discovered the law of equilibrium in the lever.* His investigations, however, were too far in advance of his time to be fully understood, and the teachings of Aristotle were long after accepted by scientific men. The law of mechanics, or of Virtual Velocities, as it is called, was discovered by Galileo.

* It is often said that Archimedes, in allusion to the tremendous power of the lever, asserted that, Give him a fulcrum and he could move the world. Had he been allowed such a chance, "the fulcrum being nine thousand leagues from the center of the earth, with a power of 200 lbs. the geometer would have required a lever 12 quadrillions of miles long and the power would have needed to move at the rate of a cannon-ball to lift the earth one inch in 27 trillions of years."

V

PRESSURE OF LIQUIDS AND GASES.

"THE waves that moan along the shore,
The winds that sigh in blowing,
Are sent to teach a mystic lore
Which men are wise in knowing."

ANALYSIS.

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PRESSURE OF LIQUIDS AND GASES.

1. HYDROSTATICS.

Hydrostatics treats of liquids at rest. Its principles apply to all liquids; but water, on account of its abundance, is taken as the type.

1. Liquids Influenced by External Pressure only. —(1.) Pascal's Law.* *Liquids transmit pressure equally in all directions, and this acts at right angles upon the surface pressed.*

Fig. 64.

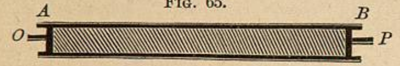
Illustration of Pascal's Law.

As the particles of a liquid move freely among themselves, there is no loss by friction, and any force will be transmitted equally upward, downward, and sidewise. Thus, if a bottle be filled with water and a pressure of 1 lb. be applied upon the cork, it will be communicated from particle to particle throughout the water. If the area of the cork be 1 sq. in., the pressure upon

* This law is named after the celebrated geometrician, Blaise Pascal, who first enunciated it in 1663. At first thought it may seem impossible for a pressure of 1 lb. to produce a pressure of 100 lbs.; but it should be remembered that the general law of mechanics applies to liquids as well as solids. If a force of 1 lb. on 1 sq. in. should *cause motion* by pressing through the medium of a liquid on 100 sq. in., the velocity of the body moved will be only $\frac{1}{100}$th of that of the body applying the pressure.

any sq. in. of the glass at *n*, *a*, *b*, or *c*, will be 1 lb. If the inside surface of the bottle be 100 sq. in., a pressure of 1 lb. upon the cork will produce a force of 100 lbs., tending to burst the bottle.

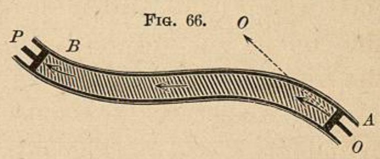
Fig. 65.



Tube with Cylinder of Lead.

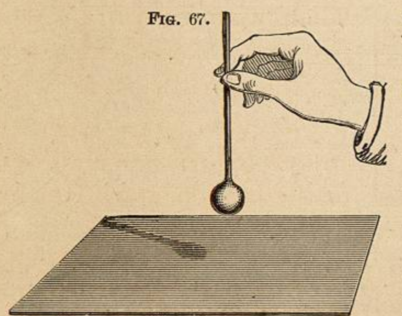
Illustrations.—The transmission of pressure by liquids under some circumstances, is more perfect than by solids. Let a straight tube, *AB*, be filled with a cylinder of lead, and a piston be fitted to the end of the tube. If a force be applied at *P*, it will be transmitted to *O* without sensible loss. If instead, we use a bent tube, the force will be transmitted in the lines of the arrows, and will act on *P* but slightly. If, however, we fill the tube with water, the force will be transmitted without diminution.* Take a glass bulb and stem full of water, as in Fig. 67.† If you are careful to let the stem slip loosely through your fingers as the bulb strikes,

Fig. 66.



Bent Tube Full of Water.

Fig. 67.



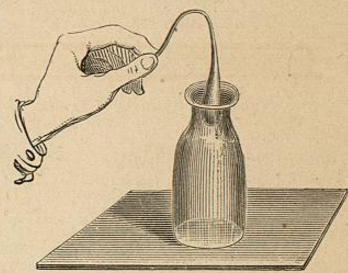
Pounding with a Glass Bulb.

