the effects produced by baths of different strengths and temperatures. The warmer, less strongly saline ones serve to soothe and relieve the weak, irritable heart, whereas those that are strong in mineral ingredients and charged with CO_2, and at the same time of low temperatures (86° to 83° F.), stimulate the organ to increased work. It is clear, therefore, that these last are permissible only after compensation has been re-established, or in cases that have never displayed very obvious weakness. It is not claimed that the balneological treatment of cardiac disease can be given only in Bad-Nauheim, but that here the advantages for this form of management are especially good. This is particularly true of the flowing effervescent bath, which, it is said, can nowhere else be given; and as it is powerfully stimulating, this kind of bath is highly beneficial in suitable cases.

Very briefly stated, the following is the method of ordering the treatment. At first, baths are prescribed which are weak in salts (about one per cent. of sodium chloride and one-tenth per cent. of calcium chloride) at a temperature of 95° to 92° F., and for a duration of from five to eight minutes. Carbonic acid is not added in the beginning of treatment, or at most in a very weak percentage of CO_2. As time proceeds and cardiac energy grows, the strength of the baths is increased until the salts mentioned approximate three per cent. of the sodium and one per cent. of the calcium chloride. Carbonic acid is added in the course of time, as determined by the judgment of the physician, and *pari passu* the temperature of the water is reduced and the length of each bath is increased, until at last the patient remains in the tub about twenty minutes.

In the fore part of the treatment the baths are interrupted by an occasional day of rest (one out of every three or four), but toward the end of the course such interruptions come at longer intervals. Patients are also required to lie down and rest after each treatment for an hour or so, in order that the effect of the bath may be retained and opportunity be given for a nap if inclination thereto be felt.

In addition to balneology patients are usually instructed to take exercise either in the form of massage, the so-called resistance exercises, or, as the heart becomes equal to it, by walking on the level or up the gentle inclines prepared for the carrying out of Oertel's terrainkur. The diet and intake of fluids are also supposed to be carefully regulated.

As has been stated in numerous medical journals, this balneological treatment can be very well given at home by means of artificial waters, and, as my experience has abundantly proved, with excellent results. It is not possible, however, successfully to imitate the current bath, and in addition it is difficult to get patients to make treatment the sole aim of existence as at Bad-Nauheim.

In concluding this brief sketch, which by reason of the limitation of space allotted is necessarily cursory and incomplete, I desire to express my sincere thanks to Dr. H. N. Heineman and to Dr. Groedel for valuable assistance rendered by them. I am also indebted to numerous papers by Dr. Schott and others. *Robert H. Babcock.*

NAVAL HYGIENE.—Introduction.—Naval hygiene may be briefly defined as being that branch of hygiene which applies the principles of sanitation to the conditions peculiar to life at sea, and especially as existing in ships of war. Although, in actual practice, appearing more or less modified to make them meet the peculiar conditions prevalent on board sea-going ships, the laws of general hygiene must remain essentially and fundamentally the same. Adaptation may at times necessitate and require a modification in the practice, but can never be allowed to go so far as to alter the principles of what is known as good hygiene, and so recognized by the best sanitarians the world over.

The importance of the study of hygiene to the naval surgeon cannot be exaggerated. Unless he possesses a profound theoretical as well as a practical knowledge of the essential and fundamental principles and purposes of hygiene, the naval surgeon of to-day can hardly be called "up-to-date," for without that knowledge he is barely able to perform but half his duties as sanitary officer on board a war-vessel. Since these duties must be confined, in form at least, to recommendations, made to his commanding officer, it is hardly to be expected that his recommendations will meet with the approval, required by regulations, unless the medical officer at the same time is able to prove to his captain that he possesses the necessary and requisite knowledge to entitle him and his recommendations to that attention and consideration which alone can make them effective.

To the naval architect the careful and conscientious study of hygiene is likewise of very great importance. At least one of the essential conditions implied in the construction of a warship is that it shall be so designed as to afford a given number of men a wholesome shelter during the performance of their duties; that the conditions on board be such as to preserve the life and health of the men, aiding them in, instead of interfering with, their most effective duties and excluding outside influences that are detrimental to these ends. The naval constructor owes it to himself, to the naval service, and to the people of his country that the best possible arrangements be made, that the best methods be adopted, and that the best work be done to advance the interests of hygienic living on board the ships which he designs and builds, as as far that may be within the range of his power. The ventilating system for a ship of modern construction, for instance, must be considered to be so essential that without it the ship would be of little value and its use limited.

Since the type and details of a ventilating system must be adapted to the type of the ship, it should from the beginning form a part in the design and structure of the ship and not be left to an afterthought. The constructor, realizing the difficulties, may commit them to an expert; but even then it is necessary that he have enough knowledge of the subject and of the results to be aimed at that he can readily and conscientiously accede to the demands of the expert, instead of regarding them as unreasonable; he should, moreover, possess enough knowledge on the subject to enable him to pass a just and proper estimate upon the value of the services of the employed expert himself. Thus, in giving out contracts, he is usually besieged by competitors. Competition leads to low bids and these lead to poor work and material. The result must be prejudicial to the interests of the naval service and to the constructor as well.

Scientific facts are stubborn things: they will not and cannot remain long ignored; mere opinions, whether official or unofficial, cannot sidetrack them, and thus the inevitable conclusion remains that we must bravely face these facts. In so far as the life of the sailor is influenced by the training which he must and can receive only on board a warship in commission and at sea, it is perfectly evident that that life is either increased or impaired in value to the service in direct proportion to the improvements in the hygiene of his immediate environments. These are intimately connected with the improvements in the construction of the ships on which he has his being.

Fortunately, there is abundant proof of the fact that within recent years, at least, a deeper recognition of the importance and of the profound significance of ships' hygiene on the part of all the officers of the naval service has become manifest. It has become clearly recognized that the strength, the power, the health, and the endurance of a ship of war, in action or out of it, whether on a mission of peace or one of war, can be but those of all its inmates combined, and, consequently, every man individually either adds or detracts from the sum total of the ship's power and endurance in direct proportion to the standard of his physical health. But the highest aims and objects of hygiene are not merely to preserve, but to raise the average standard of the health of our men to its maximum capacity. All training is more or less useless unless done on that basis.

