by permitting the water to pass into an open chamber, from which it flows over and through a circular weir supported on floats. As the water rises in the chamber the weir also rises, and a constant relation is thus obtained between the height of the water and that of the weir crest. In order to limit the necessary height of the chamber the float may be made to operate a butterfly valve on the inlet pipe, so that when the float rises the valve will partly close and thus diminish the quantity of water entering the chamber. Conversely as the float falls the valve is opened and more water permitted to enter. In neither of these two cases can the flow in the outlet pipe exceed the predetermined capacity of the circular weir. Another form of the rate of flow controller is that in which a balanced valve is operated by the differences in pressure at the throat and downstream end of a Venturi tube inserted in the line. This valve will open or close as the quantity of water decreases or increases below or above some fixed quantity. In this manner a smaller or greater loss of head is automatically introduced into the system, and since the discharge is proportional to the square root of the effective head, the mechanism operates in such a manner as to maintain a constant flow.

For determining the discharge or rate of flow within a pipe at any instant either a Venturi meter or a Pitot tube with the necessary connections may be used, as described in Arts. 38 and 41.

Loss of head gages are used in cases where it is desired to indicate at one place the loss of head which occurs between two points on a system. The most usual application is in the case of a filter bed where the loss of head is constantly varying on account of the clogging of the filter surface. In this situation a loss of head gage indicates at once whether or not a filter should be put out of service and cleaned. A gage for this service consists of a float in each of two chambers, the chambers being connected with the pipe or filter system at the points between which it is desired to measure the difference or loss of head. One of the floats is connected by means of a wire to a horizontal axis which carries a pointer, while the other is connected to another horizontal axis which carries the dial on which the pointer indicates. The two horizontal axes are concident, and the reading of the pointer indicates the loss of head. If the water in both of the chambers rises or falls an equal amount, the pointer will still indicate the same loss of head, as the directions of rotation of the pointer and dial are the same. In order to avoid a movable dial other forms of this

apparatus are arranged by the introduction of a differential mechanism, so that the loss of head is directly indicated by the pointer on a stationary dial.

Valves for maintaining a constant level in a tank or reservoir are usually constructed, for small sizes, of a ball float operating a cock as it rises and falls by means of a system of levers. On larger work an ordinary gate valve operated by a hydraulic cylinder and piston may be used. A float either on the water surface itself or on the surface of mercury in a vessel connecting with the water operates a small three-way valve which admits the water either above or below the piston of the hydraulic valve and so either closes or opens it as the water level rises above or falls below a fixed elevation. In order to prevent such valves from closing too rapidly and thus inducing water hammer, the ports of the three-way valve may be made quite small so as to cause the water to pass very slowly into the operating cylinder or else another piston may be introduced into the system and so arranged that the water behind it is permitted to escape through an orifice the size of which can be regulated. By this means the time of closing can be very nicely adjusted.

All automatic devices are more or less likely to get out of order. This is simply due to the inherent difficulty in attaining perfection in any device. In order that they may at all times retain their adjustment and properly perform the functions for which they have been designed they must be frequently inspected and always kept in good condition and repair. The selection of any particular form of regulating, control, or recording device will depend upon the conditions under which it is to operate and upon the past performance of the mechanism as attested by the experience of those who have used it.

Prob. 103. Make a sketch showing the arrangement above described for maintaining a constant level in a tank by means of a gate valve operated by a hydraulic cylinder. Show also the arrangement of the dampening piston for preventing too rapid closing of the valve.

Art. 104. Water Mains in Towns

The simplest case of the distribution of water is that where a single main is tapped by a number of service pipes near its end, as shown in Fig. 104. In designing such a main the principal consideration is that it should be large enough so that the pressure-head h_1, when all the pipes are in draft, shall be amply sufficient to deliver the water into the highest houses along the line.

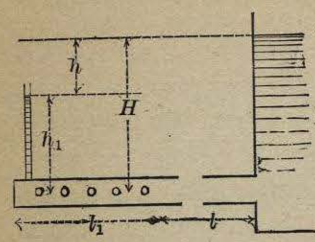

Fig. 104.

