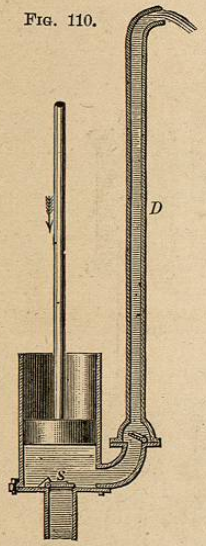
depress the pump-handle and thereby elevate the piston. This will produce a partial vacuum in the suction-pipe. The pressure of the air on the surface of the water below will force the water up the pipe, open the valve, and partly fill the chamber. Let the pump-handle be elevated again, and the piston depressed. The valve *a* will then close, the valve *c* will open, and the water will rise above the piston (Fig. 108). When the pump-handle is lowered the second time and the piston elevated, the water is lifted up to the spout, whence it flows out; while at the same time the lower valve opens and the water is forced up from below by the pressure of the air (Fig. 109).*

Fig. 110.



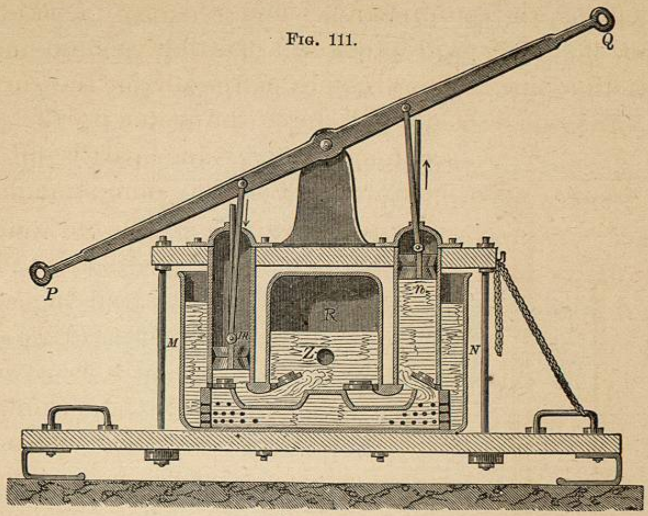
Force-pump.

(2.) The Force-pump has no valve in the piston. The water rises above the lower valve as in the lifting-pump. When the piston descends, the pressure opens the valve in the pipe *D*, and forces the water up. This pipe may be made of any length, and thus the water driven to any height.

(3.) The Fire-engine consists of two force-pumps with an air-chamber. The water is driven by the

* If the valves and piston were fitted air-tight, the water could be raised 34 feet (more exactly 13½ times the height of the barometric column) to the lower valve, but owing to various imperfections it commonly reaches about 28 feet. For a similar reason we sometimes find a dozen strokes necessary to "bring water."

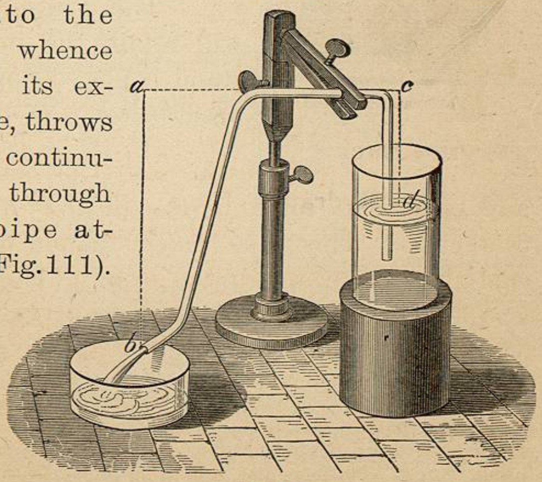
Fig. 111.



Fire-engine.

pistons *m*, *n*, alternately, into the chamber *R*, whence the air, by its expansive force, throws it out in a continuous stream through the hose-pipe attached at *Z* (Fig. 111).

Fig. 112.

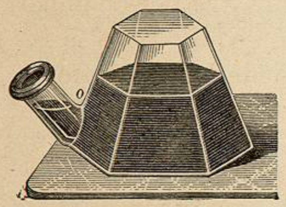


Siphon.

6. The Siphon is a U-shaped tube, having one arm longer than the other. Insert the short arm in the water, and then applying the mouth to the long arm, exhaust the air. The water will flow from the long arm until the end of the short arm is uncovered.