Having once recognized these things, it becomes our next duty to examine into the conditions, to consider some of the facts, upon which the successful solution of so high a problem depends. The three mainstays of all living things that people this earth are air, water, and food. An efficient ventilation, a good water supply, and an abundance of good and wholesome food must ever remain the principal subjects of our study and claim our first care and consideration. But before entering upon a more detailed study of these, we are impelled at least to call attention to what seems a most necessary preliminary to the successful administration of all hygienic laws in every organized body of men such as constitutes the navy. By that we mean the instruction of the men under training in the laws of the hygiene of our daily lives.

It has been found repeatedly and constitutes an almost daily lesson of the sanitarian that one of the greatest and ever-present dangers from disease, on the part of the men in both the army and navy, is the ignorance of the most simple and elementary laws of health that must govern the every-day conduct of their lives. Examples of this might be cited *ad infinitum*, but we need go no further than merely call attention to the lessons that have been taught us, during our short war with Spain, by some of our volunteer regiments. Many of our bravest sons, because untrained and uninstructed in these things, died within a few weeks of going into their first encampment. Hence the warning finger, fortified and supported by an experience that should never again be allowed to lapse into forgottenness, points directly and unwaveringly to the necessity for instructing the men in the simple and elementary laws of health. This is clearly and distinctly the duty of the medical officers of the navy, the only officers in the service who, by the very nature of their training and education, should and can be held responsible for initiating reforms and improvements in this direction.

> "Nous sommes si zélés partisans de la ventilation que nous n'hésitons pas à la considérer comme le premier facteur de l'hygiène des navires, plus important à lui seul que tous les autres réunis."—
> Rochard et Bodet.

I. Ventilation.

To supply a ship's complement of men with a pure, good, and wholesome atmosphere at all times and under the most varying conditions of activity, rest, and climate, is a problem which as yet has not been completely solved. The different climates through which men-of-war have to pass within a short space of time, and the conditions which these impose upon our problem, would alone be sufficient to demand the greatest possible elasticity in the range of adaptability from any ventilating system that is known, while the large number of small watertight compartments into which the interior of a modern warship has been systematically reduced would make it seem almost next to impossible to keep the air inside all of these in a desirable state of purity and in constant and measured circulation. While, therefore, we agree with the distinguished French hygienists whom we have quoted above as regards the very great importance, to the hygiene of war-vessels, of an efficient ventilating system, we must also recognize and acknowledge that in no other department of naval hygiene do we find ourselves confronted with as great and perplexing difficulties as we do in the ventilation of warships of recent construction. We may accordingly be pardoned for devoting to this subject more time and space than to any of the others.

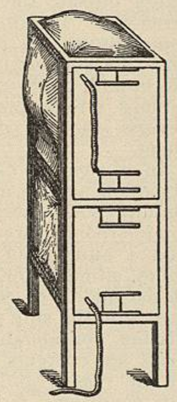

Fig. 3499.—Recknagel's Model Paper Box. (From Karl Schmidt.)

Ventilation means to produce currents in the air. Currents are produced (1) by rarefying a column of air at some place, through heat or suction, and (2) by condensing at some other place, through either cold or compression. An excellent illustration of the effects of heat and cold upon the creation of aërial currents is furnished, in nature, by our regular winds. Along the equator we have a belt of calms, several degrees in width, over which the air is rarefied and expanded, rendered specifically lighter under the influence of a vertical sun, and consequently a constant current ascends into the higher regions of the atmosphere; then this current flows north as well as south from the equator, passing over the cooler trade-winds which flow in beneath them from either hemisphere. The warm equatorial currents descend toward the surface of the earth in about the thirtieth degree of latitude. The same currents cross the winds coming from the poles and proceed converging toward them as surface winds, whence they again ascend and, now, proceeding in a direction toward the equator, they descend through the calms of Cancer and Capricorn, become surface winds, and form the trade-winds already alluded to, thus completing their figure-of-eight form of circulation.

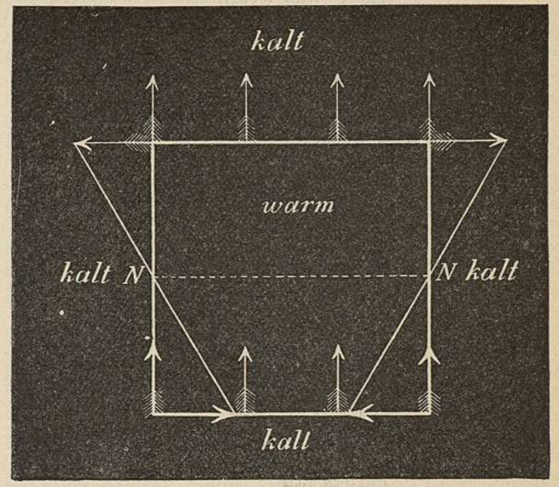

Fig. 3500.—Illustrating Distribution of Pressure in Heated Rooms. (From Rubner.)

A similar process, though on a much smaller scale, may be seen daily in the large chimneys of some of our great manufacturing establishments. Through the fires, the column of air contained inside of them is heated and rarefied. The rarefied column of air, consequently, rises very much as a stick of wood forced lengthwise under water will rise, and the specifically heavier air, outside the chimney, will press inward from below. The cause of this movement is the difference in temperature between the inside and outside columns of air, for if this difference disappears equilibrium is re-established and the movement ceases.

In houses and dwellings of all kinds, these same physical forces are constantly at work, tending to bring about a change of air within them. The porous nature of our building materials, the winds, and the differences in temperature between inside and outside air are the efficient causes of this natural ventilation. In an experiment by von Pettenkofer it was found that in a room of 75 cubic metres' capacity one complete change of air was produced in one hour through a difference in temperature between inside and outside, of 20° C.

In order to illustrate the working of the principles of this natural ventilation, Recknagel made a box of thin paper (see Fig. 3499) perfectly cubical in shape, leaving the bottom side uncovered. Through this uncovered lower side he heated the air by means of an alcohol lamp, thus imitating the conditions under which natural ventilation occurs in any heated space in which doors and windows are closed. It was shown by manometrical measurements that in the upper portion of such a box there was overpressure, while in the lower portion of it there was underpressure. In the upper portion the walls were pressed outward, in the lower portion they were pressed inward. About the middle part the pressure was = 0, and the line of this zero pressure was called the neutral zone. (See Fig. 5300, line *N N*).