* With cords, pulleys, levers, etc., we lose often more than one half of the force by friction; but this "liquid rope" transmits it with no appreciable loss.

† The process of filling such bulbs is shown on p. 248. They are cheaply purchased of apparatus dealers, and explain not only this point, but also the method of filling thermometers.

you may pound it upon a smooth surface. The force of the blow is instantly transmitted from the thin glass to the water, which is almost incompressible, and this makes the bulb nearly as solid as a ball of glass. If a Rupert's drop be held in a closed vial of water so as not to touch the glass (Fig. 68), and the tapering end be broken, the water will transmit the concussion and shatter the vial.

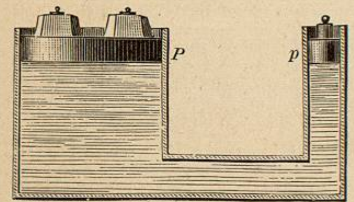
Fig. 68.



Rupert's Drop in Vial.

(2.) Water as a Mechanical Power.—Take two cylinders, *P* and *p* (Fig. 69), fitted with pistons and filled with water. Let the area of *p* be 1 sq. in. and that of *P* be 100 sq. in. Then a downward pressure of 1 lb. on each sq. in. of the small piston will produce an upward pressure of 1 lb. on each sq. in. of the large piston. Hence a *P* of 1 lb. moving at a rate of 1 in. per second will lift a W of 100 lbs. at a rate of $\frac{1}{100}$th of an inch per second.*

Fig. 69.

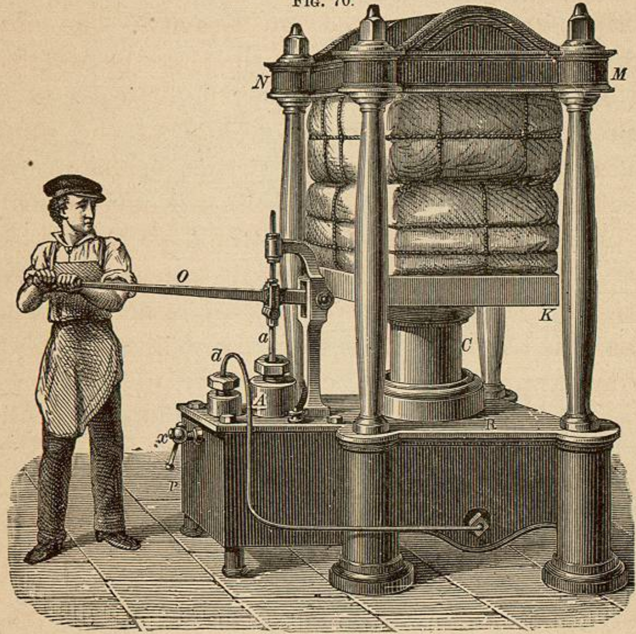


Principle of the Hydrostatic Press.

* Pascal announced the discovery of this principle in the following words: "If a vessel full of water closed on all sides has two openings, the one a hundred times as large as the other, and if each be supplied with a piston which fits exactly, a man pushing the small piston will exert a force which will balance that of a hundred men pushing the large one."

(3.) THE HYDROSTATIC PRESS (Fig. 70) utilizes the principle just explained. As the workman depresses the lever *O*, he forces down the piston *a* upon the water in the cylinder *A*. The pressure is transmitted through the bent tube of water *d* under the piston

FIG. 70.



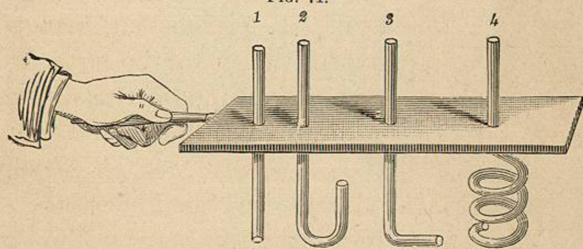
The Hydrostatic Press.