THEORY OF THE SIPHON.—The pressure of the air at *b* holds up the column of water *a b*, and the upward pressure is the weight of the air less the weight of the column of water *a b*. The upward pressure at *d* is the weight of the air minus the weight of the column of water *c d*. Now *c d* is less than *a b*, and the water in the tube is driven toward the longer arm by a force equal to the difference in the weight of the two arms.*

FIG. 113.



Pneumatic Inkstand.

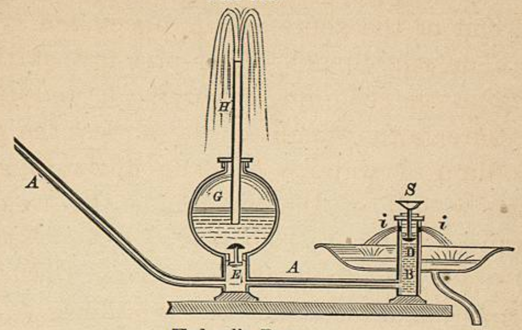
7. The Pneumatic Inkstand can be filled only when tipped so that the nozzle is at the top. The pressure of the air will retain the ink when the stand is placed upright. When used below *o*, a bubble of air passes in, forcing the ink into the nozzle.

8. The Hydraulic Ram is a machine for raising water where there is a slight fall. The water enters

* The siphon is used more conveniently if two tubes of glass or metal are connected with a flexible tube of India rubber. An instructive experiment can then be made if we allow the water to run from one tumbler into another until just before the flow ceases; then quickly elevate the glass containing the long arm, carefully keeping both ends of the siphon under the water, when the flow will set back to the first tumbler. Thus we may alternate until we see that the water flows to the lower level, and ceases whenever it reaches the same level in both glasses. It will add to the beauty of this as well as of many other experiments, to color the water in one tumbler with a few scales of magenta, or with red ink.

through the pipe *A*, fills the reservoir *B*, and lifts the valve *D*. As that closes, the shock raises the

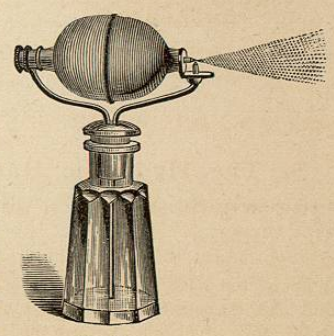
FIG. 114.



Hydraulic Ram.

valve *E* and drives the water into the air-chamber *G*. *D* falls again as soon as an equilibrium is restored. A second shock follows, and more water is thrown into *G*. When the air in *G* is sufficiently condensed, its elastic force drives the water through the pipe *H*.

FIG. 115.


Atomizer.

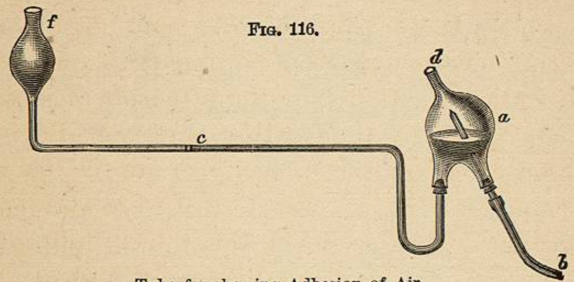
9. The Atomizer is used to turn a liquid into spray. The blast of air driven from the rubber bulb as it passes over the end of the upright tube, sweeps along the neighboring molecules of air and produces a partial vacuum in the tube.* The

* In locomotives, this principle of the adhesion of gases to gases is applied to produce a draft. The waste steam is thrown into the smoke-pipe,

pressure of the air in the bottle drives the liquid up the tube, and at the mouth the blast of air carries it off in fine drops.

The action of a current of air in dragging along with it the adjacent still atmosphere and so tending to produce a vacuum, is shown by the apparatus represented in Fig. 116. A globe, *a*, is connected

FIG. 116.



