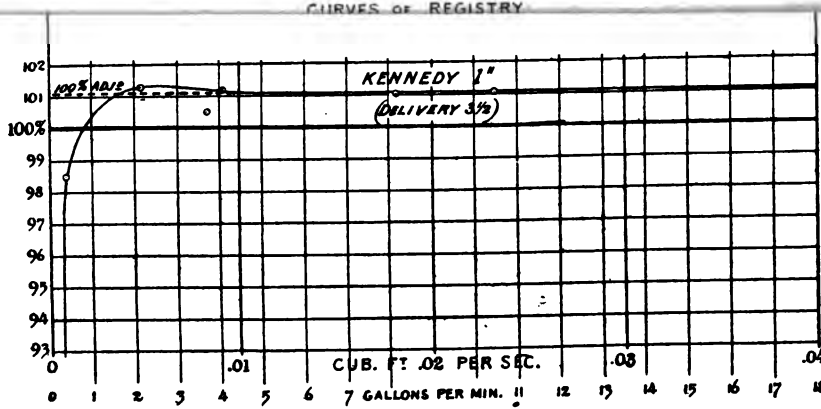
* It is presumed that by "mean head" is meant the verage head in the inlet pipe.

the curves of head lost was not important, and was probably due, as Mr. Salbach says, (mainly) to some imperfections in the manometers when under low pressure, The curves of registry were plotted from the tests made under the lower mean head, the curve from tests under the higher mean head being added for the "German" Siemens meter II—II_a lower, II_b higher mean head. The curves of head lost were plotted from the tests under the higher mean head.

The Worthington B, C *and* D curves of registry were plotted from the results of experiments conducted by Prof. Hesse, as chairman of a committee appointed by the Board of Managers the Twelfth Industrial Exhibition of the Mechanics' Institute 1878 (published in report). Meter B had never been in use, C had been in use 3 months, D 8 months. A number of others were tested showing the effect of wear, etc.

The Hesse and the Worthington A curves were plotted from the results of a set of tests conducted by the writer, with

CURVES OF REGISTRY



* UNIT OF DELIVERY 9 GALLONS PER MIN. WITH 20 FEET LOSS OF HEAD.

the assistance of Mr. H. Dikeman, a student of engineering in the University of California.

The Hesse meter tested, forms a part of some experimental apparatus in the Mechanical Laboratory.

The Worthington A is a $\frac{5}{8}$-inch meter which was specially selected by Mr. Purcell of the Oakland Water Co. to serve as a test meter.

The quantity of water delivered was weighed to $\frac{1}{10}$ lb., and the pressure measured by means of a sensitive gauge described in the *Mining and Scientific Press* of September 2, 1882, also in *Bulletin No. 1* of the College of Mechanics. With this gauge the heads could easily be measured to $\frac{1}{10}$ of a foot. The time was observed only to single seconds. The results of these tests are tabulated below. The diameters of the inlet and outlet pipes were the same at the points where connected with the pressure gauge, so that it was unnecessary to make allowance for the velocity heads at these points in order to obtain the effective difference

TESTS OF THE ACCURACY AND DELIVERY OF THE HESSE ONE-HALF INCH METER.

No. of Test.	Hydraulic Heads in Feet. Inlet H.	Outlet h.	Time in Sec's.	Weight in lbs. avoir-dupois G.	Cubic Feet. Actual $\frac{G}{62.4}$	Regis-tered.	Rate of Delivery. Cubic ft. per sec.	Gals. per min.	Head lost in Feet, $H-h$.	Ratio of Regist. to Actual Volume in per cent.
1	—	—	—	—	—	—	.00015	.07	—	—
2	59.85	59.40	1308	31.3	0.502	0.4	.00038	.17	.45	79.7
3	59.50	59.00	2543	72.2	1.157	1.0	.00046	.21	.50	86.4
4	59.00	58.15	3660	218.0	3.494	3.6	.00096	.43	.85	103.0
5	59 40	58.55	1392	119.8	1.920	2.0	.00138	.62	.85	104.2
6	50.40	58.45	1102	119.5	1.915	2.0	.00174	.78	.95	104.4
7	50 40	58.30	915	119.8	1.920	2.0	.00210	.94	1.10	104.2
8	59.20	58.05	802	120.0	1.923	2.0	.00240	1.08	1 15	104.0
9	59.10	57.90	1125	180.6	2.894	3.0	.00257	1.15	1.20	103.7
10	59.0	57.5	840	182.0	2.917	3.0	.00347	1.56	1.5	102.9

11	58.8	56.9	641	184.3	2.954	3.0	.00461	2.07	1.9	101.6
12	57.1	54.7	524	185.0	2.965	3.0	.00566	2.54	2.4	101.1
13	56.8	53.9	452	186.0	2.981	3.0	.00660	2.96	2 9	100.6
14	56.5	53.3	441	198.6	3.183	3.2	.00722	3.24	3.2	100.5
15	56.3	52.7	375	186.8	2.994	3.0	.00798	3.58	3.6	100.2
16	55.8	52.1	365	187.0	2.997	3.0	.00821	3.69	3.7	100.1
17	55.9	50.9	304	187.3	3.002	3.0	.00987	4.43	5.0	100.0
18	55.6	49 9	563	374.6	6.003	6.0	.01066	4.79	5.7	100.0
19	55.2	48.4	507	374.7	6 005	6.0	.01184	5.32	6.8	99.9
20	54.7	46.5	465	374.7	6.005	6.0	.01291	5.80	8.2	99.9
21	54.3	44 9	432	375 0	6 010	6.0	.01391	6.24	9 4	99.8
22	55.0	45.8	434	375.0	6.010	6.0	.01386	6.22	9.2	99.8
23	54.5	42.8	390	376.0	6.026	6.0	.01545	6.94	11.7	99.6
24	53.5	38.3	340	376.4	6.032	6.0	.01774	7.97	15.2	99.5
25	52.8	34 5	312	376.5	6.034	6.0	.01934	8 68	18.3	99.4
26	50.7	29.4	290	376.5	6.034	6.0	.02081	9.34	21.3	99.4
27	49.7	24.9	267	376.7	6.037	6.0	.02261	10.15	24.8	99.4
28	49.3	20.9	256	388.8	6.232	6.2	.02434	10.93	28.4	99.5
29	47.6	15.1	231	376.7	6.037	6.0	.02613	11.73	32.5	99.4
30	46 5	11.1	220	377.0	6.042	6 0	.02746	12.33	35 4	99.3
31	45.7	6.8	210	376.7	6.037	6.0	.02875	12.91	38.9	99.4

In test No. 1 the limit was reached.

of heads. The temperature of the water varied 2° F., averaging 55° F.

The possible error in these tests, it is thought, may be safely taken at 1 per cent. in the rate of delivery, at $\frac{1}{4}$ per cent. in the ratio of registered to actual delivery, and at one foot in head lost at high rates, and $\frac{2}{10}$ foot at low rates.

The Hesse meter, experimented with, had previously been subjected to various tests by the Oakland Water Co., and had delivered during four months, 62,000 cubic feet (in great part at the rate of $12\frac{1}{2}$ gallons per minute), without being in the least damaged. This is a greater quantity than would be drawn in 5 years in the average service. However, it must be borne in mind that this test involved the important element of time only to a small extent.

TESTS OF THE ACCURACY AND DELIVERY OF THE WORTHINGTON FIVE-EIGHTHS INCH METER.
(A) No. 26,737.

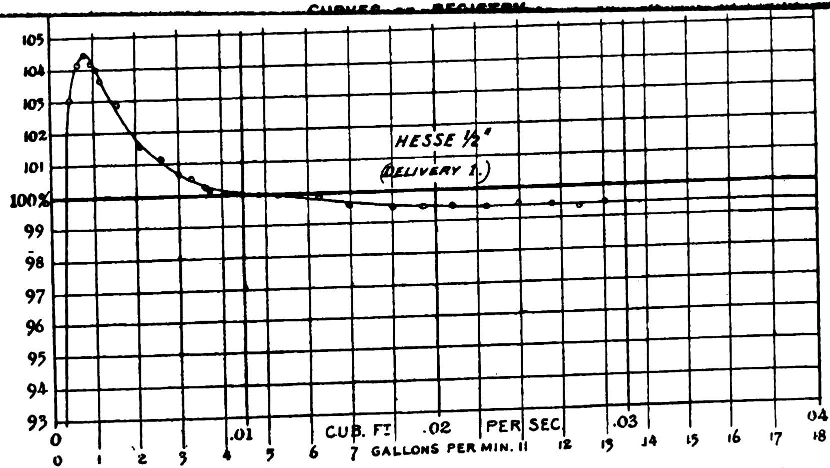
No. of Test.	Hydraulic Heads in Feet.		Time in Sec's.	Weight in lbs. avoirdupois G.	Cubic Feet.		Rate of Delivery.		Head lost in Feet, H-h.	Ratio of Regist. to Actual Volume in per cent.
	Inlet H.	Outlet h			Actual $\frac{G}{62.4}$	Registered.	Cubic ft. per sec.	Gals. per min.		
1	—	—	—	—	—	—	.00015	.07	—	—
2	59.00	58.85	1622	17.0	.2724	.30	.00017	.08	.15	110.1
3	59.00	58.80	640	15.5	.2484	.27	.00039	.18	.20	107.0
4	58.85	58.40	492	59.4	.9519	1.00	.00193	.87	.45	105.1
5	58.65	57.00	379	122.0	1.9551	2.00	.00516	2.32	1.65	102.3
6	58.15	55.40	272	122.5	1.9631	2.00	.00722	3.24	2.75	101.9
7	57.30	52.20	308	184.4	2.9551	3.00	.00960	4.31	5.10	101.5
8	56.5	49.5	255	185.0	2.9647	3.00	.01163	5.22	7.00	101.2
9	53.8	40.4	302	310.7	4.9791	5.00	.01649	7.40	13.40	100.4
10	49.1	24.9	224	313.8	5.0288	5.00	.02245	10.08	24.20	99.4
11	43.7	8.1	184	316.3	5.0689	5.00	.02755	12.37	35.60	98.6

DISCUSSION OF THE CURVES OF HEAD LOST.—These are approximately parabolic, and may be represented roughly by the equation $H-h=A+B\,Q^2$, wherein Q is the quantity delivered in cubic feet per second, A and B constants. In the Worthington ⅝-inch A=0.4, B=46,000.