It is generally recommended that this pressure-head in commercial and manufacturing districts should not be less than 150 feet, and in suburban districts not less than 100 feet. The height H to the surface of the water in the reservoir will always be greater than h_1, and the pipe is to be so designed that the losses of head may not reduce h_1 below the limit assigned. The head h to be used in the formulas is the difference $H - h_1$. The discharge per second q being known or assumed, the problem is to determine the proper diameter d of the water main.

A strict theoretical solution of even this simple case leads to very complicated calculations, and in fact cannot be made without knowing all the circumstances regarding each of the service pipes. Considering that the result of the computation is merely to enable one of the market sizes to be selected, it is plain that great precision cannot be expected, and that approximate methods may be used to give a solution entirely satisfactory. It will then be assumed that the service pipes are connected with the main at equal intervals, and that the discharge through each is the same under maximum draft. The velocity v in the main then decreases and becomes 0 at the dead end. The loss of head per linear foot in the length l_1 (Fig. 104) is hence less than in l. To determine the total loss of head in the length l_1, let v_1 be the velocity at a distance x from the dead end; then $v_1 = v \cdot x/l_1$ and the loss of head in friction in the length δx is

$$\delta h'' = f\frac{\delta x}{d}\frac{v_1^2}{2g} = f\frac{x^2}{dl_1^2}\frac{v^2}{2g}\delta x$$

and hence between the limits 0 and l_1 that loss of head is

$$h'' = f\frac{l_1}{3d}\frac{v^2}{2g} \qquad (104)$$

provided that f remains constant. This is really not the case, but no material error is thus introduced, since f must be taken larger than the tabular values in order to allow for the deterioration of the inner surface of the main. The loss of head in friction for a pipe which discharges uniformly along its length may therefore be taken at one-third of that which occurs when the discharge is entirely at the end.

Now neglecting the loss of head at entrance and the effective velocity-head of the discharge, the total head h is entirely consumed in friction, or

$$h = f\frac{l}{d}\frac{v^2}{2g} + f\frac{l_1}{3d}\frac{v^2}{2g}$$

Placing in this for v its value in terms of the total discharge q and the diameter of the pipe, and solving for d, gives

$$d^5 = (l + \tfrac{1}{3}l_1)\frac{16fq^2}{2g\pi^2 h}$$

This is the same as the formula of Art. 97, except that l has been replace by $l + \frac{1}{3}l_1$. The diameter in feet then is

$$d = 0.479(l + \tfrac{1}{3}l_1)^{\frac{1}{5}}\left(\frac{fq^2}{h}\right)^{\frac{1}{5}}$$

when h and l are in feet and q in cubic feet per second.

For example, consider a village consisting of a single street with length $l_1 = 3000$ feet, and upon which there are 100 houses, each furnished with a service pipe. The probable population is then 500, and taking 100 gallons per day as the consumption per capita, this gives for the average discharge per second along the length l_1

$$q = \frac{500 \times 100}{7.48 \times 3600 \times 24} = 0.0774 \text{ cubic feet,}$$

and since the maximum draft is often double of the average, q will be taken as 0.15 cubic feet per second. The length l to the reservoir is 4290 feet, whose surface is 90.5 feet above the dead end of the main, and it is required that under full draft the pressure-head in the main shall be 75 feet. Then $h = 90.5 - 75 =$

15.5 feet, and taking $f = 0.03$ in order to be on the safe side, the formula gives

$$d = 0.36 \text{ feet} = 4.3 \text{ inches.}$$

Accordingly a four-inch pipe is nearly large enough to satisfy the imposed conditions.

To consider the effect of fire service upon the diameter of the main, let there be four hydrants placed at equal intervals along the line l_1, each of which is required to deliver 20 cubic feet per minute under the same pressure-head of 75 feet. This gives a discharge 1.33 cubic feet per second, or, in total, $q = 1.33 + 0.15 = 1.5$ cubic feet. Inserting this in the formula, and using for f the same value as before,

$$d = 0.897 \text{ feet} = 10.8 \text{ inches.}$$

Hence a ten-inch pipe is at least required to maintain the required pressure when the four hydrants are in full draft at the same time with the service pipes.

Prob. 104. Compute the velocity v and the pressure-head h_1 for the above example, if the main is 8 inches in diameter and the discharge be 1.5 cubic feet per second. Also when the main is 12 inches in diameter.