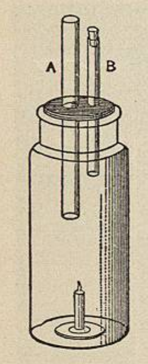

FIG. 3501.—Illustrates the Principle of Natural Ventilation of Ships. (From Munson.)

It will easily be perceived that wherever ventilation is effected by suction or exhaustion there must be underpressure, produced throughout the entire enclosure. The neutral zone will rise up to the ceiling or near the place where the exhaustion is done. The region of underpressure will rise until it prevails throughout the entire space. Under such conditions air tends to press into the enclosure from below, through cracks in the sides, or wherever underpressure extends. In case the adjoining rooms are kitchens, closets, stuffy cellars, galleys, pantries, engine- and firerooms, bilge or store-rooms, as would be the case on board ship, all the effluvia from these would be bound to pass into any of the living spaces that are ventilated after that fashion.

These facts would hold good everywhere, although a ship is vastly different in its material construction from any building on shore. A ship's bottom and sides, unlike those of a house or building, must practically be made both water- and air-tight; hence, whatever fresh air gets into a vessel must come from the top side and thence find its way, as best it can, to the various parts below. It represents a Recknagel's box with its inside air heated, but with its partly open side on top, instead of at the bottom. Whatever natural ventilation occurs in a ship can best be illustrated by the classical experiment with the unstoppered bottle. If we lower a lighted wax taper attached to the end of a wire down to the bottom of a wide-mouthed bottle, the little flame will burn brightly for a short time, then grow gradually dimmer and dimmer and finally die out altogether. If we now change the conditions of our first experiment by inserting a piece of cardboard into the neck of the bottle so as to divide the cylindrical opening into two nearly equal parts vertically, and now again introduce our lighted taper to the bottom, it will burn brightly to the end. The heated air charged with carbon dioxide will ascend through the neck on one side of the cardboard, while a current of air, pure and cold, will descend on the other side of it and support the life of the flame. As long as the hot air alone came through the neck, fresh air was prevented from entering, and whatever little did find its way into the bottle was returned before it reached the candle at the bottom.

The same principle is also well illustrated by Fig. 3501. Here the fresh air enters through the long tube *A*, and the foul air passes out through the short tube *B*.

A single central tube, being equivalent to a septum, will answer the same purpose. In this arrangement the warm-air current passes up through the central tube, while the fresh, cool current will descend outside of the tubular septum. In case, however, this central tube should be provided on top with a hood which is turned to the wind, then the cold air will pass down it and the warm air ascend around and outside it. As long as nature has her choice, the column of hot air will be found to occupy the centre and the cold-air currents will arrive from the periphery. These simple principles explain the method of ventilating ships by means of wind-sails, of no matter what construction they may be, through hatches. The essential difference in the methods of ventilating houses and ships is that, in the former, fresh air can be admitted, in fact presses in from below, with the greatest ease, while in the latter it must first be drawn from above downward, which is a matter of some difficulty, therefore also requiring special means for its accomplishment. *It should never be drawn down at a place where it meets with an ascending current of warm air.* Fresh air having arrived at the lowest compartment of the ship, its distribution to other parts of the vessel can, of course, only be effected on the same principles and by the same means that are employed in the ventilation of houses on land.

After the air has left the ventilating pipes and entered the smaller compartments and living spaces, its further distribution follows the laws of temperature and pressure differences, either existing naturally or being produced artificially. Whenever a ship happens to run against the wind, its inside temperature will be found considerably higher in the after-part of the vessel than in the forward part; with the wind on her side, the leeward side will show a higher temperature than the windward side. These differences are of course greater in the interior of the ship than on the upper deck.

These simple principles of natural ventilation would not have been dwelled on at such length, were it not that daily experience has abundantly shown that an undue lack of appreciation of them in putting them into practice is almost equivalent to entire ignorance of them, and hence their having been emphasized. The problem of ventilating ships on the best principles deserves our most serious study and devotion.

Natural-Air Currents in Steamships.—The student of ships' ventilation will do well to begin with familiarizing himself with the movements of natural-air currents within ships of different types, both under varying and under average conditions. In doing this, he will at first meet with many rather startling surprises. The currents move in quite unexpected directions and seem difficult to explain. Thus, in sailing vessels, a number of canvas wind-sails are in use (see Fig. 3502); these wind-sails are usually suspended from some point high above the upper deck and have their heads turned to the wind. The air is led down into the deepest portions of the ship by the wind-sail which passes straight down through the different hatches which are usually superimposed. Under these conditions, the foul air rises outside of the wind-sail to escape into the open. When, however, either by accident or design, the open heads of the wind-sails are turned away from the wind, these currents will be found to be exactly reversed, the wind-sail becoming an uptake for the foul air and the remaining space in the hatch, outside the wind-sail, becoming a down-take for fresh air. In sailing vessels the temperature and pressure differences are, comparatively speaking, slight and, consequently, a rather trifling circumstance suffices to reverse the air currents within them.

In a steamer of modern construction, such as a cruiser or battleship, with enormous fire- and engine-rooms, large steam pipes and a number of auxiliary engines, situated for the most part in the middle or central compartments of the ship's body and radiating considerable amounts of heat, air currents from all parts of the vessel would, under average conditions, move in their direction, that is, from the colder lower and peripheral parts toward the warmer higher and central compartments. Local heat-producing centres and open hatches will, however, here also produce interference currents which are sometimes difficult to explain, although perfectly natural when traced to their cause. The natural currents in steam vessels are not so easily diverted as those in sailing vessels, for reasons that must now seem obvious.

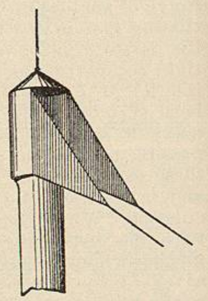

FIG. 3502.—Shows a Canvass Wind-sail of the Ordinary Pattern.

From the consideration and study of these normal air currents in ships, we derive one very important lesson with regard to the subject of the artificial ventilation of vessels in general, namely: that any air currents established by artificial means and intended for purposes of ventilation must be so directed as to have *concerting* rather than *conflicting* action with the normal ship's currents. It must be clear that the most effectual as well as the most economical plans for ventilating ships by artificial means, after natural ventilation has been found insufficient, consist in providing means intended to aid and increase the ventilating capacity of the natural currents.