These curves simply serve the purpose of determining the deliveries of the several meters, prior to making comparisons of sensitiveness, cost, &c. By following the 20 feet line it will be seen that with this loss of head the Worthington ⅝-inch delivers 9.1 gallons per minute, the Hesse ½-inch 9.1; the English Siemens 1 inch 18.5; the German Siemens 1 inch 25.1; the Kennedy 1 inch 32.0. If then the delivery of the Worthington ⅝ inch, under effective head of twenty feet,* is adopted as unit, we have: Worthington ⅝″....1, Hesse ½″....1. English Siemens 1″....2, German Siemens 1″....2¾, Kennedy 1″....3½.

It would have been of great advantage

* The velocity head in the ⅝ inch outlet is small, and is therefore neglected.


HESSE ½"
(DELIVERY I.)
105
104
103
102
101
100%
99
98
97
96
95
94
93
0
.01
CUB. FT.
.02
PER SEC.
.03
.04
0 1 2 3 4 5 6 7 GALLONS PER MIN. 11 12 13 14 15 16 17 18

in making the comparisons which follow, could the sizes of the several meters have been so selected as to make the deliveries the same under the same effective head.

Discussion of the Curves of Registry. —The notable properties of these curves are to be found in the degree of approximation to parallelism of the horizontal sweep to the axis of abscissæ, and in the proximity of the vertical sweep to the axis of ordinates. The former furnishes the true criterion for estimating the degree of accuracy which may be reached by adjustment, the latter indicates the degree of sensitiveness of the meter.

These curves may be shifted up or down, or the curves remaining stationary, the 100% lines may be so shifted by a simple adjustment of the meter. This may be effected, in each of the meters, by changing the number of teeth in one or more of the gear wheels leading to the index, since this number determines the ratio of the movements of the dial hands to the movements of the pistons in the piston meters, and of the measuring wheels in the velocity meters.

Such a change may be effected also, though to a smaller extent, as follows:

In the Worthington, by adjustment of the length of stroke.

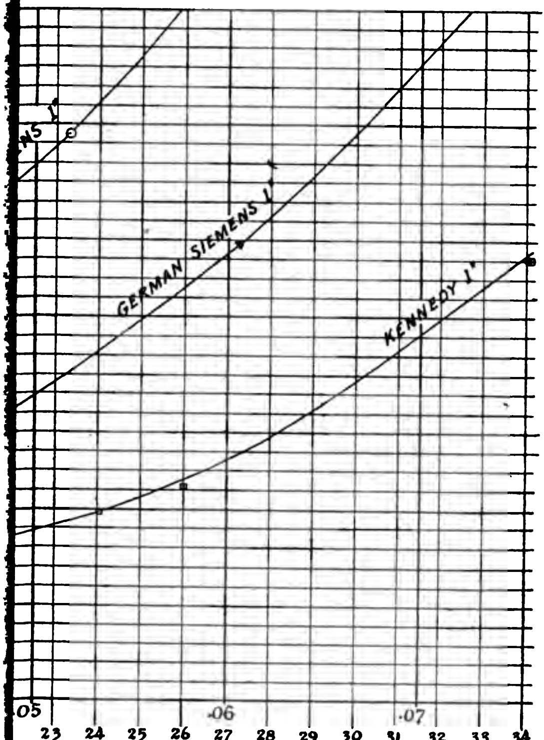
In the English Siemens, by change of the regulating vanes *a a a*.

In the German Siemens, by increase of the openings *a a a a* or *e e e e*, or by change of the buckets.

In the Hesse, by change of the number of teeth in worm wheel H, or by increase in size of openings *a a*, or by change of the buckets or stationary ribs.

An inspection of the curves will bring out some marked features.

The *Worthington curve*, for quantities above three gallons per minute, becomes practically a right line, strongly inclined to the axis of abscissæ, showing at low rates too great, and at high rates too small a registry. This is doubtless due, in the main, to the differences in length of stroke. This stroke is on the average a little above two inches. A $\frac{3}{8}$ inch rub-



NS 1"
GERMAN SIEMENS 1"
KENNEDY 1"
·05
·06
·07
23
24
25
26
27
28
29
30
31
32
33
34

ber seating is compressed at each end of the stroke by an amount, increasing with the momentum or with the velocity of the piston, hence with the rate of delivery. If the difference in the magnitude of this compression, between rates of 3 and 15 gallons per minute, is $\frac{1}{16}$ inch each seating, there results $\frac{1}{8}$ inch difference in length of stroke. The meter registers the number of strokes, hence, if adjusted to register correctly at rate of 3 gallons, it will register about $\frac{1/8}{2}=6\%$ too little at rate of 15 gallons per minute.

As the rate becomes less than 3 gallons per minute, the diminution in length of stroke is more marked.

The *Kennedy curve*, when compared with the Worthington, shows the advantage of registering the approximate distance traveled by the piston, in place of the number of strokes, the main sweep being practically parallel to the axis of abscissæ. By proper adjustment, *i. e.*, by shifting the 100% line upward 1.05% (see dotted line), this curve is made almost perfect.

The *Siemens curves* were improved by adjustment (see dotted lines). They show inferiority in point of sensitiveness. This is due to the resistances of solid friction opposing the motion of the measuring wheels.

The *Hesse curve* shows a favorable adjustment, and a degree of sensitiveness nearly equal to that of the best piston meters. The effect of solid friction is not observable for quantities exceeding one gallon per minute. The curve, following the law of combined fluid pressure and resistance, rises rapidly for quantities less than four gallons per minute. If there were absolutely no solid frictional resistance, the curve would mount to a great height as the quantity approached zero—see considerations which led to the adoption of the form of measuring wheel.

Comparison. — The meters described will be compared with reference to the considerations enumerated.

1st. The accuracy will primarily be compared by means of the adjusted curves, and without reference to permanency. Such comparison shows the Kennedy curve to be without doubt the best; then follow in order the Hesse, the Worthington A and B, the German Siemens, the English Siemens, the Worthington D.

2d. The necessity of special adjustment is greater in the Worthington than in the Kennedy, in the Siemens than in the Hesse. A close comparison is difficult without the experience of the manufacturers; it is apparent, however, from the curve, that even the Kennedy requires a special adjustment if great accuracy is sought.

3d. The difficulty of special adjustment is greater than it should be, in each of the meters excepting the Worthington. Provisions should be made for these adjustments outside of the casing. In the Hesse meter, for instance, this might be effected by suitable provision for shifting of one or more of the stationary ribs. The Worthington is easily adjusted by tightening or loosening the screws of the cap, covering one of the rubber seatings.

4th. A certain degree of sensitiveness is important. This is apparent from the fact that one gallon in three minutes can be made to supply a household by use of a small storage tank. The Kennedy 1″ will register a gallon in from 20 to 30 minutes; the Worthington ⅝″ and the Hesse ½″, a gallon in 15 minutes; the two one inch Siemens meters a gallon in from 1 to 1½ minute. A direct comparison of these figures would not be fair to the Siemens meters, as the deliveries (under given head) of the sizes tested were greater than those of the Worthington and the Hesse. However, it is safe to say that the Siemens meters are much inferior in point of sensitiveness. The wear of the Worthington piston will cause deterioration in this respect, unless the meter is judiciously used.

The sensitiveness of the Hesse meter may be greatly increased, but at the expense of the accuracy at small rates of delivery. However, a rate of one gallon in 15 minutes or 96 gallons in 24 hours, is about the minimum rate admitted in Providence, R. I., and only $\frac{1}{4}$ of the quantity passed in the average service. Such a degree of sensitiveness makes theft out of the question.

5th. With respect to permanency of sensitiveness and accuracy, it is confidently thought that the Hesse meter will stand foremost under a wide variation of wear, etc.

There is no leakage due to wear of valves and piston, no alteration due to change of friction by wear, rusting, or oiling of the registering apparatus. The only parts which might be regarded as sensitive in this respect, are the circular openings *a a*; but as these are made of hard rubber, no rusting can take place, and any tendency towards diminution in size of these openings, by deposition of sediment, is overcome by the rapid flow of water. Little of the wear which may take place in the meter is of a nature to effect its curve of registry.

It is probable that the Kennedy curve is reasonably permanent.

The effect of wear, upon the Worthington curve, is plainly shown by comparison of curves B, C and D. It must be remarked, however, that it is unfair to charge against this meter a deterioration which appears to be due to over taxation. The manufacturing company calls special attention to the fact that their $\frac{5}{8}$ inch meter should not be taxed with a delivery greater than $7\frac{1}{2}$ gallons per minute. This corresponds to an effective head of about 16 feet. In San Francisco, where the hydrostatic head runs up to two hundred and fifty feet and more, it does not seem likely that the $\frac{5}{8}''$ Worthington is large enough for the average service.

That the Siemens curves are not particularly permanent is plain from the fact already mentioned, viz.: that the accuracy and sensitiveness depend upon the magnitude of the frictional resistance of the indicating apparatus, and this will vary constantly with rusting, wear, etc. Mr. Salbach, who has given the German Siemens meter careful consideration, says it is capable of giving good results in every respect when new, but after a while the meter will deteriorate in so far as the accuracy is concerned in the measurement of quantities at small rate of flow. "The main cause," he further says, "is the oil which is contained in the first chamber above the wheel, and which in time adheres to the gear wheels. A further detrimental effect is produced by freezing or thickening of the oil in case the temperature sinks to 2 or 3° C. From these facts it is plain that the oil chamber is a bad feature of this meter, and one that there should be an energetic effort made to overcome." This has been effected in the Hesse Meter.