Omit

Art. 105. Branches and Diversions

In Fig. 105*a* is shown a main of length l and diameter d, connected with a storage reservoir, which has two branches with lengths l_1 and l_2, and diameters d_1 and d_2 leading to two smaller distributing reservoirs. These data being given, as also the heads H_1 and H_2 under which the flow occurs, it is required to find the discharges q_1 and q_2.

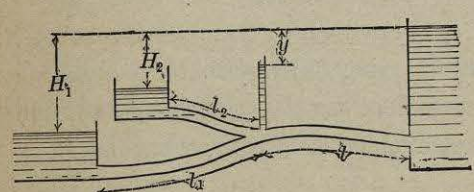

Fig. 105*a*.

Let v, v_1, and v_2 be the corresponding velocities; then for long pipes, in which all losses except those due to friction may be neglected, the friction-heads for the two branches are

$$H_1 - y = f_1 \frac{l_1}{d_1}\frac{v_1^2}{2g} \qquad H_2 - y = f_2 \frac{l_2}{d_2}\frac{v_2^2}{2g}$$

where y is the difference in level between the reservoir surface and the surface of the water in a piezometer tube supposed to be inserted at the junction. This y is the friction-head consumed in the flow in the large main, and hence from formula (90) its value is

$$y = f \frac{l}{d}\frac{v^2}{2g}$$

Inserting this in the two equations, and placing for the velocities their values in terms of the discharges, they become

$$\frac{2g\pi^2}{16} H_1 = f \frac{l}{d^5}(q_1 + q_2)^2 + f_1 \frac{l_1}{d_1^5} q_1^2$$

$$\frac{2g\pi^2}{16} H_2 = f \frac{l}{d^5}(q_1 + q_2)^2 + f_2 \frac{l_2}{d_2^5} q_2^2$$

from which the values of q_1 and q_2 are best obtained by trial.

When it is required to determine the diameters from the given lengths, heads, and discharges, there are three unknown quantities, d, d_1, d_2, to be found from only two equations, and the problem is indeterminate. If, however, d be assumed, values of d_1 and d_2 may be found; and as d may be taken at pleasure, it appears that an infinite number of solutions is possible. Another way is to assume a value of y, corresponding to a proper pressure-head at the junction; then the diameters are directly found from formula $(97)_3$ for long pipes, in which h is replaced by y for the large main, and by $H_1 - y$ and $H_2 - y$ for the two branches.

When two reservoirs, A_1 and A_2, are at a higher elevation than a third one into which they are to deliver water by pipes of length l_1 and l_2, both of which connect with a third pipe of length l which leads to the third reservoir, the above formulas also apply. In this case H_1 and H_2 are the heights of the water levels in the reservoirs A_1 and A_2 above that in the third reservoir.

When the principal main of a water-supply system enters a town, it divides into branches which deliver the water to different districts, and when such branches connect again with the principal main, they form what may be called "diversions." Figure 105*b* shows a simple case, A being the reservoir and AB the principal main, while the pipe lines BCE and BDE form two routes or diversions through which water can flow to F. Let the main AB have the length l and the diameter d, the line BCE the length l_1 and the diameter d_1, the line BDE the length l_2 and the diameter d_2, while the line EF has the length l_3 and the diameter d_3. Suppose that no water is drawn from the pipes except at F and beyond, that the pressure-head Ff at F is h_3, and that the static head Ff_1 on F is h, and let it be required to find the velocity and discharge for each of the pipes. The total head H lost in friction is $h - h_3$, and if W, W_1, W_2, and W_3 represent the weights of water

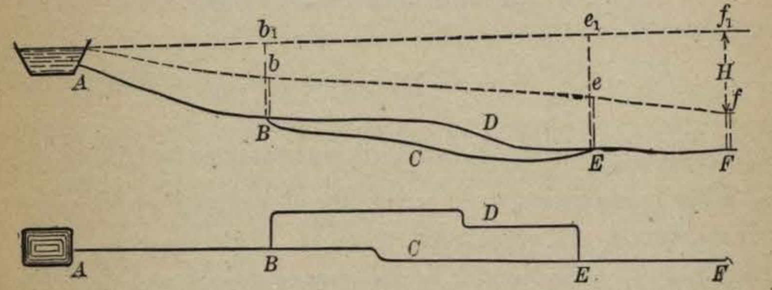

Fig. 105*b*.