Tube for showing Adhesion of Air.

with a horizontal tube, *c*, containing colored water. Close the opening *d* with the finger, and with the mouth at *b* draw the air out of the globe. A slight rarefaction will cause the liquid, by the pressure of the air at the opening *f*, to be forced into *a*. Now,

and this current sweeps off the smoke from the fire, while the pressure of the atmosphere outside forces the air through the furnace and increases the combustion.—A familiar illustration may be devised by taking two disks of card-board, the lower one fitted with a quill, and the upper one merely kept from sliding off by a pin thrust through it and extending into the quill. The more forcibly air is driven through the quill against the upper disk, the more firmly it will be held to its place. See article "Ball Paradox," in "Popular Science Monthly," April, 1877.—Faraday used to illustrate the principle thus: Hold the hand out flat with the fingers extended and pressed together. Place underneath a piece of paper two inches square. Blow through the opening between the index and the middle finger, and so long as the current is passing the paper will not fall.

if, instead of drawing the air out at *b*, a jet of air be forced through the tube and out at *d*, the same effect will be produced.

10. Height of the Atmosphere.—Three opposing forces act upon the air, viz.: gravity, which binds it to the earth, and the centrifugal and repellent forces, which tend to hurl it into space. There must be a point where these balance. At the height of 3.4 miles the mercury in the barometer stands at ·15 inches, indicating that half the atmosphere is within about 3½ miles of the earth's surface. Beyond a height of 40 miles the quantity of air is too small to be perceptible in any way.* If it were every-where as dense as it is at sea-level, the upper limit of our atmosphere would be about five miles high.

PRACTICAL QUESTIONS.

[*In these questions, assume the standard conditions mentioned on p. 136.*]

1. Why must we make two openings in a barrel of cider when we tap it?
2. What is the weight of 10 cubic feet of air?
3. What is the pressure of the air on 1 square rod of land?
4. What is the pressure on a pair of Magdeburg hemispheres 4 inches in diameter?
5. How high a column of water can the air sustain when the barometric column stands at 28 inches?
6. If we should add a pressure of two atmospheres (30 lbs. to the square inch), what would be the volume of 100 cubic inches of common air?

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* In mountain climbing, or ascending to a great height in a balloon, the voyager is apt to suffer on account of the decrease in density of the air. In 1862, Mr. Glaisher ascended nearly 7 miles, and there fainted. His assistant was barely able to open the valve and cause the balloon to descend.

7. If, while the water is running through the siphon, we quickly lift the long arm, what is the effect on the water in the siphon? If we lift the entire siphon?

8. When the mercury stands at $29\frac{1}{2}$ inches in the barometer, how high above the surface of the water can we place the lower pump-valve?

9. Can we raise water to a higher level by means of a siphon?

10. If the air in the chamber of a fire-engine be condensed to $\frac{1}{10}$ its former bulk, what will be the pressure due to the expansive force of the air on every square inch of the air-chamber?

11. What causes the bubbles to rise to the surface when we put a lump of loaf-sugar in hot tea?

12. When will a balloon stop rising? What weight can it lift?

13. The rise and fall of the barometric column shows that the air is lighter in foul and heavier in fair weather. Why is this? *Ans.* Vapor of water is only half as heavy as dry air. When there is a large quantity present in the atmosphere, displacing its own volume of air, the weight of the atmosphere will be correspondingly diminished.

14. When smoke ascends in a straight line from chimneys, is it a proof of the rarity or the density of the air?

15. Explain the action of the common leather-sucker.

16. Did you ever see a bottle really empty?

17. Why is it so tiresome to walk in miry clay? *Ans.* Because the upward pressure of the air is removed from our feet.

18. How does the variation in the pressure of the air affect those who ascend lofty mountains? Who descend in diving-bells?

19. Explain the theory of "sucking cider" through a straw.

20. Would it make any difference in the action of the siphon if the limbs were of unequal diameter?

21. What would be the effect of making a small hole in the top of a diving-bell while in use?

22. The pressure of the atmosphere being 1.03 kg. per sq. cm., what is the amount on 10 sq. meters?

SUMMARY.