6th. The liability to obstruction was not tested in the Worthington and Hesse meters, as similar data was wanting in connection with the others. A suitable screen (see Figs. 9 and 18) should be provided for each meter to keep out the coarser obstructions, such as leaves, straw, chips of wood, wads of oakum, etc., which are easily withheld. The liability to obstruction is said to be a weak feature of some of the rotary piston meters, but not of the oscillating. To be sure a sandy deposit in the measuring cylinder will cause rapid wear in the Worthington, and a certain resistance to free rolling of the rubber ring in the Kennedy; but with reasonably clear water no serious difficulty seems likely to occur if the coarser obstructions are screened, and thus wedging of valves prevented. The sandy or muddy sediment is probably less detrimental to the velocity meters when properly constructed. It is suggested that the cylindrical wheel chamber in Hesse's meter should be extended a few inches in length and provided with a waste cock at the bottom, for convenient discharge of accumulated sediment, in case it should be used for the measurement of muddy water.

7th. The greatest advisable rate of delivery is least in the Worthington, and most in the velocity meters. As already stated the Worthington is not guaranteed for an effective head exceeding 16 or 20 feet, corresponding to a delivery of $7\frac{1}{2}$ gallons per minute by the $\frac{5}{8}''$, 15 gallons by the $\frac{3}{4}''$, etc. The safe limit of effective head in the Kennedy is, according to the manufacturer's statement, about 60 feet, the $\frac{3}{8}''$ delivering 20 gallons per minute, the $\frac{1}{2}''$ 30 gallons, the $1''$ 70 gallons, etc.

In the velocity meters the limit of head is exceedingly high. In the Hesse meter this limit is dependent almost solely upon the action of the rubber diaphragm. The difference of heads in chambers B and C, measuring about twice the effective pressure upon the diaphragm, will depend upon the square of the ratio of areas of the valve opening *d* and jet openings *a a*. In the meter tested the diaphragm is subjected to but $\frac{1}{20}$ of the total pressure lost in the meter, and this may be diminished at will by simple enlargement of the valve opening. By closing the opening *h* and fastening down the valve, the diaphragm was subjected to 25 feet of pressure without damage. The diaphragm then would not give way under a total loss of head in the meter of $25 \times 20 = 500$ feet. The further question which must be considered, is: Will the bellows operate under the rapid motion of the worm wheel due to high loss of head? A greater head than 60 feet was not available for trial, but in this case the time occupied in lifting cap K was only one-half the interval of high pressure. If the velocity of registering should be too great under very high heads, the difficulty is simply remedied by increasing the width of the arm, or the number of teeth, in the worm wheel. It is not thought that this would be necessary as the rate of supply of water to the bellows chamber is nearly proportional to the velocity of the measuring wheel.

8th. The compactness of the velocity meter is great as compared with that of the oscillating piston meter. This will appear from a comparison of the weights of meters of about the same delivery.

9th. The prices are given, as near as

possible, in the following table: The price, as well as weight, increases much more rapidly with increase of delivery under the same head, in the piston meters, than of the velocity meters. In either form, the price increases at a smaller rate than the delivery. For example, a Kennedy 1 inch meter, delivering four times as much as the ⅝ inch, costs less than 2½ times as much; the English Siemens 1½ inch, delivering five times as much as the ¾ inch, costs less than twice as much. Any comparison therefore of the price of meters of different delivery should be made with caution. The fallacy is apparent in the claim made by the Kennedy Co. to the effect that their 1 inch meter, delivering 2.02 times as much as the Siemens 1 inch, has over double the proportionate money value, and as it costs about 1.63 times as much as the Siemens, is therefore $\frac{2.02-1.63}{1.63}=24\ \%$ cheaper. Reference to the table will show that the Kennedy ½ inch, delivering

TABLE OF DELIVERIES, GREATEST ADVISABLE
OF

Name of Meter.	Size of in and out-lets. Inches.	Delivery unit 9 gals. per min. under eff. head of 20 feet.
Worthington......	5/8	1.0
	3/4	?
	1	?
*Kennedy.........	3/8	1.3
	1/2	1.8
	3/4	2.8
	1	5.4
	1 1/2	11.0
English Siemens...	3/8	.2
	1/2	.5
	3/4	.8
	1	2.0
	1 1/4	2.9
	1 1/2	4.1
German Siemens..	1	2.5
Hesse	1/2	1.0

* The deliveries and greatest advisable effective heads in the Kennedy and English Siemens meters, were calculated from data furnished by the manufacturers' circulars. The Kennedy 1/4 inch meter is omitted, as it is not recommended by the manufacturing company.

RATES OF DELIVERY, WEIGHTS AND PRICES METERS.

Greatest Advisable		Weight in lbs. avoirdupois.	Price $
Rate of delivery in gals. per min.	Effective head in feet.		
7.5	16	59	17.00
15.0	——	103	27.00
30.0	——	175	33.00
19.9	60	104	19.36
30.0	——	162	27.83
50.0	——	206	33.82
70.0	——	322	46.00
150.0	——	564	75.00
* *	* *	?	12.10
——	——	?	14.76
——	——	?	18.15
——	——	?	21.30
——	——	?	26.86
——	——	?	30.75
——	——	33	26.00
——	——	21	* * *

* * The greatest advisable effective head is many times greater in the velocity than in the piston meters.

* * * A careful estimate of the cost of manufacture of the Hesse meter, indicates a price considerably less than that of any other meter named.

less than the Siemens 1 inch, costs considerably more.

The prices may be compared as follows:

(*a.*) Upon the basis of equal delivery, the list shows the Worthington to be cheaper for small sizes than the Kennedy or Siemens. As the deliveries increase, the Siemens become cheaper than the Worthington or Kennedy. The price of the Hesse has not been definitely ascertained.

(*b.*) Upon the basis of greatest advisable rate of delivery, the velocity meters are by far the cheapest, and the Worthington the most expensive. This is an important consideration only where there is on hand an abundant surplus of head for the house service. If, for example, the head is such as to make the capacity of the service pipe 10 or 12 gallons per minute, it becomes advisable to employ a $\frac{3}{4}$ inch Worthington, whereas a Siemens of far less delivery, or a $\frac{1}{2}$ inch Hesse meter will amply serve.

10th. The expense of repairs of the

English Siemens meter is permanently guaranteed by the Manufacturing Co. for 5 % annually upon the original cost. The actual expense in this and the Kennedy, seems to be in the neighborhood of 3 or 4 % per annum upon the original cost. It is claimed that the average life of the rubber roller in the Kennedy is more than three years. If the Worthington is overtaxed, the wear of the piston, etc., will necessitate expensive repairs in order to maintain its sensitiveness.

In the Hesse meter the life of the rubber diaphragm remains to be ascertained. It is known that pure rubber will deteriorate quite rapidly when exposed to air and light; but it is claimed that in cool water, under the exclusion of light and air, it will remain intact for an indefinite period. The rubber diaphragm is not taxed as is the roller of the Kennedy. There was scarcely a perceptible wear in the Hesse meter during the passage of 62,000 cubic feet of water. The velocity of the measuring wheel (190 revolutions per cubic foot) is far less than in the

Siemens meters of equal capacity, and its weight is trifling. The spindle does not pass through a stuffing box. The shaft P, which does pass through a stuffing box, makes only $\frac{1}{14}$ revolution for each cubic foot registered.

Conclusion.—The following is an attempt to rank the meters according to their merits with respect to the more definite of the considerations enumerated. This is done with a certain reserve, as, in some cases, the information at hand is not sufficiently complete to admit of positive conclusions. Where two meters are placed in the same vertical column no comparison between them is attempted.

1. Accuracy.......K. H. $W_{(A)}$. S. $W_{(D)}$.

2. Sensitiveness...K. $\left\{\begin{matrix} W_{(A)}. \\ H. \end{matrix}\right.$ $\left\{\begin{matrix} S. \\ W_{(D)}. \end{matrix}\right.$

3. Permanency....H. K. $\left\{\begin{matrix} S. \\ W. \end{matrix}\right.$

4. Greatest advisable rate of delivery. $\left\{\begin{matrix} S. \\ H. \end{matrix}\right.$ K. W.

5. Compactness........... $\left\{\begin{matrix}\text{S.}\\ \text{H.}\end{matrix}\right.$ W. K.

6. Price—(*a*). Upon basis of equal delivery under the same head............. $\left\{\begin{matrix}\text{W.}\\ \text{S.}\end{matrix}\right.$ K.

Price—(*b*). Upon basis of greatest advisable rate of delivery........... $\left\{\begin{matrix}\text{S.}\\ \text{H.}\end{matrix}\right.$ K. W.

7. Expense of repairs......H. $\left\{\begin{matrix}\text{S.}\\ \text{K.}\\ \text{W.}\end{matrix}\right.$

The Worthington, though sufficiently accurate, and quite sensitive when new, has very small advisable rate of delivery, and unless judiciously used is subject to deterioration with respect to sensitiveness.

The Kennedy, while extremely accurate and sensitive, and an excellent meter in other respects, is the heaviest and most expensive.

The Siemens meters are very compact and admit of a high effective head without damage; but, while their accuracy is sufficient for considerable rates of delivery, they are inferior in point of sensitiveness.

The Hesse meter combines, in the main, the good features of the others, with an advantage in respect to permanency of sensitiveness, price and wear.

Construction of the Hesse Measuring Wheel.—The following is an abstract of the statement made by Prof. Hesse with regard to the considerations which led him to the present construction of the measuring wheel, and the introduction of the stationary ribs.

A is the area of opening, a.

r, the radius of the wheel.

v, the velocity of the wheel.

c, the velocity of the water in passing opening a.

P, the effective pressure (reduced to radius r) of the jet upon the wheel, including all pressures, positive or negative, directly due to the action of the jet.