that pass any sections of the four pipes per second, the theorem of energy, neglecting the entrance head at A and the velocity-head at F, gives

$$WH = Wf\frac{l}{d}\frac{v^2}{2g} + W_1f_1\frac{l_1}{d_1}\frac{v_1^2}{2g} + W_2f_2\frac{l_2}{d_2}\frac{v_2^2}{2g} + W_3f_3\frac{l_3}{d_3}\frac{v_3^2}{2g}$$

Now referring to the figure where piezometers are shown on the profile at B and E it is seen that the loss of head in friction is the same for the diversions BCE and BDE; accordingly there must exist the condition

$$f_1\frac{l_1}{d_1}\frac{v_1^2}{2g} = f_2\frac{l_2}{d_2}\frac{v_2^2}{2g}$$

and since W equals $W_1 + W_2$ and also equals W_3, the above energy equation reduces to the simple form

$$H = f\frac{l}{d}\frac{v^2}{2g} + f_1\frac{l_1}{d_1}\frac{v_1^2}{2g} + f_3\frac{l_3}{d_3}\frac{v_3^2}{2g}\,.$$

The values of v_1 and v_3 in terms of v are now to be inserted in this equation in order to determine v. From the conditions of continuity of flow and that of equality of friction-head in the diversions, are found three equations,

$$d_3^2 v_3 = d^2 v \qquad d_1^2 v_1 + d_2^2 v_2 = d^2 v \qquad v_1\sqrt{f_1l_1/d_1} = v_2\sqrt{f_2l_2/d_2}$$

and accordingly, if the square roots of the quantities f_1l_1/d_1 and f_2l_2/d_2 be called e_1 and e_2 for the sake of abbreviation,

$$v_3 = \frac{d^2}{d_3^2}v \qquad v_2 = \frac{e_1d^2}{e_2d_1^2 + e_1d_2^2}v \qquad v_1 = \frac{e_2d^2}{e_2d_1^2 + e_1d_2^2}v$$

The above formula for H then reduces to

$$2gH = \left[f\frac{l}{d} + f_1\frac{l_1}{d_1}\cdot f_2\frac{l_2}{d_2}\left(\frac{d^2}{e_2d_1^2 + e_1d_2^2}\right)^2 + f_3\frac{l_3}{d_3}\left(\frac{d}{d_3}\right)^4\right]v^2$$

from which v can be computed. Then v_1, v_2, and v_3 may be found, as also the discharges q, q_1, q_2, and q_3.

As a numerical example, let l = 10 000, l_1 = 2200, l_2 = 2800, l_3 = 1200 feet, and d = 12, d_1 = 8, d_2 = 10, d_3 = 10 inches; let F be 184 feet below the water level in the reservoir and let the required pressure-head at F be 155 feet, so that H = 29 feet. Taking for the friction factors the mean value 0.02 (Art. 90), the value of fl/d is 200, that of f_1l_1/d_1 is 66, that of f_2l_2/d_2 is 67.2, and that of f_3l_3/d_3 is 28.8. The value of e_1 is then 8.12 and that of e_2 is 8.20, while d/d_3 is 1.2. Inserting these in the last formula, there is found v = 2.45 feet per second; then v_1 = 2.16, v_2 = 2.14, and v_3 = 3.53 feet per second. As a check on these results the friction-heads for the four pipes may be computed, and these are found to be 18.6 feet for l, 4.8 feet for l_1 and l_2, and 5.5 feet for l_3; the sum of these is 28.9 feet, which is a sufficiently close agreement with the given 29.0 feet for a preliminary computation. The discharges are $q = q_3$ = 1.93, q_1 = 0.75, q_2 = 1.18 cubic feet per second, and the sum of q_1 and q_2 equals q, as should be the case. The computation may now be repeated, if thought necessary, the above velocities being used to take better values of the friction factors from Table 90*a*.