C, which lifts up the platform *K*, and compresses the bales. If the area of *a* be 1 in. and that of *C* 100 in., a force of 100 lbs. will balance 10,000 lbs. The handle is a lever of the second class. If the distance of the hand from the pivot be ten times that of the piston, a *P* of 100 lbs. will produce a force

of 1,000 lbs. at *a*. This will become 100,000 lbs. at *C*.* According to the principle of mechanics, $P \times Pd = W \times Wd$, the platform will ascend $\frac{1}{1000}$ of the distance the hand descends. This machine is used for baling hay and cotton, for launching vessels, and for testing the strength of ropes, chains, etc.

2. Liquids Influenced by Gravity.—The lower part of a vessel of water must bear the weight of the upper part. Thus each particle of water at rest is pressed downward by the weight of the minute column it sustains. It must, in turn, press in every direction with the same force, else it would be driven out of its place and the liquid would no longer be at rest. Indeed, when a liquid is disturbed it comes to rest—*i. e.*, there is an equilibrium established—only when this equality of pressure is produced. The following laws obtain:

FIG. 71.



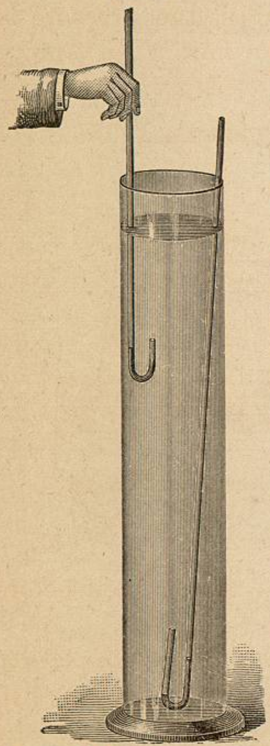
Transmission of Pressure in all Directions.

(1.) FOUR LAWS OF EQUILIBRIUM.—I. *At any point within a liquid at rest the pressure is the same in*

* The presses employed for raising the immense tubes of the Britannia Bridge across the Menai Strait, were each capable of lifting 2,672 tons, and of "throwing water in a vacuum to a height of nearly six miles, or over the top of the highest mountain."

all directions. If the series of glass tubes shown in Fig. 71 be placed in a pail of water, the liquid will be forced up 1 by the upward pressure of the water, 2 by the downward pressure, 3 by the lateral pressure, and 4 by the three combined in different portions of the tube. The water will rise in them all to the same height—*i. e.*, to the level of the water in the pail.

Fig. 72.



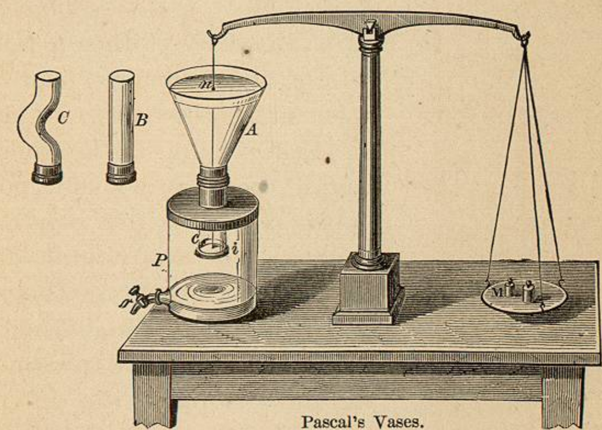
Increase of Pressure with Depth.

II. *The pressure increases with the depth.* Into a tall jar full of water put a bent tube open at both ends, as shown in Fig. 72, a little mercury having been previously poured in so as to fill the bend. The pressure of the water forces down the mercury in the short arm, that in the long arm being exposed only to the pressure of the air. Suppose the difference of level to be an inch when the tube is lowest. Then a column of mercury an inch long will just balance the weight of a column of water of the same thickness and nearly equal in length to the height of the jar. Let the tube now be raised until the surface of the mercury in the short arm is only a fourth of its previous distance from the surface. The difference

of level in the two arms is now found to be only a fourth of an inch.

A cubic foot of water weighs about 62.5 lbs. (1,000 oz.); the same volume of sea-water weighs 64.4 lbs.; hence the pressure is proportionally greater in sea-water. At the greatest depth ever measured in the sea, a little over five miles, the pressure is about six tons on every square inch. An empty

Fig. 73.