R, the resistance (reduced to radius r) caused by the displacement of the mass of the water.

F, the solid frictional resistance (reduced to radius 1), offered by the spindle journals and the worm wheel.

M and N, constant coefficients of pressure and resistance.

For permanent (uniform) motion of the wheel—

$$P = R + \frac{F}{r} \qquad (1)$$

The actual quantity of water delivered, $Q = Ac$.

The quantity registered, $Q^1 = Bv$, wherein B is a constant determined by the gearing, etc.

The ordinate in the curve of registry, $\frac{Q^1}{Q} = \frac{Bv}{Ac}$, is dependent upon P, R and $\frac{F}{r}$.

On account of the variability in the workmanship and degree of wear, etc., upon the spindle journals and the worm wheel, the magnitude of F is subject to an unavoidable fluctuation of say 50%. Therefore, by diminishing the influence of F upon $\frac{v}{c}$ the permanency of the curve of registry is increased. It is evident also that, by diminishing the value of $\frac{F}{r}$, the Q necessary to move the wheel is lessened, *i. e.*, the meter is made more sensitive.

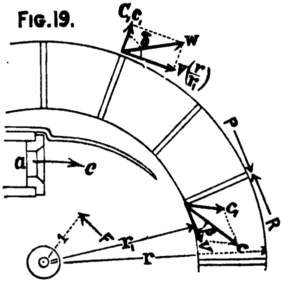
In order to show that velocity meters of this and similar forms are practicable, it is only necessary to point out that $\frac{v}{c}$ is approximately constant. If this ratio were strictly constant, such a value of B could be reached by adjustment as as to make $\frac{Bv}{Ac}=1$, and the meter would be perfectly accurate.

If the losses of head are assumed to be proportional to the squares of velocities, actual and relative, then

$$P\left(\frac{r}{r_1}\right)v=\frac{Q\gamma}{2g}(c^2-Cc_1^2-w^2),$$

wherein γ is the weight of unit volume of water, C a constant, c_1 the relative velocity of the water to the bucket, w the actual velocity of discharge. See Fig. 19. $Q=Ac$.

FIG. 19.



$$c_1^{\,2}=c^2+v^2-2vc\ \cos.\ \beta=c^2\varphi_1\left(\frac{v}{c}\right),$$

$$w_2=C_1^{\,2}c_1^{\,2}+\left(\frac{r}{r_1}\right)^2v^2-2\,(\cos.\ \delta)\left(\frac{r}{r}\right)C_1vc_1$$

Hence by transformation

$$P=\frac{A\gamma}{2g}\left(\frac{r_1}{r}\right)\left\{c^2\left(\frac{c}{v}\right)-c^2\varphi_2\left(\frac{v}{c}\right)\right.$$
$$\left.-c^2\varphi_3\left(\frac{v}{c}\right)-c^2\varphi_4\left(\frac{v}{c}\right)\right\}$$

or

$$P=Mc^2\varphi\left(\frac{v}{c}\right) \qquad (2)$$

Wherein the function of the ratio of velocities, $\varphi\left(\frac{v}{c}\right)$, increases with decrease of v—*i. e.* the pressure upon the wheel increases when c remains constant and the velocity of the bucket, v, is forcibly diminished,

$$R = Nv^2$$

For $F = o$, by introducing values of P and R into equation (1).

$$Mc^2 \varphi\left(\frac{v}{c}\right) = Nv^2,$$

$$\frac{M}{N} \varphi\left(\frac{v}{c}\right) = \left(\frac{v}{c}\right)^2.$$

If then P were strictly proportional to c^2 and $\varphi\left(\frac{v}{c}\right)$, $\frac{v}{c}$ would be a constant for $F = o$.

However, the adopted law of loss of heads is a good approximation for considerable velocities only, therefore the result obtained indicates simply that, if the influence of F could be overcome, $\frac{v}{c}$ would not vary to any great extent, excepting for small rates of delivery.

The actual curve of registry, for $F = o$, is doubtless similar to that shown in Fig. 20.

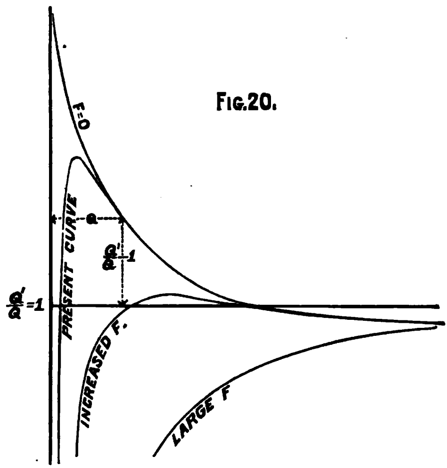


FIG. 20.

For any value of F (see equation 1)—

$$P = Nv^2 + \frac{F}{r},$$

$$v^2 = \frac{P}{N}\left(1 - \frac{F}{rP}\right)$$

The ordinate in the curve of registry—

$$\frac{Bv}{Ac} = \frac{B}{Ac}\sqrt{\frac{P}{N}\left(1 - \frac{F}{rP}\right)}$$

This approaches the condition $F=o$, and the influence of a 50 % fluctuation of F is the less, as the value of $\frac{F}{rP}$ is diminished—*i. e.* as F is diminished, or as r and P are increased.

It appears from the above that the meter will gain in sensitiveness and permanency:

(I.) by diminution of the solid frictional resistance (F);

(II.) by increase of the radius (r) of the measuring wheel;

(III.) by increase of the pressure (P) of the jet upon the wheel.

This increase of P may be effected:

(1) by reducing the area of the openings *a a*;*

---

* This is a convenient method of improving the curve of registry, but is limited in its application on account of the corresponding reduction of the delivery of the meter under a given head.

(2) by increasing the resistance (R) of the water, and thus reducing the velocity (v) of the wheel. This increase of R is accomplished:

(a) by increasing the area of bucket, *i. e.*, the effective displacing area;

(b) by introducing stationary ribs, and thus checking in part the rotation of the body of water in the measuring chamber.

In one wheel tested, a high degree of sensitiveness was reached, by curving that portion of the bucket encountered by the jet, and arranging for outer feed, thus greatly increasing the pressure. However, such refinement was found unnecessary, and the small addition to the expense was not deemed advisable.

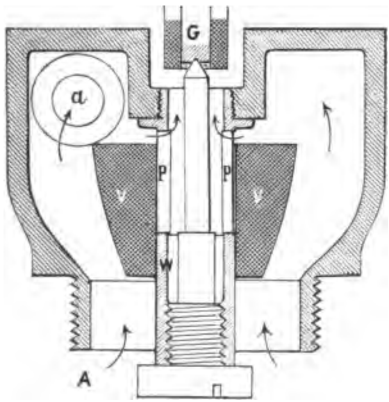
Due regard to the considerations enumerated, has led to sufficient sensitiveness and a high degree of permanency.

Improvement of the Curve of Registry.—There remains to be considered the question of a further improvement of the curve of registry. An immediate improvement of that portion of the curve corresponding to values of Q between 1 and 4 gallons per minute, may be effected by a small increase of F (see Fig. 20); but it must be borne in mind that such increase of F is necessarily accompanied by a considerable loss in sensitiveness.

Prof. Hesse devised the attachment shown in Fig. 21, with which the curve of registry was perfected without sacrifice of sensitiveness.

The light hard-rubber valve V slips freely upon the outer surface of the tube W. If Q is considerable, say 6 gallons or more per minute, the valve V is lifted to its highest position and no water can escape through the openings *p p*. If Q, hence the effective head, is less, the valve will occupy a lower position of equilibrium, and a small portion of the water will escape through the openings *pp* without assisting in the rotation of the wheel. Thus $\frac{Q^1}{Q}$ may be reduced more and more as Q becomes smaller. This reduction is experimently regulated by the width of the openings *p p*, and by the curvature of the surface of valve V.

Fig. 21.



This is important in connection with a test meter only. The present curve of registry is all that may be desired in a house meter, and certainly no device should be attached to the meter which would detract from the permanency or add to the liability to obstruction.

WATER METERS (COMPTEURS D'EAU).

BY

CH. ANDRÉ.

WATER METERS (COMPTEURS D'EAU).*

The Frazer Meter.

There are two forms of this meter: the first introduced in 1872 and the second in 1878.

In the earlier pattern the general form was cylindrical; the smaller sizes being of cast iron and the larger of wrought iron plate. The water coming within the outer casing exerted pressure upon the pistons, of which there were four joined two and two, and single acting. There are two three-port slide valves, working horizontally. The valve for each pair of piston rods regulates the flow for the cylinders of the opposite pair. The reg-

* The greater part of M. André's paper is devoted to descriptions already given in Mr. Browne's paper. Only the more important of the remaining ones are here given.

istering wheel work is moved by the pistons acting on a ratchet wheel.

In 1878 Mr. Frazer patented his later form of meter, which differs from the first in several particulars. The outlet pipe is supplied with a rubber ball-valve, which serves to mitigate the water hammer shocks on the valves. The pistons turn upon their axes while making the stroke, so as to insure a regular wear on the packing.

There are two double-action pistons in place of the four single-action, thus reducing the length, weight, and price of the machine.

The water enters from above, passes through a strainer which arrests solid particles and also serves to keep the valves in place during transportation.

The valves rotate instead of working back and forward, and are driven by a key and collar on the piston-rod. The adjustment of the parts is such as to admit of examination of the meter at any time.

Furnished with a safety valve, this me-

ter has been applied to the measure of feed-water for boilers.

The durability of the Frazer meter is very satisfactory. The packing of one at the Eastern Railway Station in Paris was recently renewed. It had registered 200,000 cubic meters, and the packing was still water-tight.

THE CROWN METER.

This meter has a rotating piston and is known in France as the Nasch Meter (Compteur Nasch).

The apparatus is enclosed in an iron box. The water enters below and passes through a copper strainer of large surface.