There are marked analogies between the flow of water in pipes and the flow of electricity in metallic conductors. Thus in Fig. 105*b*, let BCE and BDE be two wires that carry the electric current passing from A to F. If C_1 and C_2 be the currents in these circuits and R_1 and R_2 the resistances of the wires, it is an electric law that $R_1C_1 = R_2C_2$, or the currents are inversely as the resistances. For water the discharges q_1 and q_2 are analogous to the electric currents, and, from the above equation, which expresses the equality of the friction-heads, it is seen that

$$(f_1l_1/d_1^5)^{\frac{1}{2}} q_1 = (f_2l_2/d_2^5)^{\frac{1}{2}} q_2$$

and accordingly the same law holds if the coefficients of q_1 and q_2 be called resistances. If there be a third diversion BGE of length l_4 and diameter d_4 connecting B and E, the current or the discharge through AB divides between the three diversions according to the same law, and

$$f_4\frac{l_4}{d_4}\frac{v_4^2}{2g} = f_1\frac{l_1}{d_1}\frac{v_1^2}{2g} = f_2\frac{l_2}{d_2}\frac{v_2^2}{2g}$$

from which it is seen that $(f_4l_4/d_4^5)^{\frac{1}{2}}q_4$ is equal to each of the corresponding expressions for the other diversions. This subject will receive further discussion in Art. 208.

Prob. 105. From a reservoir A a pipe 10 000 feet long and 16 inches in diameter runs to a point B from which two diversions lead to E. The diversion BCE is 1600 feet long and 10 inches in diameter, while BDE consists of 2000 feet of 10-inch pipe and 1500 feet of 8-inch pipe. From the junction E, a pipe EF, 1000 feet long and 12 inches in diameter, leads to the business section of the town, where it is desired to have four fire streams deliver a total discharge of 900 gallons per minute through four hose lines of $2\frac{1}{2}$-inch smooth rubber-lined hose and $1\frac{1}{8}$-inch smooth nozzles. The point F is 180 feet below the water level in the reservoir. Compute the velocity and discharge for each pipe and hose line, the friction-head lost in each and the pressure-head at the end F.

Art. 106. Cast-iron Pipes

Cast-iron pipes generally range in size from 4 inches to 60 inches in diameter the larger sizes being usually made to order. They are cast in 12-foot lengths and dipped into a hot bath of coal-tar. The joints are of the bell and spigot type, the space about the spigot being filled with lead or other material so as to form a tight joint.

Some waters act rapidly on cast-iron causing the formation of tubercules of iron rust to such an extent that in the course of

years the diameter of the pipe may be reduced by fully 50 percent. Various machines have been devised for removing such incrustations and deposits by scraping and thus in part restoring the original capacity of the pipe. No definite rule can be laid down for the selection of a proper friction factor for use in the design of a pipe. Each particular case must be carefully studied and the proper factor determined upon. Many experiments have been made in order to determine the friction factor in clean cast-iron pipes, and the results are tabulated in Table 90*a*. Other experiments have been made on pipes of various ages and a few of the results are here given in Table 106 in order to illustrate the range which is to be expected in the values of the friction factor.

Table 106. Actual Friction Factors for Cast-iron Pipes

Diameter in Inches	Age in Years	Velocity in Feet per Second			Reference
		2.0	3.0	4.0	
12	0	0.021	0.019	0.018	Trans. Am. Soc. C. E., vol. 47
12	15	0.076		—	Hering's Kutter *
12	22	0.121	0.127	—	Hering's Kutter *
20	5	0.019	0.022	—	Trans. Am. Soc. C. E., vol. 35
20	22	0.069	0.071	0.074	Hering's Kutter *
36	$1\frac{1}{4}$			0.015	Trans. Am. Soc. C. E., vol. 44
36	$3\frac{1}{4}$			0.059	Trans. Am. Soc. C. E., vol. 44
48	0			0.013	Trans. Am. Soc. C. E., vol. 35
48	7	0.028		—	Trans. Am. Soc. C. E., vol. 28
48	16	0.023	0.023	0.023	Trans. Am. Soc. C. E., vol. 35

An inspection of the foregoing table indicates the great range in the values of the friction factor which are caused by progressive deterioration of the interior surface of a cast-iron pipe. Due allowance for this increase of the friction factor with age must be made in designing pipe lines and water mains.

Prob. 106. Compare the discharge of a new cast-iron pipe 20 inches in diameter and 10 000 feet long under a head of 100 feet with that of the same pipe when 25 years old.

* Hering and Trautwine's translation of Gauguillet and Kutter's Flow of Water in Rivers and Other Channels, New York, 1889, p. 155.

