distinct, yet the joint effect may be very peculiar. If any two systems coincide with *like phases*,—the crest of one meeting the crest of the other, and the furrow of one meeting the furrow of the other,—the resulting wave will have a height equal to the *sum of the two*. If any two systems coincide with opposite phases,—the hollow of one striking the crest of another,—the height will be the *difference of the two*. Thus, if in two systems having the same wave-length and height, one is exactly half a length behind the other, they will destroy each other. This is termed the *interference* of waves.*

The manner in which different waves move among and upon one another, is seen by dropping a handful of stones in water and watching the waves as they circle out from the various centers in ever-widening curves. In Fig. 91 is shown the beautiful appearance these waves present when reflected from the sides of a vessel.

* "In the port of Batsha the tidal-wave comes up by two distinct channels so unequal in length that their time of arrival varies by six hours. Consequently when the crest of high water reaches the harbor by one channel, it meets the low water returning by the other, and when these opposite phases are equal, they neutralize each other, so that at particular seasons there is no tide in the port, and at other times there is but one tide per day, and that equal to the difference between the ordinary morning and evening tide."—*Lloyd's Wave Theory.*

Another striking example of interference of tide-waves is seen in the immediate neighborhood of New York. The tide-wave from the ocean, coming from the south-east, divides, a part passing up New York Bay, and another part sweeping around and turning westward through Long Island Sound. The meeting-place of these two branches is at Hell Gate, the narrowest ship-channel between Long Island and New York. If a wall were built across Hell Gate, the water on one side would sometimes be five feet above that on the other. In the absence of such a wall, the current surges with great rapidity under the Brooklyn Bridge, alternately in opposite directions.

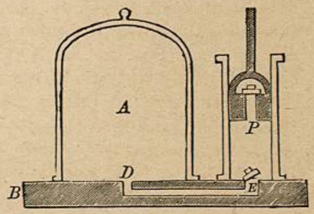
PRACTICAL QUESTIONS.

1. Two faucets, one 8 feet and the other 4 feet below the surface of the water in a cistern, are kept open for a minute. How many times as much water can be drawn from the first as the second?
2. How much water will be discharged per second from a short pipe having a diameter of 4 inches and a depth of 48 feet below the surface of the water?
3. When we pour molasses from a jug, why is the stream so much larger near the nozzle than at some distance from it?
4. Ought a faucet to extend into a barrel beyond the staves?
5. What would be the effect if both openings in one of the arms of Barker's Mill were on the same side?

III. PNEUMATICS.

Pneumatics treats of the general properties and the pressure of gases. Since the molecules move among themselves more freely even than those of liquids, the conclusions which we have reached with regard to transmission of pressure, buoyancy, and specific gravity apply also to gases. Since air is the most abundant gas, it is taken as the type of the class, just as water is of liquids.

Fig. 92.



The Air-pump.

1. The Air-pump is shown in its essential features in Fig. 92. *A* is a glass receiver standing on an oiled pump-plate. The tube *D* connecting the receiver with the cylinder, is closed by the valve *E*, opening upward. There is a second valve, *P*, in the piston, also opening upward. Suppose the piston is at the bottom and both valves shut. Let it now be raised, and a vacuum will be produced in the cylinder; the expansive force of the atmosphere in the receiver will open the valve *E* and drive the air through to fill this empty space. When the piston descends, the valve *E* will close, while the valve *P* will open, and the air will pass up above the piston. On elevating the piston a second time, this air is removed from the cylinder, while the air from the receiver passes through as before. At each stroke a portion of the atmosphere is drawn off; but the expansive force becomes less and less, until finally it is insufficient to lift the valves. For this reason a perfect vacuum can not be obtained.