It is composed of four strong pieces, only one of which is movable. One of these pieces is the so-called crown. It is substantially a heavy ring with indentations on the concave edge. A pinion rolling on the inside of this crown constitutes the piston. It separates the crown into two water ways. The piston has one tooth less than the crown. The piston has at the center of each face a cavity and a little further out a deep groove. The lower central cavity communicates with the upper groove by oblique conduits through the metal. In like manner the upper central cavity communicates with the lower groove. The piston and the crown are of the same height, and are situated between two fixed discs which perform the office of valves. These discs are perforated with curved conduits opening at their extremities on the side towards the piston. One of these extremities; the one nearest the point where the piston and crown are in contact, communicates with a groove, while the other extremity opens at 90° from this point into the open space between the teeth.

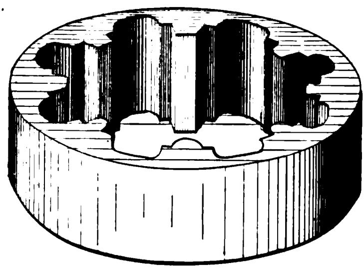
The water enters by a central hole in the lower disc, traverses the piston, is conducted into the upper groove, thence by the curved conduits into the space between the crown and piston and causes the piston to roll.

The water then goes out through the

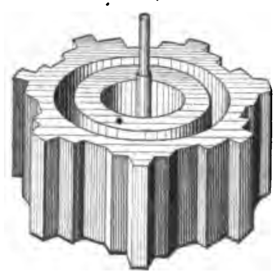
conduits of the lower plate; thence into the lower groove of the piston, passes through the piston and out through its upper central cavity.

The Crown Meter.

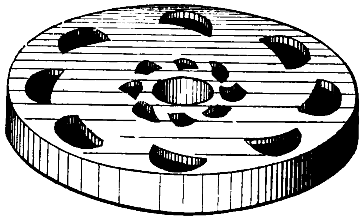
Crown, C.



Piston, P.



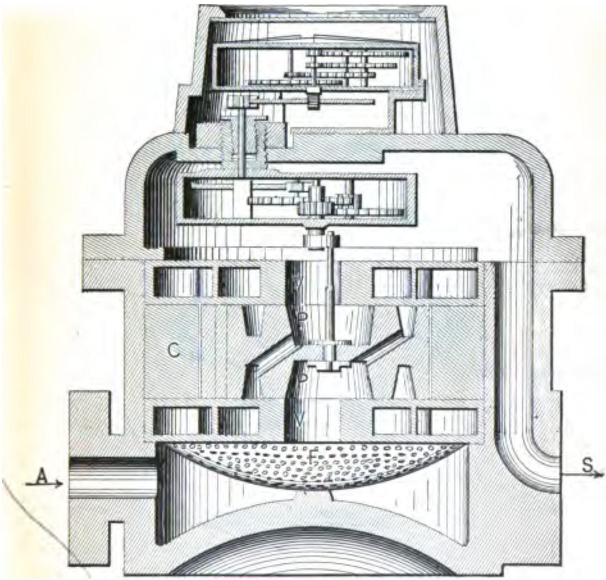
Valves, V.



The piston carries on its upper surface a bronze rod, which describes a circle and drives the registering wheels.

The crown meter is especially adapted for measurement of large quantities of water under light pressure. It is also more exact when the delivery is small than are the velocity meters, but is less so than the ordinary piston meters. This naturally follows from the fact that the Crown meter is not furnished with packing and a water-tight piston. Its efficiency depends chiefly upon precision of adjustment and lightness of its piston, which is made of vulcanite. It is put in action by a water pressure of two or

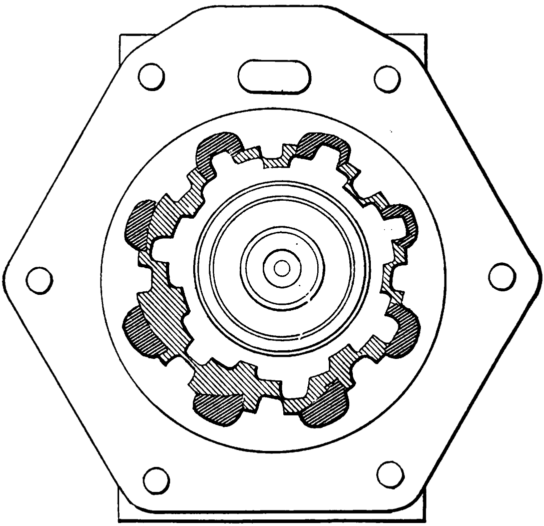
Vertical Section.



three centimeters. Six liters of water per hour will keep one at work.

From the experience in French cities, it is concluded that where exactness of measurement is regarded as the first importance, only the piston meters of ordi-

Plan View.



nary type are in use. In the provinces the English Siemens meter is most widely employed. Other kinds of meters may be profitably employed in measuring velocities. Piston meters are large and costly, but accurate and durable. The other varieties are small, easy to work, but less exact and more delicate.

The Crown meter occupies a sort of intermediate position between the two classes. Its capacity, its price, and its precision, entitle it to favorable consideration; but where solidity and durability are regarded as essential merits, the piston meters are preferred.

VALUABLE

SCIENTIFIC BOOKS

PUBLISHED BY

D. VAN NOSTRAND,

23 MURRAY STREET AND 27 WARREN STREET, N. Y.

ADAMS (J. W.) Sewers and Drains for Populous Districts. Embracing Rules and Formulas for the dimensions and construction of works of Sanitary Engineers. Second edition. 8vo, cloth...$2 50

ALEXANDER (J. H.) Universal Dictionary of Weights and Measures, Ancient and Modern, reduced to the standards of the United States of America. New edition, enlarged. 8vo, cloth...3 50

ATWOOD (GEO.) Practical Blow-Pipe Assaying. 12mo, cloth, illustrated...2 00

AUCHINCLOSS (W. S.) Link and Valve Motions Simplified. Illustrated with 37 wood-cuts and 21 lithographic plates, together with a Travel Scale and numerous useful tables. 8vo, cloth...3 00

AXON (W. E. A.) The Mechanic's Friend: a Collection of Receipts and Practical Suggestions Relating to Aquaria—Bronzing—Cements—Drawing—Dyes—Electricity—Gilding—Glass-working — Glues — Horology — Lacquers—Locomotives—Magnetism—Metal-working - Modelling — Photography—Pyrotechny—Railways—Solders—Steam-Engine—Telegraphy—Taxidermy—Varnishes—Waterproofing, and Miscellaneous Tools, Instruments, Machines, and Processes connected with the Chemical and Mechanic Arts. With numerous diagrams and wood-cuts. Fancy cloth 1 50

BACON (F. W.) A Treatise on the Richards Steam-Engine Indicator, with directions for its use. By Charles T. Porter. Revised, with notes and large additions as developed by American practice; with an appendix containing useful formulæ and rules for engineers. Illustrated. Third edition. 12mo, cloth...1 00

BARBA (J.) The Use of Steel for Constructive Purposes; Method of Working, Applying, and Testing Plates and Brass. With a Preface by A. L. Holley, C.E. 12mo, cloth. $1 50

BARNES (Lt. Com. J. S., U. S. N.) Submarine Warfare, offensive and defensive, including a discussion of the offensive Torpedo System, its effects upon Iron-Clad Ship Systems and influence upon future naval wars. With twenty lithographic plates and many wood-cuts. 8vo, cloth............ 5 00

BEILSTEIN (F.) An Introduction to Qualitative Chemical Analysis, translated by I. J. Osbun. 12mo, cloth.......... 75

BENET (Gen. S. V., U. S. A.) Electro-Ballistic Machines, and the Schultz Chronoscope. Illustrated. Second edition, 4to, cloth.. 3 00

BLAKE (W. P.) Report upon the Precious Metals: Being Statistical Notices of the principal Gold and Silver producing regions of the World, represented at the Paris Universal Exposition. 8vo, cloth.................................. 2 00

—— Ceramic Art. A Report on Pottery, Porcelain, Tiles, Terra Cotta, and Brick. 8vo, cloth....................... 2 00

BOW (R. H.) A Treatise on Bracing, with its application to Bridges and other Structures of Wood or Iron. 156 illustrations. 8vo, cloth.............................. .... 1 50

BOWSER (Prof. E. A.) An Elementary Treatise on Analytic Geometry, embracing Plane Geometry, and an Introduction to Geometry of three Dimensions. 12mo, cloth....... 1 75

—— An Elementary Treatise on the Differential and Integral Calculus. With numerous examples. 12mo, cloth......... 2 25

BURGH (N. P.) Modern Marine Engineering, applied to Paddle and Screw Propulsion. Consisting of 36 colored plates, 259 practical wood-cut illustrations, and 403 pages of descriptive matter, the whole being an exposition of the present practice of James Watt & Co., J. & G. Rennie, R. Napier & Sons, and other celebrated firms. Thick 4to vol., cloth 10 00
Half morocco......... ....15 00

BURT (W. A.) Key to the Solar Compass, and Surveyor's Companion; comprising all the rules necessary for use in the field; also description of the Linear Surveys and Public Land System of the United States, Notes on the Barometer, suggestions for an outfit for a survey of four months, etc. Second edition. Pocket-book form, tuck............. 2 50

BUTLER (Capt. J. S., U. S. A.) Projectiles and Rifled Cannon. A Critical Discussion of the Principal Systems of Rifling and Projectiles, with Practical Suggestions for their Improvement, as embraced in a Report to the Chief of Ordnance, U. S. A. 36 plates. 4to, cloth...................... 6 00

CAIN (Prof. WM.) A Practical Treatise on Voussoir and Solid and Braced Arches. 16mo, cloth extra....................$1 75

CALDWELL (Prof. GEO. C.) and BRENEMAN (Prof. A. A.) Manual of Introductory Chemical Practice, for the use of Students in Colleges and Normal and High Schools. Third edition, revised and corrected. 8vo, cloth, illustrated. New and enlarged edition.. 1 50