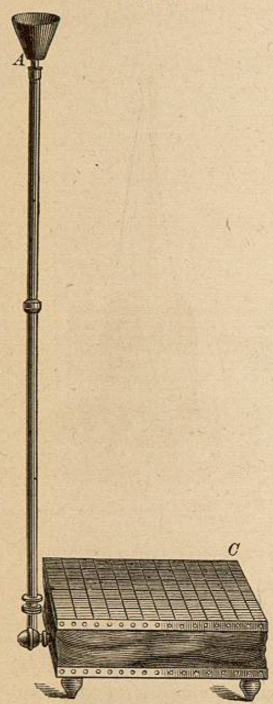


Pascal's Vases.

glass bottle securely stoppered may be crushed before sinking a hundred yards.

III. *The pressure does not depend on the shape or size of the vessel, but on the area and depth.* In the apparatus shown in Fig. 73, a disk is held up by a string against the bottom of an open tube, to which may be screwed vessels of different shapes and sizes, such as *A*, *B*, or *C*. The string is attached to the beam of a balance. In the scale pan is put such a weight, *M*, as to balance the pressure of the liquid against the disk when the vessel is full up to a certain point, *n*. The addition of any more liquid causes the disk to sink and thus spill the liquid, whether the large vessel, *A*, or the smaller ones, *B* or *C*, be used. Against the same area at the bottom the same pressure is obtained even if *A* is three times *B* in volume, provided the depth be kept the same. If the depth of water be increased, *M* has to be increased in the same ratio. Thus a pound of water in *B* may be made to exert a greater pressure at the bottom than 2 lbs. of water in *A*.

Fig. 74.



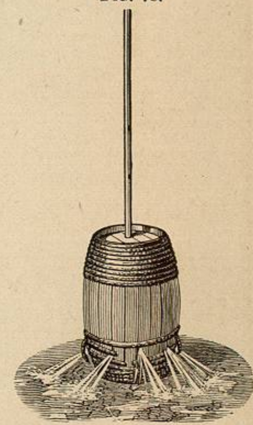
Hydrostatic Bellows.

The Hydrostatic Bellows is an application of the principles just discussed, and is like the Hydrostatic Press on a small scale. It consists of two boards connected by a band of leather and provided with a supply tube for water. Suppose the area of *C* (Fig. 74) to be 500 sq. in., and the area across the small tube *A* to be a single sq. in. Let the stiffness of the leather, along with an added weight on *C*, be equivalent to 100 lbs. Then only one fifth of a pound of water in *A* is needed to balance the 100 lbs. If at *A* we use a larger tube

across which the area is 10 sq. in., then 2 lbs. of water in it are required to maintain equilibrium. The surface of the water in *A* will be about 6 in. above *C*, whether the large or small tube is used. If a cubic inch more be poured into the small tube, the same quantity will be forced into the bellows, so that *C* rises $\frac{1}{500}$th of an inch. If a larger weight is put on *C*, a higher column in *A* is required, but still *C* can be raised by any addition to *A*, however small.

A strong cask fitted with a small pipe 30 or 40 feet long, if filled with water will be burst asunder.* The pressure is as great as if the tube were of the same diameter as the cask. In a coffee-pot the small quantity of liquid in the spout balances the large quantity in the vessel. If it were not so, it would rise in the spout and run out.

Fig. 75.



Bursting a Cask.

IV. *Water seeks its level.* In the apparatus shown in Fig. 76 the water rises to the same height in the various tubes which communicate with one another, because so long as the surfaces are not at the same level a particle below any surface

* Suppose the pipe to have an area of $\frac{1}{40}$ sq. in., and to hold $\frac{1}{2}$ lb. of water. The pressure on each $\frac{1}{40}$ of an inch of the interior of the cask would be $\frac{1}{2}$ lb., or 880 lbs. on each sq. ft.—a pressure no common barrel could sustain. The principle that a small quantity of water will thus balance another quantity, however large, or will lift any weight, however great, is frequently termed the "Hydrostatic Paradox." It is only an instance of a general law, and is no more paradoxical than the action of the lever.