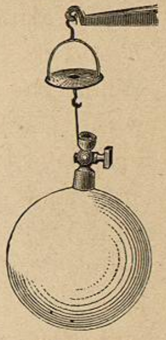
2. The Condenser, in construction, is the same as the air-pump, except that the valve opens inward instead of outward. Instead of exhausting, it forces more air into a vessel.*

3. Properties of Air.—(1.) WEIGHT.—Exhaust the air from a flask which holds 100 cubic inches, and then balance it. On turning the stop-cock, the air will rush in with a whizzing noise and the flask

* The practical applications of this pump are numerous. The soda manufacturer uses it to condense carbonic acid in soda-water reservoirs.—The engineer employs it in laying the foundations of bridges. Large tubes or *caissons* are lowered to the bed of the stream, and air being forced in, drives out the water. The workmen are let into the caissons by a sort of trap, and work in this condensed atmosphere.—Pneumatic dispatch-tubes contain a kind of train holding the mail, and back of this a piston fitting the tube Air is forced in behind the piston or exhausted before it, and so the train is driven through the tube at a high speed.—In the Westinghouse air-brake, condensed air is forced along a tube running underneath the cars, and by its elastic force drives the brakes against the wheel.

will descend (Fig. 93). It will require 31 grains or more to restore the equipoise.

FIG. 93.



Weighing Air.

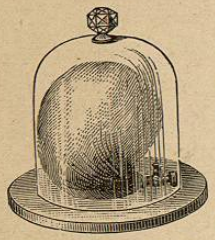
(2.) ELASTICITY is shown in a pop-gun. We compress the atmosphere in the barrel until the elastic force drives out the stopper with a loud report. As we crowd down the piston we feel the elasticity of the air yielding to our strength, like a bent spring.—The bottle-imps, or Cartesian divers, illustrate the same property. Fig. 94 represents a simple form of this apparatus. The cover of a fruit-jar is fitted with a tube, which is inserted in a syringe-bulb. The jar is filled with water and the diver placed within. This is a hollow image of glass, having a small opening at the end of the curved tail. If we squeeze the bulb, the air will be forced into the jar and the water will transmit the pressure to the air in the image. This being compressed, more water will enter, and the diver, thus becoming heavier, will descend. On relaxing the grasp of the hand on the bulb, the air will return into it, the air in the image will expand, by its elastic force driving out the water, and the diver, thus lightened of his ballast, will ascend. The nearer the image is to the bottom, the less force will be required to move it. With a little care

FIG. 94.

Cartesian Diver.

it can be made to respond to the slightest pressure, and will rise and fall as if instinct with life.*

Fig. 95.

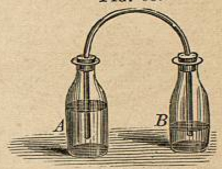


Expansibility of Air.

(3.) Expansibility.—Let a well-dried bladder be partly filled with air and tightly closed. Place it under the receiver and exhaust the air. The air in the bladder expanding will burst it into shreds.

Take two bottles partly filled with colored water. Let a bent tube be inserted tightly in *A* and loosely in *B*. Place this apparatus under the receiver and exhaust the air. The expansive force of the air in *A* will drive the water over into *B*. On readmitting the air into the receiver, the pressure will return the water into *A*. It may thus be driven from bottle to bottle at pleasure.†

Fig. 96.



Transfer of Liquid under Receiver.

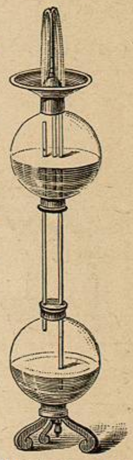
Hiero's fountain acts on the same principle, as may

* This experiment shows also the buoyant force of liquids, their transmission of pressure in every direction, and the increase of the pressure in proportion to the depth. The elasticity of the air, as well as the principles explained by the Cartesian diver, Fig. 94, may be illustrated in the following simple manner: Fill with water a wide-mouth 8-oz. bottle, and also a tiny vial, such as is used by homeopathists. Invert the vial and a few drops of water will run out. Now put it inverted into the bottle, and if it does not sink just below the surface and there float, take it out and add or remove a little water, as may be needed. When this result is reached, cork the bottle so that the cork touches the water. Any pressure on the cork will then be transmitted to the air in the vial, as in the image in Fig 94.