CAMPIN (FRANCIS). On the Construction of Iron Roofs. 8vo, with plates, cloth 2 00

CHAUVENET (Prof. W.) New method of correcting Lunar Distances, and improved method of finding the error and rate of a chronometer, by equal altitudes. 8vo, cloth...... 2 00

CHURCH (JOHN A.) Notes of a Metallurgical Journey in Europe. 8vo, cloth.. 2 00

CLARK (D. KINNEAR, C.E.) Fuel: Its Combustion and Economy, consisting of Abridgments of Treatise on the Combustion of Coal and the Prevention of Smoke, by C. W. Williams; and the Economy of Fuel, by T. S. Prideaux. With extensive additions on recent practice in the Combustion and Economy of Fuel: Coal, Coke, Wood, Peat, Petroleum, etc. 12mo, cloth... .... 1 50

—— A Manual of Rules, Tables, and Data for Mechanical Engineers. Based on the most recent investigations. Illustrated with numerous diagrams. 1,012 pages. 8vo, cloth... 7 50
Half morocco.. 10 00

CLARK (Lt. LEWIS, U. S. N.) Theoretical Navigation and Nautical Astronomy. Illustrated with 41 wood-cuts. 8vo, cloth.. 1 50

CLARKE (T. C.) Description of the Iron Railway Bridge over the Mississippi River at Quincy, Illinois. Illustrated with 21 lithographed plans. 4to, cloth 7 50

CLEVENGER (S. R.) A Treatise on the Method of Government Surveying, as prescribed by the U. S. Congress and Commissioner of the General Land Office, with complete Mathematical, Astronomical, and Practical Instructions for the use of the United States Surveyors in the field. 16mo, morocco.. 2 50

COFFIN (Prof. J. H. C.) Navigation and Nautical Astronomy. Prepared for the use of the U. S. Naval Academy. Sixth edition. 52 wood-cut illustrations. 12mo, cloth...... 3 50

COLBURN (ZERAH). The Gas-Works of London. 12mo, boards.. 60

COLLINS (JAS. E.) The Private Book of Useful Alloys and Memoranda for Goldsmiths, Jewellers, etc. 18mo, cloth... 50

CORNWALL (Prof. H. B.) Manual of Blow-Pipe Analysis, Qualitative and Quantitative, with a Complete System of Descriptive Mineralogy. 8vo, cloth, with many illustrations. N. Y., 1882 .... $2 50

CRAIG (B. F.) Weights and Measures. An account of the Decimal System, with Tables of Conversion for Commercial and Scientific Uses. Square 32mo, limp cloth.......... 50

CRAIG (Prof. THOS.) Elements of the Mathematical Theory of Fluid Motion. 16mo, cloth.............................. 1 25

DAVIS (C. B.) and RAE (F. B.) Hand-Book of Electrical Diagrams and Connections. Illustrated with 32 full-page illustrations. Second edition. Oblong 8vo, cloth extra 2 00

DIEDRICH (JOHN). The Theory of Strains: a Compendium for the Calculation and Construction of Bridges, Roofs, and Cranes. Illustrated by numerous plates and diagrams. 8vo, cloth.. 5 00

DIXON (D. B.) The Machinist's and Steam-Engineer's Practical Calculator. A Compilation of useful Rules, and Problems Arithmetically Solved, together with General Information applicable to Shop-Tools, Mill-Gearing, Pulleys and Shafts, Steam-Boilers and Engines. Embracing Valuable Tables, and Instruction in Screw-cutting, Valve and Link Motion, etc. 16mo, full morocco, pocket form ...(In press)

DODD (GEO.) Dictionary of Manufactures, Mining, Machinery, and the Industrial Arts. 12mo, cloth............ 1 50

DOUGLASS (Prof S. H.) and PRESCOTT (Prof. A B.) Qualitative Chemical Analysis. A Guide in the Practical Study of Chemistry, and in the Work of Analysis. Third edition. 8vo, cloth.. 3 50

DUBOIS (A. J.) The New Method of Graphical Statics. With 60 illustrations. 8vo, cloth 1 50

EASSIE (P. B.) Wood and its Uses. A Hand-Book for the use of Contractors, Builders, Architects, Engineers, and Timber Merchants. Upwards of 250 illustrations. 8vo, cloth 1 50

EDDY (Prof. H. T.) Researches in Graphical Statics, embracing New Constructions in Graphical Statics, a New General Method in Graphical Statics, and the Theory of Internal Stress in Graphical Statics. 8vo, cloth..................... 1 50

ELIOT (Prof. C. W.) and STORER (Prof. F. H.) A Compendious Manual of Qualitative Chemical Analysis. Revised with the co-operation of the authors. By Prof. William R. Nichols. Illustrated. 12mo, cloth......................... 1 50

ELLIOT (Maj. GEO. H., U. S. E.) European Light-House Systems. Being a Report of a Tour of Inspection made in 1873. 51 engravings and 21 wood-cuts. 8vo, cloth 5 00

ENGINEERING FACTS AND FIGURES. An Annual Register of Progress in Mechanical Engineering and Construction for the years 1863-64-65-66-67-68. Fully illustrated. 6 vols. 18mo, cloth (each volume sold separately), per vol. $2 50

FANNING (J. T.) A Practical Treatise of Water-Supply Engineering. Relating to the Hydrology, Hydrodynamics, and Practical Construction of Water-Works in North America. Third edition. With numerous tables and 180 illustrations. 650 pages. 8vo, cloth 5 00

FISKE (BRADLEY A., U. S. N.) Electricity in Theory and Practice. 8vo, cloth 2 50

FOSTER (Gen. J. G., U. S. A.) Submarine Blasting in Boston Harbor, Massachusetts. Removal of Tower and Corwin Rocks. Illustrated with seven plates. 4to, cloth 3 50

FOYE (Prof. J. C.) Chemical Problems. With brief Statements of the Principles involved. Second edition, revised and enlarged. 16mo, boards 50

FRANCIS (JAS. B., C. E.) Lowell Hydraulic Experiments: Being a selection from Experiments on Hydraulic Motors, on the Flow of Water over Weirs, in Open Canals of Uniform Rectangular Section, and through submerged Orifices and diverging Tubes. Made at Lowell, Massachusetts. Fourth edition, revised and enlarged, with many new experiments, and illustrated with twenty-three copperplate engravings. 4to, cloth 15 00

FREE-HAND DRAWING. A Guide to Ornamental Figure and Landscape Drawing. By an Art Student. 18mo, boards 50

GILLMORE (Gen. Q. A.) Treatise on Limes, Hydraulic Cements, and Mortars. Papers on Practical Engineering, U. S. Engineer Department, No. 9, containing Reports of numerous Experiments conducted in New York City during the years 1858 to 1861, inclusive. With numerous illustrations. 8vo, cloth 4 00

—— Practical Treatise on the Construction of Roads, Streets, and Pavements. With 70 illustrations. 12mo, cloth 2 00

—— Report on Strength of the Building Stones in the United States, etc. 8vo, illustrated, cloth 1 50

—— Coignet Beton and other Artificial Stone. 9 plates, views, etc. 8vo, cloth 2 50

GOODEVE (T. M.) A Text-Book on the Steam-Engine. 143 illustrations. 12mo, cloth 2 00

GORDON (J. E. H.) Four Lectures on Static Induction. 12mo, cloth 80

GRUNER (M. L.) The Manufacture of Steel. Translated from the French, by Lenox Smith, with an appendix on the Bessemer process in the United States, by the translator. Illustrated. 8vo, cloth.................................$3 50

HALF-HOURS WITH MODERN SCIENTISTS. Lectures and Essays. By Professors Huxley, Barker, Stirling, Cope, Tyndall, Wallace, Roscoe, Huggins, Lockyer, Young, Mayer, and Reed. Being the University Series bound up. With a general introduction by Noah Porter, President of Yale College. 2 vols. 12mo, cloth, illustrated 2 50

HAMILTON (W. G.) Useful Information for Railway Men. Sixth edition, revised and enlarged. 562 pages, pocket form. Morocco, gilt.. 2 00

HARRISON (W. B.) The Mechanic's Tool Book, with Practical Rules and Suggestions for Use of Machinists, Iron-Workers, and others. Illustrated with 44 engravings. 12mo, cloth... 1 50

HASKINS (C. H.) The Galvanometer and its Uses. A Manual for Electricians and Students. Second edition. 12mo, morocco.. 1 50

HENRICI (OLAUS). Skeleton Structures, especially in their application to the Building of Steel and Iron Bridges. With folding plates and diagrams. 8vo, cloth..................... 1 50

HEWSON (WM.) Principles and Practice of Embanking Lands from River Floods, as applied to the Levees of the Mississippi. 8vo, cloth.................................. 2 00

HOLLEY (ALEX. L.) A Treatise on Ordnance and Armor, embracing descriptions, discussions, and professional opinions concerning the materials, fabrication, requirements, capabilities, and endurance of European and American Guns, for Naval, Sea-Coast, and Iron-Clad Warfare, and their Rifling, Projectiles, and Breech-Loading; also, results of experiments against armor, from official records, with an appendix referring to Gun-Cotton, Hooped Guns, etc., etc. 948 pages, 493 engravings, and 147 Tables of Results, etc. 8vo, half roan 10 00

—— Railway Practice American and European Railway Practice in the economical Generation of Steam, including the Materials and Construction of Coal-burning Boilers, Combustion, the Variable Blast, Vaporization, Circulation, Superheating, Supplying and Heating Feed-water, etc., and the Adaptation of Wood and Coke-burning Engines to Coal-burning; and in Permanent Way, including Road-bed, Sleepers, Rails, Joint-fastenings, Street Railways, etc., etc. With 77 lithographed plates. Folio, cloth.................12 00