A supply of fresh air, directed in separate air shafts to the lower and most peripheral compartments of a steamship, would be the first step to be taken and quite in harmony with the general principles of ships' ventilation. Hollow masts, hatches, engine- and fireroom gratings and chimney casings, owing to the high temperature existing about these places and the consequent tendency of a strong upward current, would send the foul air out of the ship without the aid of any other power directed to effect this end. By such a system alone will it be possible to realize the nearest practicable approach to that continuous mass movement of air so desirable in artificial ventilation. The air, fresh and cool, sent into the extreme peripheral parts of a ship and starting from these parts on its way through the ship, in a direction converging toward the various natural outlets, would do the most efficient ventilating work attainable and without being turned back. Its flow can be so graded that there will not be the slightest danger from too great a draught.

Economy in Ventilation.—The best principles of economy in ventilation are met, when the arrangements are such that the air-contaminating substances are gotten rid of without becoming mixed with the incoming fresh air. The nearest possible approach to such economical mass movement, in a continuous flow, which can be realized in the ventilation of a ship, is in the vertical movement of air, when, for instance, fresh air is admitted below and foul air passes up through hatches or other natural vents. This condition clearly demands that the supply of fresh air be directed into the lowest and most peripheral compartments of a ship through channels other than those operating as the natural outlets for foul air. To cause downward currents of fresh air through these natural outlets of foul air, by creating various degrees of underpressure in the lower compartments of a ship, through exhausting the air there, must, in view of these facts, be considered contrary to every good principle involved in ships' ventilation so far considered.

Different Methods of Ventilation.—In the words of Woodbridge ("Lecture Notes") "ventilation is by the vacuum or the plenum method according as the greater motive power is in the discharge or in the supply part of the system. That power may be solely in either one or the other of the two parts, or it may be shared between them. Its predominance in the one or the other determines the vacuum or the plenum character of the ventilation."

Vacuum Method.—This method causes a movement of air into an enclosure by creating a partial vacuum within it. Into such an enclosure the air then flows through every available channel both provided and accidental. From whatever points, therefore, the pressure may be greater than in the enclosure, ventilated by the vacuum method, from thence it will move toward that enclosure. Each such space, therefore, is more or less at the mercy of its surroundings and of conditions beyond the control of its occupants. The vacuum method of ventilation on board ship puts the breather at the point of discharge of foul air and sends into the living spaces specimens of air from every part, near or remote, whether filled with good or foul air.

Plenum Method.—This method puts each compartment under a slight pressure and thus prevents leakage of air from adjoining compartments. It tends to accelerate the flow of air through natural outlets and gives the occupants control over the source and velocity of their air supply. This method puts the breather at the point of supply and consequently in position to breathe the best of air. It is recommended as the best by Rubner, Kirchner, Karl Schmidt, Notter, Harrington, and Munson. As it applies to ships, it is more nearly a method of removal than the other, and this constitutes the highest degree of efficiency for any ventilating system. We have seen that it answers to the best principles of economy. The method is the one best adapted to warm climates in which men-of-war spend at least ninety per cent. of their time. It will supply a steady current of fresh air to all the compartments in the ship alike, and, by tending to produce even conditions of temperature and pressure, it will prevent currents and counter-currents between the different enclosures in spite of free communication existing between them.

The usual objections made to the plenum system of ventilation are that it gives rise to sensible draughts and causes dangerous colds. This is very true for houses in a cold northern climate with a temperature difference between inside and outside air of from 60° to 70° F. and in which the air coming into the rooms is not sufficiently warmed.. These dangerous draughts of northern climates can, however, not be taken into account when designing a ventilating system for a ship of which it is known beforehand that it will spend ninety per cent. of its time in the tropics. We heat the air by artificial means in our northern climates before admitting it into the living rooms, in order to enable us to take in a larger supply of it without becoming sensible of it. But, in the tropics, as must be evident, we need not resort to such artificial means of heating the incoming air in order to diminish existing temperature differences, and, consequently, the dangers due to sensible draughts. Ventilation here must, on the contrary, be designed for the double purpose of having a cooling as well as a ventilating effect. Besides, a dry atmosphere of low temperature is here borne with greater ease and comfort than a moist atmosphere with a high temperature, on account of physical heat regulation being more prominently active in the warmer climates than in the colder climates. It is the common experience of hygienists and sanitarians that air currents of a temperature and velocity pronounced dangerous in northern climates must be considered well within the range of perfect safety in ships cruising in the tropics. An efficient supply of air to the lower decks of a ship in the tropics rarely, if ever, gives rise to a dangerous draught or even a noteworthy feeling of discomfort. The colds are generally caught on deck while the men are asleep in an exposed part of the ship. Many people fear draughts, and attribute to this cause not only all the colds they catch but also all their other ills into the bargain. Some are so acutely sensitive, especially within doors, that they feel air currents that are beyond being measured by the most delicate instruments of precision. The same people will sit out of doors, where the air moves at the rate of 10 metres a second, without either complaint or harm.

Of one thing I am daily growing more assured, namely: that the limits to the velocity of air currents, given in works on ventilation, for houses and buildings, do not apply to ships. To live on board ship is more like living out of doors than living within a room.

Air currents that would be both disagreeable and dangerous in rooms of houses on land are still borne with comfort and without danger on board ship; hence, also, a much larger supply of fresh outside air can be provided for in the case of ships than in that of houses and buildings on land without overstepping the safety limits.

Dilution or Removal in Ventilation.—The ideal aim of any ventilating system, in theory at least, must be the getting rid of the foul air in an enclosure and the replacing it with fresh air, without the two becoming mixed. In practice, however, and as Rubner has long since pointed out, we are obliged to take the air for inspiration from the same reservoir into which we send our expiratory air. It would, therefore, seem impossible for any ventilating system to separate the one from the other, and all ventilation must, accordingly, proceed after the manner of a process of dilution and be so arranged as to keep the enclosed air from reaching a composition very much different from the outside air.