Hydrostatics treats of the laws of equilibrium in liquids. Pressure is transmitted by liquids equally in every direction. Water thus becomes a "mechanical power," as in the "Hydraulic Press." Liquids acted on by their weight only, at the same depth, press downward, upward, and sidewise with equal force. This pressure is independent of the size of the vessel, but increases with the depth. Wells, springs, aqueducts, fountains, and the water-supply of cities illustrate the tendency of

water to seek its level. The ancients understood this law, but had no suitable material for making the immense pipes needed; just so the art of printing awaited the invention of paper. Specific gravity, or the relative weights of the same volume of different substances, is found by comparing them with the weight of the same volume of water. This is easily done, since, according to the law of Archimedes, a body immersed in water is buoyed up by a force equal to the weight of the water displaced; *i. e.*, it loses in weight an amount equal to that of the same volume of water. Hence spec. grav. $= \dfrac{\text{weight in vacuum}}{\text{weight in vacuum} - \text{weight in water}}$. A floating body displaces only its own weight of liquid. This explains the buoyancy which supports a ship, why a floating log is partly out of water, and many similar phenomena.

Hydrodynamics treats of moving liquids. The laws of falling bodies in theory apply; so that a descending jet of water will acquire the same velocity that a stone would in falling to the ground from the surface of the water; and an ascending jet would need to have the same velocity in order to reach that height. The quantity of water discharged through any orifice equals the area of the opening multiplied by the velocity of the stream. The chief resistance to the motion of a liquid is the friction of the air and against the sides of the pipe, and, in the case of rivers, against the banks and bottom of the channel. The force of falling water is utilized in the arts by means of water-wheels. There are four kinds—overshot, undershot, breast, and turbine. The principles of wave-motion, so essential to the understanding of sound, light, etc., are most easily studied in connection with water. A stone let fall into a quiet pool sets in motion a series of concentric waves, whose particles move in ellipses, while the movement passes to the outermost edge of the water, and is then transmitted to the ground beyond. The velocity of the particles is much less than that of the wave itself. A handful of stones acts in the same way, but sets in motion many series of waves. Hence arise the phenomena of interference.

Pneumatics treats of the properties and the laws of equilibrium of gases. The air being composed of matter, has all the properties we associate with matter, as weight, indestructibility, extension, compressibility, etc. The elasticity of the air, according to Mariotte's law, is inversely proportional to its volume, and this is inversely proportional to the pressure upon the air; both heat and pressure increasing the elasticity of a gas. The air, like other fluids, transmits the weight of its own particles, as well as any outside pressure, equally in every direction; hence the upward pressure or buoyant force of the atmosphere. A balloon rises because it is buoyed up by a force equal to the weight of the air it displaces. It floats in the air for the same reason that a ship floats on the ocean. When smoke falls it is heavier than the surrounding atmosphere. When it rises, it is carried up by adhesion of warm air, which is lighter than that surrounding the current. The air-pump is used for exhausting the air from, and the condenser for condensing the air into, a receiver. A vacuum in which there remains only $\frac{1}{1000000}$ of the atmosphere can be obtained by means of Sprengel's air-pump, which acts on the principle of the adhesion of the air to a column of falling mercury. The average pressure of the air being 15 lbs. to the square inch, equals that of a column of water 34 feet, and of mercury 30 inches or 760 millimeters high. This amount varies incessantly through atmospheric changes caused by alterations in the wind, heat of the sun, etc. The barometer measures the pressure of the atmosphere, and is used to determine the height of mountains and the changes of the weather. The action of the siphon, the pneumatic inkstand, and of the different kinds of pumps, is based upon the pressure of the air.

HISTORICAL SKETCH.

Hydrostatics is comparatively a modern science. The Romans had a knowledge of the fact that "liquids rise to the level of their source;" but they had no means of making iron pipes strong enough to resist the pressure.* They were therefore forced to carry water into the Imperial City by means of enormous aqueducts, one of which was 63 miles long, and was supported by arches 100 feet high. The ancient Egyptians and Chaldeans were probably the first to investigate the most obvious laws of liquids from the necessity of irrigating their land. Archimedes, in the third century B.C., invented a kind of pump called *Archimedes' Screw*, demonstrated the principle of equilibrium, known now as "*Archimedes' Law*" (p. 114), and found out the method of obtaining the specific gravity of bodies. The discovery of the last is historical. Hiero of Syracuse suspected that a gold crown had been fraudulently alloyed with silver. He accordingly asked Archimedes to find out the fact without injuring the workmanship of the crown. One day going into a bath-tub full of water, the thought struck the philosopher that as much water must run over the side as was equal to the volume of his body. Electrified by the idea, he sprang out and ran through the streets, shouting: "Eureka!" (I have found it!)