HOWARD (C. R.) Earthwork Mensuration on the Basis of the Prismoidal Formulæ. Containing simple and labor-saving method of obtaining Prismoidal Contents directly from End Areas. Illustrated by Examples, and accompanied by Plain Rules for Practical Uses. Illustrated. 8vo, cloth..$1 50

INDUCTION-COILS. How Made and How Used. 63 illustrations. 16mo, boards.................................... 50

ISHERWOOD (B. F.) Engineering Precedents for Steam Machinery. Arranged in the most practical and useful manner for Engineers. With illustrations. Two volumes in one. 8vo, cloth..... .... 2 50

JANNETTAZ (EDWARD). A Guide to the Determination of Rocks: being an Introduction to Lithology. Translated from the French by G. W. Plympton, Professor of Physical Science at Brooklyn Polytechnic Institute. 12mo, cloth.... 1 50

JEFFERS (Capt. W. N., U. S. N.) Nautical Surveying. Illustrated with 9 copperplates and 31 wood-cut illustrations. 8vo, cloth.... .... 5 00

JONES (H. CHAPMAN). Text-Book of Experimental Organic Chemistry for Students. 18mo, cloth 1 00

JOYNSON (F. H.) The Metals used in Construction: Iron, Steel, Bessemer Metal, etc., etc. Illustrated. 12mo, cloth. 75

—— Designing and Construction of Machine Gearing. Illustrated. 8vo, cloth.. 2 00

KANSAS CITY BRIDGE (THE). With an account of the Regimen of the Missouri River, and a description of the methods used for Founding in that River. By O. Chanute, Chief-Engineer, and George Morrison, Assistant-Engineer. Illustrated with five lithographic views and twelve plates of plans. 4to, cloth.. 6 00

KING (W. H.) Lessons and Practical Notes on Steam, the Steam-Engine, Propellers, etc., etc., for young Marine Engineers, Students, and others. Revised by Chief-Engineer J. W. King, U. S. Navy. Nineteenth edition, enlarged. 8vo, cloth.................. .. .. 2 00

KIRKWOOD (JAS. P.) Report on the Filtration of River Waters for the supply of Cities, as practised in Europe, made to the Board of Water Commissioners of the City of St. Louis. Illustrated by 30 double-plate engravings. 4to, cloth 15 00

LARRABEE (C. S.) Cipher and Secret Letter and Telegraphic Code, with Hogg's Improvements. The most perfect secret code ever invented or discovered. Impossible to read without the key. 18mo, cloth 1 00

LOCK (C. G.), WIGNER (G. W.), and HARLAND (R. H.) Sugar Growing and Refining. Treatise on the Culture of Sugar-Yielding Plants, and the Manufacture and Refining of Cane, Beet, and other sugars. 8vo, cloth, illustrated 12 00

LOCKWOOD (THOS. D.) Electricity, Magnetism, and Electro-Telegraphy. A Practical Guide for Students, Operators, and Inspectors. 8vo, cloth....... .... $2 50

LORING (A. E.) A Hand-Book on the Electro-Magnetic Telegraph. Paper boards.................................. 50
Cloth 75
Morocco.. 1 00

MacCORD (Prof. C. W) A Practical Treatise on the Slide-Valve by Eccentrics, examining by methods the action of the Eccentric upon the Slide-Valve, and explaining the practical processes of laying out the movements, adapting the valve for its various duties in the steam-engine. Second edition. Illustrated. 4to, cloth 2 50

McCULLOCH (Prof. R S.) Elementary Treatise on the Mechanical Theory of Heat, and its application to Air and Steam Engines. 8vo, cloth................................ 3 50

MERRILL (Col. WM. E, U. S. A.) Iron Truss Bridges for Railroads. The method of calculating strains in Trusses, with a careful comparison of the most prominent Trusses, in reference to economy in combination, etc., etc. Illustrated. 4to, cloth.............. .... 5 00

MICHAELIS (Capt. O. E., U. S. A.) The Le Boulenge Chronograph, with three lithograph folding plates of illustrations. 4to, cloth....................................... 3 00

MICHIE (Prof. P. S.) Elements of Wave Motion relating to Sound and Light. Text-Book for the U.S. Military Academy. 8vo, cloth, illustrated................................ 5 00

MINIFIE (WM.) Mechanical Drawing. A Text-Book of Geometrical Drawing for the use of Mechanics and Schools, in which the Definitions and Rules of Geometry are familiarly explained; the Practical Problems are arranged, from the most simple to the more complex, and in their description technicalities are avoided as much as possible. With illustrations for Drawing Plans, Sections, and Elevations of Railways and Machinery; an Introduction to Isometrical Drawing, and an Essay on Linear Perspective and Shadows. Illustrated with over 200 diagrams engraved on steel. Ninth edition. With an Appendix on the Theory and Application of Colors. 8vo, cloth 4 00

"It is the best work on Drawing that we have ever seen, and is especially a text-book of Geometrical Drawing for the use of Mechanics and Schools. No young Mechanic, such as a Machinist, Engineer, Cabinet-maker, Millwright, or Carpenter, should be without it."—*Scientific American.*

—— Geometrical Drawing. Abridged from the octavo edition, for the use of schools. Illustrated with forty-eight steel plates. Fifth edition. 12mo, cloth 2 00

MODERN METEOROLOGY. A Series of Six Lectures, delivered under the auspices of the Meteorological Society in 1878. Illustrated. 12mo, cloth.... ....$1 50

MORRIS (E.) Easy Rules for the Measurement of Earthworks, by Means of the Prismoidal Formula. 78 illustrations. 8vo, cloth.. 1 50

MOTT (H. A., Jr.) A Practical Treatise on Chemistry (Qualitative and Quantitative Analysis), Stoichiometry, Blow-pipe Analysis, Mineralogy, Assaying, Pharmaceutical Preparations, Human Secretions, Specific Gravities, Weights and Measures, etc., etc., etc. New edition, 1883. 650 pages. 8vo, cloth.. 4 00

NAQUET (A.) Legal Chemistry. A Guide to the Detection of Poisons, Falsification of Writings, Adulteration of Alimentary and Pharmaceutical Substances, Analysis of Ashes, and examination of Hair, Coins, Arms, and Stains, as applied to Chemical Jurisprudence, for the use of Chemists, Physicians, Lawyers, Pharmacists, and Experts. Translated, with additions, including a list of books and Memoirs on Toxicology, etc., from the French. By J. P. Battershall, Ph.D., with a preface by C. F. Chandler, Ph.D., M.D., LL.D. 12mo, cloth....... .... 2 00

NOBLE (W. H.) Useful Tables. Pocket form, cloth......... 50

NUGENT (E.) Treatise on Optics; or, Light and Sight, theoretically and practically treated, with the application to Fine Art and Industrial Pursuits. With 103 illustrations. 12mo, cloth...... .... 1 50

PEIRCE (B.) System of Analytic Mechanics. 4to, cloth.....10 00

PLANE TABLE (THE). Its Uses in Topographical Surveying. From the Papers of the U. S. Coast Survey. Illustrated. 8vo, cloth... 2 00

"This work gives a description of the Plane Table employed at the U. S. Coast Survey office, and the manner of using it."

PLATTNER. Manual of Qualitative and Quantitative Analysis with the Blow-Pipe. From the last German edition, revised and enlarged. By Prof. Th. Richter, of the Royal Saxon Mining Academy. Translated by Prof. H. B. Cornwall, assisted by John H. Caswell. Illustrated with 87 woodcuts and one lithographic plate. Fourth edition, revised, 560 pages. 8vo, cloth....................................... 5 00

PLYMPTON (Prof. GEO. W.) The Blow-Pipe. A Guide to its use in the Determination of Salts and Minerals. Compiled from various sources. 12mo, cloth......................... 1 50

—— The Aneroid Barometer: Its Construction and Use. Compiled from several sources. 16mo, boards, illustrated, 50
Morocco 1 00

PLYMPTON (Prof. GEO. W.) The Star-Finder, or Planisphere, with Movable Horizon Printed in colors on fine card-board, and in accordance with Proctor's Star Atlas... $1 00

POCKET LOGARITHMS, to Four Places of Decimals, including Logarithms of Numbers, and Logarithmic Sines and Tangents to Single Minutes. To which is added a Table of Natural Sines, Tangents, and Co-Tangents. 16mo, boards, 50
Morocco.. 1 00

POOK (S. M.) Method of Comparing the Lines and Draughting Vessels propelled by Sail or Steam. Including a chapter on Laying-off on the Mould-Loft Floor. 1 vol. 8vo, with illustrations, cloth.. 5 00

POPE (F. L.) Modern Practice of the Electric Telegraph. A Hand-Book for Electricians and Operators. Eleventh edition, revised and enlarged, and fully illustrated. 8vo, cloth. 2 00

PRESCOTT (Prof. A. B.) Outlines of Proximate Organic Analysis, for the Identification, Separation, and Quantitative Determination of the more commonly occurring Organic Compounds. 12mo, cloth.................................. 1 75

—— Chemical Examination of Alcoholic Liquors. A Manual of the Constituents of the Distilled Spirits and Fermented Liquors of Commerce, and their Qualitative and Quantitative Determinations. 12mo, cloth.......................... 1 50

—— First Book in Qualitative Chemistry. Second edition. 12mo, cloth.. 1 50

PYNCHON (Prof. T. R.) Introduction to Chemical Physics, designed for the use of Academies, Colleges, and High-Schools. Illustrated with numerous engravings, and containing copious experiments with directions for preparing them. New edition, revised and enlarged, and illustrated by 269 illustrations on wood. Crown 8vo, cloth............. 3 00

RAMMELSBERG (C. F.) Guide to a Course of Quantitative Chemical Analysis, especially of Minerals and Furnace Products. Illustrated by Examples. Translated by J. Towler, M.D. 8vo, cloth.. 2 25