According as to whether we remove the foul air and replace it with fresh air without the two becoming mixed, or whether we maintain in the air of an enclosure a composition not dangerously far from that found outside by the constant and continuous introduction of fresh air, we may be said to ventilate either by the method of *removal* or by that of *dilution*. The removal method reaches its maximum applicability and efficiency in such cases as the fireplace, the chemical hood, the kitchen range bonnet, and the blacksmith's forge. The nearest practicable approach to this method on shipboard is effected by the escape of foul air through an open hatch. Whenever and wherever air is warmed in transit, as it is in steamships in passing from the cooler peripheral compartments toward the warmer central ones, economical and effectual escape of foul air occurs by an upward movement through a hatch. The foul air, under such circumstances, makes a direct escape into the open and does not return to mix with the incoming fresh air, providing, of course, the proper outlets are free and unobstructed and it meets or passes no compartment on its way in which underpressure exists. In such ventilation, economy, efficiency, and excellence reach their maximum. What the chemical hood is to the laboratory, what the range bonnet is to the kitchen, that the vertical foul-air shaft or hatch is to the ventilation of a ship. Providing the proper number of fresh-air inlets has been provided and distributed in such a manner as to allow the incoming air to do the most effectual ventilating work, such would be the natural air currents on board every ship of the type represented in the above description.

Would any one with the full knowledge and appreciation of these principles of natural ships' ventilation choose a ventilating system at variance with them? Let us confess that it would be difficult for any one to believe that such a one exists. Ventilation by natural means having been found insufficient, let us without hesitation, and basing our arguments upon the above grounds, put the fresh air directly where it is most needed, place our power on the supply side of our system and thus give it the plenum character; let us aid rather than antagonize natural currents, and we shall have the satisfaction of coming nearer to a perfect method of ventilating a ship than by any other known means.

Perflation signifies a blowing through. When the wind moves across the deck of a ship that has its ports open on both sides, as is sometimes the case on the decks that are above the water line in fine smooth seas with light winds, such decks may be said to be ventilated by perflation. No method of either natural or artificial ventilation is comparable to this in the volume of air moved and in the ventilating effect produced. It should, therefore, be taken advantage of and used at every favorable opportunity that offers itself for the purpose of directly aërating parts of ships not generally accessible to such direct ventilation.

Relation between Size of Hatches and Tonnage of Ships.—Notwithstanding the great importance of the hatches in their relation to the ventilation of the interior of ships, there seem to exist no fixed rules for a definite relation between the square area of them and the tonnage of vessels which the constructor is bound to follow. Thus, Rochard and Bodet mention several very striking instances, illustrating this very important point, as existing in the French navy: *L'Océan* of the French navy has hatches of a total square area of 64^{m^2}, 40 and a displacement of 8,000 tons. The *Forbin* has only one-fourth of the displacement of the *Océan*, while her hatches have but one-tenth of the square area of that vessel. The *Hoche* displaces nearly one-third more than the *Océan* but her spardeck hatches have a square area of only one-half that of the *Océan*. A number of similar instances could be cited concerning ships in the American navy and showing the same lack of proper relation between the square area of the hatches and the tonnage, but the above examples suffice.

Nor are the number, size, and location of these hatches and their relation to each other on the different decks of the same vessel matters of minor importance to the interests of the ventilation of the vessel. Thus, superimposed hatches favor the natural ventilation of the lower compartments, while alternating hatches favor the circulation of air through the 'tween-deck compartments. The location of a hatch often determines its function as an up-take for foul air or a down-take of fresh air. Turrets, railings, and other obstacles in the way toward hatches and ventilators divert a large quantity of air, preventing it from going into the ship. Moreover, with the wind ahead, the forward compartments are the best ventilated, the hatches in this part becoming inlets, while the after-ones become outlets. The velocity of a head wind is increased by the speed of the vessel, so far as its ventilating effect is concerned. The opposite is true for a wind going in the same direction as the vessel. With the wind on either side, the best ventilating work is done by perflation.

Wooden gratings with which hatchways and air-shafts are covered reduce the area for ventilating purposes three-fourths of their capacity. Perforated iron gratings are recommended and come into use more and more, because they have been found superior to wooden ones. Thus, simple hexagonal openings in iron plates in which the arms, separating the openings, are just one-half the width of the openings themselves, decrease the ventilating capacity by only one-half instead of three-fourths.

Ventilation is not equally important to all compartments, and from this point of view they have been divided into four classes:

1. There are the cells of the double bottoms. These are rarely opened, and whenever opened for inspection they are never entered without the air enclosed within them being changed by means of portable ventilators. Their influence upon the hygiene of the vessel is practically nil.

2. There are the various storerooms for cordage and sails, provisions and clothing, water, ammunition, engineer's stores and others. In these it is only necessary that the air should not absolutely stagnate.

3. The 'tween-deck compartments that are inhabited by the crew are, of course, of the greatest importance and ventilation here must be ample, safe, and constant.

4. The various workshops, engine- and firerooms in which men stand watch or are kept at work for stated periods night and day. The rooms in which are located the steering, pumping, hydraulic, circulating, and condensing engines, and which in protected cruisers and battleships are found below the protective deck, need a sure and steady air supply. Ventilation of these places has the double purpose of cooling the air as well as renewing the oxygen. Inlets in these compartments should be distributed all around, in order to avoid the dangerous effects that would be produced by a single strong current.

Sources of Contamination of the Ship's Air.—The composition of the air on board ships of war is influenced: (1) By human life and activity; (2) by various nuisances of an industrial origin; (3) by the bilge water.

1. Human life and activity change both the physical and the chemical composition of an atmosphere in several ways, namely: (*a*) they take from it oxygen and replace the same with carbon dioxide; (*b*) they increase its humidity; (*c*) they add to its temperature.

From the physical side, the processes of life have been likened to the phenomena commonly observed about a steam-engine. Neither animal life nor steam-engines can be kept going without food or fuel; both do a definite amount of work, the energy for which is derived from the oxidation or combustion of substances put inside of them, and both produce certain effete end-products that are similar, namely: carbon dioxide, water, heat, and the various products of excretion (ashes).

An efficient ventilation to an overcrowded ship is as necessary and has the same significance as forced draught for a furnace overloaded with coal. A deficient ventilation is attended by the elimination of a series of products that are not normally present in either expired air or perspiration; to this class of compounds belongs the anthropotoxin of Brown-Séquard. These poisonous substances, produced under the influence of a deficient ventilation, may well be compared to the products of an incomplete combustion produced in a furnace and consisting of both invisible poisonous gases and visible smoke. Since a state of overcrowding must be looked upon as the normal condition of life on a warship and as a necessary accompaniment of all activity there, an efficient ventilation on board a ship becomes a much more serious problem than on shore.