Art. 107. Riveted Pipes

Pipes 36 inches and larger in diameter have been made of wrought-iron or steel plates riveted together. Wrought-iron, however, is now but little used, on account of its higher cost, except in the form of thin sheets for temporary pipes. Each section usually consists of a single plate, which is bent into the circular form and the edges united by a longitudinal riveted lap joint. The different sections are then riveted together in transverse joints so as to form a continuous pipe. At AB (Fig. 107a) is shown the so-called taper joint, where the end of each section

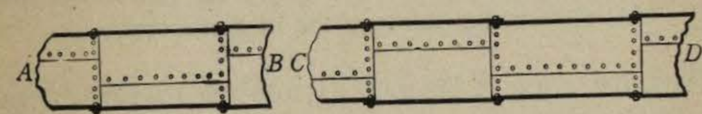

Fig. 107a.

goes into the end of the following one, as in a stovepipe, the flow occurring in the direction from A to B. At CD is seen the method of cylinder joints where the sections are alternately larger and smaller. For the large sizes double rows of rivets are used both in the longitudinal and transverse joints, the style of riveted joint depending on the pressure of water to be carried by the pipe. Riveted pipes have also been built with butt joints on both longitudinal and transverse seams, lap plates being on the outside.

Pipes of this kind have long been in use in California in temporary mining operations, the diameters being from 0.5 to 1.5 feet. In 1876 one was laid at Rochester, N.Y., partly 2 and partly 3 feet in diameter. Since 1892 several lines of large diameter have been constructed, notably the East Jersey pipe of 3, 3.5 and 4 feet diameter, the Allegheny pipe of 5 feet diameter, and the Ogden and Jersey City pipes of 6 feet diameter. The steel pipe siphons now under construction on the Catskill Aqueduct for the city of New York vary in diameter from 9.5 to 11.2 feet. These pipes will be covered with concrete as a protection against exterior corrosion and will be lined inside with 2 inches of Portland cement mortar both as a protective coating, as well as for the purpose of increasing their capacity. This, it

may be noted, is a re-adoption of the old cement-lined pipe and it may be stated that the capacity of a pipe so lined is about 25 percent greater than that of the same pipe without such lining.

Owing to the friction caused by the rivets and joints the discharge from riveted pipes is less than that from cast-iron pipes in which the obstruction caused by the joints is very slight. The following values of the friction factor f, which have been derived from the data given by Herschel,* are applicable to new clean riveted pipes coated with asphaltum in the usual manner.

Velocity in feet per second,		$v =$ 1	2	3	4	5	6
Cylinder joints	3 ft. diam.,	$f =$ 0.035	0.029	0.024	0.021	0.019	0.017
	4 ft. diam.,	$f =$ 0.025	0.022	0.020	0.020	0.021	0.021
Taper joints	$3\frac{1}{2}$ ft. diam.,	$f =$ 0.025	0.024	0.023	0.022	0.022	0.022
	4 ft. diam.,	$f =$ 0.027	0.026	0.025	0.024	0.023	0.023

These friction factors are approximately double those given for new cast-iron pipes in Art. 90, this increase being largely due to the friction of the rivet heads and lapped joints though some of it is probably chargeable to the roughness of the asphaltum coating. It must be noted that these factors increase with age, thus when four years old the upper end of the above 4-foot cylinder joint pipe gave the following values:

Velocity in feet per second,	$v =$ 1	2	3	4	5	6
Cylinder joint 4 ft. diam.,	$f =$ 0.042	0.032	0.030	0.029	0.029	0.029

while the lower portion of this same pipe gave the following values:

Velocity in feet per second,	$v =$ 1	2	3	4	5	6
Cylinder joint 4 ft. diam.,	$f =$ 0.027	0.024	0.023	0.024	0.024	0.024

The diminution in capacity here shown during a period of 4 years is greater for the upper than for the lower part of the line and this is to be ascribed in part at least to the greater number of vegetable growths which occur in most lines near, and for some distance below their intakes.

When this same pipe was 15 years old (Art. 121) the values of the friction factor for its upper end were as follows:

Velocity in feet per second,	$v =$ 1	2	3	4	5	6
Cylinder joint 4 ft. diam.,	$f =$		0.036	0.036		

* 115 Experiments on the Carrying Capacity of Large, Riveted, Metal Conduits, New York, 1897.