† Prick a hole in the small end of an egg, and place the egg with the big end up in a wine-glass. On exhausting the receiver, the bubble of air in the upper part of the egg will drive the contents down into the glass, and on admitting the air they will be forced back again.

be seen by an examination of Fig. 97. Having removed the jet-tube, the upper globe is partly filled with water. The tube being then replaced, water is poured into the basin on top. The liquid runs down the pipe at the right, into the lower globe. The air in that globe is driven up the tube at the left into the upper globe, and by its elasticity forces the water there out through the jet-tube, forming a tiny fountain.

Fig. 97.



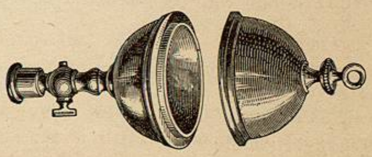
Hiero's Fountain.

Fig. 98.

Hand-glass.

4. Pressure of the Air.—(1.) The Proof.—If we cover a hand-glass with one hand, as in Fig. 98, on exhausting the air we shall find the pressure painful.* Tie over one end of the glass a piece of wet bladder. When dry, exhaust the air, and the membrane will burst with a sharp report.†

Fig. 99.



Magdeburg Hemispheres.

* The exhaustion of the air does not *produce* the pressure on the hand; it simply *reveals* it. The average pressure on each person is 16 tons. It is equal, however, on all parts of the body, and is counteracted by the air within. Hence we never notice it. Persons who go up high mountains or go down in diving-bells feel the change in the pressure.

† To show the crushing force of the atmosphere, take a tin cylinder 15 inches long and 4 inches in diameter. Fit one end with a stop-cock for the exit of the steam. Put in a little water and boil. When the air is entirely

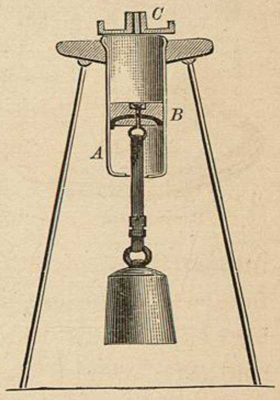
The *Magdeburg Hemispheres* are named from the city in which Guericke, their inventor, resided. They consist of two small brass hemispheres, which fit closely together, but may be separated at pleasure. If, however, the air be exhausted from within, several persons will be required to pull them apart.* In whatever position the hemispheres are held, the pressure is the same.

Fig. 100.

Water held up by Pressure of Air.

(2.) Upward Pressure.—Fill a tumbler with water, and then lay a sheet of paper over the top. Quickly invert the glass, and the water will be supported by the upward pressure of the air.—Within the glass cylinder, Fig. 101, is a piston working air-tight. Connect the nozzle above with the air-pump by means of a rubber tube and exhaust the air. The weight will leap up as if caught by a spring.

Fig. 101.



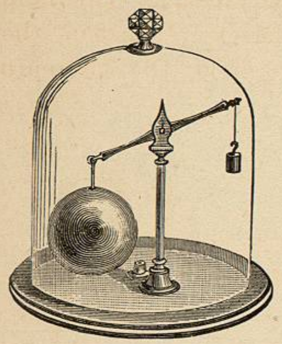
The Weight-lifter.

driven out, turn the stop-cock. Pour cold water over the outside to condense the steam, when the cylinder will collapse as if struck by a heavy blow.

* In the museum at Berlin the hemispheres used by Guericke in his experiments are preserved. They are of copper, and 22 inches interior diameter, with a flange an inch wide, making the entire diameter 2 feet. Accompanying is a Latin book by the burgomaster describing numerous pneumatic experiments which he had performed, and containing a woodcut representing three spans of horses on each side trying to separate the hemispheres.

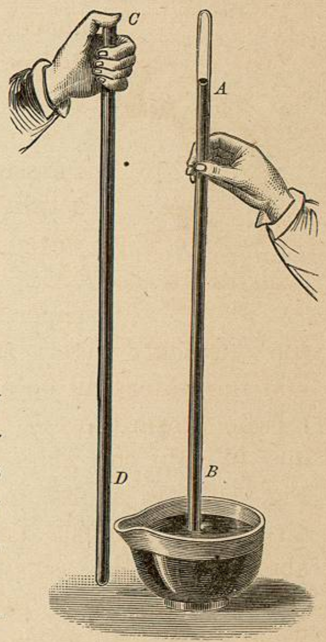
(3.) Buoyant Force of the Air.—The law of Archimedes (p. 114) holds true in gases. A hollow sphere of glass or copper, Fig. 102, is balanced in the air by a solid lead weight, but on being placed under the receiver it steadily falls while the air is becoming exhausted. This shows that its weight was partly sustained by the buoyant force of the air.