If we assume with Rochard and Bodet that, under normal conditions, a man with his respiration vitiates 1 cubic metre, or about 36 cubic feet, of air in one minute, he vitiates in one hour 60 cubic metres, in twelve hours 7,200 cubic metres. A group of 500 men, the usual number on board a battleship, would then vitiate in twelve hours 360,000 cubic metres, or about 12,960,000 cubic feet. Such a group of men living in a space of 2,500 cubic metres capacity would vitiate their available air quantum 150 times, and, to keep it pure and within respirable limits, it would need to be renewed 12.5 times per hour. How overcrowding increases, apparently in geometrical progression, the carbon dioxide, organic matter, and the number of germs in an atmosphere is shown by Carnelley, Haldane, and Anderson (Kirchner) in the following table:

TABLE I.

Living in—	Carbon dioxide. Per minute.	Organic matter. Per minute.	Number of germs. Per litre.
One room..........	1.12	0.0157	60
Two rooms........	.99	.0101	46
Three rooms.......	.77	.0045	9

No wonder that the mortality tables show a corresponding increase. People living in one room show a mortality of 23.3; those living in two rooms a mortality of 18.8, and those living in three rooms 17.2, while those who live in four or more rooms have a mortality of only 12.3 per cent, out of a general mortality of 20.7 per cent. These conditions are directly applicable to life on board ship.

But human life and activity add also heat and moisture to the atmosphere. An adult man produces in his body in twenty-four hours 2,300 large calories, an amount of heat sufficient to increase the temperature of 23 litres of water from 0° to 100° C. Through the skin, by evaporation, he loses from 600 to 2,400 c.c. of water in twenty-four hours, the exact amount depending upon the temperature, relative humidity, and the amount of movement of the atmosphere surrounding him. This would correspond to a heat loss of from 343,320 to 1,373,280 calories. The total heat loss is distributed as follows:

TABLE II.

	von Helmholtz. Per cent.	Vierordt. Per cent.
Through skin........................	77.5	86.9
Through lungs......................	19.9	11.1
Through bowels and kidneys........	2.9	2.0

2. Industrial nuisances. The modern battleship may be said to combine within its sides all the varied industries of a manufacturing town pressed into the smallest possible space with all its accompanying nuisances in a concentrated form; the principal ones among them being those which come from the engine- and firerooms, in the form of gases, heat, and moisture. The products of incomplete combustion of coal may find their way into living spaces through processes of diffusion or the wrong kind of ventilation such as the vacuum method. Heat may accumulate owing to faulty construction or imperfect covering of heat-radiating surfaces in certain living spaces, close to engines and steam pipes. Steam escapes more or less constantly from imperfect or worn-out joints. The mean loss of water from escape of steam through pipes alone in a modern protected cruiser has been estimated to be about four tons daily. Plumert mentions a case of poisoning with carbon monoxide which occurred in one of the compartments of a torpedo boat, and which shows how dangerous gases may be diverted and get into living spaces. A hole was bored through one of the bulkheads separating the smoke-room from the living spaces, for the purpose of laying electric wires, and through this small opening, the carbon monoxide had made its way from the smoke-room to the men. In an empty ammunition room which had remained closed up for some time on board the *Sachsen*, Gärtner found up to 51 parts per 1,000 of carbon dioxide. The men who entered this compartment became suddenly asphyxiated.

3. The bilge is a constant source of air contamination. This fluid accumulates perpetually near the keel, along the bottom of the very lowest compartment of a ship and corresponds to the ground water, surface water, or sewage of our buildings on land. It is sea water mixed with the off-fall from all sorts of cargo, provisions, wash water, coal, ashes, grease from machinery, dead rats, the organic matter from everything living in the sea, in short a portion of everything that finds its way sooner or later into ships, will gravitate finally into the bilge.

In iron ships the sea water comes in through the shaft alley alone, while in wooden ships it may at times press in through every seam below the water line. The bilge is therefore less abundant in the former than in the latter. Dr. Nocht found from 3,000 to 15,000,000 germs in 1 c.c. of bilge water. Fermentation is very naturally the normal condition, and the gases constantly produced pass either into the ship's atmosphere or accumulate within spaces not ordinarily included in the general atmospheric circulation. The farther away we pass from the keel of a ship, the higher we ascend the ship's ladder, the purer, the drier, and the cooler becomes its atmosphere.

Besides the above-described sources of contamination there are others which are, however, not remedied, as are these, by an efficient ventilation, and hence they were not included in the above enumeration. These are dirty personal habits and dirty clothes as well as a dirty ship. Nothing short of water, soap, the brush, and strenuous work will reach these.

Influence of Vitiated Air on Human Life.—There is, besides sudden death due to asphyxia from the inhalation of air overcharged with carbon dioxide, a process of *slow* dying, due to living in badly ventilated rooms, which is not so clearly and so generally recognized nor so directly and clearly traceable to its cause. Non-medical observers and the victims themselves do not realize the causal connection between bad ventilation and this condition; hence also the lack of complaints with regard to poor ventilation from that source. The usual and immediate effects of breathing foul air are pallor of the skin, disturbances of digestion, impairment of assimilation, loss of muscular and mental vigor, and a tendency to physical break-down and disease. The difference in the complexion between the deck-hands and the fire- and engine-room men on board a man-of-war may well be seen at a muster, when the two classes of men are drawn up in line on opposite sides of the deck of the ship. On one side you may see the ruddy and rosy faces of the deck-hands, on the other the pale, sallow features and sunken eyes of the men who work below.

Anthropotoxins in Air.—Determinations of carbon dioxide often fail to give information in all respects satisfactory as regards the degree of atmospheric contamination, and an air must often be pronounced unfit for respiration, especially on board ship, before either lack of oxygen or the undue accumulation of carbon dioxide, and even watery vapor can be accused of being the causes thereof.

What exactly these poisonous substances are and whence they originate, what their nature and chemical composition may be, we do not as yet know with certainty. In their effects they are like poisons. Since they are known especially to accumulate in places overcrowded by human beings, an exact knowledge of their origin and composition would be of great interest to naval hygiene.