RANDALL (P. M.) Quartz Operator's Hand-Book. New edition, revised and enlarged, fully illustrated. 12mo, cloth... 2 00

RANKINE (W. J. M.) Applied Mechanics, comprising Principles of Statics, Cinematics, and Dynamics, and Theory of Structures, Mechanism, and Machines. Crown 8vo, cloth. Tenth edition. London..... .... 5 00

—— A Manual of the Steam-Engine and other Prime Movers, with numerous tables and illustrations. Crown 8vo, cloth. Tenth edition. London, 1882.............................. 5 00

—— A Selection from the Miscellaneous Scientific Papers of, with Memoir by P. G. Tait, and edited by W. J. Millar, C.E. 8vo, cloth. London, 1880..............................10 00

RANKINE (W. J. M.) A Manual of Machinery and Mill-work. Fourth edition. Crown 8vo. London, 1881 .... $5 00

—— Civil Engineering, comprising Engineering Surveys, Earthwork, Foundations, Masonry, Carpentry, Metal-works, Roads, Railways, Canals, Rivers, Water-works, Harbors, etc., with numerous tables and illustrations. Fourteenth edition, revised by E. F. Bamber, C.E. 8vo. London, 1883 .... 6 50

—— Useful Rules and Tables for Architects, Builders, Carpenters, Coachbuilders, Engineers, Founders, Mechanics, Shipbuilders, Surveyors, Typefounders, Wheelwrights, etc. Sixth edition. Crown 8vo, cloth. London, 1883...... 4 00

—— and BAMBER (E. F.) A Mechanical Text-Book; or, Introduction to the Study of Mechanics and Engineering. 8vo, cloth. London, 1875 .... 3 50

RICE (Prof. J. M.) and JOHNSON (Prof. W. W.) On a New Method of Obtaining the Differentials of Functions, with especial reference to the Newtonian Conception of Rates or Velocities. 12mo, paper 50

ROGERS (Prof. H. D.) The Geology of Pennsylvania. A Government Survey, with a General View of the Geology of the United States, Essays on the Coal Formation and its Fossils, and a description of the Coal Fields of North America and Great Britain. Illustrated with Plates and Engravings in the text. 3 vols. 4to, cloth, with Portfolio of Maps. 30 00

ROEBLING (J. A.) Long and Short Span Railway Bridges. Illustrated with large copperplate engravings of plans and views. Imperial folio, cloth.............................. 25 00

ROSE (JOSHUA, M.E.) The Pattern-Maker's Assistant, embracing Lathe Work, Branch Work, Core Work, Sweep Work, and Practical Gear Constructions, the Preparation and Use of Tools, together with a large collection of useful and valuable Tables. Third edition. Illustrated with 250 engravings. 8vo, cloth 2 50

SABINE (ROBERT). History and Progress of the Electric Telegraph, with descriptions of some of the apparatus. Second edition, with additions, 12mo, cloth 1 25

SAELTZER (ALEX.) Treatise on Acoustics in connection with Ventilation. 12mo, cloth 1 00

SCHUMANN (F.) A Manual of Heating and Ventilation in its Practical Application for the use of Engineers and Architects, embracing a series of Tables and Formulæ for dimensions of heating, flow and return pipes for steam and hot-water boilers, flues, etc., etc. 12mo. Illustrated. Full roan 1 50

—— Formulas and Tables for Architects and Engineers in calculating the strains and capacity of structures in Iron and Wood. 12mo, morocco, tucks 2 50

SAWYER (W. E.) Electric-Lighting by Incandescence, and its Application to Interior Illumination. A Practical Treatise. With 96 illustrations. Third edition. 8vo, cloth. $2 50

SCRIBNER (J. M.) Engineers' and Mechanics' Companion, comprising United States Weights and Measures, Mensuration of Superfices and Solids, Tables of Squares and Cubes, Square and Cube Roots, Circumference and Areas of Circles, the Mechanical Powers, Centres of Gravity, Gravitation of Bodies, Pendulums, Specific Gravity of Bodies, Strength, Weight, and Crush of Materials, Water-Wheels, Hydrostatics, Hydraulics, Statics, Centres of Percussion and Gyration, Friction Heat, Tables of the Weight of Metals, Scantling, etc., Steam and the Steam-Engine. Nineteenth edition, revised, 16mo, full morocco............ 1 50

—— Engineers', Contractors', and Surveyors' Pocket Table-Book. Comprising Logarithms of Numbers, Logarithmic Sines and Tangents, Natural Sines and Natural Tangents, the Traverse Table, and a full and complete set of Excavation and Embankment Tables, together with numerous other valuable tables for Engineers, etc. Eleventh edition, revised, 16mo, full morocco 1 50

SHELLEN (Dr. H.) Dynamo-Electric Machines. Translated, with much new matter on American practice, and many illustrations which now appear for the first time in print. 8vo, cloth, New York............................(In press)

SHOCK (Chief-Eng. W. H.) Steam-Boilers: their Design, Construction, and Management. 450 pages text. Illustrated with 150 wood-cuts and 36 full-page plates (several double). Quarto. Illustrated. Half morocco.......................15 00

SHUNK (W. F.) The Field Engineer. A handy book of practice in the Survey, Location, and Track-work of Railroads, containing a large collection of Rules and Tables, original and selected, applicable to both the Standard and Narrow Gauge, and prepared with special reference to the wants of the young Engineer. Third edition. 12mo, morocco, tucks.. 2 50

SHIELDS (J. E.) Notes on Engineering Construction. Embracing Discussions of the Principles involved, and Descriptions of the Material employed in Tunnelling, Bridging, Canal and Road Building, etc., etc. 12mo, cloth 1 50

SHREVE (S. H.) A Treatise on the Strength of Bridges and Roofs. Comprising the determination of Algebraic formulas for strains in Horizontal, Inclined or Rafter, Triangular, Bowstring, Lenticular, and other Trusses, from fixed and moving loads, with practical applications and examples, for the use of Students and Engineers. 87 wood-cut illustrations. Third edition. 8vo, cloth......................... 3 50

SIMMS (F. W.) A Treatise on the Principles and Practice of Levelling, showing its application to purposes of Railway Engineering and the Construction of Roads, etc. Revised and corrected, with the addition of Mr. Laws's Practical Examples for setting out Railway Curves. Illustrated. 8vo, cloth $2 50

STILLMAN (PAUL.) Steam-Engine Indicator, and the Improved Manometer Steam and Vacuum Gauges—their Utility and Application. New edition. 12mo, flexible cloth 1 00

STONEY (B. D.) The Theory of Strains in Girders and similar structures, with observations on the application of Theory to Practice, and Tables of Strength and other properties of Materials. New and revised edition, enlarged. Royal 8vo, 664 pages. Complete in one volume. 8vo, cloth...... ....12 50

STUART (CHAS. B., U. S. N.) The Naval Dry Docks of the United States. Illustrated with 24 engravings on steel. Fourth edition, cloth 6 00

—— The Civil and Military Engineers of America. With 9 finely executed portraits of eminent engineers, and illustrated by engravings of some of the most important works constructed in America. 8vo, cloth 5 00

STUART (B.) How to Become a Successful Engineer. Being Hints to Youths intending to adopt the Profession. Sixth edition. 12mo, boards 50

SWEET (S. H.) Special Report on Coal, showing its Distribution, Classification, and Cost delivered over different routes to various points in the State of New York and the principal cities on the Atlantic Coast. With maps. 8vo, cloth 3 00

TEXT-BOOK (A) ON SURVEYING, Projections, and Portable Instruments, for the Use of the Cadet Midshipmen at the U. S. Naval Academy. Nine lithographed plates and several wood-cuts. 8vo, cloth 2 00

TONER (J. M.) Dictionary of Elevations and Climatic Register of the United States. Containing, in addition to Elevations, the Latitude, Mean Annual Temperature, and the total Annual Rain-fall of many localities; with a brief introduction on the Orographic and Physical Peculiarities of North America. 8vo, cloth 3 75

TUCKER (Dr. J. H.) A Manual of Sugar Analysis, including the Applications in General of Analytical Methods to the Sugar Industry. With an Introduction on the Chemistry of Cane Sugar, Dextrose, Levulose, and Milk Sugar. 8vo, cloth, illustrated.................................... 3 50

TUNNER (P.) A Treatise on Roll-Turning for the Manufacture of Iron Translated and adapted by John B. Pearse, of the Pennsylvania Steel-Works, with numerous engravings, wood-cuts, and folio atlas of plates........... .....10 00

VAN WAGENEN (T. F.) Manual of Hydraulic Mining, for the use of the Practical Miner. 12mo, cloth $1 00

WALKER (W. H.) Screw Propulsion. Notes on Screw Propulsion: Its Rise and History. 8vo, cloth 75

WANKLYN (J. A.) A Practical Treatise on the Examination of Milk and its Derivatives, Cream, Butter, and Cheese. 12mo, cloth 1 00

WATT (ALEX.) Electro-Metallurgy, Practically Treated. Sixth edition, with considerable additions. 12mo, cloth 1 00

WEISBACH (JULIUS). A Manual of Theoretical Mechanics. Translated from the fourth augmented and improved German edition, with an introduction to the Calculus, by Eckley B. Coxe, A.M., Mining Engineer. 1,100 pages, and 902 wood-cut illustrations. 8vo, cloth 10 00

WEYRAUCH (J. J.) Strength and Calculations of Dimensions of Iron and Steel Construction, with reference to the Latest Experiments. 12mo, cloth, plates 1 00

WILLIAMSON (R. S) On the use of the Barometer on Surveys and Reconnoissances. Part I. Meteorology in its Connection with Hypsometry. Part II. Barometric Hypsometry. With Illustrative Tables and Engravings. 4to, cloth 15 00

—— Practical Tables in Meteorology and Hypsometry, in connection with the use of the Barometer. 4to, cloth 2 50

Complete 112-page Catalogue of works in every department of science sent postpaid to any address on receipt of ten cents in postage stamps.