Fig. 102.



Buoyancy of Air.

Fig. 103.



Torricelli's Experiment.

(4.) At sea-level the pressure of the air sustains a column of mercury 30 inches high, or of water nearly 34 feet high, and is nearly 15 lbs. per square inch. Take a strong glass tube about three feet in length, and tie over one end a piece of wet bladder. When dry, fill the tube with mercury, and invert it in a cup of the same liquid. The mercury will sink to a height of about 30 inches. If the area across the tube be one square inch, the metal will weigh about 14.7 lbs. The weight of the column of mercury is equal to the downward pressure on each square inch of the surface of the mercury in the cup. Hence we conclude that the pressure of the atmosphere is 14.7 lbs. per square inch, and will balance a column of mercury 30 inches high. As water is 13½ times lighter than mercury, the same pressure would balance a column of that liquid 13½ times higher, or 33¾ feet.*

(5.) PRESSURE OF THE AIR VARIES.† Changes of temperature, moisture, etc., continually vary the density of the air, and change the height of the column of liquid it can support. The pressure also increases with the depth. Hence, in a valley the column of mercury stands higher than on a mountain. The pressure of the atmosphere is 29.92 inches only at the level of the sea, and at the temperature of melting ice at latitude 45°. The variation due to latitude is very slight; that due to temperature is greater, and that due to elevation is greatest. Observations on the barometer at any given station

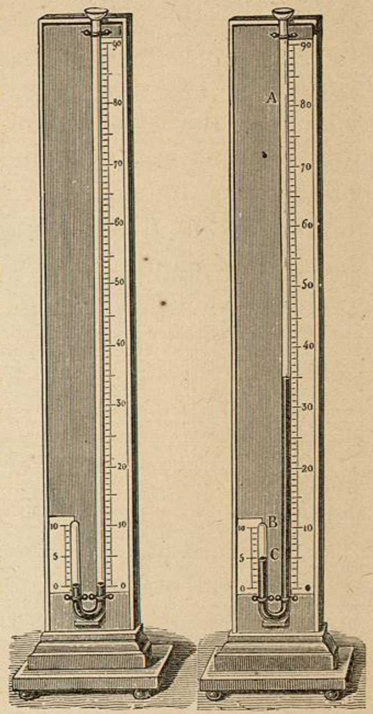
* On account of the unwieldly length of the tube required to exhibit the column of water, it is not easy to verify this. It may, however, be prettily illustrated. Pour on the mercury in the cup (Fig. 103) a little water colored with red ink. Then raise the end of the tube above the surface of the metal, but not above that of the water; this will rise in the tube, the mercury passing down in beautifully-beaded globules. The mercurial column is only 30 inches high, while the water will fill the tube. Finish the experiment by puncturing the bladder with a pin, when the water will instantly fall to the cup below.

† We live at the bottom of an aërial ocean whose depth is greater than that of the deepest sea. Its invisible currents surge round us on every side.

are generally "reduced" to what they would be under the standard conditions just mentioned.

(6.) MARIOTTE'S LAW.*—Fig. 104 represents a long, bent glass tube with the end of the short arm closed. Pour mercury into the long arm until it rises to the point marked zero.† It stands at the same height in both arms, and there is an equilibrium. The air presses on the mercury in the long arm with a force equal to a column of mercury 30 inches high, and the elastic force of the air confined in the short arm is equal to the same amount. Now pour additional mercury into the long arm until it stands at 30 inches above that in the short arm (Fig. 105), and the pressure is doubled. In the short arm, the air is condensed to one half its

Fig. 104. Fig. 105.