Brown-Séquard and d'Arsonval once believed that they had discovered in stagnant expired air a toxic alkaloid which, consequently, they named *anthropotoxin*, and which, indeed, when injected under the skin of mice, killed them within a few hours. Rauer repeated but did not confirm the experiments of Brown-Séquard. The problem has recently been taken up again by Formanek (*Archiv f. Hygiene*, Bd. xxxviii., Heft 1), who makes it appear likely that the problematic substance is an ammonia compound, not so much the result of the decomposition of expired air as it is of the decomposition of urine, fæces, and of the buccal contents of the animals experimented on. He concludes that the distress, the nausea, and the fainting fits which occur in overcrowded enclosures under poor ventilation cannot be attributed to a single and always uniform factor. It seems, therefore, that Formanek likewise has failed to confirm the results of Brown-Séquard and d'Arsonval. According to the experiments of Lübbert and Peters on guinea-pigs, the poison, if it exists at all, is not an organic, that is, not a carbon-containing or combustible substance. Wolfhügel insists that it is not contained in normal but always only in stagnant and decomposed expired air. The presence of a well-defined, well-characterized chemical poison in bad air would form one of the most convenient means of determining the degree of its contamination. Such a substance is as yet unknown. Nor is it definitely known whether these substances do their harm through being inhaled or whether their presence in the atmosphere simply inhibits the further elimination of them from our bodies, and thus gives rise to poisoning by the retention of an excretory product. Certain it is, according to Rubner, Seegen, and Nowak, that when animals are kept in closed spaces, in which care is taken to remove the expired carbon dioxide and to re-supply the used-up oxygen, the animals nevertheless succumb after a time.

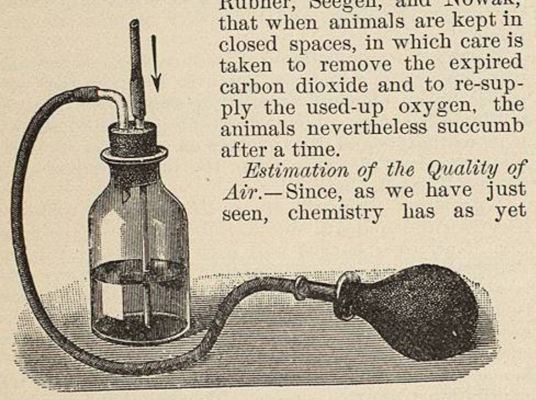

FIG. 3503.—Represents the Lunge-Zeckendorf Carbon-Dioxide Apparatus. (From Kirchner.)

Estimation of the Quality of Air.—Since, as we have just seen, chemistry has as yet failed to find a convenient chemical compound in the air by the determination of which we might standardize a normal atmosphere, we must resort to less direct methods. Experience seems to hold the chemical determination of the amount of carbon dioxide as the most reliable method for estimating the quality of a specimen of air. The method for the determination of the amount of organic matter in air with potassium permanganate has been found very inaccurate by Archarow and Emmerich, and the method proposed by Rietschel, of using the temperature as an indicator of the degree of contamination of the air, could hardly find application on board ships which produce heat in such enormous amounts as do the modern battleships and protected cruisers.

Determination of Carbon Dioxide in Air.—It is known that barium oxyhydrate combines with CO_2 according to the formula, $Ba(OH)_2 + CO_2 = BaCO_3 + H_2O$. Pettenkofer proceeds as follows: A bottle containing 5 litres of the air to be examined receives 50 c.c. of baryta water. After thorough shaking and allowing to stand for a few minutes, all the CO_2 that was in the air of the bottle is now supposed to have combined with the barium oxyhydrate. The uncombined barium is now converted into an oxalate according to the formula: $C_2O_4H_2 + Ba(OH)_2 = C_2O_4Ba + 2H_2O$. From this the amount of CO_2 in the specimen of air may easily be computed. Although accuracy is decidedly in favor of Pettenkofer's method with baryta water, other considerations will sometimes cause us to sacrifice accuracy and to decide in favor of another method on account of its convenience. Several methods of this kind have been published recently. Thus, "A Rapid Method of Determining Carbonic Acid in Air" has appeared in a recent number of the *Journal of Hygiene* (University Press, Cambridge, England) by John Haldane. The apparatus, neatly fixed in a wooden portable box, represents a simple form of Haldane's gas analysis apparatus; it is so arranged that the CO_2 is absorbed by a potash solution. The final reading indicates the parts of CO_2 contained in 10,000 parts of air. The whole observation can be made in five minutes. Lunge (see Fig. 3503) ("Zur Frage der Ventilation," Zurich, 1877) uses a bottle of 50 c.c. capacity, closed by a double perforated cork and containing 7 c.c. of a 6 to 1,000 baryta solution. Through one of the holes in the cork a long glass tube reaching to the bottom of the bottle is introduced; the outer end of this tube is closed with a piece of rubber tubing and a clamp. The second hole in the cork is provided with a short tube, the outer end of which is connected with a bulb. This rubber bulb has a slit which serves the purpose of a valve, permitting the air in the bulb to be pressed out without going into the bottle, but not to re-enter the bulb, except with the air that passes through the baryta water in the bottle by way of the long tube. To this end the clamp, of course, is taken off. The bulb having a capacity of 25 c.c. the air quantum, sent through the baryta water, can be easily estimated. When the test is made, the air is drawn through the bottle until a lead-pencil mark on the side of the bottle, opposite the eye of the observer, becomes invisible through its contents. The table below gives the values. To the number of fillings must be added two volumes representing the capacity of the bottle.

TABLE III.

Number of fillings.	Volumes per 10,000.	Number of fillings.	Volumes per 10,000.
4	22.0	8	11.0
5	17.6	9	9.8
6	14.8	10	8.8
7	12.6	11	8.0

This method has more recently been greatly improved by Lunge and Zeckendorf (*Zeitschrift f. angewandte Chemie*, 1888, Heft 14, and 1889, Heft 1). Instead of baryta water, a decinormal solution of soda is used. To 1 litre of the solution there is added 0.1 gm. of phenolphthalein which colors the solution dark blue. Two cubic centimetres of this solution are mixed with 100 c.c. of air-free distilled water. The empty bottle is now filled with the air to be examined and 10 c.c. of the dilute solution are added. The bulb is now worked once and the bottle shaken for a minute. This process is repeated until the color of the fluid has changed from blue to yellow.

The values may be seen in the next table:

TABLE IV.