The ancients never dreamed of associating the air with gross matter. To them it was the spirit, the life, the breath. Noticing how the atmosphere rushes in to fill any vacant space, the followers of Aristotle explained it by saying, "Nature abhors a vacuum." This principle answered the purpose of philosophers for 2,000 years. In 1640, some workmen were employed by the Duke of Tuscany to dig a deep well near Florence. They found to their surprise that the water would not rise in the pump as high as the lower valve. More disgusted with nature than nature was with the vacuum in their pump, they applied to Galileo. The aged philosopher answered—half in jest, we hope, certainly he was half in earnest—"Nature does not abhor a vacuum beyond 34 feet." His pupil, Torricelli, however, discovered the secret. He reasoned that there is a force which holds up the water, and as mercury is $13\frac{1}{2}$ times as heavy as water, it would sustain a column of that liquid only 34 feet $\div 13\frac{1}{2} = 30$ inches high. Trying the experiment shown in Fig. 103, he verified the conclusion that the weight of the air is the unknown force. But the opinion was not generally received.

* The ancient engineers sometimes availed themselves of this principle. Not far from Rachel's Tomb, Jerusalem, are the remains of a conduit once used for supplying the city with water. The valley was crossed by means of an inverted siphon. The pipe was about two miles long and fifteen inches in diameter. It consisted of perforated blocks of stone, ground smooth at the joints, and fastened with a hard cement.

Pascal next reasoned that if the weight of the air is really the force, then at the summit of a high mountain it is weakened, and the column would be lower. He accordingly carried his apparatus to the top of a tower, and finding a slight fall in the mercury, he asked his brother-in-law, Perrier, who lived near Puy de Dôme, a mountain in Southern France, to test the conclusion. On trial, it was found that the mercury fell 3 inches. "A result," wrote Perrier, "which ravished us with admiration and astonishment." Thus was discovered the germ of our modern barometer, and the dogma of the philosophers soon gave place to the law of gravitation and our present views concerning the atmosphere.

Consult Pepper's "Cyclopedic Science"; Bert's "Atmospheric Pressure and Life," in "Popular Science Monthly," Vol. XI., p. 316; "Appleton's Cyclopedia," Articles on Hydromechanics, Atmosphere, Pneumatics, etc.; Delaunay, "Mécanique Rationelle"; Boutan et D'Almeida, "Cours de Physique"; Müller, "Lehrbuch der Physik und Meteorologie."

On the theory of Wave-motion, and the subjects of Sound and Light, which are now to follow, consult Lockyer's "Studies in Spectrum Analysis"; Lloyd's "Wave Theory"; Taylor's "Science of Music"; Blaserna's "Theory of Sound in Relation to Music"; Tyndall's "Sound" and "Light"; Lockyer's "Water-waves and Sound-waves" in "Popular Science Monthly," Vol. XIII., p. 166; Shaw's "How Sound and Words are Produced," in "Popular Science Monthly," Vol. XIII., p. 43; Mayer on "Sound"; Schellen's "Spectrum Analysis"; Airy's "Optics"; Lockyer's "Spectroscope"; Chevreul's "Colors"; Spottiswoode's "Polarization of Light"; Lömmel's "Nature of Light"; Helmholtz's "Popular Lectures on Scientific Subjects"; "Appleton's Cyclopedia," Articles on Sound, Light, Spectrum, Spectrum Analysis, Spectacles, Heat, etc.; Stokes' "Absorption and Colors," and Forbes' "Radiation," in "Science Lectures at South Kensington," Vol. I.; Mayer and Barnard's "Light"; Draper's "Popular Exposition of some Scientific Experiments," in "Harper's Magazine" for 1877; Core's "Modern Discoveries in Sound," in Manchester Science Lectures, '77-8; Dolbear's "Art of Projecting"; Draper's "Scientific Memoirs"; Steele's "Physiology," Section on Sight, pp. 187-196.

VI.

ON SOUND.

"SCIENCE ought to teach us to see the invisible as well as the visible in nature: to picture to our mind's eye those operations that entirely elude the eye of the body; to look at the very atoms of matter, in motion and in rest, and to follow them forth into the world of the senses."—TYNDALL.