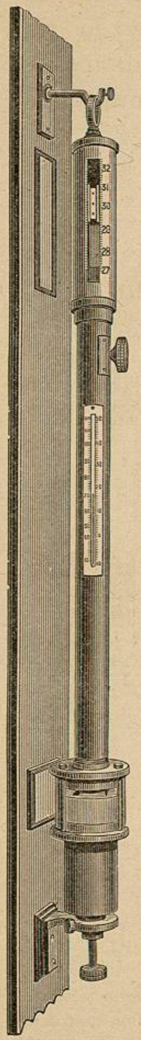


Mariotte's Tube.

* This law was independently discovered by the Englishman, Boyle, and the Frenchman, Mariotte, during the latter part of the seventeenth century. It is often called Boyle's Law.

† By cautiously inclining the apparatus, when a little air will escape, and adding more mercury if needed, the liquid can be made to stand at zero in both arms.

Fig. 106.



The Barometer.

former dimensions, and the elastic force is also doubled.* We therefore conclude that *the elasticity of a gas increases, and the volume diminishes in proportion to the pressure upon it.*

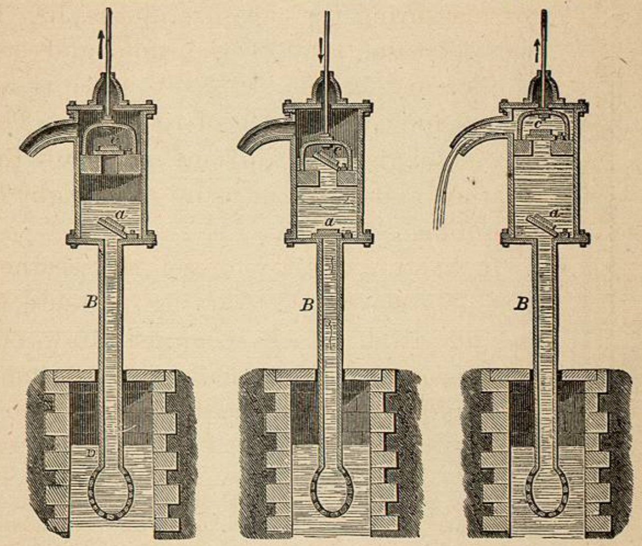
(7.) The Barometer is an instrument for measuring the pressure of the air. It consists essentially of the tube and cup of mercury in Fig. 103. A scale is attached for convenience of reference. The barometer is used (*a*) to indicate the weather, and (*b*) to measure the height of mountains.

It does not directly foretell the weather. It simply shows the varying pressure of the air, from which we must draw our conclusions. A continued rise of the mercury indicates fair weather, and a continued fall, foul weather.† Since the pressure diminishes above the level of the sea, the observer ascertains the fall of the mercury in the barometer, and the temperature by the thermometer; and then, by reference to tables, determines the height.

* The force with which the flying molecules of air beat against the walls of any confining vessel will increase with the diminution of the space through which they can pass. If we give them only half the distance to fly through, they will strike twice as often and exert twice the pressure.

† Mercury is used for filling the barometer because of its weight and low freezing-point. It is said that the first barometer was filled with water. The inventor, Otto von Guericke, erected a tall tube reaching from a cistern in the cellar up through the roof of his house. A wooden image was placed within the tube, floating upon the water. On fine days, this novel weather-prophet would rise above the roof-top and peep out upon the queer old gables of that ancient city, while in foul weather he would retire to the protection of the garret. The accuracy of these movements attracted the attention of the neighbors. Finally, becoming suspicious of Otto's piety, they accused him of being in league with the devil. So the offending philosopher relieved this wicked wooden man from longer dancing attendance upon the weather, and the staid old city was once more at peace.

Fig. 107. Fig. 108. Fig. 109.



The Lifting-pump.

5. Pumps.—(1.) The Lifting-pump contains two valves opening upward—one, *a*, at the top of the *suction-pipe*, *B*; the other, *c*, in the piston. Suppose the handle to be raised, the piston being at the bottom of the cylinder and both valves closed. Now