Number of fillings.	Volumes per 1,000.	Number of fillings.	Volumes per 1,000.
48	0.3	8	1.2
35	.4	7	1.4
27	.5	6	1.5
21	.6	5	1.8
17	.7	4	2.1
10	.9	3	2.5
9	1.0	2	3.0

More recently still a neat and handy method similar to the preceding, and based on practically the same principles, has been devised by Dr. G. W. Fitz. This method is carried out by shaking a small quantity of dilute lime water, colored pink with phenolphthalein, with successive portions of air until the solution is decolorized. The method has of late been made still more practicable by Woodman and Richards (*Technology Quarterly*, vol. xiv., No. 2, June, 1901). Since I have used this method quite a little and have found it to answer every purpose on board ship, being easy of application, also sufficiently accurate, a detailed description, given by Woodman and Richards, will here follow:

Description of Method of Using the Shaker for Determining the Amount of Carbon Dioxide in the Air.—"The method of preparation of the solutions and the manner of making the tests which have been found to give the best results will be described in detail, since experience has shown that these directions cannot be too minute.

"*Preparation of the Test Solution.*—The solution used is a dilute solution of lime water colored with phenolphthalein. To freshly slaked lime add twenty times its weight of water in a bottle of such size that it is not more than two-thirds full. Shake the mixture continuously for twenty minutes, and then allow it to settle over night or until perfectly clear. The resulting solution is the stock lime solution, or 'saturated lime water.' If made in the manner indicated, each cubic centimetre of it ought to be very nearly equivalent to 1 mgm. of carbon dioxide. If, however, it is desired to know the strength of it more exactly, it may be determined by standard acid.

"To prepare the 'test solution,' pour into the 1-litre bottle of the testing apparatus one measured litre of distilled water, and add 5 c.c. of solution of phenolphthalein (made by dissolving 0.7 gm. of phenolphthalein in 50 c.c. of alcohol and adding an equal volume of water). Stand the bottle on a sheet of white paper and add the 'saturated lime water,' drop by drop from a pipette, shaking the bottle thoroughly after each addition, until a faint pink color is produced which is permanent for one minute. Now add 12.6 c.c. of the 'saturated lime water,' shake, and immediately connect the bottle again to the apparatus.

TABLE A.

Standard test solution. CO_2 in 10,000.	Cubic centimetres of air.	"Half solution." CO_2 in 10,000.	Standard test solution. CO_2 in 10,000.	Cubic centimetres of air.	"Half solution." CO_2 in 10,000.
22.2	50	15.6	5.9	270	4.1
18.0	70	12.4	5.6	290	3.95
15.1	90	10.2	5.4	310	3.8
13.0	110	8.7	5.1	330	3.7
11.3	130	7.5	4.8	350	3.6
9.9	150	6.6	4.7	370	....
8.8	170	5.8	4.5	390	....
8.0	190	5.2	4.4	410	....
7.3	210	4.8	4.2	450	....
6.8	230	4.5	4.0	490	....
6.3	250	4.3	3.9	530	....

"To shorten the time required in testing air which is low in carbon dioxide, it may be found advantageous to use a solution only half as strong as the above. This 'half solution' is prepared in precisely the same way, using 2.5 c.c. of the phenolphthalein solution and 6.3 c.c. of the 'saturated lime water.'

"While this procedure does not give an exact volume of solution, it is believed to be the best for the preparation of this dilute test solution, since it obviates the necessity for pouring the prepared solution from the measuring flask into the bottle in which it is kept; 12.6 c.c. of the stock lime solution is added rather than 10 c.c., in order to keep the values obtained with the resulting solution more nearly comparable with the older values calculated on the supposition that 10 c.c. of 'saturated lime water' was equivalent to 12.6 mgm. of carbon dioxide.

"*Method of Making the Test.*—See that the inner tube of the shaker slides readily in the outer one, moistening the rubber collar slightly if necessary. Have the inner tube pressed down to the bottom of the larger one, and measure into the apparatus 10 c.c. of the test solution from the automatic pipette. Pull the inner tube up to the 5 c.c. mark (the bottom of the inner tube serving as the index) and close the end of the tube with the finger. Hold the apparatus horizontally, and shake it vigorously for exactly thirty seconds.

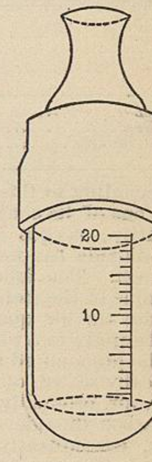

FIG. 3504.—The Fitz Shaker, Full Size. (From Woodman and Richards.)

"The amount of air which is thus brought in contact with the solution is equivalent to 30 c.c., as there are 25 c.c. of air above the liquid when the small tube is forced to the bottom of the larger. Remove the finger, press down the small tube again to the bottom of the larger and draw it up to the 20 c.c. mark. Shake the apparatus again for thirty seconds. The amount of air brought in contact with the solution is now $30 + 20 = 50$ c.c. Repeat the shaking, using 20 c.c. of fresh air each time until the pink color is discharged. The amount of carbon dioxide corresponding to the number of cubic centimetres of air used will be found in Table A.

"*Notes and Precautions.*—Care should be taken that the finger used to close the end of the tube is perfectly clean, since on a warm day the free acid in the perspiration might easily vitiate the results.

"If greater accuracy is desired, the shaker should be filled with the air to be tested before running in the test solution. This may be done readily by filling the shaker with water and emptying it or by forcing air into the tube by means of a small rubber bulb.

"The apparatus should be shaken vigorously and continuously during the thirty seconds in order to absorb practically all of the carbon dioxide in 20 c.c. of air. The number of shakings ought not to be less than one hundred during this time.

"Care should be taken not to contaminate the air while the sample is being taken. The breath should be held momentarily while the air in the apparatus is being replaced, and the sample should be collected as far to one side of the body as possible. It ought not to require over ten seconds to replace the air, and the entire test, with air containing, say, 8 parts of carbon dioxide per 10,000, should not require over six minutes.

"If less than 90 c.c. of air is required to discharge the pink color, the test should be repeated, using 10 c.c. of air each time after the first 30 c.c.

"It is not necessary to rinse out the shaker after making each test, but it should be carefully washed and dried after using, and the parts kept separate when not in use.

"The 'half-solution' is used in exactly the same manner and amount as the regular test solution, reference being made to the appropriate portion of the table."

Air Quantum Needed.—The ventilating plant to be designed for a place or ship must be given a ventilating